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the U.S. Army Corps of Engineers, Portland District
Portland, Oregon
under a Related Services Agreement
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Entrainment of Dungeness Crab in the Desdemona Shoals Reach of the Lower Columbia River Navigation Channel

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Executive Summary

Proposed dredging of the Columbia River has raised concerns about related impacts on Dungeness crab in the Columbia River Estuary (CRE). This study follows two major efforts, sponsored by the Portland District of the U. S. Army Corps of Engineers (USACE), to quantify the number of crabs entrained by a hopper dredge working in the CRE. From June 2002 through September 2002, Pacific Northwest National Laboratory (PNNL) conducted direct measurements of crab entrainment in the CRE from the mouth of the Columbia River (river mile -3 to +3) upriver as far as Miller Sands (river mile 21 to 24). These studies constituted a major step in quantifying crab entrainment in the CRE, and allowed statistically bounded projections of adult equivalent loss (AEL) for Dungeness crab populations under a range of future construction dredging and maintenance dredging scenarios (Pearson et al. 2002, 2003). In 2004, PNNL performed additional measurements to improve estimates of crab entrainment at Desdemona Shoals and at Flavel Bar, a reach near Astoria that had not been adequately sampled in 2002. The 2004 data were used to update the crab-loss projections for channel construction to -43 ft mean lower low water (MLLW). In addition, a correlation between bottom water salinity and adult (age 2+ and 3+, >100 mm carapace width [CW]) crab entrainment was developed using 2002 data, and elaborated upon with the 2004 data. This crab salinity model was applied to forecasting seasonal (monthly) entrainment rates and AEL using seasonal variations in salinity (Pearson et al. 2005).

In the previous studies, entrainment rates in Desdemona Shoals were more variable than in any of the other reaches. For example, the entrainment rate of juvenile crab (<100 mm CW) was 0.198 crab/cy in June of 2002, 0.022 crab/cy in September of 2002, and 0.014 crab/cy in August of 2004. Entrainment rates of first year crab (age 1+, 50 mm to 100 mm CW) in Desdemona Shoals were particularly variable, accounting for the entire 0.198 juvenile crab/cy in June 2002 but dropping to 0.022 and 0.00 age 1+ crab/cy in September 2002 and August 2004, respectively. The study by Pearson et al. (2005) found that juvenile crab entrainment rates were not significantly correlated with salinity as it is for older crab, and concluded that "the dynamics behind the variable entrainment rates at Desdemona Shoals are not fully understood."

The present study was undertaken to address the question of whether the high age 1+ entrainment rate at Desdemona Shoals in June 2002 was unusual, or whether it would be observed again under similar conditions. PNNL and USACE personnel directly measured crab entrainment by the USACE hopper dredge, *Essayons*, working in Desdemona Shoals in June 2006. In addition to quantifying crab entrainment of all age classes, bottom salinity was directly measured in as many samples as possible, so that the relationship between crab entrainment rate and salinity could be further evaluated. All 2006 data were collected and analyzed in a manner consistent with the previous entrainment studies (Pearson et al. 2002, 2003, 2005). A total of 77,252 cy were dredged in 26 loads of material from Desdemona Shoals, June 15-17, 2006, when tidal conditions were the same as when sampling occurred in 2002 (one day past peak spring tides), and when a very large range of salinity was expected

during the sampling period. The target sampling rate of 3 entrainment samples per load was accomplished for 19 loads, which allowed for a statistically sound comparison with prior Desdemona sampling efforts (17 loads in June 2002, 18 loads in September 2004). The other 7 loads had 1 or 2 samples each; in all, 69 samples were collected, and data from all were used in the entrainment rate and AEL analysis.

In all, 76 crabs were entrained, most of which (79%) were young of the year in the 6- to 12-mm size range. The only other crabs entrained were age 2+ (20%), and age 3+ (1 crab). No age 1+ crabs (50- to 100-mm CW) were encountered. The entrainment rate for all age classes of Dungeness crab combined was 0.241 crab/cy from Desdemona Shoals in June 2006, a similar overall entrainment rate to that observed in June 2002 (0.223 crab/cy). However, the contribution of each age class to overall entrainment rate was very different in June 2006 than in June 2002. The June 2006 rate was mainly driven by the age 0+ entrainment rate of 0.187 crab/cy; 2006 entrainment rates for age classes 1+, 2+, and 3+ were 0.00, 0.052, and 0.002 crab/cy respectively. In contrast, June 2002 overall entrainment rate was driven by the age 1+ crab entrainment rate of 0.193 crab/cy; June 2002 entrainment rates for age classes 0+, 2+, and 3+ were 0.005, 0.024, and 0.001 crab/cy respectively.

In summary, the age 1+ crab entrainment rate observed in June 2002 was not observed again in June 2006 despite sampling under very similar conditions; the June 2002 entrainment rates for age 1+ crab cannot be assumed to be typical of all years. Variable crab entrainment rates for Desdemona Shoals were not surprising, as prior studies of both crab entrainment in the navigational channel and crab density outside the channel near the mouth of the Columbia River reported a wide range of results, especially for juvenile Dungeness crab. The Desdemona Shoals 2006 salinity and entrainment rates were used to update the crab salinity model of Pearson et al. (2005). The overall relationship between crab entrainment and salinity remained significant for ages 2+ and 3+ crab and not significant for ages 0+ and 1+ crab. Juvenile crab entrainment rates in the navigation channel still appear to be governed by factors other than, or in addition to, salinity.

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Acronyms

AEL	Adult equivalent loss
cfs	Cubic feet per second
CI	Confidence interval
CORIE	**Co**lumbia **Ri**ver **E**nvironmental Observing and Forecasting System
CRE	Columbia River Estuary
CV	Coefficient of variation
CW	Carapace width
cy	Cubic yards
DIM	Dredge impact model
E	Entrainment (number crabs)
kcy	Thousand cubic yards
LCR	Lower Columbia River
LRTF	Loss of recruits to fishery
MCR	Mouth of the Columbia River
MLLW	Mean lower low water
MSL	Marine Sciences Laboratory
PNNL	Pacific Northwest National Laboratory
psu	Practical salinity units
R	Entrainment **R**ate (crab/cy)
RM	River mile
UID	Unidentified
USACE	U. S. Army Corps of Engineers
YOY	Young of the year

1.0 Introduction

1.1 Background

Proposed dredging of the Columbia River has raised concerns about related impacts on Dungeness crab (*Cancer magister*) in the Columbia River Estuary (CRE). One of the impacts is the taking up, or entrainment, of Dungeness crab by the dredges as they remove sediment from the channel. During 2002, the Pacific Northwest National Laboratory (PNNL) Marine Sciences Laboratory (MSL) performed crab entrainment studies for the Portland District of the U. S. Army Corps of Engineers (USACE) at the mouth of the Columbia River (MCR), as well as in the Desdemona Shoals, Upper Sands, and Miller Sands reaches of the Lower Columbia River Navigation Project (Pearson et al. 2002, 2003) (Figure 1). In 2004, MSL performed additional measurements to improve estimates of crab entrainment at Desdemona Shoals and at Flavel Bar, a reach between Desdemona Shoals and Upper Sands near Astoria that had not been adequately sampled in 2002 (Figure 1). These studies constituted a major step in quantifying crab entrainment in the CRE, and allowed statistically bounded projections of adult equivalent loss (AEL) for Dungeness crab populations under a range of future construction dredging and maintenance dredging scenarios.

Once Dungeness crab entrainment was quantified throughout most of a CRE dredging season (approximately June through October), Pearson et al. (2002) investigated whether variation in crab entrainment rates could be explained by bottom salinity. After regression analysis of the natural logarithm of entrainment rates against several different expressions of salinity, researchers found that most of the variation between entrainment rates was explained by the proportion of salinity observations that were <16 practical salinity units (psu). Total crab entrainment rate (all ages) was significantly correlated with salinity <16 psu ($p=0.0114$, $R^2=75\%$). Adult crab (age 2+ and 3+, >100 mm carapace width [CW]) entrainment was significantly correlated with both the proportion of salinity measurements <16 psu and the proportion >32 psu. This crab salinity model was further elaborated upon with the 2004 entrainment data (Pearson et al. 2005). With the additional direct measurements of entrainment and bottom salinity in Desdemona Shoals (river mile [RM] 4 to 10) and Flavel Bar (RM 10 to 13), the reaches where salinity is highly variable, Pearson et al. (2005) were able to confirm that entrainment rates of age 2+ and age 3+ crabs were significantly correlated with the proportion of salinity observations <16 psu ($p < 0.001$, $R^2=86\%$). but concluded that entrainment of age 0+ and 1+ crab were “governed by factors in addition to or other than salinity.”

In the previous studies, entrainment rates in Desdemona Shoals were more variable than in any of the other reaches (Figure 2, Table 1). For example, entrainment of juvenile crab (<100 mm CW) was 0.198 crab/cy in June of 2002, 0.022 crab/cy in September of 2002, and 0.014 crab/cy in September of 2004. Entrainment of first year crab (age 1+, 50 mm to 100 mm CW) in Desdemona Shoals was particularly variable, accounting for the entire 0.198 crab/cy in June 2002 but dropping to 0.022 and 0.00 crab/cy in September 2002 and 2004, respectively. The variability in crab entrainment rates and lack of relationship with salinity led the USACE Portland District to request MSL to conduct additional entrainment studies of Dungeness crab in Desdemona Shoals in early summer.

1.2 Objectives and Approach

As noted above, it was the June 2002 entrainment of age 1+ crabs that was higher than that in September 2002 and August 2004 and not related to salinity as were older age classes of crabs (Pearson et al. 2005). No other early-season entrainment sampling has been conducted since June 2002. The objective of the 2006 Dungeness crab entrainment study was to address the question of whether the high age 1+ entrainment rate at Desdemona Shoals in June 2002 was unusual or whether it would be observed again under similar conditions. Conditions during June 2002 entrainment sampling in Desdemona Shoals were those of peak spring tides during spring runoff; 2006 Desdemona Shoals dredging and entrainment sampling were scheduled for the equivalent period in 2006 (Figure 3). Unlike later entrainment sampling efforts, channel bottom salinity was not directly measured in each June 2002 sample, and could not be verified against the salinity values obtained from the Columbia River Estuary environmental observation network (CORIE) that were used in the salinity model. Therefore, the present study focused solely on late spring-early summer entrainment of Dungeness crab in the Desdemona Shoal reach, and on the relationship of crab entrainment to measured and modeled bottom salinity.

A sampling design was developed that would result in data that were statistically comparable with previously collected data. This design called for direct measurement of crab entrainment on the USACE hopper dredge, *Essayons*, quantifying all age classes of entrained crab, as well as listing other entrained organisms, and measuring bottom salinity at the time each entrainment sample was collected. The 2006 data were compared with previous years of data from Desdemona Shoals, and the entrainment-salinity was examined with respect to the existing salinity model. The 2006 data were also used to update the crab-salinity model.

2.0 Methods

Entrainment of Dungeness crab and other organisms was measured in the same manner as earlier entrainment studies conducted aboard the Corps hopper dredge, *Essayons* (Pearson et al. 2002, 2005). These methods are briefly described below, including relevant modifications to reduce variance. Entrainment calculation methods, the dredge impact model (DIM) used to estimate AEL and loss of recruits to the Dungeness crab fishery (LRTF), and the crab salinity model update are also described in this section.

2.1 Direct Measurement of Entrainment

The estimation of total crab entrainment was based on a two-stage sampling scheme. The first stage was the systematic sampling of every load of material dredged from Desdemona Shoals. The second stage of sampling was the random sampling of dredge material within each load of dredged material. Within a dredge load, a minimum of three “crab basket” samples, randomly selected from eight time intervals during the period of load collection (approximately 0.7 to 1 h), were processed. Hence, two aspects of the sampling protocol were 1) systematic sampling of every load, and 2) the random selection of “basket” samples within a load. This systematic sampling of every load represented a change from the previous studies in which randomly selected loads were selected for sampling.

In Desdemona Shoals, the volume of sediment was likely to be relatively small and require only a few days to dredge. Therefore, sampling every load was the best way to increase precision and reduce sample variance for the time period of interest (late spring/early summer), while sampling over a range of bottom salinities. The statistical synopsis in Appendix A shows that the best precision would be achieved in a scenario in which 34 of 34 loads were sampled. A scenario in which 17 of 17 loads were sampled yielded the second best precision, whereas a scenario in which 17 of 34 loads were sampled yielded the worst precision. The number of loads used in the scenarios was based on the number of loads dredged and/or sampled in previous efforts at Desdemona Shoal (Table 1). It was determined that the 2006 sampling effort would be best served by a dredge volume of at least 17 loads; any more loads would serve to increase precision and decrease variance as long as every load was sampled. Fewer loads would probably increase variance and decrease not only precision but also the temporal and salinity ranges examined.

2.1.1 Field Sampling Methods

The USACE dredge *Essayons* is a 350-ft side-arm hopper dredge with two drag-arms that are lowered to the bottom of the channel to pump sediment into a ~6000-cy capacity hopper. A quantitative subsample of dredged material was collected by diverting a portion of the sediment flow from the drag-arms to the hopper. On-deck sampling followed methods previously used to operate the crab basket sampler and gate valve (Pearson et al. 2002, 2003, 2005). During normal dredge operation, sediment was pumped from the drag-arms through pipes that distribute sediment to the hopper via four valves (starboard valves 16 and 17, port valves 16 and 17 (Figure 4, left). To collect an entrainment sample, starboard valve 17 was closed, and a gate valve to a large crab sampling "basket" was opened, causing one fourth of the flow to be diverted into the crab sampling basket (Figure 4, right). Sampling time intervals were guided by the volume of dredged material that could be reliably sorted within the course of a load, which at upriver sites with a lot of woody debris, was determined to be approximately 30 seconds from valve opening to final closure.

With each basket sample, bottom water was obtained from a catch pan under the pipe carrying material to the basket sampler. Bottom water temperature (degrees Celsius) and salinity (psu) were measured using a YSI Model 600XL Sonde multiple probe system. Substrate and organisms trapped in the basket were removed to a sorting table on deck. Whole and parts of living organisms were sorted from the sample, and individuals from the following taxa were identified and enumerated: crab (*Cancer magister* and other species), shrimp (e.g., *Crangon* spp.), razor clams, and all fish species. The CW of each crab was measured, and its sex determined if possible. If half of a crab carapace was present, this portion was measured and used to estimate total CW. Crabs were only counted if more than half the carapace was recovered or if matching parts (e.g., telson, legs, chela, thorax) constituting at least one third of a crab were recovered; otherwise, it was noted that the sample contained only parts. In cases in which an animal other than crab was crushed or only pieces were collected, the animal was counted only if the head was present (see details below on quantifying crushed crab). Researchers noted the relative abundance of other species (e.g., polychaetes) and recorded the species and total length (length from the tip of the upper jaw to the end of the caudal fin) of fishes. All crab, crab pieces, and other organisms were dumped into the dredge hopper to prevent duplicate counts on subsequent passes.

2.1.2 Data Management

Entrainment sampling personnel maintained detailed records of field data. Individual load sample records contained all information on each basket sample of each load: date, time, sampling time interval, organisms entrained, substrate type, bottom water salinity and temperature, tide stage, direction of dredging, and weather observations. The organism entrainment records were compiled into a within-load record summarizing basket sample data by load (time, numbers and size of *C. magister,* species and numbers of fish, and presence of other organisms). Total load volumes (cubic yards), distance dredged (feet), and number of cuts or passes for all loads during the survey were obtained from the *Essayons* dredge log and recorded on the load-by-load record. Raw data from sampling records were entered into an Excel spreadsheet as soon as possible after data collection. Complete digital records were proofread by an independent analyst and corrected if necessary. All digital files are backed up daily by PNNL's automated backup system.

2.2 Entrainment Rate, Total Entrainment, and Variance Estimates

The methods for estimating Dungeness crab entrainment rates, total crab entrainment, and associated variance are detailed in the prior entrainment study reports (Pearson et al. 2002, 2003, 2005) and in Appendix A of this report. The necessary input parameters for these estimates are listed in Table 2.

The entrainment rate (R) is an estimate of the number of crabs per cubic yard (crab/cy) that were entrained during the survey, based on quantitative sampling of each load of dredged material. The number of crabs in each age class in each basket sample is divided into the volume of material sampled; this sample volume is derived by multiplying effective sampling time (t) by mean load rate (cy/t) of the discharge pipe feeding the basket sampler. As in Larson (1993), a mean load rate for each load was calculated by dividing total load volume in cubic yards by total pumping time. Because the pipe feeding the basket sampler carries one fourth of the dredged material flow (half of one drag-arm), a factor of 0.25 is applied to the mean load rate to correct the proportion of the flow that is being sampled. This factor was verified by actual flow rate measurements conducted in 2002 (Pearson et al. 2002). Additional details on the calculation of effective sampling time, which accounts for the proportion of flow sampled during opening and closing of the gate valve to the crab sampler basket, in addition to the time the valve is fully open, are also provided in Pearson et al. (2002).

Crab entrainment by load is estimated by multiplying the average entrainment rate (crab/cy) for each crab age class in a dredge load by the total volume (cy) of that load to get a number of crab entrained. Entrained crab in all loads are summed by age class and then divided by the total volume of the sampled loads to get the overall entrainment rate (R) for the entire sampled reach in crab/cy. Total crab entrainment (E) for the sampled reach is estimated by multiplying the overall entrainment rate times the total volume dredged from the reach. The estimator of total entrainment E for a specific age class of crabs can be expressed as follows:

$$\hat{E}_i = \frac{\sum_{j=1}^{h}\left[\frac{V_j}{b_j}\sum_{l=1}^{b_j} x_{ijl}\right]}{\sum_{j=1}^{h} V_i} \cdot \sum_{j=1}^{H} V_j \qquad (1)$$

where

x_{ijl} = number of age class $i\ (i = 1,\ldots,A)$ crabs/Y^3 measured in the *l*th basket sample $(l = 1,\ldots,b_j)$ in the *j*th haul $(j = 1,\ldots,h)$

b_j = number of basket samples observed in the *j*th haul $(j = 1,\ldots,h)$

h = number of hauls selected for sampling of crab density

H = total number of hauls at a dredge location

V_j = total volume of dredge materials in the *j*th haul $(j = 1,\ldots,h)$.

In turn, x_{ijl} can be expressed in terms of the number of crabs counted and the volume of the *l*th basket sample of *j*th haul, where

$$x_{ijl} = \frac{c_{ijl}}{w_{jl}}$$

and where

c_{ijl} = number of age class i crabs $(i = 1,\ldots,A)$ in the *l*th basket sample $(l = 1,\ldots,b_i)$ in the jth haul $(j = 1,\ldots,h)$

w_{jl} = volume of the material sampled in the *l*th basket sample $(l = 1,\ldots,b_i)$ in the *j*th haul $(j = 1,\ldots,h)$.

As such, the estimator of total crab entrainment for age class i crabs $(i = 1,\ldots,A)$ can be expressed as

$$\hat{E}_i = \frac{\sum_{j=1}^{h}\left[V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right]}{\sum_{j=1}^{h} V_j} \cdot \sum_{j=1}^{H} V_j\ . \qquad (2)$$

Estimators (1) and (2) will be the same if sample values $w_{ij} = w_i$ are equal within a haul. If sample volumes vary, then estimator (2) is the preferred estimator of total entrainment. In the 2006 survey of Desdemona Shoals, estimator (1) was used, as sample volumes were equal within each load ($w_{ij} = w_i$).

Estimation of variance on entrainment rate by load $\hat{R}_j$ and total entrainment by age class $\hat{E}_i$ is also described in detail in Appendix A. The variance estimator for $\hat{E}$ can be written as follows:

$$\hat{V}\text{ar}\left(\hat{E}_i\right) = H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{(h-1)} + \frac{H}{h}\sum_{j=1}^{h}V_j^2 \cdot \hat{V}\text{ar}\left(\hat{R}_j\right) \qquad (3)$$

where the following simplified variance estimator of entrainment rate $\hat{R}_j$ was used:

$$\hat{V}\text{ar}\left(\hat{R}_j\right) = \frac{\sum_{l=1}^{b_j}\left(c_{ijl} - \hat{R}_j w_{jl}\right)^2}{\bar{w}_j^2 b_j\left(b_j - 1\right)}$$

and where

$$\bar{w}_j = \frac{\sum_{l=1}^{b_j} w_{jl}}{b_j}.$$

Asymptotic $(1-\alpha)$ 100% confidence interval estimates for $\hat{E}_i$ were calculated as

$$\hat{E}_i \pm Z_{1-\frac{\alpha}{2}}\sqrt{\hat{V}\text{ar}\left(\hat{E}_i\right)}.$$

2.3 Calculation of Adult Equivalent Loss

The DIM described by Wainwright et al. (1992) as an extension of a model developed by Armstrong et al. (1987) was used to estimate AEL. The model was modified by Pearson et al. (2002, 2003, 2005) to incorporate direct measurement of crab entrainment by hopper dredge in the MCR entrainment studies, which is the most statistically robust approach to estimating AEL. The DIM follows these steps, numbered in Figure 5:

1. Use entrainment rate by age class (R, crab/cy) derived from direct measurements (described in previous section).
2. Multiply entrainment rate by dredged volume (cy) to get entrainment by age class (E).
3. Apply dredge-related crab mortality rates (by age class 0+, 1+, 2+, 3+ years) from Wainwright et al. (1992) to get immediate crab loss.
4. Apply the natural survivorship rates from Wainwright et al. (1992) to get the AEL (number of crab) to midwinter age 2+. The equivalent AEL 2+ for age 3+ entrained crab was back-calculated by applying the reciprocal of the survival rate (45% from age 2+ to age 3+) to the number of age 3+ crab. The AEL for age 3+ crab was then calculated using the 45% survival rate from midwinter age 2+ to midwinter age 3+ (Armstrong et al. 1987).

5. Apply a fishery harvest rate of 70% (Wainwright et al. 1992) to age 3+ male crab to obtain LRTF.

The mortality rates applied in step 3 varied with age, as hopper dredge entrainment studies have shown that smaller crab are more likely to survive dredge entrainment than are larger crab (Armstrong et al. 1987). The assumed mortality rates were 10% for age 0+, 60% for age 1+, and 86% for crab older than age 1+. The natural survivorship rates used to calculate AEL in step 4, taken from Wainwright et al. (1992), were 1.7% for age 0+, 16% for age 1+, 64.9% for age 2+, and 45% for age 3+. Although size regulations vary slightly between Washington and Oregon and between commercial and recreational crab fisheries, harvestable male crab are generally age 3+ and up. The harvest rate of 70% applied to the estimated number of entrained age 3+ males was consistent with previous applications of the DIM (Armstrong et al. 1987; Wainwright et al. 1992; Pearson et al. 2002, 2003, 2005). Once AEL 2+, AEL 3+, and LRTF were calculated, the variance and 95% confidence interval for each endpoint was calculated.

2.4 Crab Salinity Model Update

As noted in the introduction, one of the goals of this study was to examine the relationship observed between crab entrainment and bottom salinity when both were directly measured early in the LCR dredging season (i.e., month of June). In particular, would the additional data provide any insight to the distribution of juvenile crab in the estuary, and would entrainment of adult crab be as predicted, given the salinity? Bottom salinity data obtained during the June 2006 Desdemona field effort were compiled, and the proportion of measurements <16 psu were input to the existing crab salinity model of Pearson et al. (2005) (Figure 6) to predict age 2+ and 3+ crab entrainment, which was then compared with directly measured crab entrainment.

The existing crab salinity model was developed using regressions of the natural log of entrainment rate (lnR) against the proportion of salinity <16 psu in seven data sets: Miller Sands 2002, Upper Sands 2002, Desdemona 2002 (September only), MCR 2002, Flavel Bar 2004, Desdemona 2004, and MCR 2004 (Pearson et al. 2005). Each age class was modeled separately; the relationship between salinity and entrainment rate was not significant for age 0+ and age 1+ crab, but the regression relationship was significant for age 2+ and age 3+ crab. The age 2+ and age 3+ regression lines were compared and found to be not significantly different (p = 0.79 for slopes and p = 0.76 for intercepts). Therefore, the final crab salinity model of Pearson et al. (2005) was based on the lnR for age 2+ and age 3+ pooled observations (n=14), with resulting regression equation: $\ln R = -5.799(x) - 4.151$ ($p<0.0001$, $R^2=86\%$), where R is entrainment in crab/cy and x is proportion salinity <16 psu. Figure 6 shows the model line with raw entrainment (R) on y-axis as well as the linear model with lnR on the y-axis, which allows the 95% confidence interval to be plotted.
To test whether the new observations from 2006 fall within the sampling error of the existing model, an asymptotic Z-test was conducted based on the deviation of the new observations ($\ln R_{06}$) from the predicted values from the existing model ($\ln \hat{R}_{06}$). Under the null hypothesis that the observed entrainment rate in 2006 is distributed the same as the 2002-2004 data, then the ratio

$$\frac{\ln R_{06} - \ln \hat{R}_{06}}{\sqrt{\mathrm{Var}(\ln R_{06}) + \mathrm{Var}(\ln \hat{R}_{06})}}$$ is distributed as a standard normal random variable. The Var(ln R_{06}) is based on the sampling error during the June 2006 dredge entrainment survey. The $\mathrm{Var}(\ln \hat{R}_{06})$ is estimated as $\mathrm{MSE}\,(1+\frac{1}{n}+\frac{(x_{06}-\bar{x}_{05})^2}{\sum_{i=1}^{n}(x_{i05}-\bar{x}_{05})^2})$ where MSE= is the mean squared error from the 2005 regression model.

The crab salinity model was updated by adding the Desdemona 2006 data and repeating the regression analyses for each age class and determining significance of the relationship. The monthly predictions of entrainment based on salinity distribution observed by the CORIE monitoring network could not be updated, as the 9-m deep sensors at the RED26 station (Upper Desdemona Shoal) were not operating between June 4 and June 19, 2006.

