Grays Harbor Shell Mitigation Project
2004 Annual Crab Production Report

FINAL REPORT

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Eileen P. Visser
Perkins Point Consulting
Potsdam, New York

Executive Summary

A total of 1.33 million juvenile (J4 instar equivalent) Dungeness crabs were produced during summer 2004 according to data from the three sampling sessions conducted in June, July and August. The best performing plot was the 2003 Up plot, which accounted for 0.41 million of the total. The next highest production was realized by the 1995 Island plot with 0.20 million crabs. This brings the cumulative sum of J4 individuals produced by Grays Harbor mitigation plots to 22.22 million over the 15 year period since its inception in 1990.

Production rate per square meter of habitat created averaged 7.9 crabs •m^{-2} for the plots sampled this year, while two plots actually met the original mitigation target goal of 10 crabs/m2 (the 1995 Island plot at 11 crabs •m^{-2} and 2000 East at 10 crabs •m^{-2}).

Mortality rates for summer 2004 were slightly higher than average for old shell, but showed extremely high variation, with survival rates between 32.8% and 83.4% among the 9 plots sampled.

Of the many factors thought to contribute to production values on the shell mitigation plots, the following is a partial list of those factors considered in our data.

Shell cover

Eelgrass cover

Hemigrapsus density

Plot age

Plot-specific mortality rate

Settlement density/larval supply

Plot elevation

Overlay vs. bare mud placement

Plot size/area

The first two factors are strong predictors of mitigation success as measured by J4 juvenile Dungeness crab productivity. Shell cover correlates extremely well with production rate, particularly shell cover values early in the summer when crab densities are the highest. Eelgrass densities are highest on plots with highest productivity.

The next three factors are dropping out of the conceptual model as their correlation with Dungeness crab productivity diminishes. *Hemigrapsus oregonensis* densities have been near zero for several years now and thus interspecific competition for refuge spaces no longer predicting juvenile Dungeness crab success on mitigation plots. Plot age, beyond the new versus old shell comparison distinguishing plots in their initial year of construction does not predict productivity at all. Mortality rates are extremely variable among plots, but also within any given plot from year to year. Plots do not have a consistent ranking of survival rates, nor do their survival rates on any given year correlate well with that year's production.

The next factor on the list, larval supply, certainly has a strong influence on the success of annual mitigation efforts, but at this point is unpredictable and out of our range of influence. Although trying to predict years of strong larval supply and place new shell in those years to optimize production/cost and effort ratios may eventually come to the fore, this does not seem to be a prudent focus for this year's efforts.

Factors to prioritize upcoming studies on include tidal elevation, overlay strategy, and plot size constraints. These factors show promising correlations with mitigation success in recent years but sufficient data has not been gathered for rigorous evaluation of their contribution.

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Scope and Objective

The objective of summer 2004 sampling efforts was to obtain production estimates for all shell mitigation plots with adequate remaining shell cover to serve as protective habitat for juvenile Dungeness crabs. Production estimates for J4 juveniles were computed using monthly densities and size composition of early benthic phase *Cancer magister*. While data on all sizes of crab was collected, only field densities of J2 and J3 crab were used to compute J4 production by calculating and applying appropriate natural mortality rates. Percent shell cover data were also collected for all plots which had a significant percentage ($\geq$ 20%) of shell as surface substrate. Abundance of *Hemigrapsus oregonensis* and presence of eelgrass, both of which can influence production of juvenile Dungeness crab, were surveyed and recorded as well.

Background

History

Although periodic dredging of the shipping channel through Grays Harbor estuary has taken place since the early 1900's, controversy over Dungeness crab *(Cancer magister)* mortality due to dredge entrainment did not become an issue until the late 1980's. The U.S. Army Corps of Engineers (ACOE) plan, authorized by Congress in 1986, to widen and deepen the shipping channel into Aberdeen as part of the Grays Harbor Navigation Improvement Project (McGraw et al. 1988, Wainwright et al. 1992, Dinnel 1996), brought environmental and economic concerns to a head. Mitigation was deemed necessary by state and federal agencies and in 1990, the ACOE adopted the current mitigation strategy, which includes attempts to avoid and minimize the impact, as well as compensation for the impact. This agreement was last revised in 1998. Despite efforts by the ACOE to select gear type and plan timing of operations to minimize impacts, an estimated 26% of resident crab in the hopper dredge path become entrained (Wainwright et al. 1992), which represents 1-4% of the annual crab fishery in Grays

Harbor. Construction of intertidal juvenile habitat by depositing inert oyster shells on the surface of the mudflat (Fig. 1) was initiated in 1990 to increase survival rates during the first summer of growth (Dumbauld et al. 1993), and thereby "replace" crabs lost to the population by increasing crab survival through a vulnerable period of their life history. By 1994, South Channel was chosen as the sole location of mitigation efforts after comparisons throughout Grays Harbor estuary. Several years of efforts in both South Channel and North Bay indicated that shell longevity and productivity, as well as feasibility were greatest in South Channel (Armstrong et al. 1991). The entrainment impact, or estimated crab mortality, is determined for each dredging effort using the Dredge Impact Model (Armstrong et al. 1987, Wainwright et al. 1992), which uses crab population density, the volume of sediment dredged, and a regression function to give the number of crabs lost to the population. After accounting for natural mortality over the time it takes for juvenile crabs to reach legal fishery size, the number of crabs required for impact compensation was reached. Thus the target goal for mitigation efforts became 9 million J4 juveniles after the initial widening and deepening project. This target goal was met in 2001 and the mitigation for construction impacts completed. Mitigation for ongoing operation and maintenance impacts continues, and total crab production since 1990 is over 22 million J4 juveniles.

Ecology and Life History

Dungeness crab megalopae select flood tide currents as transport mechanisms into Grays Harbor and settle into intertidal areas during late spring and early summer. They subsequently metamorphose into first juvenile instars (J1; 6-9 mm carapace width), with initial densities generally 100-200 crabs per m^2 (Visser and Armstrong 1998). Megalopae and early juvenile instars select shell habitat and survive better in shell than either bare sediment or eelgrass (Fernandez et al. 1993a, Eggleston and Armstrong 1995). Artificial shell mitigation plots and relic deposits of *Mya arenaria* (eastern softshell) serve as important refuge habitat (Armstrong et al. 1992, Palacios 1994) throughout the first summer. By early fall, the juvenile Dungeness crab migrate to subtidal regions and no longer make extensive use of the shell refuge habitat (Gutermuth and Armstrong 1989, Gunderson et al. 1990, Wainwright and Armstrong 1993). By this time, the crabs have reached the J5 instar (20-26 mm carapace width, Figure 1) and shell habitat no longer seems to be crucial refuge habitat for them. Thus the shell mitigation concept is to provide key habitat during this initial vulnerable period in order to increase the number of >25mm carapace width individuals entering the subtidal population.