3.0 Results

3.1 Direct Measurement of Entrainment, June 2006

Desdemona Shoals was dredged June 15-17, 2006, by the USACE dredge, *Essayons*. The total dredged volume was 77,252 cy in 26 loads. Entrainment sampling was conducted on every dredge load, as planned. Of the 26 loads dredged, 19 loads had at least 3 basket samples, 5 loads had 2, and 2 loads had 1 basket sample. Load times, volumes, load rates, and sampling rates are provided in Table 3. The number of crab in each age class recovered in each basket sample is provided in Table 4; a summary of crab entrained by age class and sex is provided in Table 5. In all, 76 crab were entrained. Most (60) were young of the year (YOY) in the 6- to 12-mm size range, newly settled megalopae and early instar crabs entering the estuary. The only other crab entrained were 15 in the 100- to 150-mm (age 2+) range, and 1 crab >150 mm (age 3+). No crab in the 50- to 100-mm (age 1+) size range were encountered, which is in direct contrast to results of the June 2002 sampling.

Complete entrainment data for each load and basket sample, including sampling times and conditions, bottom temperature and salinity, crab by age class and sex, fish and other organisms entrained, are provided in Appendix B. The only other invertebrate entrained in large numbers was *Crangon* shrimp, sometimes over 200 per sample in samples collected closer to the MCR (RM 4 to 7). Although ten species of fish were identified in entrainment samples, no more than two individuals of a species were counted in any one basket sample. Snake prickleback, *Lumpenus sagitta,* were encountered most often (10 samples, 14 fish), followed by Pacific sandlance, *Ammodytes hexapterus,* (8 samples, 9 fish) and staghorn sculpin, *Leptocottus armatus,* (5 samples, 5 fish).

3.2 Entrainment Rates and Crab Losses for Desdemona Shoals, June 2006

Entrainment rates, total entrainment by age class, and the variances on entrainment by age class were estimated from the dredge load and basket sample data following the methods described in Section 2.2. The Desdemona Shoals June 2006 entrainment rate for all age classes of Dungeness crab combined was 0.241 crab/cy, mainly driven by the age 0+ entrainment rate of 0.187 crab/cy (Table 6). Entrainment rates for other age classes were 0.00, 0.052, and 0.002 crab/cy for 1+, 2+, and 3+ crab, respectively. The entrainment rate for each age class was multiplied by the dredged volume of 77,252 cy to obtain the total number of crab entrained. Because of their higher entrainment rate, age 0+ crab accounted for 78% of the total crab entrainment estimate (14,434 YOY crab out of 18,622 total crab); the estimated number of crab entrained in the other age classes were 0 age 1+, 4009 age 2+, and 179 age 3+ (Table 6).

The 2006 entrainment rates, total entrainment and associated variance by age class, along with the dredge-related crab mortality rates and natural survivorship rates of Wainwright et al. (1992), were input to the DIM to estimate AEL at age 2+ and 3+ and LRTF and associated 95% confidence intervals as described in Section 2.3. The resulting loss estimates are provided in Table 7; detailed model inputs, steps, and outputs are provided in Appendix C. In summary, crab losses (±95% confidence limit) were estimated to be 2604 (±2338) to age 2+, 1172 (±1052) to age 3+, and 410 (±368) LRTF. These 2006 Desdemona Shoals entrainment rate and crab loss estimates are compared with entrainment data from previous studies in Section 4.0.

3.3 Salinity and Crab Distribution

The previous entrainment studies of Pearson et al. (2002, 2005) provide substantial background discussion of salinity influences on crab distribution. Distribution of adult crab (age 2+ and older) is significantly related to salinity: crab density decreases as salinity decreases. Pearson et al. (2005) used direct measurements of salinity taken during entrainment sampling to describe a significant linear relationship between the proportion of salinity measurements <16 psu and the natural logarithm of the age 2+ and 3+ crab entrainment rates (Section 2.4, Figure 6). As described in Section 2.4, the crab salinity model developed by Pearson et al. (2005) was used to predict expected entrainment rates for age 2+ and 3+ crab in Desdemona Shoals in 2006. The statistical approach for comparing observed and predicted entrainment rates is detailed in Appendix D.

Directly measured bottom salinities ranging from 2.4 psu to 27.0 psu were obtained for 64 of the 69 entrainment basket samples (Appendix D). Because of the large spring tide range and higher than average river flow, bottom salinities were very low on ebb tide (Figure 7). Mean salinity was calculated for each load; the proportion of loads with salinity <16 psu was 0.20. At this proportion salinity <16 psu, the Pearson et al. (2005) crab salinity model predicted a lnR of -5.310, or entrainment rates of 0.0049 crab/cy for age 2+ and age 3+ crab. The observed lnR for age 2+ crab in Desdemona Shoals in 2006 was higher than that predicted (-2.956), but the observed variability of lnR (95% confidence limit of ±1.851) was such that the observed entrainment rate was not significantly different from predicted (p=0.351) (Figure 8). The observed lnR for age 3+ crab (-6.023 ±0.736) was also not significantly different from that predicted (p=0.979) (Figure 8). Additional detail on the existing model predictions and comparison to actual 2006 observations is provided in Appendix D.

The crab salinity model was updated by adding the Desdemona June 2006 entrainment rate (by age class) and salinity data pairs to the existing data and then rerunning the regressions for each age class individually. The revised output is summarized in Table 8; the individual regression results and final model are provided in Appendix D. Despite the variation in 2006 entrainment rates between age classes, the updated individual regressions for age 2+ and 3+ crabs versus salinity distribution were not significantly different from each other (Appendix D). Therefore, it is still possible to use one model in which age 2+ and 3+ entrainment rates and salinity distribution are pooled. An updated (2006) model was estimated based on the pooled age 2+ and 3+ data from 2002 through 2006 (n=16) (Figure 9). This model had a significant slope ($p < 0.001$) and an R^2 value of 0.81: the updated model equation is $\ln R = -5.855(x) - 4.033$, where R is entrainment in crab/cy and *x* is the proportion of salinities <16 psu. The updated model was not significantly different from the existing model at $\alpha=0.05$ (p=0.065) (Figure 10, Appendix D).

4.0 Discussion and Conclusions

The June 2006 entrainment sampling was conducted under as similar timing (i.e., day length) and tidal conditions as possible to the June 2002 sampling. However, Columbia River discharge, which generally peaks from mid-May to mid-June (USGS 2006), was about 18% higher than the 17-year average in mid-June 2006 than in mid-June 2002, when discharge was similar to the 17-year average (Figure 3). The results of June 2006 entrainment sampling are compared with those of June 2002 in Table 9. It is clear that Dungeness crab entrainment rates by age class in 2006 were not similar to those in 2002. In particular, the high entrainment rate of age 1+ crab observed in June 2002 was not observed in 2006; in fact, *no* age 1+ crab were observed in June 2006 samples. However, the entrainment rate of YOY crab in 2006 was higher than observed previously.

Wide variation in Desdemona Shoals crab entrainment rates was not entirely unexpected: historical surveys of crab densities and crab entrainment in the CRE also show considerable variation over time and space (McCabe et al. 1986, McCabe and McConnell 1989, Larson 1993), particularly for juvenile crab. McCabe and McConnell (1989) reported mean densities of YOY crab on the Columbia Bar (approximately RM 0 to RM 1) ranging from 10 crab/ha to 1876 crab/ha in June over a 5-year period; 10 miles upstream at Flavel Bar, mean densities of YOY crab ranged from 0 crab/ha to 164 crab/ha (Table 10). Desdemona Shoals Reach of the LCR navigation channel lies directly between these two stations. In a study of direct dredge entrainment on the *Essayons* at the mouth of the Columbia River, Larson (1993) found that average entrainment rates for YOY crab <50 mm CW ranged from 0.32 crab/cy to 10.78 crab/cy in the years 1985 through 1988, and that the observed range of entrainment rates for crab >50 mm CW was 0.03 crab/cy to 0.18 crab/cy. YOY crab entrainment rates were also variable from month to month, with the highest YOY entrainment rates observed in May or June of each year (Larson 1993).

Despite the wide variation in crab entrainment rates of individual age classes between June 2002 and June 2006, the overall entrainment rates (all age classes combined) were remarkably similar, at 0.241 crab/cy in 2006 and 0.223 crab/cy in 2002 (Table 9), with juvenile crab (age 0+ and 1+) dominating June entrainment. Natural mortality rates are much higher for juvenile crabs than for adult crabs, but dredge-related mortality rates are lower. The model used to estimate crab losses incorporates both age-related natural mortality and age-related dredge-related mortality. In an exercise to determine the impact of the varying age class entrainment rates observed in June 2002 and June 2006, the DIM was run with June 2002 and June 2006 entrainment rates for each age class, using a standardized dredge volume of 40,000 cy. Resulting crab losses were similar between years, but the proportion contribution of each age class was not (Table 9).

In conclusion, the age 1+ crab entrainment rate observed in June 2002 was not observed again in June 2006 despite sampling under very similar conditions. In fact, no age 1+ crabs were recovered in 2006 samples. Therefore, the June 2002 entrainment rates for age 1+ crab cannot be assumed to be typical of all years. The Desdemona Shoals 2006 salinity and entrainment rates were used to update the crab salinity model for age 2+ and 3+ crabs. There was no significant difference between the updated model and the existing model (Figure 10). The overall relationship between crab entrainment and salinity remains significant for adult crab and not significant for juvenile crab. Juvenile crab entrainment rates in the Desdemona Shoals reach of the Lower Columbia River navigation channel still appear to be governed by factors other than, or in addition to, salinity.

5.0 Figures and Tables

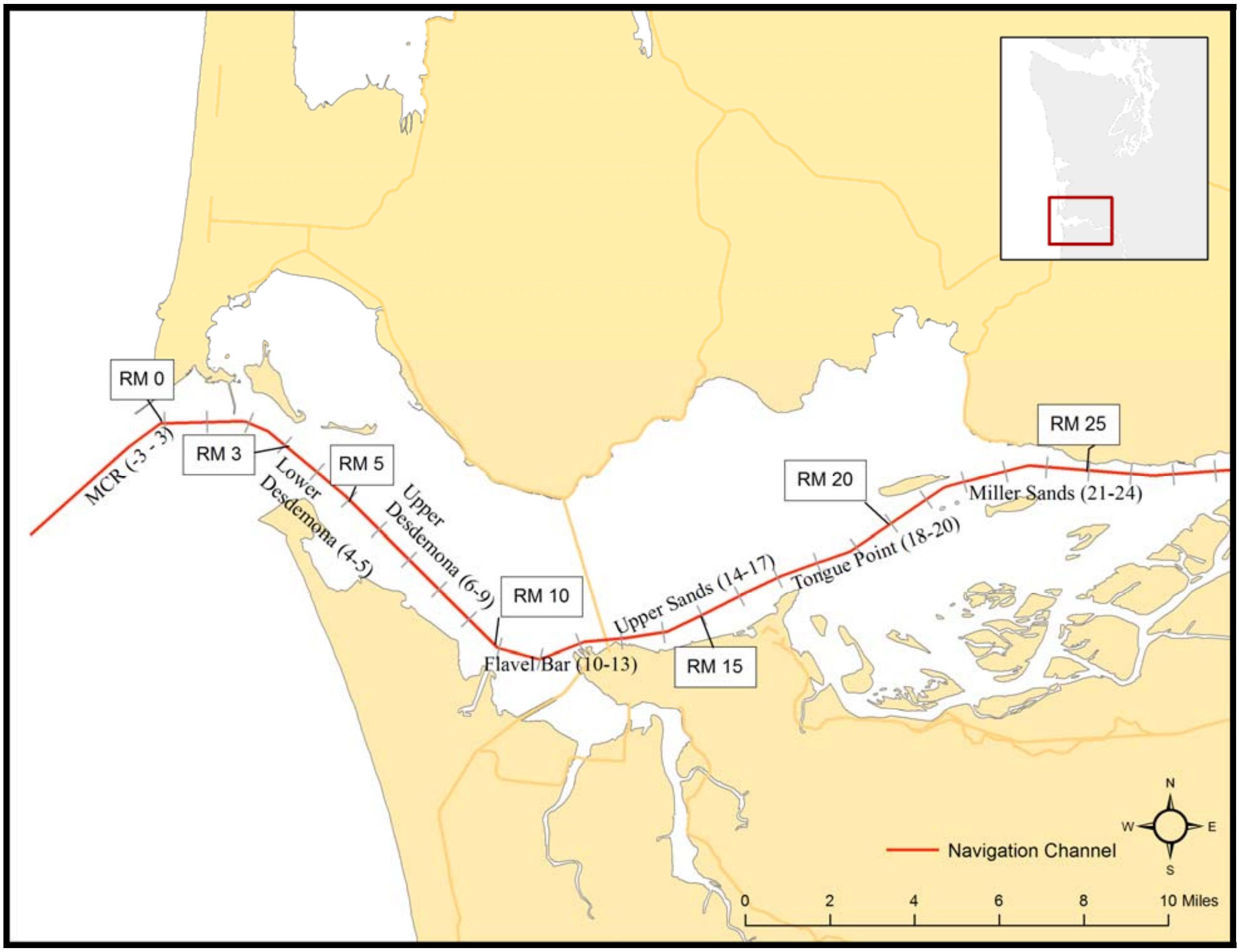


Figure 1. Desdemona Shoals and Other Reaches of the Lower Columbia River Navigation Channel

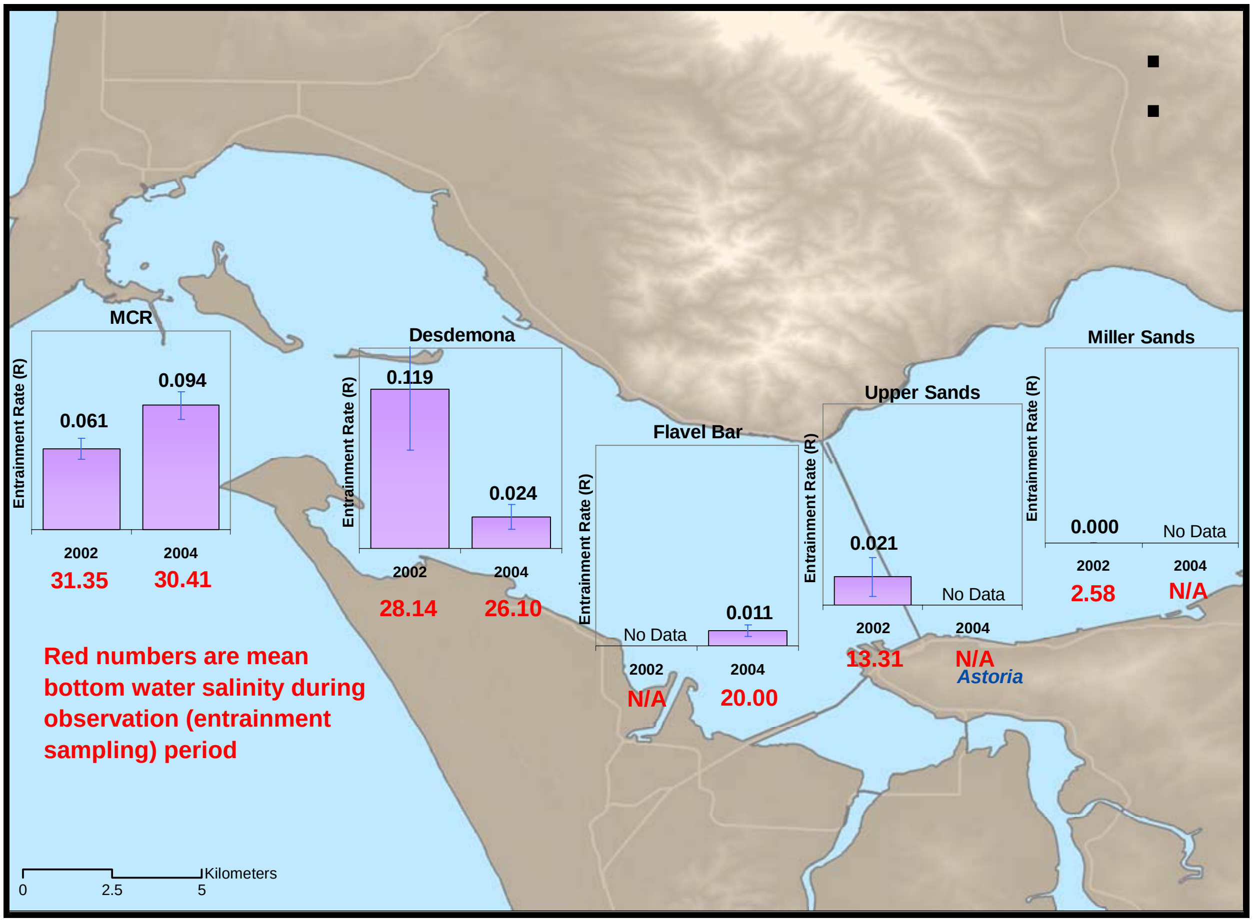
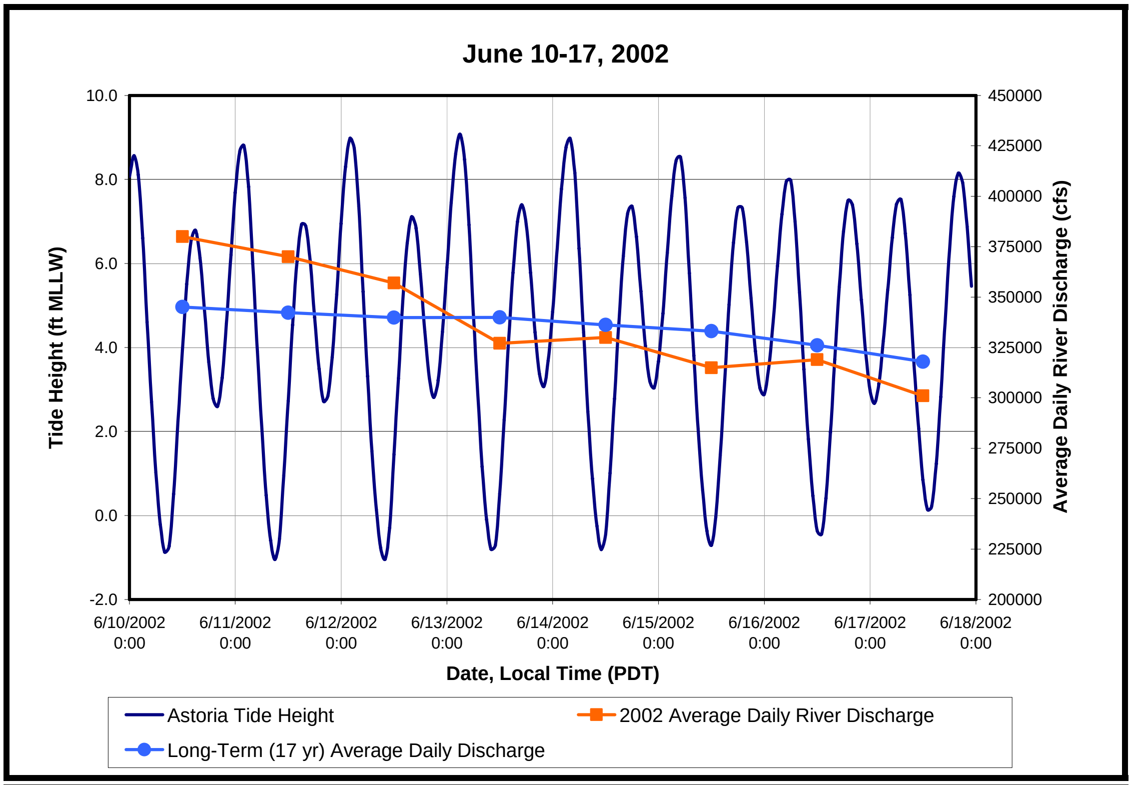


Figure 2. Total Crab Entrainment Rates (all ages) for 2002 and 2004 in the Lower Columbia River Channel Reaches and the Mouth of the Columbia River



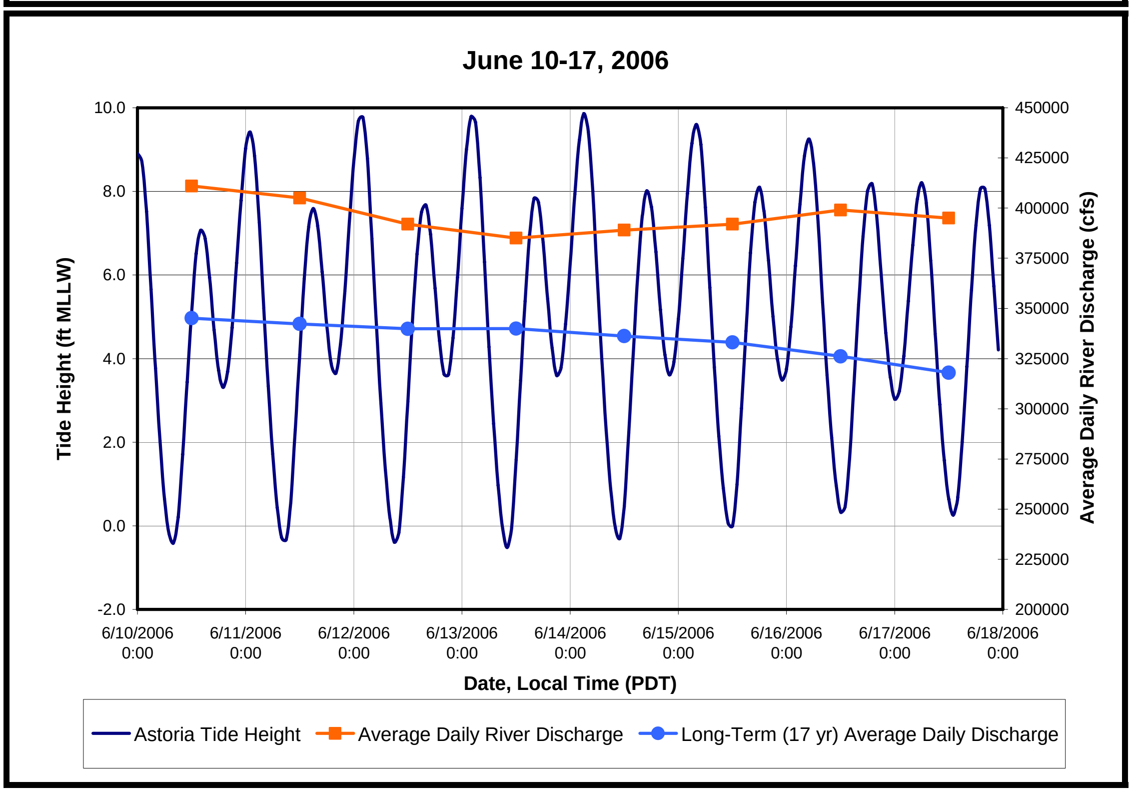


Figure 3. Columbia River Estuary Tidal and River Flow Conditions During 2002 and 2006 Entrainment Sampling in Desdemona Shoals

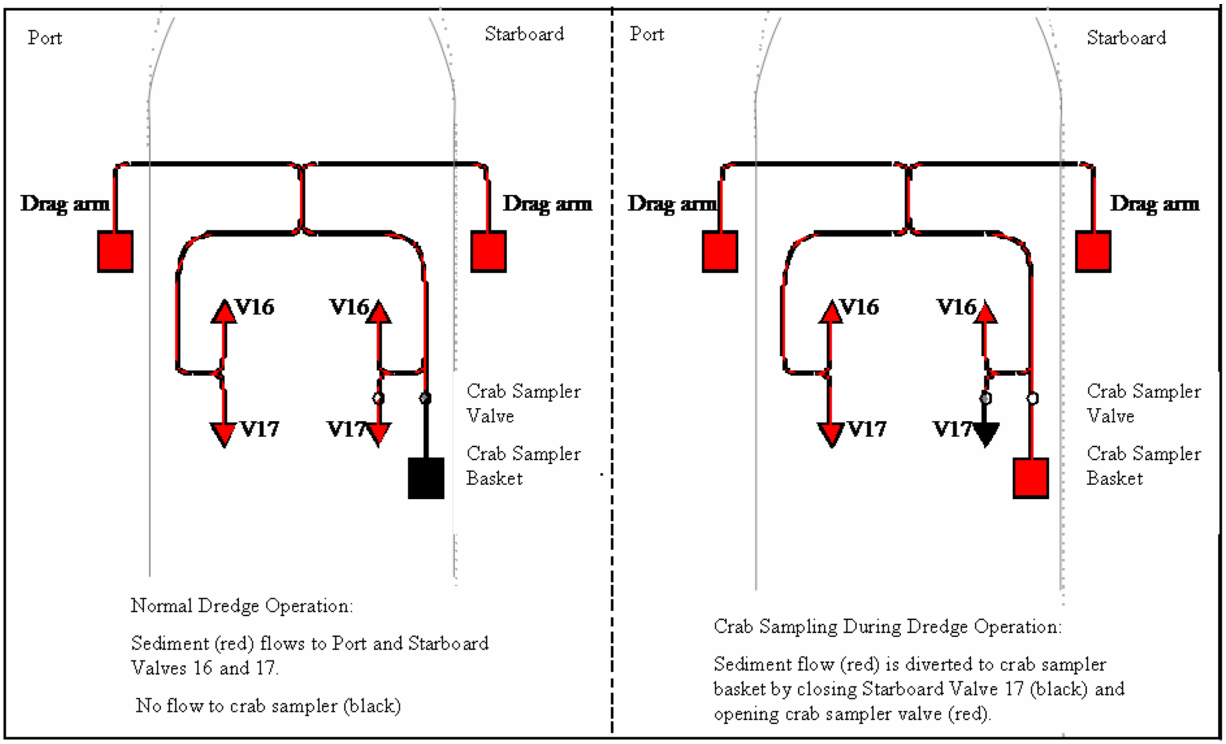


Figure 4. Dredge drag-arm and valve configuration

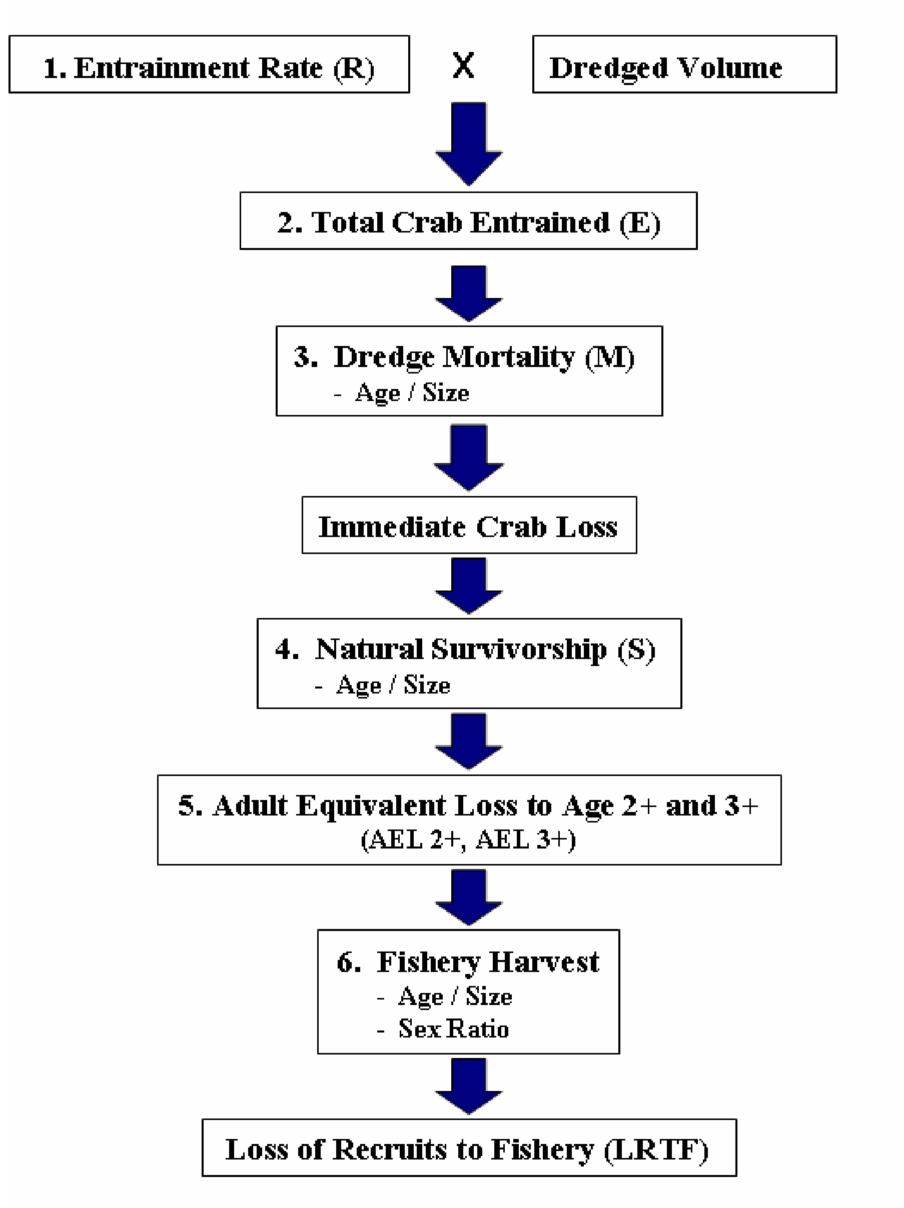


Figure 5. Dredge Impact Model (modified from Wainwright et al. 1992)