Hemigrapsus oregonensis colonized the shell mitigation plots after initial construction, to the detriment of juvenile Dungeness crab production (Visser 1997, Dumbauld et al. 2000, Visser et al. 2004). For 1992-1997, the typical pattern was high productivity as evidenced by high densities of *Cancer magister* during the initial year after shell plot construction followed by much lower densities of Dungeness crab and much higher abundance of *Hemigrapsus* during subsequent years. Competitive dominance by *Hemigrapsus oregonensis* for refuge space seemed to play the major role in the interaction between the populations (Visser 1997, Visser et al. 2004). These competitive interactions, as well as some predation on settling Dungeness megalopae by resident adult *Hemigrapsus*, combined with loss of shell cover due to bioturbation and sediment destabilization by *Neotrypea pugetensis* and *Upogebia californiensis*, led to lost effectiveness of shell plots after their initial year of construction, at least as measured in terms of Dungeness crab productivity. During 1998-2003, the pattern has changed due to an apparent recruitment failure of *Hemigrapsus* (Visser et al. 2004). Insufficient data exists to determine whether this is a reproductive failure or a population distribution issue, since our sampling regime is limited to South Channel mitigation plots. While productivity is still greatest on new shell, production per square meter on shell mitigation plots $\geq$ 1 year since construction is much greater than before 1998. The ongoing challenge of the habitat mitigation project is to conduct rigorous sampling to accurately assess the number of juvenile Dungeness crabs being produced by the current habitat, to optimize areas for shell placement in years when appropriate, and to identify patterns in the crab population data that might suggest improved strategies.

Figure 1. Crabs typically found in ACOE shell mitigation samples (clockwise from left: J5 and J1 Dungeness instars and large male *Hemigrapsus oregonensis*).

Methodology

Field protocol

The standard sampling protocol used in past years was followed to obtain juvenile *Cancer magister* and *Hemigrapsus oregonensis* density and size composition data. Plots were surveyed in early June to determine which sites would be sampled and to measure boundaries, as well as map and mark the plots chosen, sampling trips were made once monthly beginning in June. The nine plots sampled during summer 2004 were the 1995 Island, 1995 Mainland, 1996/1997 Overlay, 1997 East, 2000 Up, 2000 East, 2003 Up, 2003 Down, and 2003 East plots (Figure 2). Plots are named according to the year they were initially constructed. Since percent shell cover strongly affects juvenile Dungeness crab survival in the intertidal (Dumbauld et al. 1993), any plot which did not retain $\geq$

20% of shell remaining on the surface was not sampled. These areas yield little to no production of juvenile Dungeness crab and do not merit sampling effort as there is little refuge available to the crabs, and thus extremely low juvenile densities and thus productivity.

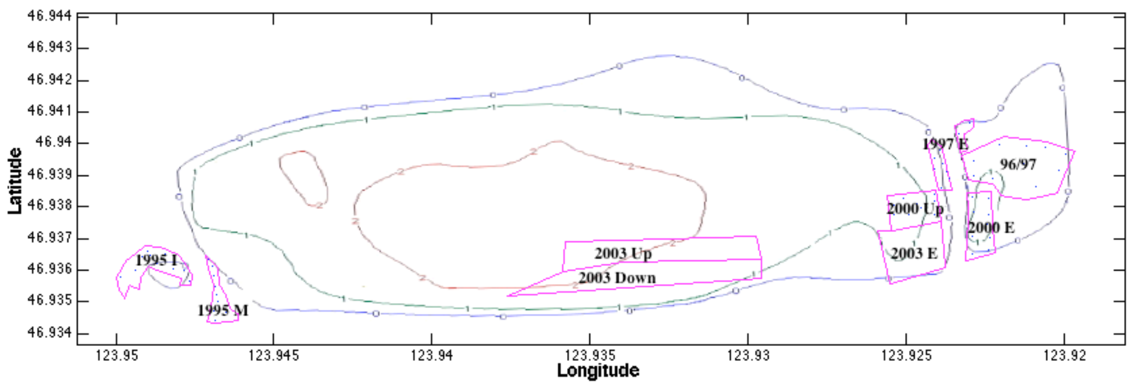


Figure 2. Map of the Army Corps of Engineers shell mitigation plots in South Channel, Grays Harbor, WA, as of summer 2004.

A sampling crew consisting of 6-7 excavation samplers and 2-4 additional shell estimators was taken to the shell mitigation plots by personnel aboard the US Army Corps of Engineers ship Shoalhunter during low spring tides each month (Table 1). About 2 hours before low tide, the crew was delivered to the mudflats to begin sampling. Ten replicate excavation samples were taken monthly from each of the nine plots sampled in 2004 to obtain monthly crab density data for each plot. (Only nine replicates were possible for 1995 Mainland and 1997 East plots due to loss of shell along boundaries and consequential decreased size of plots.) Collection of these samples consisted of haphazardly placing a 0.1 m^2 quadrat on a section of 100% shell cover within the plot to be sampled. All shell material from within the quadrat was removed, including all the mud down to 5 cm below the shell layer, and was sorted by hand and seived through a 3 mm mesh screen (Figure 3). All crabs retained by the screen were

Table 1. Sampling dates, approximate times, and estimated tidal heights for data collection during summer 2004 at South Channel crab mitigation sites. There were three sampling dates each month; the initial tide in June was used for field site preparation.

Date	Low tide time	Low tide height (ft)
2 June	7:04 AM	-2.5
3-June	7:52	-3.0
4-June	8:41	-3.2
5-June	9:29	-3.0
2-July	7:37	-3.1
3-July	8:26	-3.1
4-July	9:13	-2.9
31-July	7:21	-2.6
1-August	8:08	-2.6
2-August	8:52	-2.3

Note: Times and heights given are based on computer estimation of tides at Markham, WA (predicted from actual readings at Aberdeen and Westport, WA, see Port of Grays Harbor Tide Tables).

Figure 3. Sampling procedure, showing digging of 0.1 m^2 sample, quadrat full of shell material, and sorting technique of rinsing and visual inspection for animals.

placed into bags to be identified to species and measured back on the ship after the tide rose. Crabs were identified to species, measured to the nearest 0.1 cm carapace width, and recorded. For *Hemigrapsus oregonensis,* gender and state of ovigery for females was also recorded.

Estimates of amount of refuge area available within each plot were necessary in order to translate the crab density data into total number of crabs produced. Total amount of refuge space was computed by multiplying plot size by percent shell cover. These percent shell cover estimates were taken by 4 to 6 observers visually studying each of ten marked subplots (20m x 20m) throughout each of the nine plots sampled in 2004. (Only nine subplots were surveyed in the 1995 Mainland and 1997 East plots due to space constraints. Shell along the southern boundaries of these plots had completely sunk beneath the surface, necessitating adjustment of plot boundaries and subsequent recomputation of plot areas.) The amount of shell remaining above the surface of the mud and therefore representing refuge space available to the juvenile crabs was recorded (Figure 4). Thus, the overall monthly shell cover estimate for each plot was based on 40-60 individual independent estimates, resulting in a mean and a standard deviation as input for the production model.

Although shell provides the optimal refuge habitat for very young juvenile Dungeness crabs, both as evidenced by survival rates and by habitat preference experiments (Fernandez et al. 1993), eelgrass *(Zostera marina)* serves as habitat and provides some protection as well. Part of the mitigation strategy in Grays Harbor has been to avoid placing shell in areas where eelgrass flourishes in order not to disturb any natural refuge function within the estuary. On plots where eelgrass beds flourish, shell placement is therefore patchy (Figure 5). Percent cover estimates for eelgrass have been added to the mitigation sampling scheme in recent years so that trends in eelgrass coverage can be tracked. One theory currently under investigation is that eelgrass propagation, distribution, and abundance may be enhanced by the shell placement program by contributing to sediment stability.

Figure 4. Variation in shell habitat quality, showing approximately 100%, 50%, and 5% coverage of mud surface.