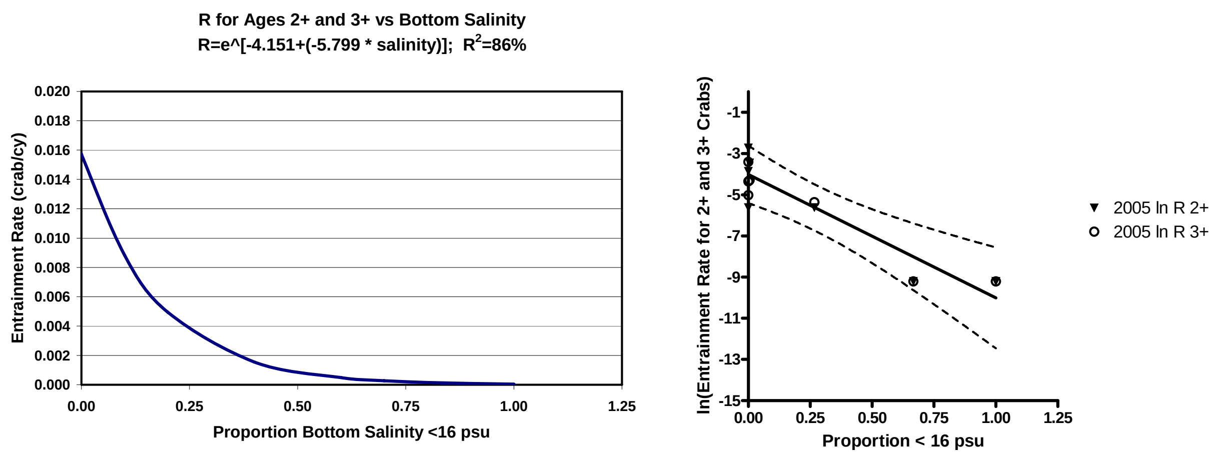


Figure 6. Crab-Salinity Model for Adult Crab Developed by Pearson et al. (2005)

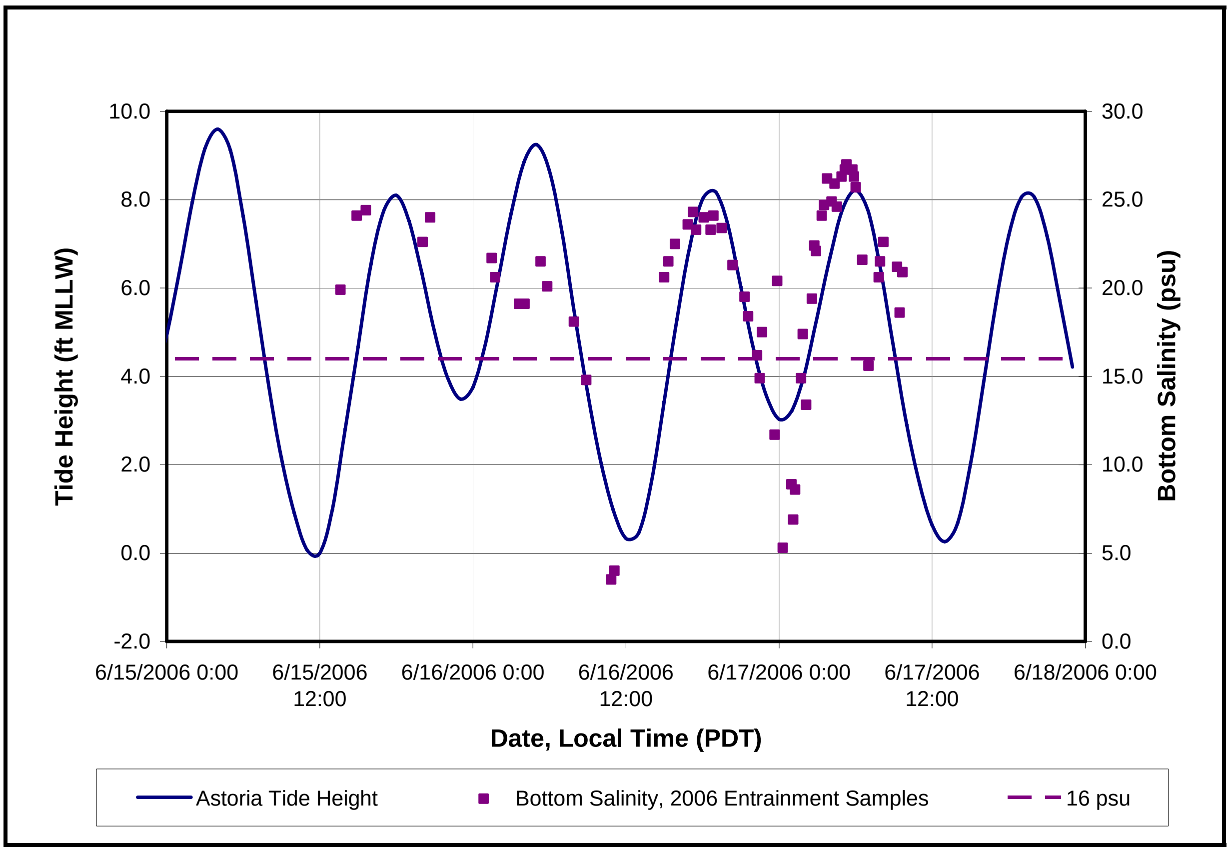


Figure 7. Bottom Water Salinity Measurements, Desdemona Shoals, June 2006

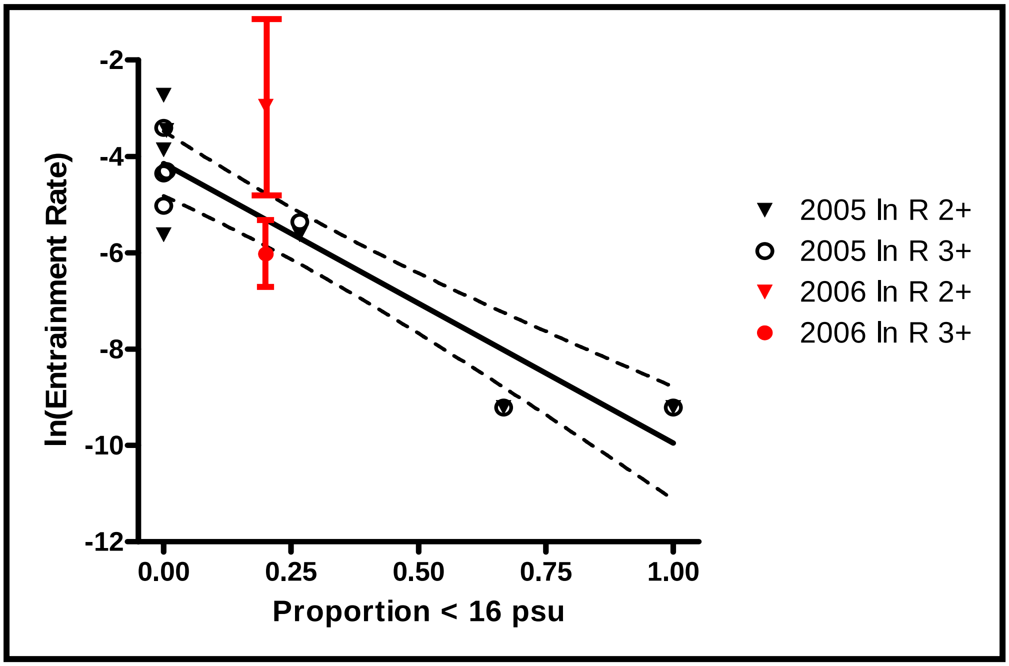


Figure 8. Desdemona 2006 Observed Entrainment Rates Compared with Crab Salinity Model of Pearson et al. (2005)

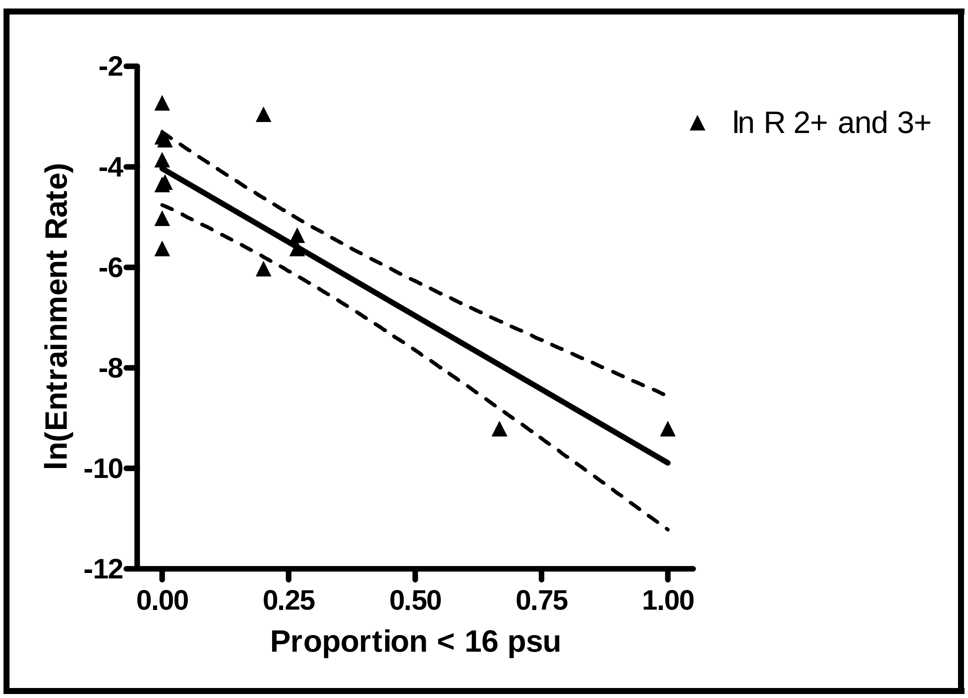


Figure 9. Updated Crab Salinity Model with 95% Confidence Bounds (n=16)

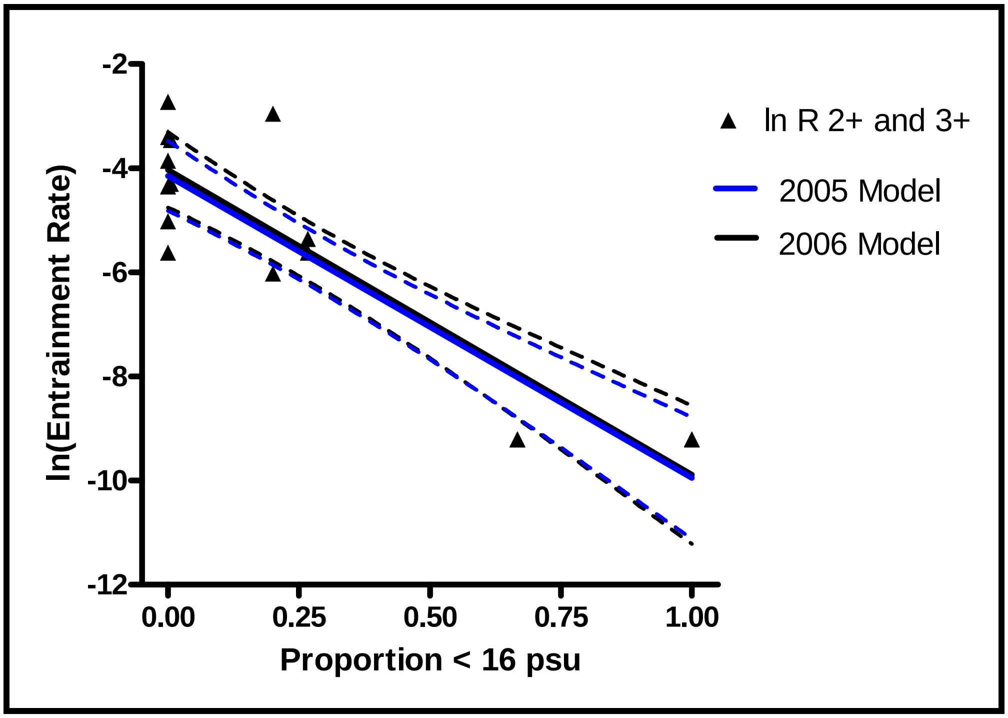


Figure 10. Comparison of Existing (Pearson et al. 2005) and Updated Crab Salinity Models

Table 1. 2002 and 2004 Entrainment Sampling in Desdemona Shoals

Dates	Total Dredged Volume (cy)	Number Loads Dredged	Number Loads Sampled	Total Crab Basket Samples	Crab Entrainment Rate (crab/cy)			
					Age 0+	Age 1+	Age 2+	Age 3+
June 11-16, 2002	186,737	33	17	169	0.005	0.193	0.024	0.001
September 17, 2002	30,012	6	4	12	0.000	0.022	0.065	0.033
August 20-24, 2004	100,239	18	18	54	0.014	0.000	0.004	0.007

Table 2. Required Data for Crab Entrainment and Variance Estimates

Parameter Description	Units	Derivation
Total number of loads or hauls (H)	Whole number	*Essayons* dredge log
Dredged material volume per load (V_j)	cy	*Essayons* dredge log
Pumping time (time drag-arms are actively dredging)	min	*Essayons* dredge log
Average load rate	cy/min	Calculated from load volume and pumping time
Sample load rate	cy/min	Calculated from load rate; sample load rate is 0.25 times load rate if both dragarms are operating
Number of loads sampled (h)	Whole number	Field sampling record
Total number of basket samples (B)	Whole number	Field sampling record
Number of basket samples per load (b)	Whole number	Field sampling record
Duration of sample collection (t)	Seconds (s)	Field measurement
Effective sampling time (t_{eff})	Seconds (s)	Calculated from sample collection duration (t)
Sample volume (w_{jl}) of each basket sample (l) in each haul (j)	cy	Calculated from sample load rate and effective sampling time
Dungeness crab (x_{ijl}) at each age class (i) in each basket sample (l) in each haul (j)	Number CW (mm) Sex (M, F, or unidentified [UID])	Field measurement

Table 3. Dredge Load Information, Desdemona 2006 Entrainment Sampling

Load Sequence	Date	Load Start Time	Load Volume (cy)	Total Distance Traveled (ft)	Cuts (Passes)	Basket Samples Taken	Dragarms in Operation	Pumping Time (min)	Average Load Rate (cy/min)	Sample Load Rate (cy/min)	Location (Buoy # and/or RM)
06-01	6/15/2006	1305	4524	9600	8	4[a]	2	330	13.7	3.4	Red 20-22 (6+00 to 7+00)
06-02	6/15/2006	1951	5030	20400	2	3	2	125	40.2	10.1	Red 20-22 , Green 25-27
06-03	6/15/2006	2325	4290	8800	3	1	2	60	71.5	17.9	Green 25-27, (8+30 to 9+20)
06-04	6/16/2006	0127	3696	8800	2	2	2	58	63.7	15.9	Green 25-27, (8+30 to 9+20)
06-05	6/16/2006	0327	3605	8800	2	2	2	53	68.0	17.0	Green 25-27, (8+30 to 9+20)
06-06	6/16/2006	0518	3900	8800	2	2	2	63	61.9	15.5	Green 25-27, (8+30 to 9+20)
06-07	6/16/2006	0742	4470	8800	2	2	2	82	54.5	13.6	Green 25-27, (8+30 to 9+20)
06-08	6/16/2006	1045	3939	8800	2	2	2	58	67.9	17.0	Green 25-27, (8+30 to 9+20)
06-09	6/16/2006	1244	4567	8800	2	1	2	77	59.3	14.8	Green 25-27, (8+30 to 9+20)
06-10	6/16/2006	1456	3500	8000	2	3	2	58	60.3	15.1	Red 14, 20 (4+30 to 5+20)
06-11	6/16/2006	1633	3226	8000	2	3	2	51	63.3	15.8	Red 14, 20 (4+30 to 5+20)
06-12	6/16/2006	1801	3661	8000	2	3	2	52	70.4	17.6	Red 14, 20 (4+30 to 5+20)
06-13	6/16/2006	1927	4354	8000	2	3	2	56	77.8	19.4	Red 14, 20 (4+30 to 5+20)
06-14	6/16/2006	2114	2100	8000	2	3	2	25	84.0	21.0	Red 14, 20 (4+30 to 5+20)
06-15	6/16/2006	2215	2547	8000	1	3	2	36	70.8	17.7	Red 14, 20 (4+30 to 5+20)
06-16	6/16/2006	2333	1666	8000	2	3	2	48	34.7	8.7	Red 14, 20 (4+30 to 5+20)
06-17	6/17/2006	0052	1745	4000	1	3	2	31	56.3	14.1	Red 14, 20 (4+30 to 5+20)
06-18	6/17/2006	0142	1760	6000	2	3	2	30	58.7	14.7	Red 14, 20 (4+30 to 5+20)
06-19	6/17/2006	0234	1502	4000	1	3	2	28	53.6	13.4	Red 14, 20 (4+30 to 5+20)
06-20	6/17/2006	0319	1847	4000	1	3	2	28	66.0	16.5	Red 14, 20 (4+30 to 5+20)
06-21	6/17/2006	0405	1637	4000	1	3	2	31	52.8	13.2	Red 14, 20 (4+30 to 5+20)
06-22	6/17/2006	0452	1581	4000	1	3	2	32	49.4	12.4	Red 14, 20 (4+30 to 5+20)
06-23	6/17/2006	0544	1200	4000	1	3	2	15	80.0	20.0	Red 14, 20 (4+30 to 5+20)
06-24	6/17/2006	0631	2723	8000	2	3	2	44	61.9	15.5	Red 14, 20 (4+30 to 5+20)
06-25	6/17/2006	0748	2014	4000	1	3	2	30	67.1	16.8	Red 14, 20 (4+30 to 5+20)
06-26	6/17/2006	0913	2168	4000	1	3	2	41	52.9	13.2	Red 14, 20 (4+30 to 5+20)

a. 4th basket sampled because dredge was not pumping sediment during 2nd basket; result is 3 baskets for entrainment analysis.

Table 4. Dungeness Crab in Basket Samples, Desdemona Shoals 2006

Load Sequence Number	Date	Sample Number	Substrate Type[a]	Number of Crabs in Age/Size Class: 0+ <50 mm CW	1+ 51-100 mm CW	2+ 101-150 mm CW	3+ >150 mm CW	Total Crab	UID Pieces
06-01	06/15/06	1	G, M, S, WC	1	0	0	0	1	N
06-01	06/15/06	2	None	NA[b]	NA	NA	NA	NA	NA
06-01	06/15/06	3	SH	3	0	2	0	5	N
06-01	06/15/06	4	M, S, WC	2	0	0	0	2	N
06-02	06/15/06	1	M,S	4	0	1	0	5	N
06-02	06/15/06	2	S, G, SH	2	0	1	0	3	N
06-02	06/15/06	3	MF	0	0	0	0	0	N
06-03	06/15/06	1	M, MF, WC	0	0	0	0	0	N
06-04	06/16/06	1	M,S	2	0	0	0	2	N
06-04	06/16/06	2	M, S, WC	0	0	0	0	0	N
06-05	06/16/06	1	S, WC	0	0	1	0	1	N
06-05	06/16/06	2	M, S, WC	0	0	0	0	0	N
06-06	06/16/06	1	MF, WC	0	0	0	0	0	N
06-06	06/16/06	2	S, WC	0	0	0	0	0	N
06-07	06/16/06	1	S, WC	0	0	0	0	0	Y
06-07	06/16/06	2	S, WC	0	0	0	0	0	N
06-08	06/16/06	1	M, WC	0	0	0	0	0	N
06-08	06/16/06	2	WC	1	0	2	0	3	Y
06-09	06/16/06	1	S, WC	0	0	0	0	0	Y
06-10	06/16/06	1	M, WC, RH	5	0	0	0	5	Y
06-10	06/16/06	2	M, WC	3	0	0	0	3	Y
06-10	06/16/06	3	M, WC, O	1	0	0	0	1	Y
06-11	06/16/06	1	M	0	0	0	0	0	Y
06-11	06/16/06	2	M, WC	1	0	0	0	1	N
06-11	06/16/06	3	M, WC, SH	0	0	0	0	0	N
06-12	06/16/06	1	M, MF, WC	7	0	1	0	8	N
06-12	06/16/06	2	M, MF, WC	0	0	0	0	0	N
06-12	06/16/06	3	not recorded	2	0	0	0	2	N
06-13	06/16/06	1	MF, SH	1	0	1	0	2	N
06-13	06/16/06	2	not recorded	3	0	0	0	3	N
06-13	06/16/06	3	not recorded	0	0	0	0	0	N
06-14	06/16/06	1	MF, MB	0	0	0	0	0	N
06-14	06/16/06	2	MF, S, SH	2	0	0	0	2	N
06-14	06/16/06	3	not recorded	2	0	0	0	2	N
06-15	06/16/06	1	not recorded	1	0	1	0	2	N
06-15	06/16/06	2	MF, SH, WC	0	0	0	0	0	N
06-15	06/16/06	3	M, WC	1	0	0	0	1	N
06-16	06/16/06	1	not recorded	4	0	0	1	5	N
06-16	06/16/06	2	not recorded	2	0	0	0	2	N
06-16	06/17/06	3	not recorded	0	0	0	0	0	N

Table 4. (contd)

Load Sequence Number	Date	Sample Number	Substrate Type[a]	Number of Crabs in Age/Size Class 0+ <50 mm CW	1+ 51-100 mm CW	2+ 101-150 mm CW	3+ >150 mm CW	Total Crab	UID Pieces
06-17	06/17/06	1	MF, WC	0	0	0	0	0	N
06-17	06/17/06	2	MF, WC	0	0	1	0	1	N
06-17	06/17/06	3	MF, SH, WC	0	0	0	0	0	N
06-18	06/17/06	1	not recorded	1	0	1	0	2	N
06-18	06/17/06	2	MF, WC	0	0	0	0	0	N
06-18	06/17/06	3	MF, WC	0	0	0	0	0	N
06-19	06/17/06	1	MF, WC	1	0	0	0	1	Y
06-19	06/17/06	2	MF, WC	1	0	0	0	1	N
06-19	06/17/06	3	M, WC	0	0	0	0	0	N
06-20	06/17/06	1	M, S, WC, SH	0	0	0	0	0	N
06-20	06/17/06	2	not recorded	0	0	0	0	0	N
06-20	06/17/06	3	M, G, SH, WC	0	0	0	0	0	N
06-21	06/17/06	1	M, MF, SH, WC	1	0	0	0	1	N
06-21	06/17/06	2	M, MF, SH, WC	1	0	0	0	1	N
06-21	06/17/06	3	M, MF, SH, WC	0	0	0	0	0	N
06-22	06/17/06	1	M, MF, SH	1	0	0	0	1	N
06-22	06/17/06	2	not recorded	0	0	1	0	1	N
06-22	06/17/06	3	not recorded	0	0	1	0	1	N
06-23	06/17/06	1	M, SH, WC	0	0	0	0	0	N
06-23	06/17/06	2	MF, SH, WC	1	0	1	0	2	N
06-23	06/17/06	3	M, MF, SH, WC	1	0	0	0	1	Y
06-24	06/17/06	1	M, S, WC	0	0	0	0	0	N
06-24	06/17/06	2	SH, WC	0	0	0	0	0	N
06-24	06/17/06	3	SH, WC	0	0	0	0	0	Y
06-25	06/17/06	1	M, WC	1	0	0	0	1	N
06-25	06/17/06	2	M, WC	0	0	0	0	0	N
06-25	06/17/06	3	M, WC	1	0	0	0	1	N
06-26	06/17/06	1	M, S, G, WC	0	0	0	0	0	Y
06-26	06/17/06	2	M, WC	0	0	0	0	0	Y,
06-26	06/17/06	3	M, G, WC	0	0	0	0	0	Y

a. Substrate type codes: G=Gravel, M=Mud, S=Sand, WC=Wood Chips, SH=Shell Hash, MF=Mixed Fines, MB=Mud Balls, RH=Rhizomes, O=Other.

b. NA Not applicable; dredge was not pumping sediment at time basket sample was taken.

Table 5. Summary of Dungeness Crab in Entrainment Samples, Desdemona Shoals, June 2006

Crab Sex	Number of Crab by Age/Size Class YOY <50 mm	1+ 51-100	2+ 101-150	3+ >150	Total by Sex	Percentage by Sex
Male	NA	0	6	0	**6**	8%
Female	NA	0	2	0	**2**	3%
Unidentified	60	0	7	1	**68**	89%
Total By Age Class	60	0	15	1	**76**	
Percentage by Age/Size	79%	0%	20%	1%		

Table 6. Dungeness Crab Entrainment Rates and Total Entrainment in Desdemona Shoals, June 2006

Endpoint	Result for Age/Size Class 0+ 0-50	1+ 51-100	2+ 101-150	3+ >150	All Crab
Entrainment Rate R (crabs/cy)	0.1868	0.0000	0.0519	0.0023	0.241
Entrainment E (crabs)[a]	14434	0	4009	179	18622
Standard Error of E	2645	0	2047	179	
Coefficient of Variation of E	0.183	NA	0.510	1.000	

a. In dredged volume of 77,252 cy.

Table 7. Dungeness Crab Adult Equivalent Loss and Loss of Recruits to Fishery Estimated by Dredge Impact Model for Desdemona Shoals, June 2006

Endpoint	Estimated Crabs Lost	95% CI	95% Confidence Range of Crabs Lost
AEL 2+	2604	2338	266 to 4942
AEL 3+	1172	1052	120 to 2224
LRTF	410	368	42 to 778

Table 8. Significance of Salinity-Entrainment Regression After 2006 Update

Independent Variable	Dependent variable	N	p-value	F-value	Significan t	R^2
R Age 0+	Proportion < 16 psu	8	0.4312	0.712	No	0.106
R age 1+	Proportion < 16 psu	8	0.4868	0.549	No	0.084
R Age 2+	Proportion < 16 psu	8	0.0042	20.076	Yes	0.770
R Age 3+	Proportion < 16 psu	8	0.0004	49.434	Yes	0.892
R Ages 2+ and 3+	**Proportion < 16 psu**	**16**	**2.2540E-06**	**58.712**	**Yes**	**0.807**

Table 9. Comparison of Desdemona Shoals June 2002 and June 2006 Sampling Conditions, Observed Salinity and Crab Entrainment Rates, and Projected Crab Losses

Parameter	June 15-17, 2006	June 11-15, 2002
River Conditions		
Minimum Tide (Astoria), ft MLLW [a]	0.00	-1.05
Maximum Tide (Astoria), ft MLLW [a]	9.60	9.08
Minimum Average Daily River Discharge (cfs)[b]	392,000	301,000
Maximum Average Daily River Discharge (cfs)[b]	399,000	370,000
Entrainment Sampling		
Volume Dredged (cy)	77,252	186,737
Loads Dredged	26	33
Loads Sampled	26	17
Total Basket Samples	69	169
Observed Bottom Water Salinity		
Measured Bottom Salinity Range (psu)	2.4 to 27.0	not measured
Measured Bottom Salinity (proportion <16 psu)	0.20	not measured
Observed Entrainment Rates		
Age 0+ Entrainment Rate (crab/cy)	0.187	0.005
Age 1+ Entrainment Rate (crab/cy)	0.000	0.193
Age 2+ Entrainment Rate (crab/cy)	0.052	0.024
Age 3+ Entrainment Rate (crab/cy)	0.002	0.001
All Crab Entrainment Rate (crab/cy)	0.241	0.223
Projected Crab Loss in 40,000 cy[c]		
AEL2+	1349	1353
AEL 3+	607	609
LRTF	212	256
Age Class Contribution to Projected Crab Loss		
Age 0+ Contribution to AEL, LRTF	0.91%	0.03%
Age 1+ Contribution to AEL, LRTF	0.00%	54.87%
Age 2+ Contribution to AEL, LRTF	85.92%	40.10%
Age 3+ Contribution to AEL, LRTF	13.17%	5.00%

a. From NOAA CO-OPS Station 9439040 Astoria/Tongue Point, actual recorded tide data.

b. From USGS Station 14246900, Columbia River at Beaver Army Terminal near Quincy, OR (USGS 2006).

c. Estimated annual maintenance volume used by Pearson et al. (2002).

Table 10. Crab Densities in Month of June, From McCabe and McConnell (1989)

Location[a]	Age/Size	Mean density in June of year (crab/ha)				
		1984	1985	1986	1987	1988
Columbia River Bar	Y0Y or <50 mm (0+)	96	1876	14	19	10
Flavel Bar	Y0Y or <50 mm (0+)	ND[b]	164	98	0	12
Columbia River Bar	50-99 mm (1+)	0	0	16	0	0
Flavel Bar	50-99 mm (1+)	ND	296	1131	10	631
Columbia River Bar	100-129 mm	4	1	40	4	2
Flavel Bar	100-129 mm	ND	0	15	14	0
Columbia River Bar	>129 mm	10	6	15	10	7
Flavel Bar	>129 mm	ND	0	0	10	0

a. Location: Columbia River Bar trawl locations were generally RM 0 to RM1, data are from 5-12 trawls per month; Flavel Bar trawl locations were approximately RM 10.5, data are from 1 trawl per month.

b. ND no data.

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APPENDIX A

Statistical Synopsis for the Design and Analysis of the 2006 Dredge Entrainment Study at Desdemona Shoals

Statistical Synopsis for the Design and Analysis of the 2006 Dredge Entrainment Study at Desdemona Shoals

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1.0 Introduction

The purpose of the 2006 spring dredging study is to estimate crab densities at Desdemona Shoals and potentially relate entrainment densities to water salinity, tidal phase, etc. The duration of the study will be 2−4 days, and the duration may have an effect on sampling allocation.

2.0 Estimating Total Entrainment of an Age Class of Crabs

This section describes the probabilistic sampling and estimation of total crab entrainment by age class from multiple loads taken at Desdemona Shoals.

2.1 Estimator

In a random sample of hauls, crab entrainment densities are estimated from a random sample of dredge material. Hence, the sampling design consists of a two-stage sampling scheme; Stage 1: Random sample of h of H hauls and Stage 2: Random sample of dredge materials based on b of B basket samples. The estimator of total entrainment for a specific age class (i.e., size class) of crabs can be expressed as follows:

$$\hat{E}_i = \frac{\sum_{j=1}^{h}\left[\frac{V_j}{b_j}\sum_{l=1}^{b_j} x_{ijl}\right]}{\sum_{j=1}^{h} V_i} \cdot \sum_{j=1}^{H} V_j \qquad (1)$$

where

x_{ijl} = number of age class i $(i = 1,\ldots, A)$ crabs/Y^3 measured in the lth basket sample $(l = 1,\ldots,b_j)$ in the jth haul $(j = 1,\ldots,h)$;

b_j = number of basket samples observed in the jth haul $(j = 1,\ldots,h)$;

h = number of hauls selected for sampling of crab density;

H = total number of hauls at a dredge location;

V_j = total volume of dredge materials in the jth haul $(j = 1,\ldots,h)$.

In turn, x_{ijl} can be expressed in terms of the number of crabs counted and the volume of the lth basket sample of jth haul, where

$$x_{ijl} = \frac{c_{ijl}}{w_{jl}}$$

and where

c_{ijl} = number of age class i crabs $(i=1,\ldots,A)$ in the lth basket sample $(l=1,\ldots,b_i)$ in the jth haul $(j=1,\ldots,h)$;

w_{jl} = volume of the material sampled in the lth basket sample $(l=1,\ldots,b_i)$ in the jth haul $(j=1,\ldots,h)$.

As such, the estimator of total crab entrainment for age class i crabs $(i=1,\ldots,A)$ can be expressed as

$$\hat{E}_i = \frac{\sum_{j=1}^{h}\left[V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right]}{\sum_{j=1}^{h} V_j} \cdot \sum_{j=1}^{H} V_j . \tag{2}$$

Estimators (1) and (2) will be the same if sample values $w_{ij} = w_i$ are equal within a haul. If sample volumes vary, then estimator (2) is the preferred estimator of total entrainment.

2.2 Variance of Estimator $\hat{E}_i$

The variance of $\hat{E}_i$ is found by taking the variance in stages (Appendix A). The variance of $\hat{E}_i$ [Eq. (2)] can then be expressed as follows:

$$\mathrm{Var}\left(\hat{E}_i\right) = H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{H}\left(V_j R_j - RV_j\right)^2}{h(H-1)} + \frac{H}{h}\sum_{j=1}^{H}\left[V_j^2 \cdot \mathrm{Var}\left(\hat{R}_j\right)\right], \tag{3}$$

where

$R_j = \frac{\sum_{l=1}^{B_j} c_{ijl}}{\sum_{l=1}^{B_j} w_{jl}}$ = true density of age class i crabs (i.e., crabs/Y^3) in the jth haul $(j=1,\ldots,H)$;

$$R = \frac{\sum_{j=1}^{H} R_j V_j}{\sum_{j=1}^{H} V_j} = \text{ true density of crabs (i.e., crabs/}Y^3\text{) across all } H \text{ levels;}$$

$$\text{Var}\left(\hat{R}_j\right) = \frac{\left(1 - \frac{b_j}{B_j}\right)}{b_j \bar{w}_j} \frac{\sum_{l=1}^{B_j} \left(c_{ijl} - R_j w_{jl}\right)^2}{\left(B_j - 1\right)};$$

and where

$$\bar{w}_j = \frac{\sum_{l=1}^{B_j} w_{jl}}{B_j} = \text{ average volume of basket sample in the } i\text{th haul;}$$

$B_j =$ total number of possible basket samples within the jth haul.

Variance formula (3) cannot be used to analyze the field data because it is dependent upon unknown parameter values. Instead, an estimated variance must be calculated and used in confidence interval estimates.

2.3 Estimated Variance of the Estimator $\hat{E}$

An approximately unbiased variance estimator was derived in Appendix B. The variance estimator for $\hat{E}$ can be written as follows:

$$\widehat{\text{Var}}\left(\hat{E}_i\right) = H^2 \left(1 - \frac{h}{H}\right) \frac{\sum_{j=1}^{h} \left(V_j \hat{R}_j - \hat{R} V_j\right)^2}{(h-1)} + \frac{H}{h} \sum_{j=1}^{h} V_j^2 \cdot \widehat{\text{Var}}\left(\hat{R}_j\right) \quad (4)$$

where

$$\hat{R}_j = \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}},$$

$$\hat{R} = \frac{\sum_{j=1}^{h}\left[V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right]}{\sum_{j=1}^{h} V_j},$$

$$\text{Var}\left(\hat{R}_j\right) = \frac{\left(1 - \frac{b_j}{B_j}\right)}{b_j \bar{w}_j^2} \frac{\sum_{l=1}^{b_j}\left(c_{ijl} - \hat{R}_j w_{jl}\right)^2}{\left(b_j - 1\right)},$$

which, when B_j is very large, simplifies to

$$\text{Var}\left(\hat{R}_j\right) = \frac{\sum_{l=1}^{b_j}\left(c_{ijl} - \hat{R}_j w_{jl}\right)^2}{\bar{w}_j^2 b_j \left(b_j - 1\right)},$$

and where

$$\bar{w}_j = \frac{\sum_{l=1}^{b_j} w_{jl}}{b_j}.$$

Asymptotic $(1-\alpha)$ 100% confidence interval estimates for $\hat{E}_i$ can be calculated as

$$\hat{E}_i \pm Z_{1-\frac{\alpha}{2}} \sqrt{\text{Var}\left(\hat{E}_i\right)}.$$

An annotated example of estimating total entrainment and its associated variance can be found in Appendix C.

3.0 Sampling Precision of $\hat{E}$

The precision of the estimate of total entrainment $\left(\hat{E}\right)$ will be defined by the quantity

$$P\left(\left|\frac{\hat{E} - E}{E}\right| < \varepsilon\right) = 1 - \alpha, \qquad (5)$$

Precision, as expressed by Eq. (5), state that the desired relative error in estimation $\left(\text{i.e., } \frac{\hat{E}-E}{E}\right)$ is to be less than ε, $(1-\alpha)$ 100% of the time. For example, if the desired precision is to be within $\pm 25\,\%$ of the true value of *E*, 95% of the time, then Eq. (5) would be written as follows:

$$P\left(\left|\frac{\hat{E}-E}{E}\right| < 0.25\right) = 0.95 .$$

Assuming asymptotic normality

$$\varepsilon = Z_{1-\frac{\alpha}{2}} \cdot \mathrm{CV}\left(\hat{E}\right),$$

where CV is the coefficient of variation.

4.0 Sample Size – Precision Calculations

Three alternative scenarios for sampling at Desdemona Shoals in 2006 were considered:

Scenario #1: 2 days – all 17 of 17 loads and 3 basket samples/load
Scenario #2: 4 days – all 34 of 34 loads and 3 basket samples/load
Scenario #3: 4 days – 17 of 34 loads and 3 basket samples/load

For each of these three scenarios, the anticipated precision was calculated based on survey data collected in 2002 by age class (Table 1).

Table 1. Estimated coefficients of variation $\widehat{CV}\left(\hat{R}_j\right)$ and $\overline{\widehat{CV}\left(c_i\right)}$ for crab entrainment at Lower Desdemona in 2002.

Age Class	$\widehat{CV}\left(\hat{R}_j\right)$	$\overline{\widehat{CV}\left(c_i\right)}$
0+	1.889	2.900
1+	0.512	1.091
2+	0.635	2.563
3+	3.889	3.162

The values of ε were calculated based on $Z_{1-\frac{\alpha}{2}}$ = 1.96 (i.e., $1-\alpha$ = 0.95) (Table 2).

Table 2. Anticipated precision ε at $(1-\alpha)$ 100% = 0.95 for three alternative sampling scenarios by age class.

Sampling Scenario	Age Class 0+	1+	2+	3+
#1	0.7959	0.2994	0.6960	0.8678
#2	0.5628	0.2117	0.4921	0.6136
#3	1.0182	0.3454	0.7351	1.5691

Scenario #3 has the worst precision, while scenario #2 has the best precision.

5.0 Salinity Regression

The individual estimates of entrainment density $(\hat{D}_i)$, i.e.,

$$\hat{D}_i = \frac{\hat{E}_i}{V_i},$$

where V_i = volume of the ith load $(i = 1,\ldots,l)$ will be regressed against measured salinity values (S_i) on a load-by-load basis. Weighted least squares will be used where the sum of squares to be minimized is

$$\text{SS} = \sum_{i=1}^{h} w_i \left(\hat{D}_i - \left(\alpha + \beta S_i\right)\right)^2, \tag{6}$$

where

$$w_i = \frac{V_i^2}{\text{Var}\left(\hat{E}_i\right)}.$$

The analyses will be used to assess the relationship between crab density and water salinity. Multivariate regression may be used to incorporate tidal stage and other environmental covariates.

Appendix A: Derivation of the Variance of $\hat{E}$

In these derivations, the subscript i for age class will be dropped for convenience. Taking the variance of $\hat{E}$ in stages, the overall variance can be expressed as

$$\mathrm{Var}\left(\hat{E}\right) = \mathrm{Var}_1\left[E_2\left(\hat{E}\middle|1\right)\right] + E_1\left[\mathrm{Var}_2\left(\hat{E}\middle|1\right)\right] \tag{A1}$$

where

1 denotes stage 1 sampling of *h* of *H* hauls,

2 denotes stage 2 sampling of b_j of B_j basket samples in the *i*th haul $(j = 1,\ldots,H)$.

$\mathrm{Var}\left(\hat{E}\right)$ is derived as follows:

$$\mathrm{Var}\left(\hat{E}\right) = \mathrm{Var}_1\left[E_2\left[\left(\sum_{j=1}^{h} V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right)\cdot\frac{\sum_{j=1}^{H} V_j}{\sum_{j=1}^{h} V_j}\middle|1\right]\right] + E_1\left[\mathrm{Var}_2\left[\left(\sum_{j=1}^{h} V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right)\cdot\frac{\sum_{j=1}^{H} V_j}{\sum_{j=1}^{h} V_j}\middle|1\right]\right]$$

$$= \mathrm{Var}_1\left[\frac{\sum_{j=1}^{h} V_j R_j}{\sum_{j=1}^{h} V_j}\cdot\sum_{j=1}^{H} V_j\right] + E_1\left[\left(\frac{\sum_{j=1}^{H} V_j}{\sum_{j=1}^{h} V_j}\right)^2 \sum_{j=1}^{h} V_j \cdot \mathrm{Var}\left(\hat{R}_j\right)\right]$$

$$= V_{\cdot}^2 \;\mathrm{Var}_1\left[\frac{\sum_{j=1}^{h} V_j R_j}{\sum_{j=1}^{h} V_j}\right] + V_{\cdot}^2 \; E_1\left[\frac{\sum_{j=1}^{h} V_j \;\mathrm{Var}\left(\hat{R}_j\right)}{\left(\sum_{j=1}^{h} V_j\right)^2}\right]$$

where

$$V_{\cdot} = \sum_{j=1}^{H} V_j \,.$$

$$\mathrm{Var}\left(\hat{E}\right) \doteq V_{\square}^2 \left[\frac{\left(1-\frac{h}{H}\right)}{h\bar{V}^2} \frac{\sum_{i=1}^{H}\left(V_j R_j - RV_j\right)^2}{(H-1)} \right] + V_{\square}^2 \left[\frac{\frac{h}{H}\sum_{i=1}^{H} V_j^2 \cdot \mathrm{Var}\left(\hat{R}_j\right)}{\left(\frac{h}{H}\sum_{i=1}^{H} V_j\right)^2} \right]$$

where

$$\bar{V} = \frac{\sum_{j=1}^{H} V_j}{H},$$

$$R = \frac{\sum_{j=1}^{H} V_j R_j}{\sum_{j=1}^{H} V_j},$$

which simplifies to

$$\mathrm{Var}\left(\hat{E}\right) = \frac{H^2\left(1-\frac{h}{H}\right)}{h} \frac{\sum_{i=1}^{H}\left(V_j R_j - RV_j\right)^2}{(H-1)} + \frac{H}{h}\sum_{i=1}^{H} V_j^2 \cdot \mathrm{Var}\left(\hat{R}_j\right). \qquad \text{(A2)}$$

Appendix B: Derivation of the Estimated Variance for $\hat{E}$

The variance of $\hat{E}$ is composed of two terms where

$$\mathrm{Var}\left(\hat{E}\right) = H^2\left(1-\frac{h}{H}\right)\frac{\sum_{i=1}^{h}\left(V_jR_j - RV_j\right)^2}{h(H-1)} + \frac{H}{h}\sum_{j=1}^{h}V_j^2\,\widehat{\mathrm{Var}}\left(\hat{R}_j\right).$$

The second term can be estimated approximately unbiasedly by the expression

$$\frac{H}{h}\cdot\frac{H}{h}\sum_{j=1}^{h}V_j^2\,\widehat{\mathrm{Var}}\left(\hat{R}_j\right) = \left(\frac{H}{h}\right)^2\sum_{j=1}^{h}V_j^2\cdot\widehat{\mathrm{Var}}\left(\hat{R}_j\right)$$

where

$$\widehat{\mathrm{Var}}\left(\hat{R}_j\right) = \frac{\left(1-\frac{b_j}{B_j}\right)}{b_j\bar{w}_j^2}\frac{\sum_{l=1}^{b_j}\left(c_{ijl} - \hat{R}_jw_{jl}\right)^2}{\left(b_j-1\right)}. \tag{B2}$$

The first term can be estimated by the expression

$$H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{h(h-1)}$$

which has the approximate expected value of

$$E\left[H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{h(h-1)}\right] = \\ H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{H}\left(V_jR_j - RV_j\right)^2}{h(h-1)} + \frac{H^2\left(1-\frac{h}{H}\right)}{hH}\sum_{j=1}^{H}V_j^2\cdot\mathrm{Var}\left(\hat{R}_j\right) \tag{B2}$$

which has a positive bias of

$$\frac{H^2\left(1-\frac{h}{H}\right)}{hH}\sum_{j=1}^{H} V_j^2 \cdot \text{Var}\left(\hat{R}_j\right) \tag{B3}$$

which can be estimated by the quantity

$$\frac{H^2\left(1-\frac{h}{H}\right)}{h^2}\sum_{j=1}^{h} V_j^2 \, \widehat{\text{Var}}\left(\hat{R}_j\right).$$

Consequently, an unbiased variance estimate can be constructed as

$$\widehat{\text{Var}}\left(\hat{E}\right) = H^2\left(1-\frac{h}{H}\right)\frac{\sum_{i=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{h(h-1)} - \frac{H^2\left(1-\frac{h}{H}\right)}{h^2}\sum_{i=1}^{h} V_j^2 \, \widehat{\text{Var}}\left(\hat{R}_j\right) + \left(\frac{H}{h}\right)^2 \sum_{i=1}^{h} V_j^2 \, \widehat{\text{Var}}\left(\hat{R}_j\right)$$

which simplifies to

$$\widehat{\text{Var}}\left(\hat{E}\right) = H^2\left(1-\frac{h}{H}\right)\frac{\sum_{i=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{h(h-1)} + \frac{H}{h}\sum_{j=1}^{h} V_j^2 \cdot \widehat{\text{Var}}\left(\hat{R}_j\right). \tag{B4}$$

Appendix C: Sample Analysis of Crab Entrainment

Data

Consider the simple case of $H = 7$ hauls of which $h = 3$ were actually sampled. The haul volumes of the $H = 7$ hauls are as follows:

Haul	Volume (Y^3)
1	5,000
2	5,050
3	5,500
4	5,550
5	5,400
6	5,100
7	5,250
Total	36,850

The three hauls selected for sampling are 2, 5, and 6. The sample results by basket sample per haul are presented below:

	Haul #2		
	$C_{11} = 5$	$w_{11} = 6$	$b = 5$
	$C_{12} = 3$	$w_{12} = 4$	
	$C_{13} = 7$	$w_{13} = 7$	
	$C_{14} = 8$	$w_{14} = 7$	
	$C_{15} = 12$	$w_{15} = 9$	
Total	35	33	
Mean		6.6	

$$\hat{R}_1 = \frac{35}{33} = 1.0\overline{606}$$

	Haul #5		
	$C_{21} = 0$	$w_{21} = 5$	$b = 4$
	$C_{22} = 1$	$w_{22} = 6$	
	$C_{23} = 2$	$w_{23} = 6$	
	$C_{24} = 1$	$w_{24} = 5$	
Total	4	22	
Mean		5.5	

$$\hat{R}_2 = \frac{4}{22} = 0.18\overline{18}$$

	Haul #6		
	$C_{31} = 10$	$w_{31} = 7$	$b = 5$
	$C_{32} = 11$	$w_{32} = 8$	
	$C_{33} = 8$	$w_{33} = 6$	
	$C_{34} = 13$	$w_{34} = 8$	
	$C_{35} = 7$	$w_{35} = 6$	
Total	49	35	
Mean		7	

$$\hat{R}_3 = \frac{49}{35} = 1.40$$

Estimating E

Using Equation (2)

$$\hat{E}_i = \frac{\sum_{j=1}^{h}\left[V_j \frac{\sum_{l=1}^{b_j} c_{ijl}}{\sum_{l=1}^{b_j} w_{jl}}\right]}{\sum_{j=1}^{h} V_j} \cdot \sum_{j=1}^{H} V_j$$

$$\hat{E} = \frac{\left[5050\left(1.06\overline{06}\right) + 5400\left(0.18\overline{18}\right) + 5100\left(1.40\right)\right]}{\left[5050 + 5400 + 5100\right]} \cdot \left(36,850\right)$$

$$= \frac{13477.\overline{87}}{15550}\left(36,850\right)$$

$$\hat{E} = 0.866745\left(36,850\right) = 31,939.54 \text{ crabs}$$

Overall best estimate of density:

$$\hat{R} = \frac{1.06\overline{06}\left(5050\right) + 0.18\overline{18}\left(5400\right) + 1.40\left(5100\right)}{5050 + 5400 + 5100}$$

$$= \frac{13477.\overline{87}}{15550}$$

$$\hat{R} = 0.866745 \text{ crabs/}Y^3$$

Estimating the Variance

Using Eq. (4)

$$\widehat{\mathrm{Var}}\left(\hat{E}\right) = \left(1 - \frac{h}{H}\right)\frac{\sum_{j=1}^{h}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{\left(h-1\right)} + \frac{H}{h}\sum_{j=1}^{h} V_j^2 \cdot \widehat{\mathrm{Var}}\left(\hat{R}_j\right)$$

or more specifically

$$\widehat{\mathrm{Var}}\left(\hat{E}\right) = \left(1 - \frac{3}{7}\right)\frac{\sum_{j=1}^{3}\left(V_j\hat{R}_j - \hat{R}V_j\right)^2}{\left(3-1\right)} + \frac{7}{3}\sum_{j=1}^{3} V_j^2 \cdot \widehat{\mathrm{Var}}\left(\hat{R}_j\right)$$