We do not yet have a dataset with long enough timeframe to determine if the apparent trends are consistent with shell coverage. Because eelgrass supports much lower densities of crabs, and particularly because it is a naturally occurring phenomenon rather than a direct result of mitigation efforts, estimates of eelgrass coverage are for information purposes only and do not factor into the production model at all. Assumptions inherent in the theory of the mitigation project include production estimates from shell plot sites representing extra crabs produced in Grays Harbor as a direct result of the artificial habitat created by mitigation efforts, and the assumption that this production is directly additive with natural production from other habitats within the estuary and that the natural relationships among the populations within Grays Harbor are not altered by the addition of these crabs.

Figure 5. Example from the 2000 East plot, showing patchiness of habitat and proximity of shell and eelgrass habitats.

Data analysis

Data from the field notebooks were entered into Microsoft Excel spreadsheets, analyzed using the production model originally developed by Armstrong et al. (1995) and modified by Visser and Armstrong (1998). This model applies a plot-specific mortality function to the crab density data over an instar-based molt interval. Density of J2 instars are used as input for the model since J1 density is extremely variable, especially at the beginning of the summer depending on how the timing of specific settlement events correlates with the timing of the initial sampling period in any given year. When J3 instars are present at the first sampling date, they are treated as early settlers and inputted into the model as well, using the same mortality function computed for that specific plot, but over the shorter period of time a J3 instar takes to reach the J4 size class. The mortality rates for each plot are computed each year by fitting an exponential function to the declining Dungeness crab density data for each field season. In some years the data require computing the mortality function without the initial settlement peak of J1 instars

(J2 mortality), which was again the case for 2004 data since peak crab settlement occurred before the first sampling date June 3-5. Multiplying the density of surviving crabs by the effective refuge area (the product of total habitat area constructed and percent shell cover) gives the number of crabs produced by each plot for each month over the summer. Thus, Production = $J2 * e^{-35k} + J3 \bullet e^{-20k} \bullet \% \bullet AREA$

The J4 instar serves as the accepted production unit, as per the agreement by ACOE and agency personnel. By the time the crabs reach J5 instars, they are no longer at as great a risk and begin to move to subtidal areas, making their intertidal densities a poor measurement of their population abundance. Thus, the computed mortality rate is applied over a 35 day interval for J2 instars and a 20 day interval for J3 instars, the time it takes for each instar to reach the fourth juvenile instar, J4 or 16-19 mm carapace width. Results in the form of production of crabs per plot and annual comparisons, crab density and instar composition, and shell cover, as well as eelgrass abundance and mortality rates are presented and discussed. Since intertidal juvenile Dungeness crab densities are less than 5 crabs • m^{-2} and generally zero in areas with no shell or eelgrass refuge, all crabs produced on the shell mitigation plots are attributed to the mitigation efforts. The sampling regime does not test the possibility that the mitigation plots attract crabs that may otherwise be settling elsewhere within the Grays Harbor system. Nor does it consider the carrying capacity of the subtidal channels and whether or not enhanced production of intertidal juveniles actually translates through the next stages of life history into increased number of legal adults entering the fishery three to four years later.

Results and Discussion

2004 Production

Sampling during summer 2004 resulted in production estimates of 1.3 (+ 0.13) million crabs. Of this total, 0.7 million was from the shell placed in April 2003 (2003 Up, Down, and East), and 0.2 million crabs were produced on the two shell plots erected in 2000 (2000 Up and 2000 East) and the remaining 0.4 million was produced by the 1995 Island, 1996/1997, 1995 Mainland, and 1997 East plots (Table 2). Early settlement played an enormous role this year compared to previous years, comprising 63.1% of the total. Due to the late date of the initial sampling, the previous low spring tide would have been May 4-6, which often predates megalopal influx to the estuary. In order to avoid a costly sampling session with no crab numbers to report it was decided to delay sampling until early June. The data shows protracted settlement, with the many juvenile Dungeness crab settling during the early May first tide, but protracted settlement continuing through early June. As usual, most of the production resulted from the June sampling series, with 78.5% of the total production coming from June data. July was next highest, with 14.2% of the total 1.3 million crabs produced coming from July data. August was much lower, with only 7.3% of the total production. If serious budget constraints ever arise in management of crab mitigation efforts in Grays Harbor, foregoing the August sampling date still seems a reasonable consideration.

The breakdown of total crab production over the four month sampling season by plot shows that, like last year, the 2003 Up plot produced the greatest number of crabs, followed by the 1995 Island plot, the 2003 Down, 1996/1997, and 2000 East plots (Figure 6). These production differences are not simply due to plot size as the 1996/1997 plot is by far the largest followed by 2003 Down, 2003 Up, 1995 Island, and 2003 East (Table 2), yet performed worse than the 2003 Up plot. The 1995 Island plot consistently performs well, although it is one of the oldest plots still sampled.

Table 2. Summary data for the 2004 production model; output is production of J4 instars.

Habitat	Month	J2 /m2	sd	Mortality	Area	Shell	sd	Production	Early	Total Prod	sd
1995 Island	June	10	12.47	0.0264	19051	0.68	0.36	51490	130077	203250	37314
	July	1	3.16	0.0264	19051	0.71	0.34	5404			
	August	3	4.83	0.0264	19051	0.72	0.35	16279			
1995 Mainland	June	2	6.67	0.0101	7479	0.43	0.22	4512	26257	33578	5402
	July	1	3.33	0.0101	7479	0.53	0.23	2809			
	August	0	0.00	0.0101	7479	0.47	0.24	0			
1996/1997	June	0	0.00	0.0052	42662	0.28	0.17	0	119515	170405	0
	July	2	4.22	0.0052	42662	0.71	0.34	50890			
	August	0	0.00	0.0052	42662	0.32	0.18	0			
1997 East	June	2	4.41	0.0106	7224	0.35	0.24	3476	14261	21529	3507
	July	1	3.33	0.0106	7224	0.40	0.26	1988			
	August	1	3.33	0.0106	7224	0.36	0.25	1804			
2000 Up	June	4	6.99	0.0318	13912	0.46	0.20	8315	56964	65278	6253
	July	0	0.00	0.0318	13912	0.49	0.20	0			
	August	0	0.00	0.0318	13912	0.50	0.16	0			
2000 East	June	2	4.22	0.0163	13695	0.64	0.29	9877	94667	141719	8353
	July	7	8.23	0.0163	13695	0.60	0.34	32630			
	August	1	3.16	0.0163	13695	0.59	0.35	4544			
2003 Up	June	15	11.79	0.0263	20145	0.67	0.12	80816	247661	405543	32102
	July	11	11.01	0.0263	20145	0.63	0.13	55383			
	August	5	8.50	0.0263	20145	0.54	0.14	21682			
2003 Down	June	4	6.99	0.0180	25422	0.50	0.19	27352	98512	192618	19561
	July	4	5.16	0.0180	25422	0.44	0.15	23685			
	August	7	8.23	0.0180	25422	0.45	0.17	43069			
2003 East	June	6	9.66	0.0172	16126	0.36	0.22	19357	54255	100499	16048
	July	5	8.50	0.0172	16126	0.39	0.22	17233			
	August	3	4.83	0.0172	16126	0.36	0.24	9654			
Total										**1334419**	**128541**

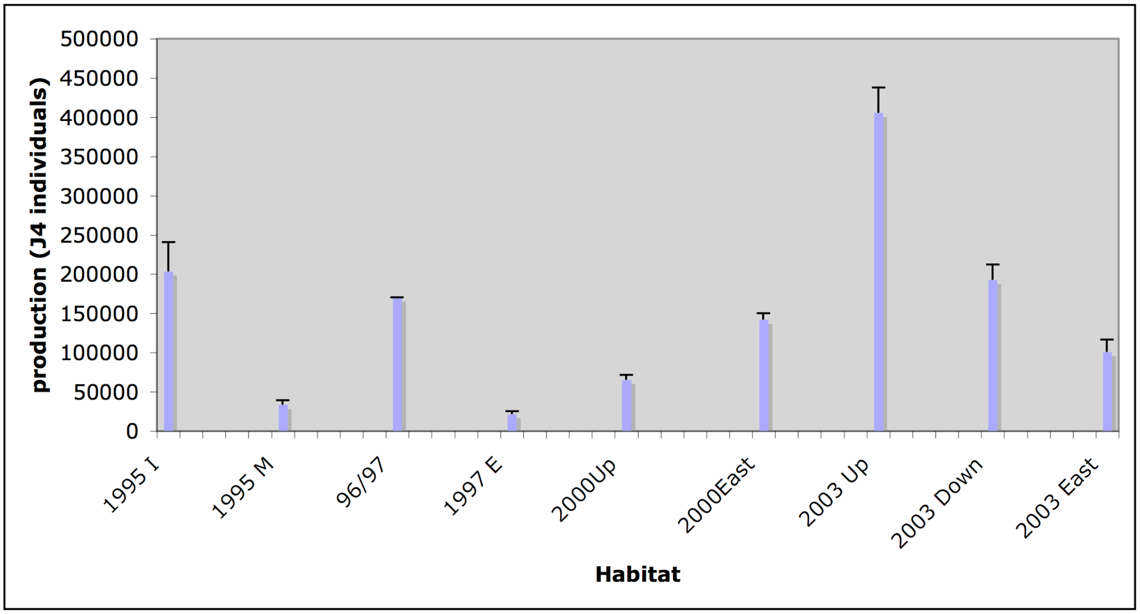


Figure 6. Annual crab production during summer 2004 by each of the nine plots sampled this season.

Cumulative production values

Total production of juvenile Dungeness crab from the South Channel shell mitigation plots is over 22 million J4 individuals thus far (Table 3). About 2/3 of this production is from plots in their initial year after construction (63.5%) while the remaining 36.5% is from old plots one or more years post-construction. The same information is shown in graphical form (Figure 7) where the contribution of new and old shell to each year's production total can be compared by bar color.

Table 3. Annual production by new and old shell plots sampled since the beginning of the shell mitigation project. Note that unlike other tables, 'year' here is year of sampling, not year of plot construction.

Year	New	Old	Total	st.dev.
1990	109,710	N/A	109,710	29,172
1991	204,984	117,987	322,971	77,615
1992	3,226,965		3,226,965	670,204
1993	N/A	44,222	44,222	27,042
1994	1,633,038	0	1,633,038	701,685
1995	2,054,273	124,945	2,179,217	788,633
1996	684,584	328,064	1,012,648	136,052
1997	275,729		275,729	
1998	235,167	1,320,398	1,555,565	287,290
1999	1,164,115	254,838	1,418,953	167,137
2000	2,503,377	913,513	3,416,889	285,964
2001	N/A	2,382,476	2,382,476	408,102
2002	N/A	493,780	493,780	100,899
2003	2,028,516	787,181	2,815,697	352,682
2004	N/A	1,334,419	1,334,419	128,541
Total	**14,120,458**	**8,101,823**	**22,222,2790**	**4,161,018**

Average production per unit refuge area, or per meter squared production was 7.9 crabs /m^2 during summer 2004 comparable to per meter squared production for old shell in 2003, but higher than average old shell production (1-6 crabs/ m^2). While new shell consistently produces more crabs per unit of viable habitat, there is much fluctuation among new plots as a group as well as among old plots as a group (Figure 8). Age of shell alone does not correlate well with productivity rate. Plots vary between 3 and over 50 crabs • m^{-2} in their first year (the high being very early in mitigation efforts before colonization by other crab species, particularly *Hemigrapsus oregonensis*. and between 0 and 30 crabs • m^{-2} in subsequent years. Considering that no new shell was placed in 2004, the 7.9 crabs/m^2 comes surprisingly close to the original mitigation goal of 10 crabs/m^2 overall target average. The 1995 Island plot continues to show high per m^2 production despite the plot age (11 crabs/m^2 for the three month sampling period), as did the 2000 East and 2003 Down plots (10 and 8 crabs/m^2 respectively). The 1995 Mainland, 1996/1997, 1997 East, 2000 Up, and 20003 East all produced between 3 and 6 crabs /m^2. At 20 crabs/m2, the 2003 Up plot had the highest juvenile crab densities and thus gave the best production rate. Compared with other shell plots produced, the 2003 shell showed lower average drop in its second year after creation (Figure 9), possibly due to lack of colonization by space competitor *Hemigrapsus oregonensis*.

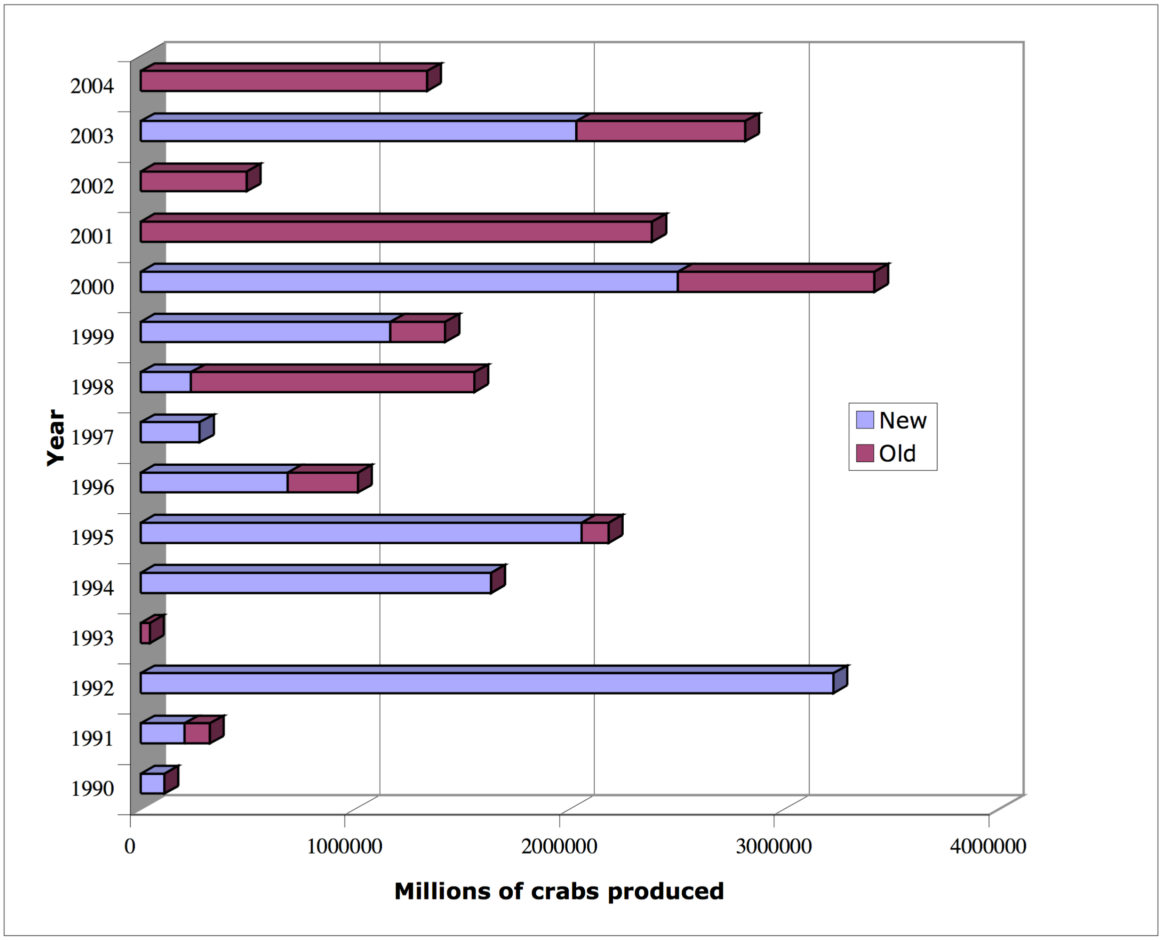


Figure 7. Cumulative production of the shell mitigation project by year. Colors show amount of each year's total attributable to shell placed in that year versus older shell placed in previous years. No new shell habitat was created in 1993, 2001, 2002 or 2004, so there are no blue portions of the bars for these years. Likewise, old shell was not sampled in 1992 or 1994 and no red portion exists for these years. Actual production of crab on ACOE mitigation plots is thus higher reported, since all plots which were in fact producing crabs were not sampled.