Estimating the First Term of Eq. (4)

$$\frac{\left(1-\frac{3}{7}\right)\left[\left(5050\left(1.06\overline{06}\right)-0.866745(5050)\right)^2 + \left(5400\left(0.18\overline{18}\right)-0.866745(5400)\right)^2 + \left(5100(1.40)-0.866745(5100)\right)^2\right]}{(3-1)} = \frac{0.571428(22034342.26)}{2}$$

$$= 6,295,526.361$$

Estimating the Second Term of Equation (4)

Hauls	V_j	$\widehat{\text{Var}}\left(\hat{R}_j\right)$
1	5050	0.0114088544
2	5400	0.0045989573
3	5100	0.0055510204

Note:

$$\widehat{\text{Var}}\left(\hat{R}_1\right) = \frac{\left[\left(5-1.\overline{06}(6)\right)^2 + \left(3-1.\overline{06}(4)\right)^2 \cdots \left(12-1.\overline{06}(9)\right)^2\right]}{(6.6)^2\, 5(5-1)}$$

$$= \frac{9.93\overline{93}}{871.2}$$

$$= 0.0114088544$$

Note:

$$\widehat{\text{Var}}\left(\hat{R}_2\right) = \frac{\left[\left(0-5\left(0.18\overline{18}\right)\right)^2 + \left(1-6\left(0.18\overline{18}\right)^2\right) + \ldots \left(1-5\left(0.18\overline{18}\right)^2\right)\right]}{(5.5)^2\, 4(4-1)}$$

$$= \frac{1.669421488}{363}$$

$$= 0.0045989573$$

Note:

$$\widehat{\text{Var}}\left(\hat{R}_3\right) = \frac{\left[(10-7(1.4))^2 + \left(11-8(1.4)^2\right) + \ldots + \left(7-6(1.4)^2\right)\right]}{(7)^2\,5(5-1)}$$
$$= \frac{5.44}{980}$$
$$= 0.0055510204$$

The second term then becomes

$$\frac{7}{3}\left[(5050)^2(0.0114\ldots) + (5400)^2(0.004598\ldots) + (5100)(0.005551\ldots)\right] = 569{,}441.944$$

The Overall Variance Estimate is then

$$\widehat{\text{Var}}\left(\hat{E}\right) = 6{,}295{,}526.361 + 569{,}441.944$$
$$= 6{,}864{,}968.305$$

Standard Error

$$\widehat{\text{SE}}\left(\hat{E}\right) = \sqrt{\widehat{\text{Var}}\left(\hat{E}\right)} = 2620.11$$

Coefficient of Variation

$$\widehat{\text{CV}}\left(\hat{E}\right) = \frac{2620.11}{31939.54} = 0.0820 \text{ or } 8.2\%$$

Appendix D: Anticipated CV of $\hat{E}$

The variance of the estimate of total entrainment can be written as

$$\begin{aligned}\operatorname{Var}\left(\hat{E}\right) &= H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{H}\left(V_jR_j - V_jR\right)^2}{h(H-1)} + \frac{H}{h}\sum_{j=1}^{H}V_j^2\operatorname{Var}\left(\hat{R}_j\right) \\ &= H^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1} V_j^2\left(R_j - R\right)^2}{h(H-1)} + \frac{H}{h}\sum_{j=1}^{H}V_j^2\operatorname{Var}\left(\hat{R}_j\right)\end{aligned}$$

Letting $V_j = V \ \forall_j$, then

$$\begin{aligned}\operatorname{Var}\left(\hat{E}\right) &= H^2V^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{H}\left(R_j - R\right)^2}{h(H-1)} + \frac{H^2V^2\,\overline{\operatorname{Var}\left(\hat{R}_j\right)}}{h} \\ &= V_{\cdot}^2\left(1-\frac{h}{H}\right)\frac{\sum_{j=1}^{H}\left(R_j - R\right)^2}{h(H-1)} + \frac{V_{\cdot}^2\,\overline{\operatorname{Var}\left(\hat{R}_j\right)}}{h}\end{aligned}$$

where

$V_{\cdot} = \sum_{j=1}^{H}V_j$. Let $\sigma_{R_j}^2 = \dfrac{\sum_{j=1}^{H}\left(R_j - R\right)^2}{(H-1)}$, then

$$\operatorname{Var}\left(\hat{E}\right) = V_{\cdot}^2\left[\left(1-\frac{h}{H}\right)\frac{\sigma_{R_j}^2}{h} + \frac{\overline{\operatorname{Var}\left(R_j\right)}}{h}\right].$$

Then

$$
\begin{aligned}
\mathrm{CV}(\hat{E}) &= \frac{\sqrt{\mathrm{Var}(\hat{E})}}{E} \\
&= \frac{\sqrt{V_{\square}^{2}\left[\left(1-\frac{h}{H}\right)\frac{\sigma_{R_j}^{2}}{h} + \frac{\overline{\mathrm{Var}(\hat{R}_j)}}{h}\right]}}{V_{\square}R} \\
&= \sqrt{\left(1-\frac{h}{H}\right)\frac{\sigma_{R_j}^{2}}{R^{2}h} + \frac{\overline{\mathrm{Var}(\hat{R}_j)}}{R^{2}h}} \\
\mathrm{CV}(\hat{E}) &= \sqrt{\left(1-\frac{h}{H}\right)\mathrm{CV}(\hat{R}_j)^{2} + \frac{\overline{\mathrm{Var}(\hat{R}_j)}}{R^{2}h}}.
\end{aligned}
\tag{D1}
$$

Estimate $\overline{\mathrm{Var}(\hat{R}_j)}$ by the term

$$
\begin{aligned}
\mathrm{Var}(\hat{R}_j) &= \frac{\left(1-\frac{b}{B}\right)\sum_{i=1}^{B}\left(c_i - R_j w_i\right)^{2}}{b\overline{w}^{2}(B-1)} \\
&\approx \frac{\sum_{i=1}^{B}\left(c_i - R_j w_i\right)^{2}}{b(\overline{w})^{2}(B-1)}.
\end{aligned}
$$

Then if $w_i = \overline{w}\ \forall_i$, then

$$
\mathrm{Var}(\hat{R}_j) = \frac{\sum_{i=1}^{B}\left(c_i - \overline{c}\right)^{2}}{b\overline{w}^{2}(B-1)}
$$

which can be estimated by

$$
\widehat{\mathrm{Var}}(R_j) = \frac{s_{c_i}^{2}}{b\overline{w}^{2}}. \tag{D2}
$$

Substituting (D2) into (D1) where

$$\mathrm{CV}(\hat{E}) = \sqrt{\frac{\left(1-\frac{h}{H}\right)\mathrm{CV}(R_j)^2}{h} + \frac{s_{c_i}^2}{b\bar{w}^2 R^2 h}}$$
$$= \sqrt{\frac{\left(1-\frac{h}{H}\right)\mathrm{CV}(R_j)^2}{h} + \frac{\bar{s}_{c_i}^2}{b\bar{c}^2 h}}$$

$$\mathrm{CV}(\hat{E}) = \sqrt{\frac{\left(1-\frac{h}{H}\right)\mathrm{CV}(R_j)^2}{h} + \frac{\mathrm{CV}(c_i)^2}{bh}}. \qquad \text{(D3)}$$

APPENDIX B

Basket Sample Data, Desdemona Shoals Entrainment Sampling 2006

Table B-1. Sampling Time, Bottom Salinity and Temperature, and Dredging Conditions

Load Sequence Number	Date	Sample Number	Start Time (hhmm)	Sample Time (s, valve start closing)	Total Sampling Interval (s, start open to end close)	Effective Sampling Time (s)	Bottom Water Temperature (°C)	Bottom Water Salinity (psu)	Vessel Direction	Tide Stage
06-01	06/15/06	1	1338	30	43	36.4	16.1	19.9	Upstream	Rising
06-01	06/15/06	3	1454	30	43	36.4	15.5	24.1	Upstream	Rising
06-01	06/15/06	4	1537	30	43	36.4	15.3	24.4	Downstream	High Slack
06-02	06/15/06	1	2004	30	43	36.4	15.0	22.6	Upstream	Falling
06-02	06/15/06	2	2039	30	43	36.4	14.7	24.0	Upstream	Falling
06-02	06/15/06	3	2120	30	43	36.4	not recorded	not recorded	Upstream	Falling
06-03	06/15/06	1	2335	30	43	36.4	not recorded	not recorded	Upstream	Rising
06-04	06/16/06	1	0129	15	28	21.4	14.4	21.7	Upstream	Rising
06-04	06/16/06	2	0145	15	28	21.4	14.5	20.6	Upstream	Rising
06-05	06/16/06	1	0337	15	28	21.4	14.7	19.1	Upstream	Rising
06-05	06/16/06	2	0403	15	28	21.4	14.7	19.1	Upstream	Rising
06-06	06/16/06	1	0519	15	28	21.4	14.9	21.5	Upstream	Falling
06-06	06/16/06	2	0550	15	28	21.4	14.8	20.1	Upstream	Falling
06-07	06/16/06	1	0755	15	28	21.4	14.9	18.1	Upstream	Falling
06-07	06/16/06	2	0853	15	28	21.4	15.0	14.8	Upstream	Falling
06-08	06/16/06	1	1051	15	28	21.4	16.3	3.5	Upstream	Falling
06-08	06/16/06	2	1106	15	28	21.4	16.2	4.0	Upstream	Falling
06-09	06/16/06	1	1255	15	28	21.4	17.3	2.4	not recorded	Rising
06-10	06/16/06	1	1500	15	28	21.4	16.5	20.6	Downstream	Rising
06-10	06/16/06	2	1520	15	28	21.4	16.4	21.5	Downstream	Rising
06-10	06/16/06	3	1551	15	28	21.4	16.0	22.5	Downstream	Rising
06-11	06/16/06	1	1651	15	28	21.4	16.0	23.6	Downstream	Rising
06-11	06/16/06	2	1716	15	28	21.4	15.6	24.3	Downstream	Rising
06-11	06/16/06	3	1730	15	28	21.4	15.2	23.3	Downstream	Rising
06-12	06/16/06	1	1806	15	28	21.4	15.1	24.0	Upstream	Rising
06-12	06/16/06	2	1838	15	28	21.4	14.7	23.3	Upstream	Falling

Table B-1. Sampling Time, Bottom Salinity and Temperature, and Dredging Conditions (continued)

Load Sequence Number	Date	Sample Number	Start Time (hhmm)	Sample Time (s, valve start closing)	Total Sampling Interval (s, start open to end close)	Effective Sampling Time (s)	Bottom Water Temperature (°C)	Bottom Water Salinity (psu)	Vessel Direction	Tide Stage
06-12	06/16/06	3	1851	15	28	21.4	14.9	24.1	Upstream	Falling
06-13	06/16/06	1	1930	15	28	21.4	15.1	23.4	Upstream	Falling
06-13	06/16/06	2	1946	15	28	21.4	not recorded	not recorded	Upstream	Falling
06-13	06/16/06	3	2022	15	28	21.4	14.9	21.3	Upstream	Falling
06-14	06/16/06	1	2118	15	28	21.4	15.2	19.5	Downstream	Falling
06-14	06/16/06	2	2135	15	28	21.4	15.1	18.4	Upstream	Falling
06-14	06/16/06	3	2150	15	28	21.4	not recorded	not recorded	not recorded	Falling
06-15	06/16/06	1	2217	15	28	21.4	15.4	16.2	Upstream	Falling
06-15	06/16/06	2	2229	15	28	21.4	15.1	14.9	Upstream	Falling
06-15	06/16/06	3	2240	15	28	21.4	14.5	17.5	Upstream	Falling
06-16	06/16/06	1	2339	15	28	21.4	14.9	11.7	Upstream	Low Slack
06-16	06/16/06	2	2351	15	28	21.4	14.6	20.4	Upstream	Low Slack
06-16	06/17/06	3	0017	15	28	21.4	15.8	5.3	Upstream	Rising
06-17	06/17/06	1	0059	15	28	21.4	15.6	8.9	Upstream	Rising
06-17	06/17/06	2	0107	15	28	21.4	15.5	6.9	Upstream	Rising
06-17	06/17/06	3	0116	15	28	21.4	15.4	8.6	Upstream	Rising
06-18	06/17/06	1	0144	15	28	21.4	15.3	14.9	Upstream	Rising
06-18	06/17/06	2	0152	15	28	21.4	15.3	17.4	Upstream	Rising
06-18	06/17/06	3	0208	15	28	21.4	15.2	13.4	Downstream	Rising
06-19	06/17/06	1	0235	15	28	21.4	14.9	19.4	Downstream	Rising
06-19	06/17/06	2	0246	15	28	21.4	14.9	22.4	Downstream	Rising
06-19	06/17/06	3	0254	15	28	21.4	14.5	22.1	Downstream	Rising
06-20	06/17/06	1	0321	15	28	21.4	14.1	24.1	Downstream	Rising
06-20	06/17/06	2	0332	15	28	21.4	14.5	24.7	Downstream	Rising
06-20	06/17/06	3	0346	15	28	21.4	14.3	26.2	Downstream	Rising
06-21	06/17/06	1	0407	15	28	21.4	14.4	24.9	Downstream	Rising
06-21	06/17/06	2	0421	15	28	21.4	14.4	25.9	Downstream	Rising

Table B-1. Sampling Time, Bottom Salinity and Temperature, and Dredging Conditions (continued)

Load Sequence Number	Date	Sample Number	Start Time (hhmm)	Sample Time (s, valve start closing)	Total Sampling Interval (s, start open to end close)	Effective Sampling Time (s)	Bottom Water Temperature (°C)	Bottom Water Salinity (psu)	Vessel Direction	Tide Stage
06-21	06/17/06	3	0432	15	28	21.4	14.4	24.6	Downstream	Rising
06-22	06/17/06	1	0454	15	28	21.4	14.3	26.3	Downstream	Rising
06-22	06/17/06	2	0509	15	28	21.4	14.1	26.7	Downstream	Rising
06-22	06/17/06	3	0517	15	28	21.4	14.3	27.0	Downstream	High Slack
06-23	06/17/06	1	0545	15	28	21.4	14.3	26.7	Downstream	High Slack
06-23	06/17/06	2	0552	15	28	21.4	14.3	26.3	not recorded	Falling
06-23	06/17/06	3	0600	15	28	21.4	14.2	25.7	Downstream	Falling
06-24	06/17/06	1	0632	15	28	21.4	14.4	21.6	Downstream	Falling
06-24	06/17/06	2	0652	15	28	21.4	not recorded	not recorded	Upstream	Falling
06-24	06/17/06	3	0701	15	28	21.4	14.4	15.6	Upstream	Falling
06-25	06/17/06	1	0749	15	28	21.4	14.5	20.6	Upstream	Falling
06-25	06/17/06	2	0755	15	28	21.4	14.7	21.5	Upstream	Falling
06-25	06/17/06	3	0811	15	28	21.4	14.9	22.6	Upstream	Falling
06-26	06/17/06	1	0927	15	28	21.4	15.2	18.6	Upstream	Falling
06-26	06/17/06	2	0940	15	28	21.4	15.2	20.9	Upstream	Falling
06-26	06/17/06	3	0915	15	28	21.4	15.4	21.2	Upstream	Falling

Table B-2. Dungeness Crab in Basket Samples

Load Sequence Number	Date	Sample Number	Substrate Type	Number YOY Sex UID <50 mm	No. of MALE 1+ 51-100	No. of MALE 2+ 101-150	No. of MALE 3+ >150	No. of FEMALE 1+ 51-100	No. of FEMALE 2+ 101-150	No. of FEMALE 3+ >150	No. of UID Sex 1+ 51-100	No. of UID Sex 2+ 101-150	No. of UID Sex 3+ >150	UID Pieces	Total in Age/Size Class 0+ <50	Total in Age/Size Class 1+ 51-100	Total in Age/Size Class 2+ 101-150	Total in Age/Size Class 3+ >150	Total Crab
06-01	06/15/06	1	G, M, S, WC	1										N	1	0	0	0	1
06-01	06/15/06	3	SH	3		1			1					N	3	0	2	0	5
06-01	06/15/06	4	M, S, WC	2										N	2	0	0	0	2
06-02	06/15/06	1	M,S	4		1								N	4	0	1	0	5
06-02	06/15/06	2	S, G, SH	2								1		N	2	0	1	0	3
06-02	06/15/06	3	MF	0										N	0	0	0	0	0
06-03	06/15/06	1	M, MF, WC											N	0	0	0	0	0
06-04	06/16/06	1	M,S	2										N	2	0	0	0	2
06-04	06/16/06	2	M, S, WC											N	0	0	0	0	0
06-05	06/16/06	1	S, WC									1		N	0	0	1	0	1
06-05	06/16/06	2	M, S, WC											N	0	0	0	0	0
06-06	06/16/06	1	MF, WC											N	0	0	0	0	0
06-06	06/16/06	2	S, WC											N	0	0	0	0	0
06-07	06/16/06	1	S, WC											Y	0	0	0	0	0
06-07	06/16/06	2	S, WC											N	0	0	0	0	0
06-08	06/16/06	1	M, WC											N	0	0	0	0	0
06-08	06/16/06	2	WC	1		1						1		Y	1	0	2	0	3
06-09	06/16/06	1	S, WC											Y	0	0	0	0	0
06-10	06/16/06	1	M, WC, RH	5										Y	5	0	0	0	5

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-2. Dungeness Crab in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Number YOY	Number of MALE Crabs			Number of FEMALE Crabs			Number of UID Sex			UID	Total in Age/Size Class				Total
				Sex UID <50 mm	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	Pieces	0+ <50	1+ 51-100	2+ 101-150	3+ >150	Crab
06-10	06/16/06	2	M, WC	3										Y	3	0	0	0	3
06-10	06/16/06	3	M, WC, O	1										Y	1	0	0	0	1
06-11	06/16/06	1	M											Y	0	0	0	0	0
06-11	06/16/06	2	M, WC	1										N	1	0	0	0	1
06-11	06/16/06	3	M, WC, SH											N	0	0	0	0	0
06-12	06/16/06	1	M, MF, WC	7								1		N	7	0	1	0	8
06-12	06/16/06	2	M, MF, WC											N	0	0	0	0	0
06-12	06/16/06	3	nd	2										N	2	0	0	0	2
06-13	06/16/06	1	MF, SH	1								1		N	1	0	1	0	2
06-13	06/16/06	2	nd	3										N	3	0	0	0	3
06-13	06/16/06	3	nd											N	0	0	0	0	0
06-14	06/16/06	1	MF, MB											N	0	0	0	0	0
06-14	06/16/06	2	MF, S, SH	2										N	2	0	0	0	2
06-14	06/16/06	3	nd	2										N	2	0	0	0	2
06-15	06/16/06	1	nd	1					1					N	1	0	1	0	2
06-15	06/16/06	2	MF, SH, WC											N	0	0	0	0	0
06-15	06/16/06	3	M, WC	1										N	1	0	0	0	1
06-16	06/16/06	1	nd	4									1	N	4	0	0	1	5
06-16	06/16/06	2	nd	2										N	2	0	0	0	2

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-2. Dungeness Crab in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Number YOY	Number of MALE Crabs			Number of FEMALE Crabs			Number of UID Sex			UID	Total in Age/Size Class				Total
				Sex UID <50 mm	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	Pieces	0+ <50	1+ 51-100	2+ 101-150	3+ >150	Crab
06-16	06/17/06	3	nd											N	0	0	0	0	0
06-17	06/17/06	1	MF, WC											N	0	0	0	0	0
06-17	06/17/06	2	MF, WC									1		N	0	0	1	0	1
06-17	06/17/06	3	MF, SH, WC											N	0	0	0	0	0
06-18	06/17/06	1	nd	1								1		N	1	0	1	0	2
06-18	06/17/06	2	MF, WC											N	0	0	0	0	0
06-18	06/17/06	3	MF, WC											N	0	0	0	0	0
06-19	06/17/06	1	MF, WC	1										Y	1	0	0	0	1
06-19	06/17/06	2	MF, WC	1										N	1	0	0	0	1
06-19	06/17/06	3	M, WC											N	0	0	0	0	0
06-20	06/17/06	1	M, S, WC, SH											N	0	0	0	0	0
06-20	06/17/06	2	nd											N	0	0	0	0	0
06-20	06/17/06	3	M, G, SH, WC											N	0	0	0	0	0
06-21	06/17/06	1	M, MF, SH, WC	1										N	1	0	0	0	1
06-21	06/17/06	2	M, MF, SH, WC	1										N	1	0	0	0	1
06-21	06/17/06	3	M, MF, SH, WC											N	0	0	0	0	0
06-22	06/17/06	1	M, MF, SH	1										N	1	0	0	0	1
06-22	06/17/06	2	nd			1								N	0	0	1	0	1
06-22	06/17/06	3	nd			1								N	0	0	1	0	1

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-2. Dungeness Crab in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Number YOY	Number of MALE Crabs			Number of FEMALE Crabs			Number of UID Sex			UID	Total in Age/Size Class				Total
				Sex UID <50 mm	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	1+ 51-100	2+ 101-150	3+ >150	Pieces	0+ <50	1+ 51-100	2+ 101-150	3+ >150	Crab
06-23	06/17/06	1	M, SH, WC											N	0	0	0	0	0
06-23	06/17/06	2	MF, SH, WC	1		1								N	1	0	1	0	2
06-23	06/17/06	3	M, MF, SH, WC	1										Y	1	0	0	0	1
06-24	06/17/06	1	M, S, WC											N	0	0	0	0	0
06-24	06/17/06	2	SH, WC											N	0	0	0	0	0
06-24	06/17/06	3	SH, WC											Y	0	0	0	0	0
06-25	06/17/06	1	M, WC	1										N	1	0	0	0	1
06-25	06/17/06	2	M, WC											N	0	0	0	0	0
06-25	06/17/06	3	M, WC	1										N	1	0	0	0	1
06-26	06/17/06	1	M, S, G, WC											Y	0	0	0	0	0
06-26	06/17/06	2	M, WC											Y	0	0	0	0	0
06-26	06/17/06	3	M, G, WC											Y	0	0	0	0	0
06-23	06/17/06	1	M, SH, WC											N	0	0	0	0	0
06-23	06/17/06	2	MF, SH, WC	1		1								N	1	0	1	0	2
06-23	06/17/06	3	M, MF, SH, WC	1										Y	1	0	0	0	1
06-24	06/17/06	1	M, S, WC											N	0	0	0	0	0
06-24	06/17/06	2	SH, WC											N	0	0	0	0	0
06-24	06/17/06	3	SH, WC											Y	0	0	0	0	0
06-25	06/17/06	1	M, WC	1										N	1	0	0	0	1

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-3. Fish in Basket Samples

Load Sequence Number	Date	Sample Number	Substrate Type	Fish Counts									
				Snake Prickleback	Staghorn Sculpin	Shiner Perch	Sand Sole	Pacific Sandlance	Northern Anchovy	Pacific Lamprey	Saddleback Gunnel	UID Snailfish	Longfin Smelt
06-01	06/15/06	1	G, M, S, WC	2									
06-01	06/15/06	3	SH	1	1		2	1					
06-01	06/15/06	4	M, S, WC		1								
06-02	06/15/06	1	M,S	0	0				0				
06-02	06/15/06	2	S, G, SH	1	1				1				
06-02	06/15/06	3	MF	0	0				0				
06-03	06/15/06	1	M, MF, WC										
06-04	06/16/06	1	M,S								1		
06-04	06/16/06	2	M, S, WC										
06-05	06/16/06	1	S, WC										
06-05	06/16/06	2	M, S, WC										
06-06	06/16/06	1	MF, WC										
06-06	06/16/06	2	S, WC					1					
06-07	06/16/06	1	S, WC										
06-07	06/16/06	2	S, WC										
06-08	06/16/06	1	M, WC										
06-08	06/16/06	2	WC	1									
06-09	06/16/06	1	S, WC										
06-10	06/16/06	1	M, WC, RH		1	1		1					

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-3. Fish in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Fish Counts									
				Snake Prickleback	Staghorn Sculpin	Shiner Perch	Sand Sole	Pacific Sandlance	Northern Anchovy	Pacific Lamprey	Saddleback Gunnel	UID Snailfish	Longfin Smelt
06-10	06/16/06	2	M, WC	2				1					
06-10	06/16/06	3	M, WC, O	2									
06-11	06/16/06	1	M										
06-11	06/16/06	2	M, WC	2		1					1		
06-11	06/16/06	3	M, WC, SH										
06-12	06/16/06	1	M, MF, WC	1									
06-12	06/16/06	2	M, MF, WC										
06-12	06/16/06	3	nd									1	
06-13	06/16/06	1	MF, SH										
06-13	06/16/06	2	nd							1			
06-13	06/16/06	3	nd					2					
06-14	06/16/06	1	MF, MB										
06-14	06/16/06	2	MF, S, SH										
06-14	06/16/06	3	nd						1				
06-15	06/16/06	1	nd						1				
06-15	06/16/06	2	MF, SH, WC										
06-15	06/16/06	3	M, WC										
06-16	06/16/06	1	nd	1			1						

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-3. Fish in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Fish Counts									
				Snake Prickleback	Staghorn Sculpin	Shiner Perch	Sand Sole	Pacific Sandlance	Northern Anchovy	Pacific Lamprey	Saddleback Gunnel	UID Snailfish	Longfin Smelt
06-16	06/16/06	2	nd	1									
06-16	06/17/06	3	nd										
06-17	06/17/06	1	MF, WC										
06-17	06/17/06	2	MF, WC										
06-17	06/17/06	3	MF, SH, WC										
06-18	06/17/06	1	nd										
06-18	06/17/06	2	MF, WC										
06-18	06/17/06	3	MF, WC										
06-19	06/17/06	1	MF, WC			1							
06-19	06/17/06	2	MF, WC										
06-19	06/17/06	3	M, WC										
06-20	06/17/06	1	M, S, WC, SH										
06-20	06/17/06	2	nd										
06-20	06/17/06	3	M, G, SH, WC		1								
06-21	06/17/06	1	M, MF, SH, WC										
06-21	06/17/06	2	M, MF, SH, WC										
06-21	06/17/06	3	M, MF, SH, WC										
06-22	06/17/06	1	M, MF, SH										