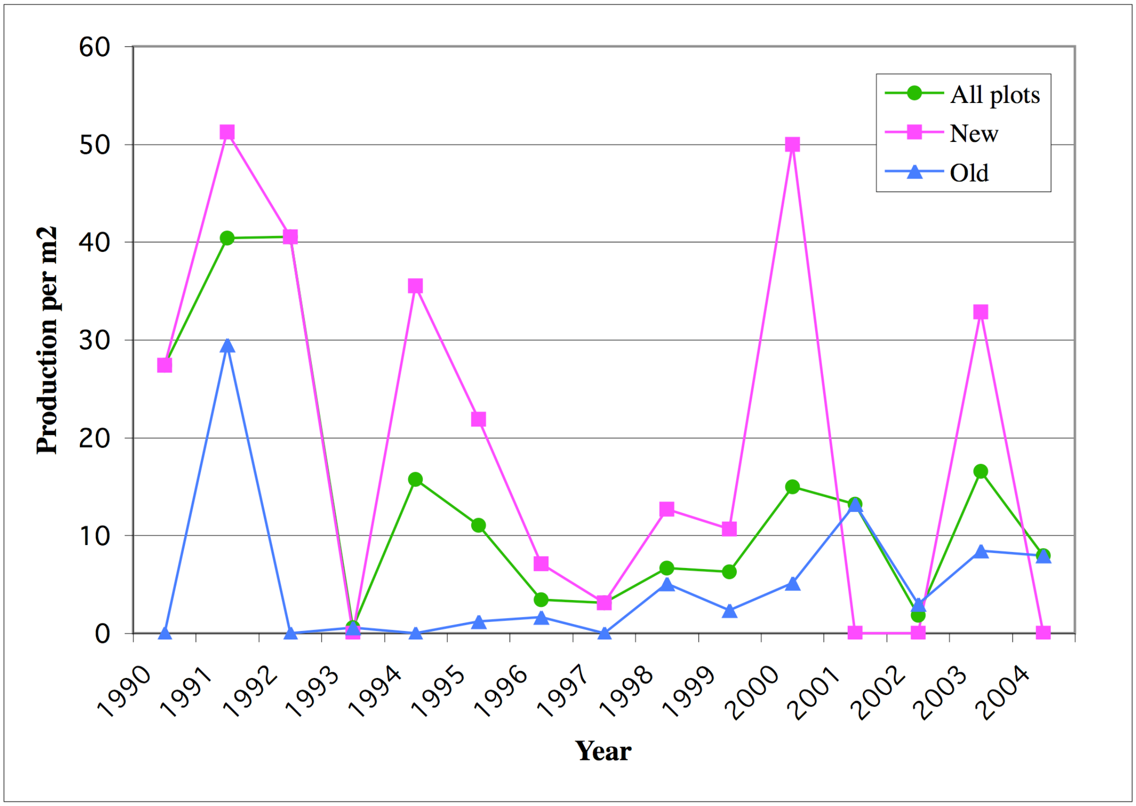


Figure 8. Average production rates (J4 crabs per m^2) for new, old, and all plots over the 15 year history of the mitigation project. Zero values indicate either no new shell placement (1993, 2001, 2002 and 2004 new shell) or no sampling effort allocated (1992 and 1997 old shell).

Crab density and instar composition

Dungeness crab density data showed the typical trends, with settlement evident in May by high abundance of early J1 instars in the samples (Figures 10-18) and high total crab density. As the crabs grew through larger instar sizes, their density dropped off, showing the natural mortality rate. (Dividing the coefficient for x in the trendline equation by 30 days per month gives the daily mortality rate z used in the production model.) Several plots show evidence of settlement of a second cohort in July, particularly the 1995 Mainland (Figure 11), 1997 East (Figure 13), and 2000 East (Figure 15) plots which show presence of J1 in July as well as the 1995 Island, 2000 East, 2003 Up, 2003 Down and 2003 East plots (Figures 10, 15, 16, 17 and 18 respectively) which

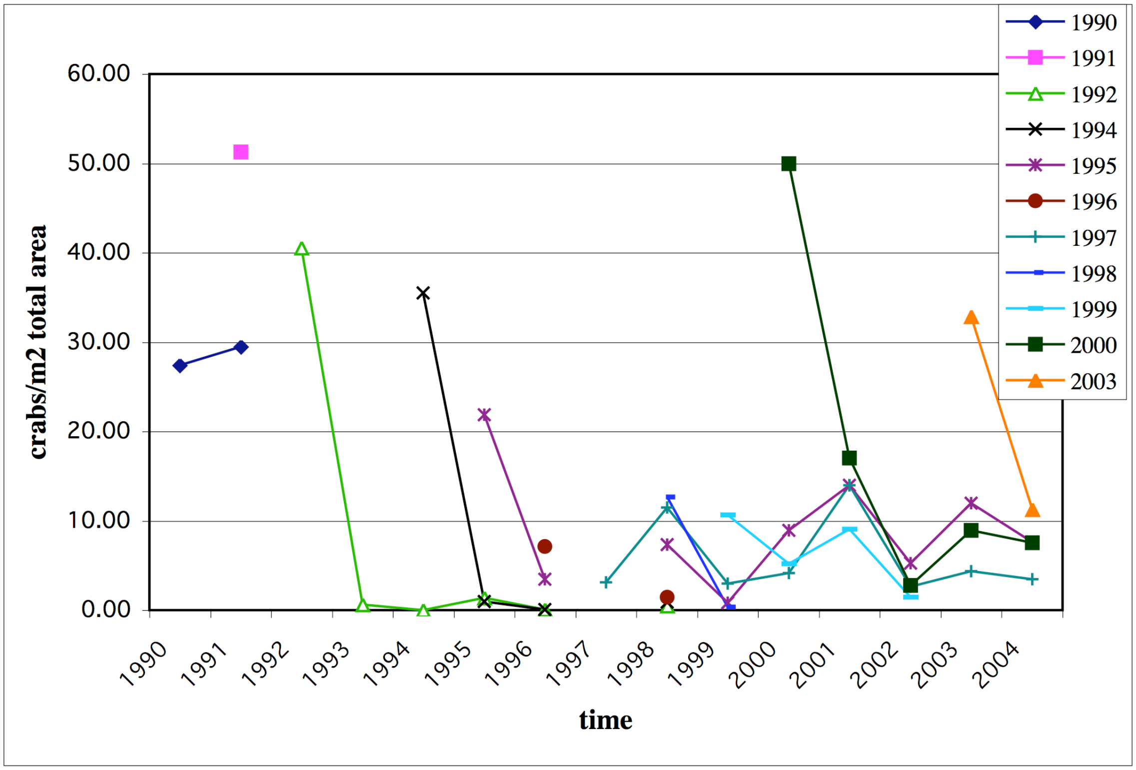


Figure 9. Plot production rate by shell plot created over time for total area of habitat constructed (not corrected for shell cover). The colors and year labels in legend represent shell plots constructed in each year, while the years across the bottom are chronological sampling dates. Thus, green squares show the 2000 shell plot sampled four times: first in 2000 as new shell, then in 2001, 2002, and 2003 as old shell.

show that J2 were present as late as mid-August 2004. Due to the timing of the spring tides in 2004 (very early in the month), the first sampling efforts occurred in June rather than May, in order to avoid the likelihood of the first sampling preceding the initial crab settlement and finding no crabs. Megalopae in fact settled gradually throughout late April and May, as indicated by the range (J1-J5) of instars present in early June samples (Figures 10-18, but especially 11, 13, 14, and 18).