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-3. Fish in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Fish Counts									
				Snake Prickleback	Staghorn Sculpin	Shiner Perch	Sand Sole	Pacific Sandlance	Northern Anchovy	Pacific Lamprey	Saddleback Gunnel	UID Snailfish	Longfin Smelt
06-22	06/17/06	2	nd			1							1
06-22	06/17/06	3	nd										
06-23	06/17/06	1	M, SH, WC								1		
06-23	06/17/06	2	MF, SH, WC										
06-23	06/17/06	3	M, MF, SH, WC				1	1					
06-24	06/17/06	1	M, S, WC										
06-24	06/17/06	2	SH, WC										
06-24	06/17/06	3	SH, WC										
06-25	06/17/06	1	M, WC										
06-25	06/17/06	2	M, WC										
06-25	06/17/06	3	M, WC					1	1				
06-26	06/17/06	1	M, S, G, WC										
06-26	06/17/06	2	M, WC					1					
06-26	06/17/06	3	M, G, WC				1						

a. Substrate Codes:
S=Sand
M=Mud
MB=Mud Balls
MF=Mixed Fines
G=Gravel
SH=Shell Hash
WC=Wood Chips
RH=Rhizomes
O=Other

Table B-4. Other Organisms in Basket Samples

Load Sequence Number	Date	Sample Number	Substrate Type	Crangon Shrimp			Razor Clams	Polychaetes	Amphipods	Isopods	Pink Clams	Olives
				Total (All)	Small (<50 mm)	Large (>50 mm)						
06-01	06/15/06	1	G, M, S, WC	242	189	53						
06-01	06/15/06	3	SH	251	120	131						
06-01	06/15/06	4	M, S, WC	100	40	60						
06-02	06/15/06	1	M,S	10	3	7						
06-02	06/15/06	2	S, G, SH	31	10	21						
06-02	06/15/06	3	MF	8	4	4						
06-03	06/15/06	1	M, MF, WC	2		2						
06-04	06/16/06	1	M,S	2		2						
06-04	06/16/06	2	M, S, WC	1								
06-05	06/16/06	1	S, WC	6					1			
06-05	06/16/06	2	M, S, WC									
06-06	06/16/06	1	MF, WC									
06-06	06/16/06	2	S, WC	13	3	10				1	1	
06-07	06/16/06	1	S, WC	1	1							
06-07	06/16/06	2	S, WC	4	4							
06-08	06/16/06	1	M, WC	4	4							
06-08	06/16/06	2	WC	1	1						3	
06-09	06/16/06	1	S, WC	21	21						2	
06-10	06/16/06	1	M, WC, RH	108	69	39		11	2			
06-10	06/16/06	2	M, WC	89	70	19		4				
06-10	06/16/06	3	M, WC, O	41	25	16		4				
06-11	06/16/06	1	M	15	7	8						
06-11	06/16/06	2	M, WC	73	43	30		3				
06-11	06/16/06	3	M, WC, SH	17	10	7						

a. Substrate Codes:

S=Sand
M=Mud
MB=Mud Balls
MF=Mixed Fines
G=Gravel
SH=Shell Hash
WC=Wood Chips
RH=Rhizomes
O=Other

Table B-4. Other Organisms in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Crangon Shrimp			Razor Clams	Polychaetes	Amphipods	Isopods	Pink Clams	Olives
				Total (All)	Small (<50 mm)	Large (>50 mm)						
06-12	06/16/06	1	M, MF, WC	171	103	68		4				
06-12	06/16/06	2	M, MF, WC	11	6	5						
06-12	06/16/06	3	nd	41	17	24		3				
06-13	06/16/06	1	MF, SH	5	2	3		1				
06-13	06/16/06	2	nd	16	6	10		1				
06-13	06/16/06	3	nd	4		4						
06-14	06/16/06	1	MF, MB	4	3	1		1				
06-14	06/16/06	2	MF, S, SH	2	1	1						
06-14	06/16/06	3	nd	1	1	1						
06-15	06/16/06	1	nd	11	8	3		1				
06-15	06/16/06	2	MF, SH, WC	2	1	1						
06-15	06/16/06	3	M, WC									
06-16	06/16/06	1	nd	2	1	1						
06-16	06/16/06	2	nd	2	0	1						
06-16	06/17/06	3	nd									
06-17	06/17/06	1	MF, WC	3	3			1				
06-17	06/17/06	2	MF, WC	5	4	1						
06-17	06/17/06	3	MF, SH, WC	2	1	1						
06-18	06/17/06	1	nd									
06-18	06/17/06	2	MF, WC	3	3							
06-18	06/17/06	3	MF, WC	6	5	1						
06-19	06/17/06	1	MF, WC	3		3						
06-19	06/17/06	2	MF, WC	3	2	1						
06-19	06/17/06	3	M, WC	3	1	2						

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

Table B-4. Other Organisms in Basket Samples (continued)

Load Sequence Number	Date	Sample Number	Substrate Type	Crangon Shrimp			Razor Clams	Polychaetes	Amphipods	Isopods	Pink Clams	Olives
				Total (All)	Small (<50 mm)	Large (>50 mm)						
06-20	06/17/06	1	M, S, WC, SH	1	1							
06-20	06/17/06	2	nd	4		4						
06-20	06/17/06	3	M, G, SH, WC									
06-21	06/17/06	1	M, MF, SH, WC	1	1							
06-21	06/17/06	2	M, MF, SH, WC	4		4						
06-21	06/17/06	3	M, MF, SH, WC									
06-22	06/17/06	1	M, MF, SH	3		3						
06-22	06/17/06	2	nd									
06-22	06/17/06	3	nd	7		7						
06-23	06/17/06	1	M, SH, WC	34	14	20						
06-23	06/17/06	2	MF, SH, WC	2		2						
06-23	06/17/06	3	M, MF, SH, WC	13	9	4						
06-24	06/17/06	1	M, S, WC	6	2	4						
06-24	06/17/06	2	SH, WC	2	2							
06-24	06/17/06	3	SH, WC	2	2							
06-25	06/17/06	1	M, WC						1			
06-25	06/17/06	2	M, WC									
06-25	06/17/06	3	M, WC	1		1		2				
06-26	06/17/06	1	M, S, G, WC									
06-26	06/17/06	2	M, WC	1		1		1	1			8
06-26	06/17/06	3	M, G, WC									

a. Substrate Codes: S=Sand, M=Mud, MB=Mud Balls, MF=Mixed Fines, G=Gravel, SH=Shell Hash, WC=Wood Chips, RH=Rhizomes, O=Other

APPENDIX C

Dredge Impact Model Estimates of Crab Losses, Desdemona Shoals 2006

Table C-1. Summary of Calculation of Adult Equivalent Loss
Based on Modified Dredge Impact Model and Direct Measurement of Entrainment Rates

This calculation run is for

Location	Start Date	End Date	Total Volume Dredged V (cy)
Desdemona	***15-Jun-06***	***17-Jun-06***	***77252***

Overall Summary Statements

Adult Equivalent Loss of all age classes taken to 2+ is	**2604**	with 95% CI	**2338**
We are 95% confident that the true value lies between	**267**	and	**4942**
Adult Equivalent Loss of all age classes taken to 3+ is	**1172**	with 95% CI	**1052**
We are 95% confident that the true value lies between	**120**	and	**2224**
Number of MALE recruits lost to fishery is estimated to be	**410**	with 95% CI	**368**
We are 95% confident that the true value lies between	**42**	and	**778**

Sex Ratios by Age Class Derived from Field Observations

Age Class	Total			Measured Proportion		Proportion for DIM		
	Male	Female	Sexed	Male	Female	Male	Female	
YOY	NA	NA	0	NA	NA	0.50	0.50	* low sample size - ratio assumed to be 1:1.
1+	0	0	0	NA	NA	0.50	0.50	* low sample size - ratio assumed to be 1:1.
2+	6	2	8	0.75	0.25	0.50	0.50	* low sample size - ratio assumed to be 1:1.
3+	0	0	0	NA	NA	0.50	0.50	* low sample size - ratio assumed to be 1:1.

Estimates of Crab Entrainment Rate (R), Number of Crabs Entrained (E), Adult Equivalent Loss (AEL at 2+), and Variance (AEL at 2+)

Age Class	R (crab/cy)	E (crab in V)	Var(E)	M	S to 2+	AEL at 2+	VAR(AEL 2+)	AEL at 3+	VAR(AEL 3+)
YOY	0.18684	14434	6995481	0.10	0.017	24	19	11	4
1+	0.00000	0	0	0.60	0.160	0	0	0	0
2+	0.05190	4009	4189009	0.86	0.649	2238	1304961	1007	264255
3+	0.00232	179	32198	0.86	2.222	343	117576	154	23809
All	**0.2411**	**18622**	**11216688**			**2604**	**1422556**	**1172**	**288068**

Note: Entrained 3+ crab are back-calculated to provide AEL at 2+.

R = Crab entrainment rate (crab/cy)
E = Crabs Entrained (number of Crabs)
M = Post-Entrainment Mortality (proportion); taken from Armstrong et al 1987, Table 3.3, p. 61, for crabs collected in June-September
S = Natural Survivorship (proportion); Survival rates for crab to age 2+ are from Wainwright et al. 1992 Table 6, p. 178 for crab collected June-Sept. (*no data for June alone)*
AEL = Adult Equivalent Loss
VAR(AEL) =AEL Variance
AEL at 3+: Survival age 2+ to 3+ is assumed to be 45% (Armstrong et al. 1987)

Table C-1. Summary of Calculation of Adult Equivalent Loss … (con't.)

AGE 2+ Calculations

Contribution to Adult Equivalent Loss (AEL at 2+) and Variance (AEL at 2+) by Sex (MALE/FEMALE) and Age Class

Age Class	Female			Male		
	Proportion	AEL	VAR(AEL)	Proportion	AEL	VAR(AEL)
YOY	0.50	11.9	5	0.50	11.9	5
1+	0.50	0.0	0	0.50	0.0	0
2+	0.50	1118.9	326240	0.50	1118.9	326240
3+	0.50	171.4	29394	0.50	171.4	29394
All		**1302.2**	**355639**		**1302.2**	**355639**
						711278

Age Class Distribution

Age Class	% of Total	
	of Entrained	of AEL at 2+
YOY	77.51	0.91
1+	0.00	0.00
2+	21.53	85.92
3+	0.96	13.17

Age Class	Proportion of Total AEL 2+	
	Male	Female
YOY	0.0046	0.0046
1+	0.0000	0.0000
2+	0.4296	0.4296
3+	0.0658	0.0658
ALL	0.50	0.50

AGE 3+ Calculations

Contribution to Adult Equivalent Loss (AEL at 3+) and Variance (AEL at 3+) by Sex (MALE/FEMALE) and Age Class

Age Class	Female			Male		
	Proportion	AEL	VAR(AEL)	Proportion	AEL	VAR(AEL)
YOY	0.50	5.4	1	0.50	5.4	1
1+	0.50	0.0	0	0.50	0.0	0
2+	0.50	503.5	66064	0.50	503.5	66064
3+	0.50	77.2	5952	0.50	77.2	5952
All		**586.0**	**72017**		**586.0**	**72017**
					1172.019	144033.839

Age Class Distribution

Age Class	% of Total	
	of Entrained	of AEL at 3+
YOY	77.51	0.91
1+	0.00	0.00
2+	21.53	85.92
3+	0.96	13.17

Age Class	Proportion of Total AEL at 3+	
	Male	Female
YOY	0.0046	0.0046
1+	0.0000	0.0000
2+	0.4296	0.4296
3+	0.0658	0.0658
ALL	0.50	0.50

SUMMARY VARIANCE DATA

Entrainment with Confidence Limits

E	18622
Var(E)	11216688
SE E	3349
Z at 0.975	1.95996
95% C. I.	6564
CV E (%)	18.0%

TOTAL AEL at 2+ with Confidence Limits

AEL at 2+	2604
Var(AEL2+)	1422556
SE AEL	1193
Z at 0.975	1.95996
95% C. I.	2338
CV AEL (%)	45.8%

TOTAL AEL at 3+ with Confidence Limits

AEL at 3+	1172
Var(AEL3+)	288068
SE AEL	537
Z at 0.975	1.95996
95% C. I.	1052
CV AEL (%)	45.8%

SE = Standard Error
Z = Value of Z from Normal Distribution
C.I. = Confidence Interval
CV = Coefficient of Variation in %

MALE AEL at 3+ with Confidence Limits

AEL at 3+	586.0
Var(AEL)	72016.9
SE AEL	268.4
Z at 0.975	1.95996
95% C. I.	526.0
CV AEL (%)	45.8%

FEMALE AEL at 3+ with Confidence Limits

AEL at 3+	586.0
Var(AEL)	72016.9
SE AEL	268.4
Z at 0.975	1.95996
95% C. I.	526.0
CV AEL (%)	45.8%

TOTAL LOSS TO MALE FISHERY

(This total would be distributed over 3-4 years)

Male Age 3+ (number of crab)	Harvest Rate (proportion)	Lost to Fishery (number of crab)
586.0	0.70	**410**

Harvest rate of 0.70 is taken from Armstrong et al. (1987).

Loss to Fishery with Confidence Limits

Loss to Fishery	410.2
Var(AEL)	35288.3
SE LF	187.9
Z at 0.975	1.95996
95% C. I.	368.2
CV LF (%)	45.8%

Table C-2. Estimating Entrainment Rate, Total Entrainment, and Variance –Calculations

		Entrainment Rate, Crab/CY Rj				Var Rj (from Variance-by-load sheet)				Entrainment (E); Rj * Vj			
Load # (j)	Vj (CY)	YOY	1+	2+	3+	YOY	1+	2+	3+	YOY	1+	2+	3+
	Haul Volume	0-50	51-100	101-150	>150	0-50	51-100	101-150	>150	0-50	51-100	101-150	>150
06-01	4524	0.962	0.000	0.321	0.000	0.077	0.000	0.103	0.000	4352	0	1451	0
06-02	5030	0.328	0.000	0.109	0.000	0.036	0.000	0.003	0.000	1648	0	549	0
06-03	4290	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-04	3696	0.176	0.000	0.000	0.000	0.077	0.000	0.103	0.000	650	0	0	0
06-05	3605	0.000	0.000	0.082	0.000	0.036	0.000	0.003	0.000	0	0	297	0
06-06	3900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-07	4470	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-08	3939	0.083	0.000	0.165	0.000	0.007	0.000	0.027	0.000	325	0	650	0
06-09	4567	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-10	3500	0.558	0.000	0.000	0.000	0.046	0.000	0.000	0.000	1951	0	0	0
06-11	3226	0.059	0.000	0.000	0.000	0.003	0.000	0.000	0.000	191	0	0	0
06-12	3661	0.478	0.000	0.053	0.000	0.110	0.000	0.003	0.000	1750	0	194	0
06-13	4354	0.192	0.000	0.048	0.000	0.016	0.000	0.002	0.000	837	0	209	0
06-14	2100	0.178	0.000	0.000	0.000	0.008	0.000	0.000	0.000	374	0	0	0
06-15	2547	0.106	0.000	0.053	0.000	0.003	0.000	0.003	0.000	269	0	135	0
06-16	1666	0.646	0.000	0.000	0.108	0.139	0.000	0.000	0.012	1077	0	0	179
06-17	1745	0.000	0.000	0.066	0.000	0.000	0.000	0.004	0.000	0	0	116	0
06-18	1760	0.064	0.000	0.064	0.000	0.004	0.000	0.004	0.000	112	0	112	0
06-19	1502	0.139	0.000	0.000	0.000	0.005	0.000	0.000	0.000	209	0	0	0
06-20	1847	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-21	1637	0.142	0.000	0.000	0.000	0.005	0.000	0.000	0.000	232	0	0	0
06-22	1581	0.076	0.000	0.151	0.000	0.006	0.000	0.006	0.000	120	0	239	0
06-23	1200	0.093	0.000	0.047	0.000	0.002	0.000	0.002	0.000	112	0	56	0
06-24	2723	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
06-25	2014	0.111	0.000	0.000	0.000	0.003	0.000	0.000	0.000	224	0	0	0
06-26	2168	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
								numerator	**(# crab)**	14434	0	4009	179
								denominator	**(total cy)**	77252	77252	77252	77252
								R	**(crab/cy)**	0.187	0.000	0.052	0.002
									% by age	78%	0%	22%	1%

h	**26**
Vh	**77252**
H	**26**
VH	**77252**

Table C-3. Estimating Entrainment Rate, Total Entrainment, and Variance – Summary

	YOY 0-50	1+ 51-100	2+ 101-150	3+ >150	All Crab
R (crabs/cy)	0.1868	0.0000	0.0519	0.0023	0.241
E (crabs)	14434	0	4009	179	18622
% by age	78%	0%	22%	1%	100%
Var(E)	6,995,481	0	4,189,009	32,198	
SE (E)	2645	0	2047	179	
CV(E)	0.183	NA	0.510	1.000	

h	26
Vh	77252
H	26
VH	77252

Estimating Variance and CV of E

first term (haul to haul variability)

step 1 H2*(1-h/H) 0

		YOY 0-50	1+ 51-100	2+ 101-150	3+ >150
step 2 (VjR^j-R^Vj)		12294779	0	1478062	110
		502049	0	83172	137
		642462	0	49573	99
		1607	0	36795	74
		453673	0	12122	70
		530960	0	40969	82
		697505	0	53820	108
		168693	0	198947	84
		728106	0	56181	113
		1683421	0	32996	66
		169815	0	28032	56
		1135327	0	19	72
		571	0	276	102
		343	0	11879	24
		42733	0	6	35
		585780	0	7476	30825
		106298	0	641	16
		46953	0	433	17
		5082	0	6077	12
		119088	0	9189	18
		5488	0	7218	14
		30893	0	24712	13
		12557	0	38	8
		258838	0	19972	40
		23102	0	10926	22
		164078	0	12660	25
step 3 (sum of squares)		20410200	0	2182191	32243
step 4 (h-1)	25				
step 5		0	0	0	0

Table C-3. Estimating Entrainment Rate, Total Entrainment, and Variance – Summary (con't.)

Estimating Variance and CV of E

second term (Basket to basket variability)

step 1 (H/h) 1.0

step 2 (Vj2 * Var Rj)

	YOY 0-50	1+ 51-100	2+ 101-150	3+ >150
	1578070	0	2104094	0
	905688	0	75474	0
	0	0	0	0
	1053283	0	1404377	0
	465214	0	38768	0
	0	0	0	0
	0	0	0	0
	105777	0	423108	0
	0	0	0	0
	564144	0	0	0
	36349	0	0	0
	1473750	0	37788	0
	306780	0	43826	0
	34938	0	0	0
	18112	0	18112	0
	386381	0	0	32198
	0	0	13430	0
	12578	0	12578	0
	10956	0	0	0
	0	0	0	0
	13430	0	0	0
	14310	0	14310	0
	3144	0	3144	0
	0	0	0	0
	12578	0	0	0
	0	0	0	0
step 3 (sum of Vj2*Var Rj))	6995481	0	4189009	32198
step 4 (H/h * step 3 result)	6995481	0	4189009	32198
Var(E)	6995481	0	4189009	32198
SE (E)	2645	0	2047	179
CV(E)	0.1832	NA	0.5105	1.0000

Table C-4. Variance by Load

Load Sequence Number (j)	Date	Sample Number (l)	Number of Crabs				Sample Volume (CY)	Entrainment Rate (Rilj), crabs/CY					Sum of Squares (by load - w2)			
			YOY	1+	2+	3+		YOY	1+	2+	3+		YOY	1+	2+	3+
			0-50	51-100	101-150	>150	(w)	0-50	51-100	101-150	>150		0-50	51-100	101-150	>150
06-01	06/15/06	1	1	0	0	0	2.08	0.48	0.00	0.00	0.00		1.00	0.00	0.44	0.00
06-01	06/15/06	3	3	0	2	0	2.08	1.44	0.00	0.96	0.00		1.00	0.00	1.78	0.00
06-01	06/15/06	4	2	0	0	0	2.08	0.96	0.00	0.00	0.00		0.00	0.00	0.44	0.00
	Total (b)	**3**	**6**	**0**	**2**	**0**	**6.24**	**2.886**	**0.000**	**0.962**	**0.000**		**2.00**	**0.00**	**2.67**	**0.00**
	Mean (cij)		2.0	0.0	0.7	0.0	Rj check	0.962	0.000	0.321	0.000	Rj	0.962	0.000	0.321	0.000
												Var Rj	0.077	0.000	0.103	0.000
06-02	06/15/06	1	4	0	1	0	6.10	0.66	0.00	0.16	0.00		4.0	0.0	0.1	0.0
06-02	06/15/06	2	2	0	1	0	6.10	0.33	0.00	0.16	0.00		0.0	0.0	0.1	0.0
06-02	06/15/06	3	0	0	0	0	6.10	0.00	0.00	0.00	0.00		4.0	0.0	0.4	0.0
	Total (b)	**3**	**6**	**0**	**2**	**0**	**18.31**	**0.983**	**0.000**	**0.328**	**0.000**		**8.00**	**0.00**	**0.67**	**0.00**
	Mean (cij)		2.0	0.0	0.7	0.0	Rj check	0.328	0.000	0.109	0.000	Rj	0.328	0.000	0.109	0.000
												Var Rj	0.036	0.000	0.003	0.000
06-03	06/17/06	1	0	0	0	0	10.84	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**1**	**0**	**0**	**0**	**0**	**10.84**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
06-04	06/16/06	1	2	0	0	0	5.68	0.35	0.00	0.00	0.00		1.0	0.0	0.0	0.0
06-04	06/16/06	2	0	0	0	0	5.68	0.00	0.00	0.00	0.00		1.0	0.0	0.0	0.0
	Total (b)	**2**	**2**	**0**	**0**	**0**	**11.36**	**0.352**	**0.000**	**0.000**	**0.000**		**2.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		1.0	0.0	0.0	0.0	Rj check	0.176	0.000	0.000	0.000	Rj	0.176	0.000	0.000	0.000
												Var Rj	0.031	0.000	0.000	0.000
06-05	06/16/06	1	0	0	1	0	6.07	0.00	0.00	0.16	0.00		0.0	0.0	0.3	0.0
06-05	06/16/06	2	0	0	0	0	6.07	0.00	0.00	0.00	0.00		0.0	0.0	0.3	0.0
	Total (b)	**2**	**0**	**0**	**1**	**0**	**12.13**	**0.000**	**0.000**	**0.165**	**0.000**		**0.00**	**0.00**	**0.50**	**0.00**
	Mean (cij)		0.0	0.0	0.5	0.0	Rj check	0.000	0.000	0.082	0.000	Rj	0.000	0.000	0.082	0.000
												Var Rj	0.000	0.000	0.007	0.000
06-06	06/16/06	1	0	0	0	0	5.52	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-06	06/16/06	2	0	0	0	0	5.52	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**2**	**0**	**0**	**0**	**0**	**11.04**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj	0.000	0.000	0.000	0.000
06-07	06/16/06	1	0	0	0	0	4.86	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-07	06/16/06	2	0	0	0	0	4.86	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**2**	**0**	**0**	**0**	**0**	**9.72**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj	0.000	0.000	0.000	0.000

Table C-4. Variance by Load (con't.)

Load Sequence Number (j)	Date	Sample Number (l)	Number of Crabs YOY	1+	2+	3+	Sample Volume (CY)	Entrainment Rate (Rilj), crabs/CY YOY	1+	2+	3+		Sum of Squares (by load - w2) YOY	1+	2+	3+
			0-50	51-100	101-150	>150	(w)	0-50	51-100	101-150	>150		0-50	51-100	101-150	>150
06-08	06/16/06	1	0	0	0	0	6.06	0.00	0.00	0.00	0.00		0.3	0.0	1.0	0.0
06-08	06/16/06	2	1	0	2	0	6.06	0.17	0.00	0.33	0.00		0.3	0.0	1.0	0.0
	Total (b)	**2**	**1**	**0**	**2**	**0**	**12.11**	**0.165**	**0.000**	**0.330**	**0.000**		**0.50**	**0.00**	**2.00**	**0.00**
	Mean (cij)		0.5	0.0	1.0	0.0	Rj check	0.083	0.000	0.165	0.000	Rj	0.083	0.000	0.165	0.000
												Var Rj	0.007	0.000	0.027	0.000
06-09	06/17/06	1	0	0	0	0	5.29	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**1**	**0**	**0**	**0**	**0**	**5.29**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj				
06-10	06/16/06	1	5	0	0	0	5.38	0.93	0.00	0.00	0.00		4.0	0.0	0.0	0.0
06-10	06/16/06	2	3	0	0	0	5.38	0.56	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-10	6/16/06	3	1	0	0	0	5.38	0.19	0.00	0.00	0.00		4.0	0.0	0.0	0.0
	Total (b)	**3**	**9**	**0**	**0**	**0**	**16.14**	**1.673**	**0.000**	**0.000**	**0.000**		**8.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		3.0	0.0	0.0	0.0	Rj check	0.558	0.000	0.000	0.000	Rj	0.558	0.000	0.000	0.000
												Var Rj	0.046	0.000	0.000	0.000
06-11	06/16/06	1	0	0	0	0	5.64	0.00	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-11	06/16/06	2	1	0	0	0	5.64	0.18	0.00	0.00	0.00		0.4	0.0	0.0	0.0
06-11	6/16/06	3	0	0	0	0	5.64	0.00	0.00	0.00	0.00		0.1	0.0	0.0	0.0
	Total (b)	**3**	**1**	**0**	**0**	**0**	**16.92**	**0.177**	**0.000**	**0.000**	**0.000**		**0.67**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.3	0.0	0.0	0.0	Rj check	0.059	0.000	0.000	0.000	Rj	0.059	0.000	0.000	0.000
												Var Rj	0.003	0.000	0.000	0.000
06-12	06/16/06	1	7	0	1	0	6.28	1.12	0.00	0.16	0.00		16.0	0.0	0.4	0.0
06-12	06/16/06	2	0	0	0	0	6.28	0.00	0.00	0.00	0.00		9.0	0.0	0.1	0.0
06-12	6/16/06	3	2	0	0	0	6.28	0.32	0.00	0.00	0.00		1.0	0.0	0.1	0.0
	Total (b)	**3**	**9**	**0**	**1**	**0**	**18.83**	**1.434**	**0.000**	**0.159**	**0.000**		**26.00**	**0.00**	**0.67**	**0.00**
	Mean (cij)		3.0	0.0	0.3	0.0	Rj check	0.478	0.000	0.053	0.000	Rj	0.478	0.000	0.053	0.000
												Var Rj	0.110	0.000	0.003	0.000
06-13	06/16/06	1	1	0	1	0	6.93	0.14	0.00	0.14	0.00		0.1	0.0	0.4	0.0
06-13	06/16/06	2	3	0	0	0	6.93	0.43	0.00	0.00	0.00		2.8	0.0	0.1	0.0
06-13	6/16/06	3	0	0	0	0	6.93	0.00	0.00	0.00	0.00		1.8	0.0	0.1	0.0
	Total (b)	**3**	**4**	**0**	**1**	**0**	**20.80**	**0.577**	**0.000**	**0.144**	**0.000**		**4.67**	**0.00**	**0.67**	**0.00**
	Mean (cij)		1.3	0.0	0.3	0.0	Rj check	0.192	0.000	0.048	0.000	Rj	0.192	0.000	0.048	0.000
												Var Rj	0.016	0.000	0.002	0.000
06-14	06/16/06	1	0	0	0	0	7.49	0.00	0.00	0.00	0.00		1.8	0.0	0.0	0.0
06-14	06/16/06	2	2	0	0	0	7.49	0.27	0.00	0.00	0.00		0.4	0.0	0.0	0.0
06-14	6/16/06	3	2	0	0	0	7.49	0.27	0.00	0.00	0.00		0.4	0.0	0.0	0.0
	Total (b)	**3**	**4**	**0**	**0**	**0**	**22.47**	**0.534**	**0.000**	**0.000**	**0.000**		**2.67**	**0.00**	**0.00**	**0.00**
	Mean (cij)		1.3	0.0	0.0	0.0	Rj check	0.178	0.000	0.000	0.000	Rj	0.178	0.000	0.000	0.000
												Var Rj	0.008	0.000	0.000	0.000

Table C-4. Variance by Load (con't.)

Load Sequence Number (j)	Date	Sample Number (l)	Number of Crabs				Sample Volume (CY)	Entrainment Rate (Rilj), crabs/CY					Sum of Squares (by load - w2)			
			YOY	1+	2+	3+		YOY	1+	2+	3+		YOY	1+	2+	3+
			0-50	51-100	101-150	>150	(w)	0-50	51-100	101-150	>150		0-50	51-100	101-150	>150
06-15	06/16/06	1	1	0	1	0	6.31	0.16	0.00	0.16	0.00		0.1	0.0	0.4	0.0
06-15	06/16/06	2	0	0	0	0	6.31	0.00	0.00	0.00	0.00		0.4	0.0	0.1	0.0
06-15	6/16/06	3	1	0	0	0	6.31	0.16	0.00	0.00	0.00		0.1	0.0	0.1	0.0
	Total (b)	**3**	**2**	**0**	**1**	**0**	**18.93**	**0.317**	**0.000**	**0.159**	**0.000**		**0.67**	**0.00**	**0.67**	**0.00**
	Mean (cij)		0.7	0.0	0.3	0.0	Rj check	0.106	0.000	0.053	0.000	Rj	0.106	0.000	0.053	0.000
												Var Rj	0.003	0.000	0.003	0.000
06-16	06/16/06	1	4	0	0	1	3.09	1.29	0.00	0.00	0.32		4.0	0.0	0.0	0.4
06-16	06/16/06	2	2	0	0	0	3.09	0.65	0.00	0.00	0.00		0.0	0.0	0.0	0.1
06-16	6/17/06	3	0	0	0	0	3.09	0.00	0.00	0.00	0.00		4.0	0.0	0.0	0.1
	Total (b)	**3**	**6**	**0**	**0**	**1**	**9.28**	**1.939**	**0.000**	**0.000**	**0.323**		**8.00**	**0.00**	**0.00**	**0.67**
	Mean (cij)		2.0	0.0	0.0	0.3	Rj check	0.646	0.000	0.000	0.108	Rj	0.646	0.000	0.000	0.108
												Var Rj	0.139	0.000	0.000	0.012
06-17	06/17/06	1	0	0	0	0	5.02	0.00	0.00	0.00	0.00		0.0	0.0	0.1	0.0
06-17	06/17/06	2	0	0	1	0	5.02	0.00	0.00	0.20	0.00		0.0	0.0	0.4	0.0
06-17	6/17/06	3	0	0	0	0	5.02	0.00	0.00	0.00	0.00		0.0	0.0	0.1	0.0
	Total (b)	**3**	**0**	**0**	**1**	**0**	**15.06**	**0.000**	**0.000**	**0.199**	**0.000**		**0.00**	**0.00**	**0.67**	**0.00**
	Mean (cij)		0.0	0.0	0.3	0.0	Rj check	0.000	0.000	0.066	0.000	Rj	0.000	0.000	0.066	0.000
												Var Rj	0.000	0.000	0.004	0.000
06-18	06/17/06	1	1	0	1	0	5.23	0.19	0.00	0.19	0.00		0.4	0.0	0.4	0.0
06-18	06/17/06	2	0	0	0	0	5.23	0.00	0.00	0.00	0.00		0.1	0.0	0.1	0.0
06-18	6/17/06	3	0	0	0	0	5.23	0.00	0.00	0.00	0.00		0.1	0.0	0.1	0.0
	Total (b)	**3**	**1**	**0**	**1**	**0**	**15.69**	**0.191**	**0.000**	**0.191**	**0.000**		**0.67**	**0.00**	**0.67**	**0.00**
	Mean (cij)		0.3	0.0	0.3	0.0	Rj check	0.064	0.000	0.064	0.000	Rj	0.064	0.000	0.064	0.000
												Var Rj	0.004	0.000	0.004	0.000
06-19	06/17/06	1	1	0	0	0	4.78	0.21	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-19	06/17/06	2	1	0	0	0	4.78	0.21	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-19	6/17/06	3	0	0	0	0	4.78	0.00	0.00	0.00	0.00		0.4	0.0	0.0	0.0
	Total (b)	**3**	**2**	**0**	**0**	**0**	**14.35**	**0.418**	**0.000**	**0.000**	**0.000**		**0.67**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.7	0.0	0.0	0.0	Rj check	0.139	0.000	0.000	0.000	Rj	0.139	0.000	0.000	0.000
												Var Rj	0.005	0.000	0.000	0.000
06-20	06/17/06	1	0	0	0	0	5.88	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-20	06/17/06	2	0	0	0	0	5.88	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-20	6/17/06	3	0	0	0	0	5.88	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**3**	**0**	**0**	**0**	**0**	**17.65**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj	0.000	0.000	0.000	0.000

Table C-4. Variance by Load (con't.)

Load Sequence Number (j)	Date	Sample Number (l)	Number of Crabs YOY				Sample Volume (CY)	Entrainment Rate (Rilj), crabs/CY YOY					Sum of Squares (by load - w2) YOY			
			YOY	1+	2+	3+		YOY	1+	2+	3+		YOY	1+	2+	3+
			0-50	51-100	101-150	>150	(w)	0-50	51-100	101-150	>150		0-50	51-100	101-150	>150
06-21	06/17/06	1	1	0	0	0	4.71	0.21	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-21	06/17/06	2	1	0	0	0	4.71	0.21	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-21	6/17/06	3	0	0	0	0	4.71	0.00	0.00	0.00	0.00		0.4	0.0	0.0	0.0
	Total (b)	**3**	**2**	**0**	**0**	**0**	**14.13**	**0.425**	**0.000**	**0.000**	**0.000**		**0.67**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.7	0.0	0.0	0.0	Rj check	0.142	0.000	0.000	0.000	Rj	0.142	0.000	0.000	0.000
												Var Rj	0.005	0.000	0.000	0.000
06-22	06/17/06	1	1	0	0	0	4.41	0.23	0.00	0.00	0.00		0.4	0.0	0.4	0.0
06-22	06/17/06	2	0	0	1	0	4.41	0.00	0.00	0.23	0.00		0.1	0.0	0.1	0.0
06-22	6/17/06	3	0	0	1	0	4.41	0.00	0.00	0.23	0.00		0.1	0.0	0.1	0.0
	Total (b)	**3**	**1**	**0**	**2**	**0**	**13.22**	**0.227**	**0.000**	**0.454**	**0.000**		**0.67**	**0.00**	**0.67**	**0.00**
	Mean (cij)		0.3	0.0	0.7	0.0	Rj check	0.076	0.000	0.151	0.000	Rj	0.076	0.000	0.151	0.000
												Var Rj	0.006	0.000	0.006	0.000
06-23	06/17/06	1	0	0	0	0	7.13	0.00	0.00	0.00	0.00		0.4	0.0	0.1	0.0
06-23	06/17/06	2	1	0	1	0	7.13	0.14	0.00	0.14	0.00		0.1	0.0	0.4	0.0
06-23	6/17/06	3	1	0	0	0	7.13	0.14	0.00	0.00	0.00		0.1	0.0	0.1	0.0
	Total (b)	**3**	**2**	**0**	**1**	**0**	**21.40**	**0.280**	**0.000**	**0.140**	**0.000**		**0.67**	**0.00**	**0.67**	**0.00**
	Mean (cij)		0.7	0.0	0.3	0.0	Rj check	0.093	0.000	0.047	0.000	Rj	0.093	0.000	0.047	0.000
												Var Rj	0.002	0.000	0.002	0.000
06-24	06/17/06	1	0	0	0	0	5.52	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-24	06/17/06	2	0	0	0	0	5.52	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-24	6/17/06	3	0	0	0	0	5.52	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**3**	**0**	**0**	**0**	**0**	**16.55**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj	0.000	0.000	0.000	0.000
06-25	06/17/06	1	1	0	0	0	5.99	0.17	0.00	0.00	0.00		0.1	0.0	0.0	0.0
06-25	06/17/06	2	0	0	0	0	5.99	0.00	0.00	0.00	0.00		0.4	0.0	0.0	0.0
06-25	6/17/06	3	1	0	0	0	5.99	0.17	0.00	0.00	0.00		0.1	0.0	0.0	0.0
	Total (b)	**3**	**2**	**0**	**0**	**0**	**17.96**	**0.334**	**0.000**	**0.000**	**0.000**		**0.67**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.7	0.0	0.0	0.0	Rj check	0.111	0.000	0.000	0.000	Rj	0.111	0.000	0.000	0.000
												Var Rj	0.003	0.000	0.000	0.000
06-26	06/17/06	1	0	0	0	0	4.71	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-26	06/17/06	2	0	0	0	0	4.71	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
06-26	6/17/06	3	0	0	0	0	4.71	0.00	0.00	0.00	0.00		0.0	0.0	0.0	0.0
	Total (b)	**3**	**0**	**0**	**0**	**0**	**14.14**	**0.000**	**0.000**	**0.000**	**0.000**		**0.00**	**0.00**	**0.00**	**0.00**
	Mean (cij)		0.0	0.0	0.0	0.0	Rj check	0.000	0.000	0.000	0.000	Rj	0.000	0.000	0.000	0.000
												Var Rj	0.000	0.000	0.000	0.000

Table C-5. Entrainment Rate by Load

Load # (j)	Total Load Volume, CY (V)	# Samples (b)	Total Sample Volume, CY (v)	Totals by Age Class ci				Entrainment Rate by Age Class (crab/cy) Rij			
				YOY	1+	2+	3+	YOY	1+	2+	3+
				0-50	51-100	101-150	>150	0-50	51-100	101-150	>150
06-01	4524	3	6.24	6	0	2	0	0.962	0.000	0.321	0.000
06-02	5030	3	18.31	6	0	2	0	0.328	0.000	0.109	0.000
06-03	4290	1	10.84	0	0	0	0	0.000	0.000	0.000	0.000
06-04	3696	2	11.36	2	0	0	0	0.176	0.000	0.000	0.000
06-05	3605	2	12.13	0	0	1	0	0.000	0.000	0.082	0.000
06-06	3900	2	11.04	0	0	0	0	0.000	0.000	0.000	0.000
06-07	4470	2	9.72	0	0	0	0	0.000	0.000	0.000	0.000
06-08	3939	2	12.11	1	0	2	0	0.083	0.000	0.165	0.000
06-09	4567	1	5.29	0	0	0	0	0.000	0.000	0.000	0.000
06-10	3500	3	16.14	9	0	0	0	0.558	0.000	0.000	0.000
06-11	3226	3	16.92	1	0	0	0	0.059	0.000	0.000	0.000
06-12	3661	3	18.83	9	0	1	0	0.478	0.000	0.053	0.000
06-13	4354	3	20.80	4	0	1	0	0.192	0.000	0.048	0.000
06-14	2100	3	22.47	4	0	0	0	0.178	0.000	0.000	0.000
06-15	2547	3	18.93	2	0	1	0	0.106	0.000	0.053	0.000
06-16	1666	3	9.28	6	0	0	1	0.646	0.000	0.000	0.108
06-17	1745	3	15.06	0	0	1	0	0.000	0.000	0.066	0.000
06-18	1760	3	15.69	1	0	1	0	0.064	0.000	0.064	0.000
06-19	1502	3	14.35	2	0	0	0	0.139	0.000	0.000	0.000
06-20	1847	3	17.65	0	0	0	0	0.000	0.000	0.000	0.000
06-21	1637	3	14.13	2	0	0	0	0.142	0.000	0.000	0.000
06-22	1581	3	13.22	1	0	2	0	0.076	0.000	0.151	0.000
06-23	1200	3	21.40	2	0	1	0	0.093	0.000	0.047	0.000
06-24	2723	3	16.55	0	0	0	0	0.000	0.000	0.000	0.000
06-25	2014	3	17.96	2	0	0	0	0.111	0.000	0.000	0.000
06-26	2168	3	14.14	0	0	0	0	0.000	0.000	0.000	0.000
	Total (B)	**69**	**380.57**	60	0	15	1				

Table C-6. Within Load Record

Load Sequence Number (j)	Date	Sample Number (l)	Start Time (h:m)	Sample Load Rate (cy/min)	Effective Sample Time (sec)	Sample Volume (cy) (w)	Salinity (ppt)	Number of Crabs (c) by age class (i)				
								YOY 0-50	1+ 51-100	2+ 101-150	3+ >150	UID
06-01	06/15/06	1	1338	3.43	36.4	2.08	19.9	1	0	0	0	N
06-01	06/15/06	3	1454	3.43	36.4	2.08	24.1	3	0	2	0	N
06-01	06/15/06	4	1537	3.43	36.4	2.08	24.4	2	0	0	0	N
06-02	06/15/06	1	2004	10.06	36.4	6.10	22.6	4	0	1	0	N
06-02	06/15/06	2	2039	10.06	36.4	6.10	24.0	2	0	1	0	N
06-02	06/15/06	3	2120	10.06	36.4	6.10	nd	0	0	0	0	N
06-03	06/15/06	1	4290	17.88	36.4	10.84	nd	0	0	0	0	N
06-04	06/16/06	1	0129	15.93	21.4	5.68	21.7	2	0	0	0	N
06-04	06/16/06	2	0145	15.93	21.4	5.68	20.6	0	0	0	0	N
06-05	06/16/06	1	0337	17.00	21.4	6.07	19.1	0	0	1	0	N
06-05	06/16/06	2	0403	17.00	21.4	6.07	19.1	0	0	0	0	N
06-06	06/16/06	1	0519	15.48	21.4	5.52	21.5	0	0	0	0	N
06-06	06/16/06	2	0550	15.48	21.4	5.52	20.1	0	0	0	0	N
06-07	06/16/06	1	0755	13.63	21.4	4.86	18.1	0	0	0	0	Y
06-07	06/16/06	2	0853	13.63	21.4	4.86	14.8	0	0	0	0	N
06-08	06/16/06	1	1051	16.98	21.4	6.06	3.5	0	0	0	0	N
06-08	06/16/06	2	1106	16.98	21.4	6.06	4.0	1	0	2	0	Y
06-09	06/16/06	1	1255	14.83	21.4	5.29	2.4	0	0	0	0	Y
06-10	06/16/06	1	1500	15.09	21.4	5.38	20.6	5	0	0	0	Y
06-10	06/16/06	2	1520	15.09	21.4	5.38	21.5	3	0	0	0	Y
06-10	06/16/06	3	1551	15.09	21.4	5.38	22.5	1	0	0	0	Y
06-11	06/16/06	1	1651	15.81	21.4	5.64	23.6	0	0	0	0	Y
06-11	06/16/06	2	1716	15.81	21.4	5.64	24.3	1	0	0	0	N
06-11	06/16/06	3	1730	15.81	21.4	5.64	23.3	0	0	0	0	N
06-12	06/16/06	1	1806	17.60	21.4	6.28	24.0	7	0	1	0	N
06-12	06/16/06	2	1838	17.60	21.4	6.28	23.3	0	0	0	0	N
06-12	06/16/06	3	1851	17.60	21.4	6.28	24.1	2	0	0	0	N
06-13	06/16/06	1	1930	19.44	21.4	6.93	23.4	1	0	1	0	N
06-13	06/16/06	2	1946	19.44	21.4	6.93	nd	3	0	0	0	N
06-13	06/16/06	3	2022	19.44	21.4	6.93	21.3	0	0	0	0	N

Table C-6. Within Load Record (con't.)

Load Sequence Number (j)	Date	Sample Number (l)	Start Time (h:m)	Sample Load Rate (cy/min)	Effective Sample Time (sec)	Sample Volume (cy) (w)	Salinity (ppt)	Number of Crabs (c) by age class (i)				
								YOY 0-50	1+ 51-100	2+ 101-150	3+ >150	UID
06-14	06/16/06	1	2118	21.00	21.4	7.49	19.5	0	0	0	0	N
06-14	06/16/06	2	2135	21.00	21.4	7.49	18.4	2	0	0	0	N
06-14	06/16/06	3	2150	21.00	21.4	7.49	nd	2	0	0	0	N
06-15	06/16/06	1	2217	17.69	21.4	6.31	16.2	1	0	1	0	N
06-15	06/16/06	2	2229	17.69	21.4	6.31	14.9	0	0	0	0	N
06-15	06/16/06	3	2240	17.69	21.4	6.31	17.5	1	0	0	0	N
06-16	06/16/06	1	2339	8.68	21.4	3.09	11.7	4	0	0	1	N
06-16	06/16/06	2	2351	8.68	21.4	3.09	20.4	2	0	0	0	N
06-16	06/17/06	3	0017	8.68	21.4	3.09	5.3	0	0	0	0	N
06-17	06/17/06	1	0059	14.07	21.4	5.02	8.9	0	0	0	0	N
06-17	06/17/06	2	0107	14.07	21.4	5.02	6.9	0	0	1	0	N
06-17	06/17/06	3	0116	14.07	21.4	5.02	8.6	0	0	0	0	N
06-18	06/17/06	1	0144	14.67	21.4	5.23	14.9	1	0	1	0	N
06-18	06/17/06	2	0152	14.67	21.4	5.23	17.4	0	0	0	0	N
06-18	06/17/06	3	0208	14.67	21.4	5.23	13.4	0	0	0	0	N
06-19	06/17/06	1	0235	13.41	21.4	4.78	19.4	1	0	0	0	Y
06-19	06/17/06	2	0246	13.41	21.4	4.78	22.4	1	0	0	0	N
06-19	06/17/06	3	0254	13.41	21.4	4.78	22.1	0	0	0	0	N
06-20	06/17/06	1	0321	16.49	21.4	5.88	24.1	0	0	0	0	N
06-20	06/17/06	2	0332	16.49	21.4	5.88	24.7	0	0	0	0	N
06-20	06/17/06	3	0346	16.49	21.4	5.88	26.2	0	0	0	0	N
06-21	06/17/06	1	0407	13.20	21.4	4.71	24.9	1	0	0	0	N
06-21	06/17/06	2	0421	13.20	21.4	4.71	25.9	1	0	0	0	N
06-21	06/17/06	3	0432	13.20	21.4	4.71	24.6	0	0	0	0	N
06-22	06/17/06	1	0454	12.35	21.4	4.41	26.3	1	0	0	0	N
06-22	06/17/06	2	0509	12.35	21.4	4.41	26.7	0	0	1	0	N
06-22	06/17/06	3	0517	12.35	21.4	4.41	27.0	0	0	1	0	N
06-23	06/17/06	1	0545	20.00	21.4	7.13	26.7	0	0	0	0	N
06-23	06/17/06	2	0552	20.00	21.4	7.13	26.3	1	0	1	0	N
06-23	06/17/06	3	0600	20.00	21.4	7.13	25.7	1	0	0	0	Y

Table C-6. Within Load Record (con't.)

Load Sequence Number (j)	Date	Sample Number (l)	Start Time (h:m)	Sample Load Rate (cy/min)	Effective Sample Time (sec)	Sample Volume (cy) (w)	Salinity (ppt)	Number of Crabs (c) by age class (i)				
								YOY 0-50	1+ 51-100	2+ 101-150	3+ >150	UID
06-24	06/17/06	1	0632	15.47	21.4	5.52	21.6	0	0	0	0	N
06-24	06/17/06	2	0652	15.47	21.4	5.52		0	0	0	0	N
06-24	06/17/06	3	0701	15.47	21.4	5.52	15.6	0	0	0	0	Y
06-25	06/17/06	1	0749	16.78	21.4	5.99	20.6	1	0	0	0	N
06-25	06/17/06	2	0755	16.78	21.4	5.99	21.5	0	0	0	0	N
06-25	06/17/06	3	0811	16.78	21.4	5.99	22.6	1	0	0	0	N
06-26	06/17/06	1	0927	13.22	21.4	4.71	18.6	0	0	0	0	Y
06-26	06/17/06	2	0940	13.22	21.4	4.71	20.9	0	0	0	0	Y
06-26	06/17/06	3	0915	13.22	21.4	4.71	21.2	0	0	0	0	Y

APPENDIX D

Salinity Model Data, Desdemona Shoals Entrainment Sampling 2006

Comparing 2006 Results
to Past Salinity Model Predictions

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13 September 2006

Using the 2002–2004 data, ln-linear regression models of the form

$$\ln y_i = \alpha + \beta x_i \tag{1}$$

were generated, where

y_i = crab entrainment density (#/m^3),

x_i = salinity.

These models can be used to predict the crab density in 2006, based on observed bottom salinity. Let

$$\ln \hat{y}_{06} = \alpha + \beta x_{06}, \tag{2}$$

be the model predicated of ln density based on observed salinity in 2006. Let the value

$$\ln y_{06}$$

be the ln-transformed value of the actual observed crab density in 2006.

These two values can be compared using an asymptotic *Z* test of the form

$$Z = \frac{\left|\ln y_{06} - \ln \hat{y}_{06}\right|}{\sqrt{\operatorname{Var}\left(\ln y_{06}\right) + \operatorname{Var}\left(\ln \hat{y}_{06}\right)}} \tag{3}$$

or, equivalently,

$$Z = \frac{\left|\ln y_{06} - \ln \hat{y}_{06}\right|}{\sqrt{\dfrac{\widehat{\operatorname{Var}}\left(y_{06}\right)}{y_{06}^2} + \operatorname{MSE} \cdot \left[1 + \dfrac{1}{n} + \dfrac{\left(x_{06} - \bar{x}\right)^2}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\right]}}, \tag{4}$$

where

$\widehat{\operatorname{Var}}\left(y_{06}\right)$ = variance associated with the entrainment estimate in 2006

$\left[\text{i.e., } \widehat{\operatorname{Var}}\left(y_{06}\right) = \widehat{\operatorname{SE}}\left(y_{06}\right)^2\right]$, MSE = mean square for the error term in the 2002–2004 regression of ln density versus salinity,

n = number of observations used in the 2002–2006 regression analyses,

x_{06} = salinity value observed in 2006,

x_i = salinity values observed in 2002–2004 and used in regression $(i = 1, \ldots, n)$,

$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ = average salinity value used in the 2002–2004 regression analysis.

Reject the null hypothesis that y_{06} is from the same crab density/salinity relationship as the 2002–2004 data at:

$$P = 0.10 \text{ if } Z > 1.645$$
$$P = 0.05 \text{ if } Z > 1.96$$
$$P = 0.01 \text{ if } Z > 2.573.$$

Example:

Using the results reported on Friday, 8 September 06, the 2002–2004 regression of 2+ and 3+ combined had the following data:

$$n = 7$$
$$\text{MSE} = 0.944$$

with the predictive model

$$\ln y_i = -3.408 - 5.86 x_i .$$

These facts would be used in comparing the old model predictions to the 2006 result.