Crab density and instar composition data shows typical patterns of increasing size and decreasing numbers as the individual juvenile Dungeness crabs grow while the population suffers natural mortality. 2003 Down (Figure 17) shows immigration as well with densities almost doubling from June to July (20 crabs • m^{-2} to 38 crabs • m^{-2}). 1996/1997 data (Figure 12) shows the same trend, but the 4 crabs • m^{-2} difference from June to July is within the error bars and doesn't necessarily indicate immigration.

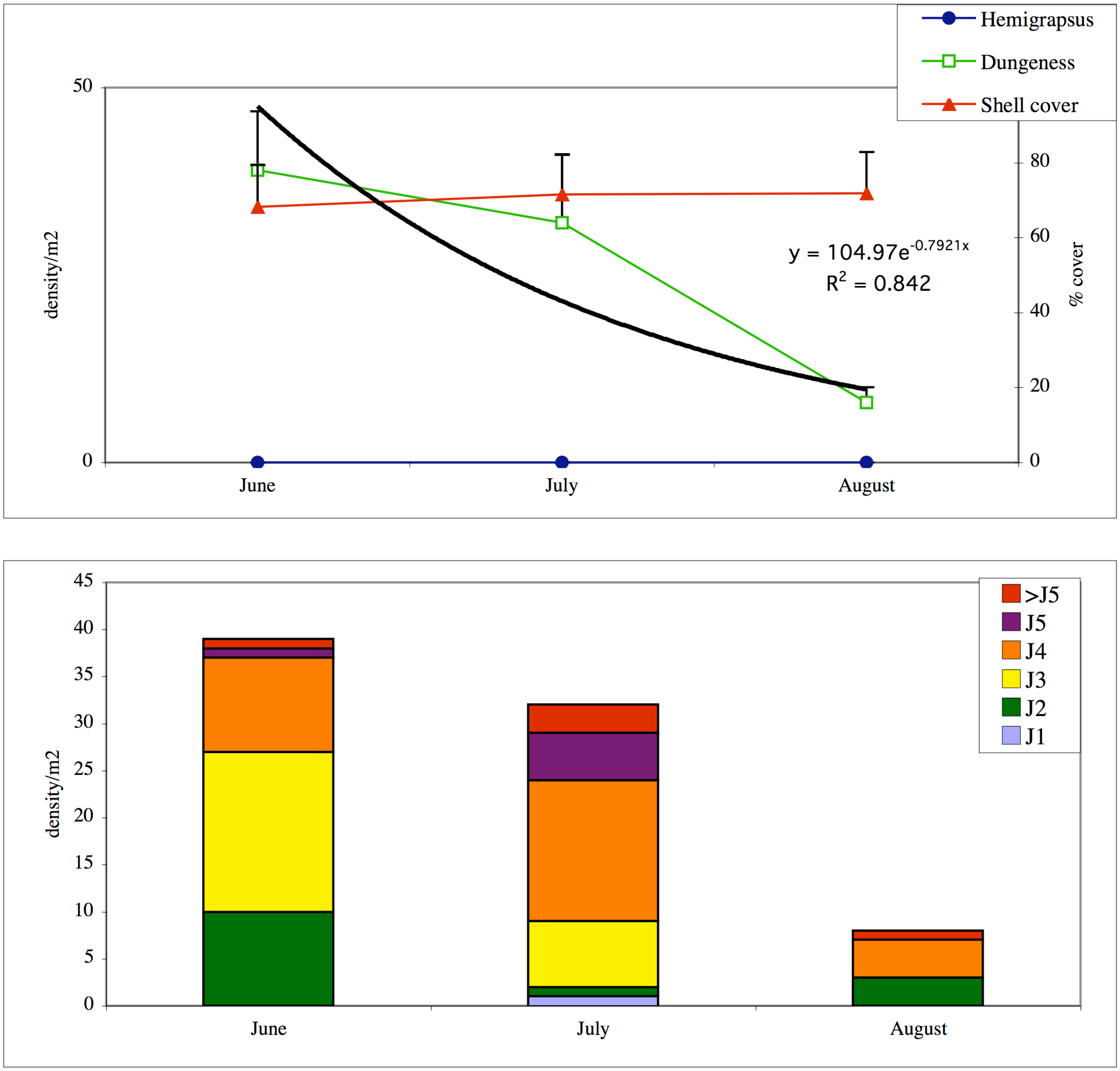
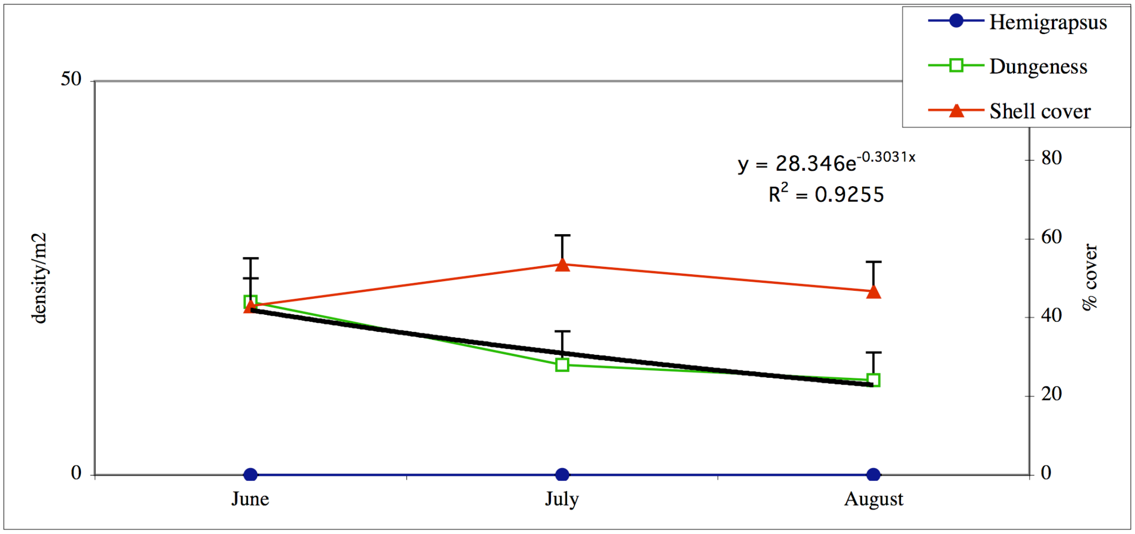