Desdemona 2006: Measured Bottom Salinity

Sample Salinities

Load Sequence Number (j)	Date	Sample Number (l)	Start Time (h:m)	Salinity (PSU)
06-01	06/15/06	1	1338	19.9
06-01	06/15/06	3	1454	24.1
06-01	06/15/06	4	1537	24.4
06-02	06/15/06	1	2004	22.6
06-02	06/15/06	2	2039	24.0
06-02	06/15/06	3	2120	nd
06-03	06/15/06	1	2335	nd
06-04	06/16/06	1	0129	21.7
06-04	06/16/06	2	0145	20.6
06-05	06/16/06	1	0337	19.1
06-05	06/16/06	2	0403	19.1
06-06	06/16/06	1	0519	21.5
06-06	06/16/06	2	0550	20.1
06-07	06/16/06	1	0755	18.1
06-07	06/16/06	2	0853	14.8
06-08	06/16/06	1	1051	3.5
06-08	06/16/06	2	1106	4.0
06-09	06/16/06	1	1255	2.4
06-10	06/16/06	1	1500	20.6
06-10	06/16/06	2	1520	21.5
06-10	06/16/06	3	1551	22.5
06-11	06/16/06	1	1651	23.6
06-11	06/16/06	2	1716	24.3
06-11	06/16/06	3	1730	23.3
06-12	06/16/06	1	1806	24.0
06-12	06/16/06	2	1838	23.3
06-12	06/16/06	3	1851	24.1
06-13	06/16/06	1	1930	23.4
06-13	06/16/06	2	1946	nd
06-13	06/16/06	3	2022	21.3
06-14	06/16/06	1	2118	19.5
06-14	06/16/06	2	2135	18.4
06-14	06/16/06	3	2150	nd
06-15	06/16/06	1	2217	16.2
06-15	06/16/06	2	2229	14.9
06-15	06/16/06	3	2240	17.5
06-16	06/16/06	1	2339	11.7
06-16	06/16/06	2	2351	20.4
06-16	06/17/06	3	0017	5.3
06-17	06/17/06	1	0059	8.9
06-17	06/17/06	2	0107	6.9
06-17	06/17/06	3	0116	8.6

Mean Load Salinity

Load Sequence Number (j)	Average Salinity (psu)
06-01	22.8
06-02	23.3
06-04	21.2
06-05	19.1
06-06	20.8
06-07	16.5
06-08	3.8
06-09	2.4
06-10	21.5
06-11	23.7
06-12	23.8
06-13	22.4
06-14	19.0
06-15	16.2
06-16	12.5
06-17	8.1
06-18	15.2
06-19	21.3
06-20	25.0
06-21	25.1
06-22	26.7
06-23	26.2
06-24	18.6
06-25	21.6
06-26	20.2

n mean salinities	25
n mean S <16 psu	5
prop mean S <16 psu	**0.20**

Desdemona 2006: Measured Bottom Salinity (continued)

Sample Salinities (continued)

Load Sequence Number (j)	Date	Sample Number (l)	Start Time (h:m)	Salinity (PSU)
06-18	06/17/06	1	0144	14.9
06-18	06/17/06	2	0152	17.4
06-18	06/17/06	3	0208	13.4
06-19	06/17/06	1	0235	19.4
06-19	06/17/06	2	0246	22.4
06-19	06/17/06	3	0254	22.1
06-20	06/17/06	1	0321	24.1
06-20	06/17/06	2	0332	24.7
06-20	06/17/06	3	0346	26.2
06-21	06/17/06	1	0407	24.9
06-21	06/17/06	2	0421	25.9
06-21	06/17/06	3	0432	24.6
06-22	06/17/06	1	0454	26.3
06-22	06/17/06	2	0509	26.7
06-22	06/17/06	3	0517	27.0
06-23	06/17/06	1	0545	26.7
06-23	06/17/06	2	0552	26.3
06-23	06/17/06	3	0600	25.7
06-24	06/17/06	1	0632	21.6
06-24	06/17/06	2	0652	nd
06-24	06/17/06	3	0701	15.6
06-25	06/17/06	1	0749	20.6
06-25	06/17/06	2	0755	21.5
06-25	06/17/06	3	0811	22.6
06-26	06/17/06	1	0915	18.6
06-26	06/17/06	2	0927	20.9
06-26	06/17/06	3	0940	21.2

2005 Model and Desdemona 2006: Salinity vs R data

Salinity and Entrainment Rate (R) for each age class					
Area	**p psu <16**	**R 0+**	**R 1+**	**R 2+**	**R 3+**
Miller Sands	1.000	0.0001	0.0001	0.0001	0.0001
Upper Sands	0.667	0.0101	0.0101	0.0001	0.0001
Flavel Bar	0.267	0.0001	0.0032	0.0036	0.0047
Desdemona 02	0.000	0.0001	0.0221	0.0651	0.0331
Desdemona 04	0.000	0.0140	0.0001	0.0036	0.0066
MCR 02	0.005	0.0032	0.0133	0.0314	0.0135
MCR 04	0.000	0.0573	0.0029	0.0211	0.0129
Desdemona 06	*0.200*	*0.1869*	*0.0001*	*0.0520*	*0.0024*

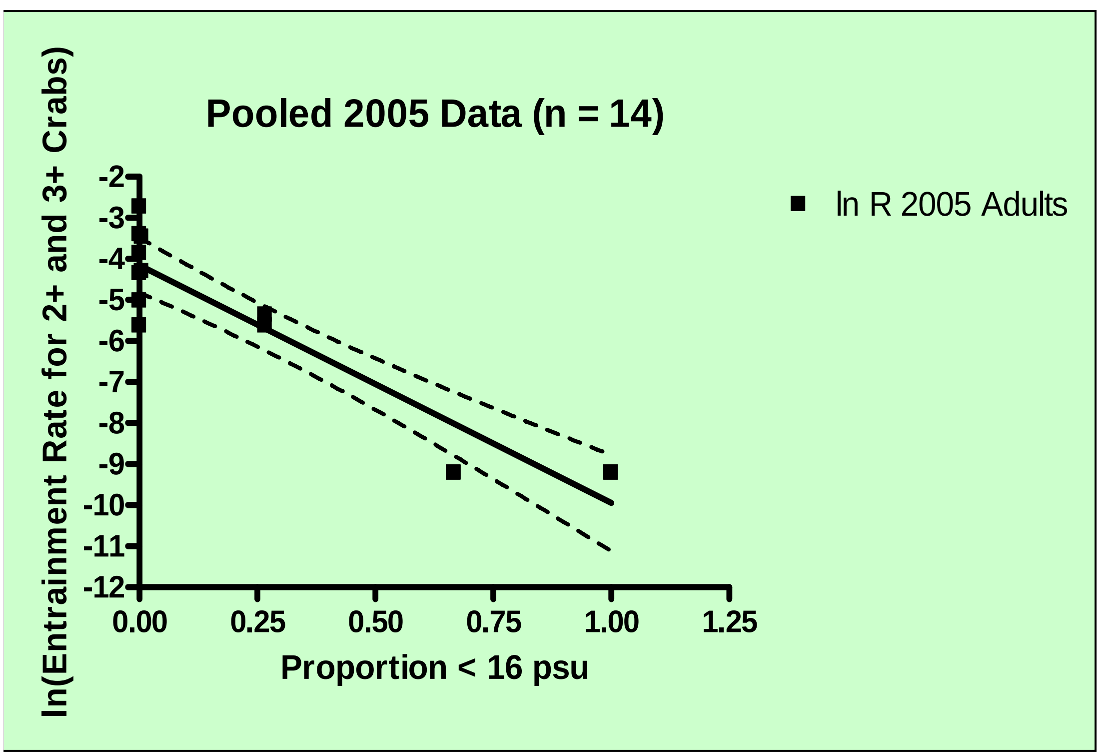
Salinity and Natural Log of Entrainment Rate (lnR) for each age class					
Area	**p psu <16**	**ln R 0+**	**ln R 1+**	**ln R 2+**	**ln R 3+**
Miller Sands	1.000	-9.2103	-9.2103	-9.2103	-9.2103
Upper Sands	0.667	-4.5952	-4.5952	-9.2103	-9.2103
Flavel Bar	0.267	-9.2103	-5.7446	-5.6268	-5.3602
Desdemona 02	0.000	-9.2103	-3.8122	-2.7318	-3.4082
Desdemona 04	0.000	-4.2687	-9.2103	-5.6268	-5.0207
MCR 02	0.005	-5.7446	-4.3200	-3.4609	-4.3051
MCR 04	0.000	-2.8595	-5.8430	-3.8585	-4.3505
Desdemona 06	*0.200*	*-1.6770*	*-9.2103*	*-2.9565*	*-6.0228*

Note: Desdemona 06 only used to obtain predicted values for comparison with existing model, and to update model in 2006.

S and lnR of age 2+ and 3+ combined for final model		
Area	**p psu <16**	**ln R 2+,3+**
Miller Sands	1.000	-9.2103
Upper Sands	0.667	-9.2103
Flavel Bar	0.267	-5.6268
Desdemona 02	0.000	-2.7318
Desdemona 04	0.000	-5.6268
MCR 02	0.005	-3.4609
MCR 04	0.000	-3.8585
Desdemona 06	*0.200*	*-2.9565*
Miller Sands	1.000	-9.2103
Upper Sands	0.667	-9.2103
Flavel Bar	0.267	-5.3602
Desdemona 02	0.000	-3.4082
Desdemona 04	0.000	-5.0207
MCR 02	0.005	-4.3051
MCR 04	0.000	-4.3505
Desdemona 06	*0.200*	*-6.0228*

2005 Model: Pooled data

2005 Final Model based on pooled data		ln R = -5.799 x - 4.150
	ln R 2005 Adults	
Best-fit values		
Slope	-5.799 ± 0.6592	-5.79917
Y-intercept	-4.150 ± 0.3068	-4.15013
X-intercept	-0.7156	
1/slope	-0.1724	
95% Confidence Intervals		
Slope	-7.236 to -4.363	
Y-intercept when X=0.2	-5.858 to -4.761	
Goodness of Fit		
r^2	0.8658	MSE
Sy.x	0.9225	0.85100625
Is slope significantly non-zero?		
F	77.39	
DFn, DFd	1.000, 12.00	
P value	< 0.0001	
Deviation from zero?	Significant	
Data		
Number of X values	14	
Maximum number of Y replicates	1	
Total number of values	14	
Number of missing values	0	



2006 Desdemona: Observed vs Predicted

Question: **How do the 2006 observed entrainment rates compare with entrainment rates predicted by the Pearson et al. (2005) Crab Salinity Model?**

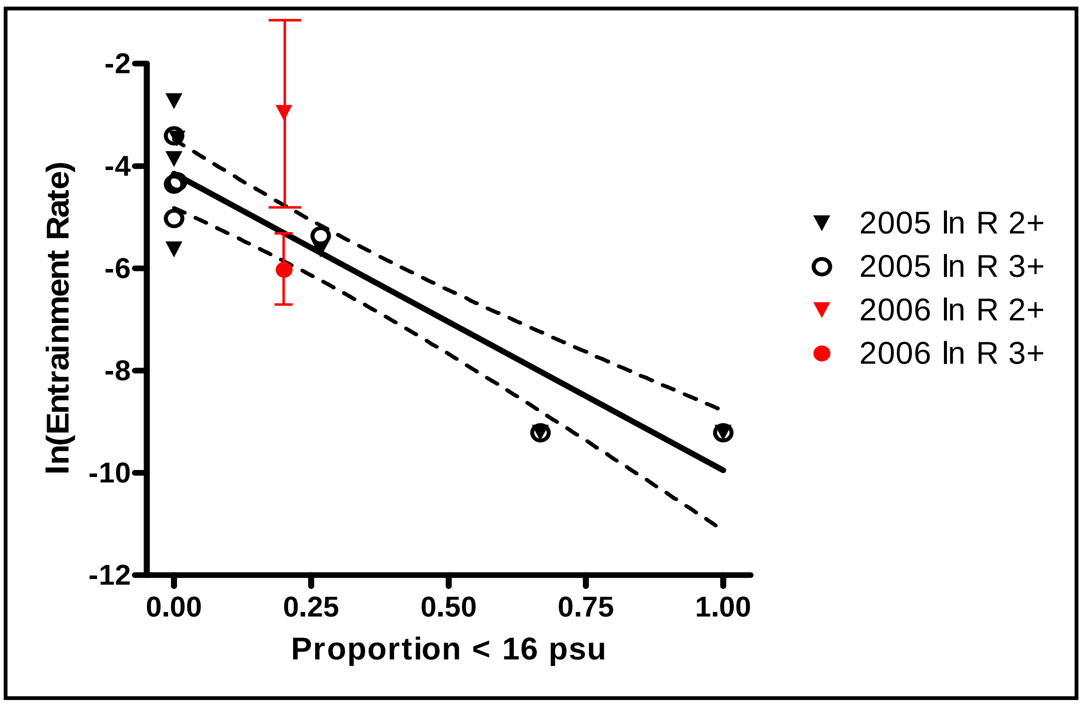
	2005 model			
Age Class	Slope	Intercept	n	MSE
2+	-5.7992	-4.1510	14	0.85100625
3+	-5.7992	-4.1510	14	0.85100625

	2006 predicted $(\ln\hat{y}_{06})$			
Age Class	Desdemona Salinity x_{06} (p <16 psu)	Predicted ln R	Predicted R (crab/cy)	Var Predicted ln R
2+	0.2	-5.3108	0.0049	0.9777
3+	0.2	-5.3108	0.0049	0.9777

	2006 Observed (y_{06}, ln y_{06})				
Age Class	y_{06} (Observed R, crab/cy)	Observed ln y_{06}	SE(y06)	CV (y06)	± 95CL lny06
2+	0.0520	-2.9565	0.014600	5.3996	1.850704144
3+	0.0024	-6.0228	0.004143	705.74	0.735467089

Age Class	Z numerator	Z denominator	Z statistic	Significance p-value	Decision using alpha = 0.1
2+	2.3543	2.5253	0.9323	0.351	Fail to reject Ho
3+	0.7121	26.5841	0.0268	0.979	Fail to reject Ho

P=0.05 if Z >1.96
P=0.1 if Z >1.645



2006 SUMMARY OUTPUT

LnR age 0+ vs Salinity <16 psu

Significant? No

p= 4.312E-01

R^2 = 11%

Regression Equation:

LnR2 = -5.143 -2.633 X p Salinity < 16psu

Regression Statistics	
Multiple R	0.325683864
R Square	0.106069979
Adjusted R Square	-0.042918357
Standard Error	3.095611034
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.822334116	6.82233412	0.71193478	0.43115027
Residual	6	57.49684604	9.58280767		
Total	7	64.31918015			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.14336533	1.375963596	-3.7380097	0.00964508	-8.510227	-1.77650371	-8.51022695	-1.77650371
p psu <16	-2.632850701	3.120370233	-0.8437623	0.43115027	-10.268122	5.00242019	-10.2681216	5.00242019

RESIDUAL OUTPUT

Observation	*Predicted ln R 0+*	*Residuals*
1	-7.776216031	-1.434124341
2	-6.89859913	2.303379275
3	-5.84545885	-3.364881522
4	-5.14336533	-4.066975042
5	-5.14336533	0.874667381
6	-5.155668371	-0.588936099
7	-5.14336533	2.283910675
8	-5.66993547	3.992959673

2006 SUMMARY OUTPUT

LnR age 1+ vs Salinity <16 psu

Significant? No

p= 4.868E-01

R^2 = 8%

Regression Equation:

LnR2 = -6.008 -1.814 X p Salinity < 16psu

Regression Statistics	
Multiple R	0.289492251
R Square	0.083805764
Adjusted R Square	-0.068893276
Standard Error	2.429199112
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.238648458	3.23864846	0.54882967	0.48676597
Residual	6	35.40604997	5.90100833		
Total	7	38.64469843			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-6.00845958	1.079751141	-5.5646707	0.0014266	-8.65051544	-3.36640372	-8.65051544	-3.36640372
p psu <16	-1.814018221	2.448628241	-0.7408304	0.48676597	-7.80559567	4.17755923	-7.80559567	4.17755923

Observation	*Predicted ln R 1+*	*Residuals*
1	-7.822477801	-1.387862571
2	-7.21780506	2.622585205
3	-6.492197772	0.747593303
4	-6.00845958	2.196281909
5	-6.00845958	-3.201880792
6	-6.0169363	1.696945057
7	-6.00845958	0.165415038
8	-6.371263224	-2.839077148

2006 SUMMARY OUTPUT

LnR age 2+ vs Salinity <16 psu

Significant? Yes

p= 4.190E-03

R^2 = 77%

Regression Equation:

LnR2 = -3.692 -6.149 X p Salinity < 16psu

Regression Statistics	
Multiple R	0.877439101
R Square	0.769899377
Adjusted R Square	0.731549273
Standard Error	1.361456333
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	37.21130118	37.2113012	20.0755487	0.00418982
Residual	6	11.12138009	1.85356335		
Total	7	48.33268126			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.691965644	0.605151724	-6.1008926	0.00088357	-5.1727186	-2.21121272	-5.17271857	-2.21121272
p psu <16	-6.148896295	1.372345482	-4.4805746	0.00418982	-9.5069047	-2.79088788	-9.50690471	-2.79088788

RESIDUAL OUTPUT

Observation	*Predicted ln R 2+*	*Residuals*
1	-9.840861939	0.630521567
2	-7.791229841	-1.419110531
3	-5.331671323	-0.295150111
4	-3.691965644	0.960134914
5	-3.691965644	-1.934855789
6	-3.720698804	0.259751418
7	-3.691965644	-0.166516594
8	-4.921744903	1.965225126

2006 SUMMARY OUTPUT

LnR age 3+ vs Salinity <16 psu

Significant? Yes

p= 4.135E-04

R^2 = 89%

Regression Equation:

LnR2 = -4.375 -5.562 X p Salinity < 16psu

Regression Statistics	
Multiple R	0.94433163
R Square	0.891762228
Adjusted R Square	0.873722599
Standard Error	0.78475121
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	30.4428611	30.4428611	49.433513	0.00041348
Residual	6	3.695006767	0.61583446		
Total	7	34.13786787			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-4.374675641	0.348812911	-12.54161	1.572E-05	-5.228190086	-3.5211612	-5.228190086	-3.5211612
p psu <16	-5.56163487	0.791027777	-7.0308971	0.0004135	-7.497210108	-3.62605963	-7.497210108	-3.62605963

RESIDUAL OUTPUT

Observation	*Predicted ln R 3+*	*Residuals*
1	-9.936310511	0.725970139
2	-8.082432221	-1.127908151
3	-5.857778273	0.497585503
4	-4.374675641	0.966453644
5	-4.374675641	-0.646009989
6	-4.400664589	0.095598996
7	-4.374675641	0.024147673
8	-5.487002615	-0.535837815

2006 SUMMARY OUTPUT

LnR age 2+,3+ vs Salinity <16 psu

Significant? Yes

p= 2.254E-06

R^2 = 81%

Regression Equation:

LnR2 = -4.033 -5.855 X p Salinity < 16psu

Regression Statistics	
Multiple R	0.898587535
R Square	0.807459558
Adjusted R Squai	0.793706669
Standard Error	1.072107738
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	67.48444992	67.4844499	58.7119968	2.25396E-06
Residual	14	16.09181003	1.149415		
Total	15	83.57625995			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-4.033320643	0.336964377	-11.969576	9.6631E-09	-4.75603735	-3.31060393	-4.75603735	-3.31060393
p psu <16	-5.855265582	0.764158016	-7.6623754	2.254E-06	-7.494221516	-4.21630965	-7.494221516	-4.21630965

RESIDUAL OUTPUT

Observation	*Predicted ln R 2+,3+*	*Residuals*
1	-9.888586225	0.678245853
2	-7.936831031	-1.273509341
3	-5.594724798	-0.032096636
4	-4.033320643	1.301489913
5	-4.033320643	-1.593500791
6	-4.060681697	0.599734311
7	-4.033320643	0.174838404
8	-5.204373759	2.247853982
9	-9.888586225	0.678245853
10	-7.936831031	-1.273509341
11	-5.594724798	0.234532028
12	-4.033320643	0.625098646
13	-4.033320643	-0.987364987
14	-4.060681697	-0.244383897
15	-4.033320643	-0.317207325
16	-5.204373759	-0.818466671

Question: After adding 2006 Desdemona data,
are the age 2+ and 3+ crab-salinity regressions significantly different?

If fit individually:	ln R 2+	ln R 3+
Best-fit values		
Y-intercept	-3.691 ± 0.6051	-4.374 ± 0.3488
X-intercept	-0.6003	-0.7865
Slope	-6.149 ± 1.372	-5.562 ± 0.7908
Y-intercept when X=0.2	-6.120 to -3.722	-6.177 to -4.795
Goodness of Fit		
r^2	0.77	0.8918
Sy.x	1.361	0.7845
Is slope significantly non-zero?		
F	20.09	49.46
DFn, DFd	1.000, 6.000	1.000, 6.000
P value	0.0042	0.0004
Deviation from zero?	Significant	Significant
Data		
Number of X values	8	8
Maximum number of Y replicates	1	1
Total number of values	8	8
Number of missing values	8	8

Are the slopes equal?
F = 0.13767. DFn=1 DFd=12
P=0.7171

If the overall slopes were identical, there is a 72% chance of randomly choosing data points with slopes this different. You can conclude that the differences between the slopes are not significant.

Since the slopes are not significantly different, it is possible to calculate one slope for all the data. The pooled slope equals -5.85532

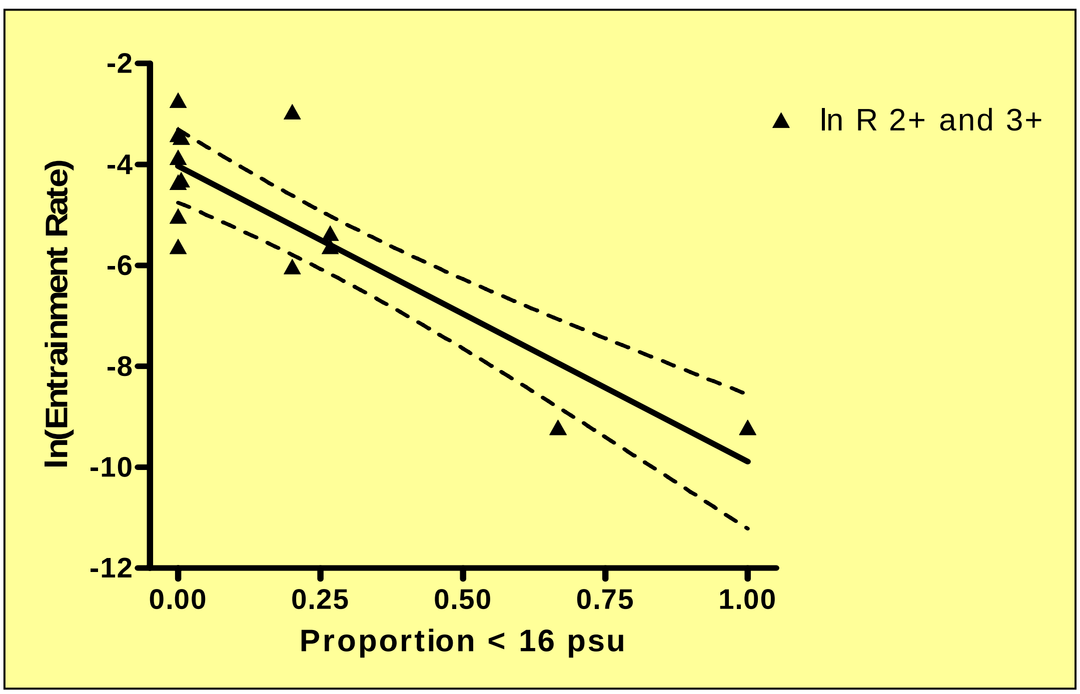
Are the elevations or intercepts equal?
F = 0.959654. DFn=1 DFd=13
P=0.3452

If the overall elevations were identical, there is a 35% chance of randomly choosing data points with elevations this different. You can conclude that the differences between theelevations are not significant.

Since the Y intercepts are not significantly different, it is possibleto calculate one Y intercept for all the data. The pooled intercept equals -4.03258

Outcome: Updated Crab Salinity Model, 2006

Combined Data Updated Model, 2006	
2005+2006 Mode	ln R 2+ and 3+
Slope	-5.855 ± 0.7639
Y-intercept	-4.033 ± 0.3369
Best-fit values	
Slope	-7.494 to -4.217
Y-intercept when X=0.2	-5.789 to -4.618
Goodness of Fit	
r^2	0.8076
Sy.x	1.072
Is slope significantly non-zero?	
F	58.75
DFn, DFd	1.000, 14.00
P value	< 0.0001
Deviation from zero?	Significant
Data	
Number of X values	16
Maximum number of Y replicates	1
Total number of values	16
Number of missing values	0



Comparison of 2005 and 2006 Models

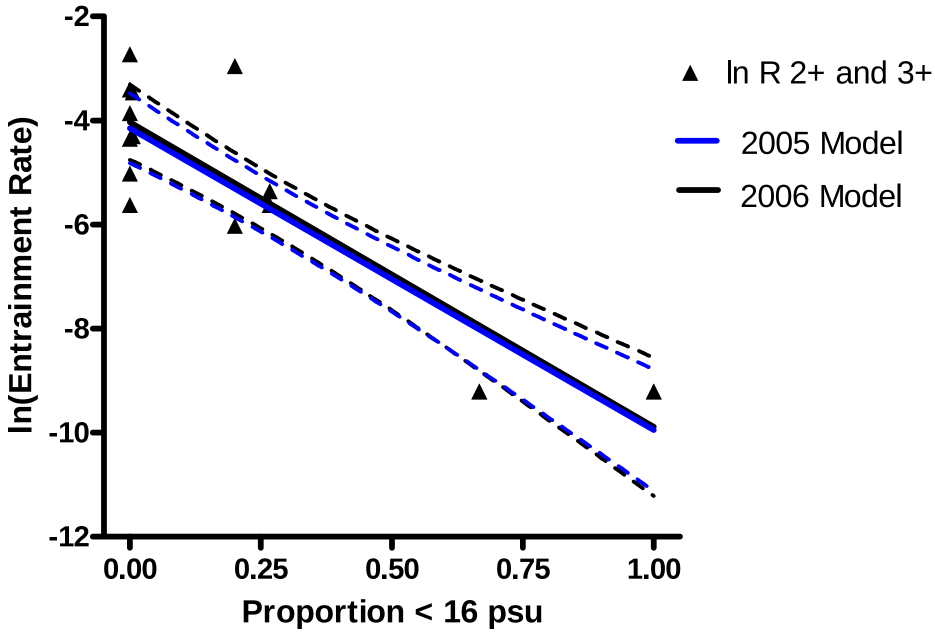


Figure 2005 and 2006 Models

2005 Model:	Slope	-7.236 to -4.363
2006 Model:	Slope	-7.494 to -4.217
2005 Model:	Y-intercept	-4.150 ± 0.3068
2006 Model:	Y-intercept	-4.033 ± 0.3369

The only difference between these two models is the addition of the 2006 data. The MSE05 with 12 degrees of freedom is 0.851. The MSE06 with 14 degrees of freedom is 1.149.

An F-test calculated as the difference in the error sum of squares divided by the difference in degrees of freedom divided by the 2005 mean squared error is distributed as an F with 2 and 12 degrees of freedom allows for a comparison between models by asking if the difference in the error between them is no greater than the original error in the 2005 Model.

F-calc = [(16.086 – 10.212)/2]/0.851 = 2.937/0.851 = 3.45 p-value = 0.065

Thus, the models are not significantly different at alpha = 0.05.

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