Figure 10. 1995 Island data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



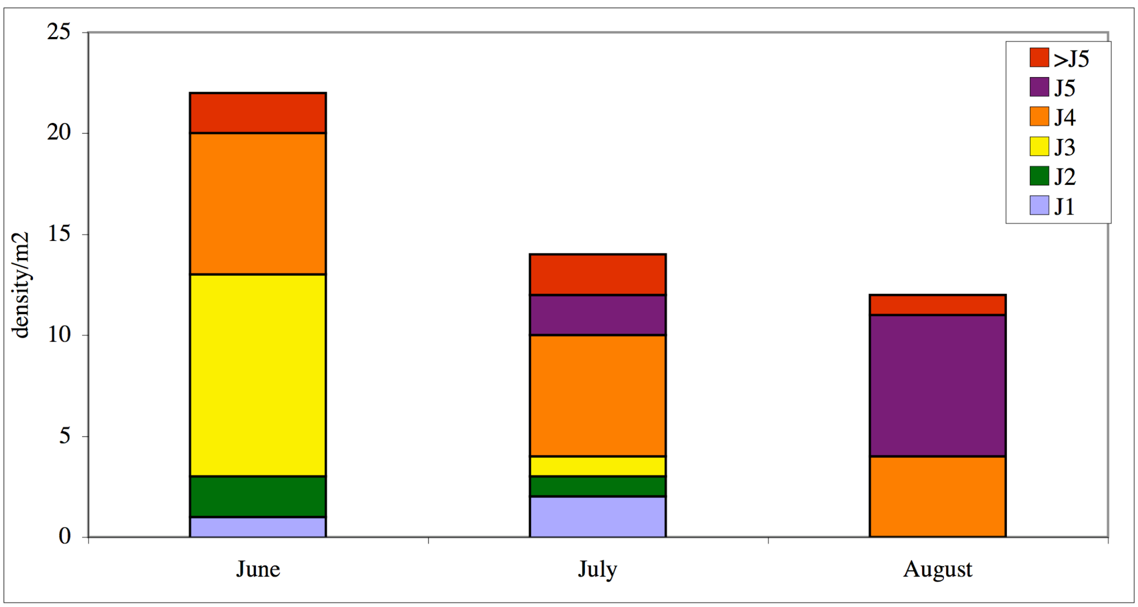
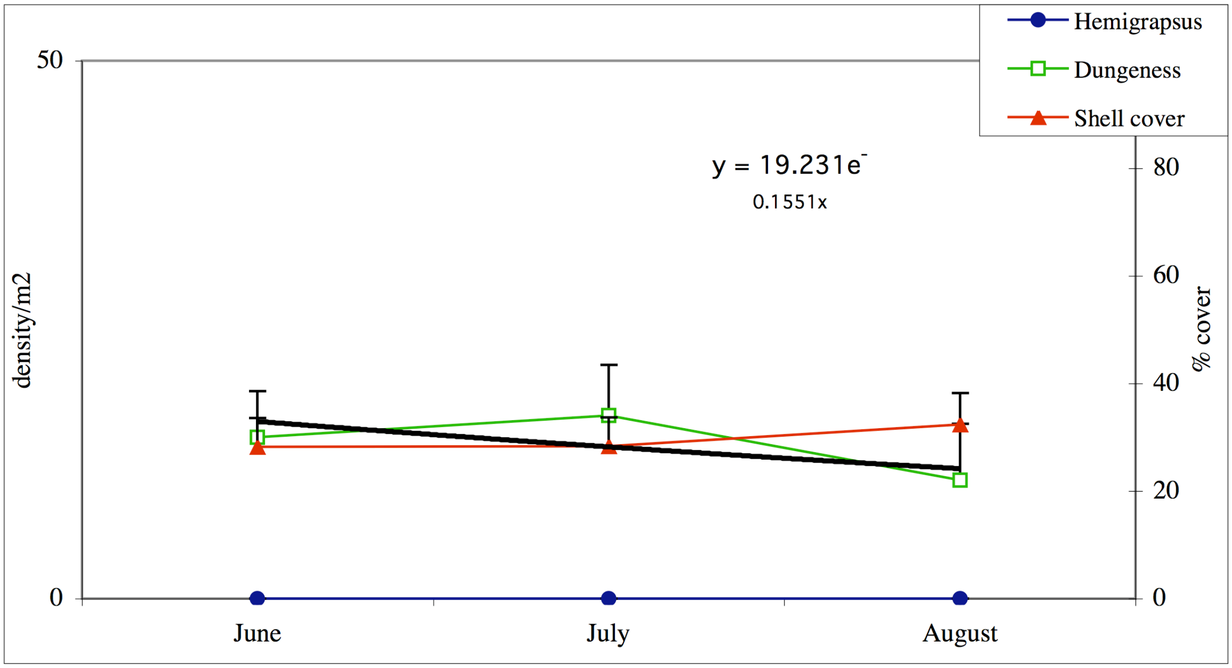


Figure 11. 1995 Mainland data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



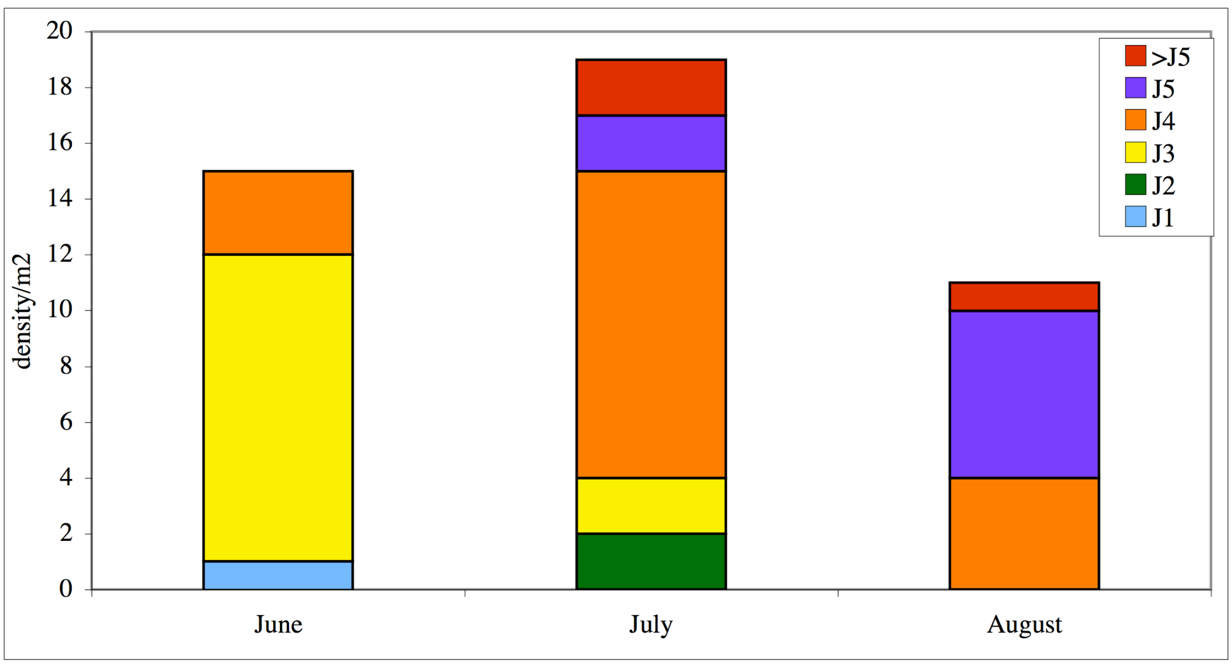
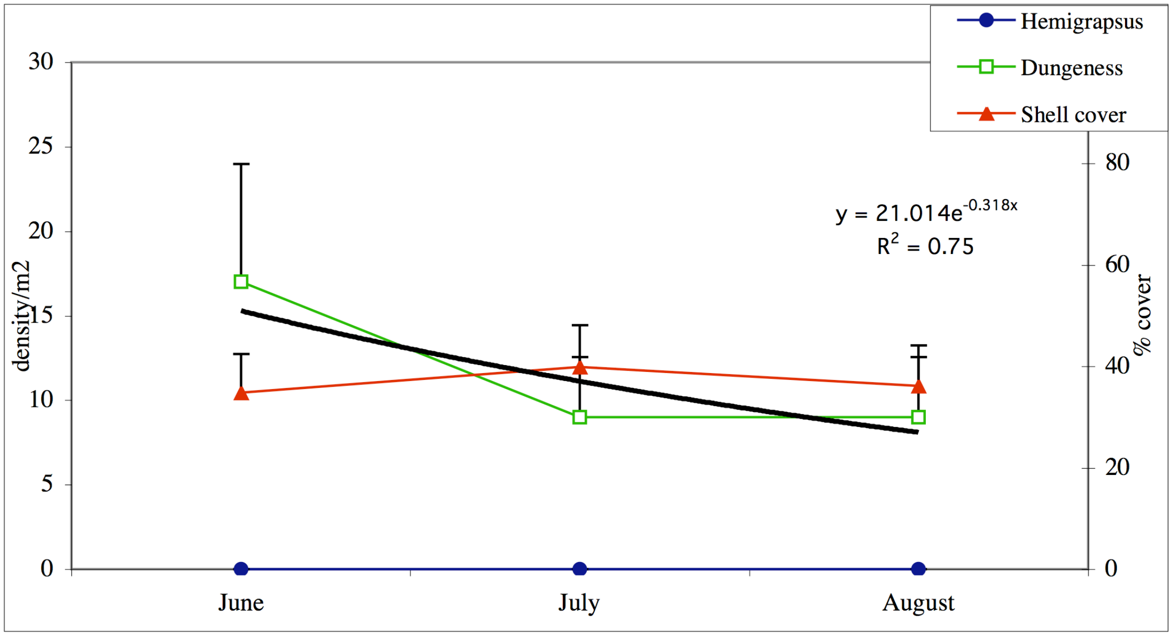


Figure 12. 1996/1997 data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



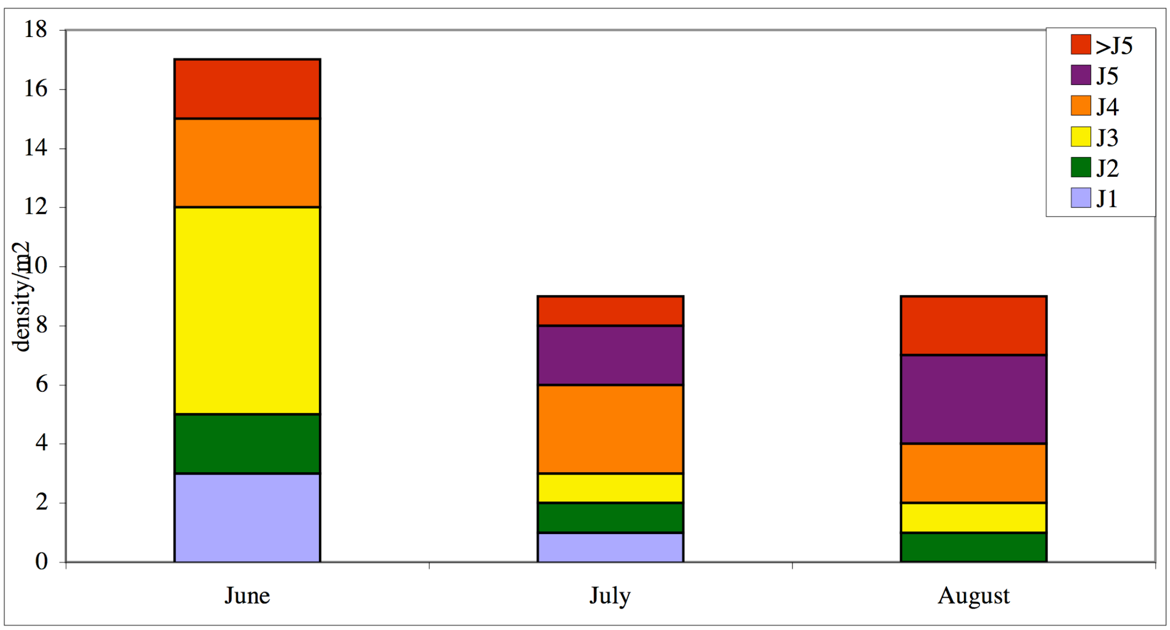
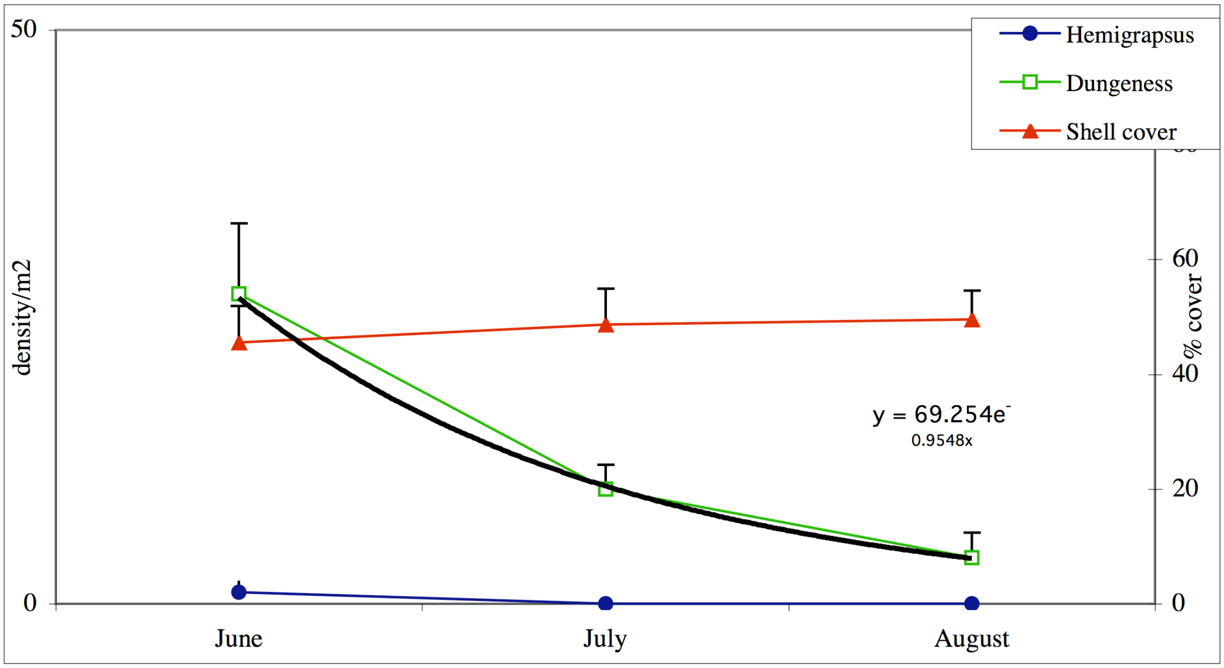


Figure 13. 1997 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



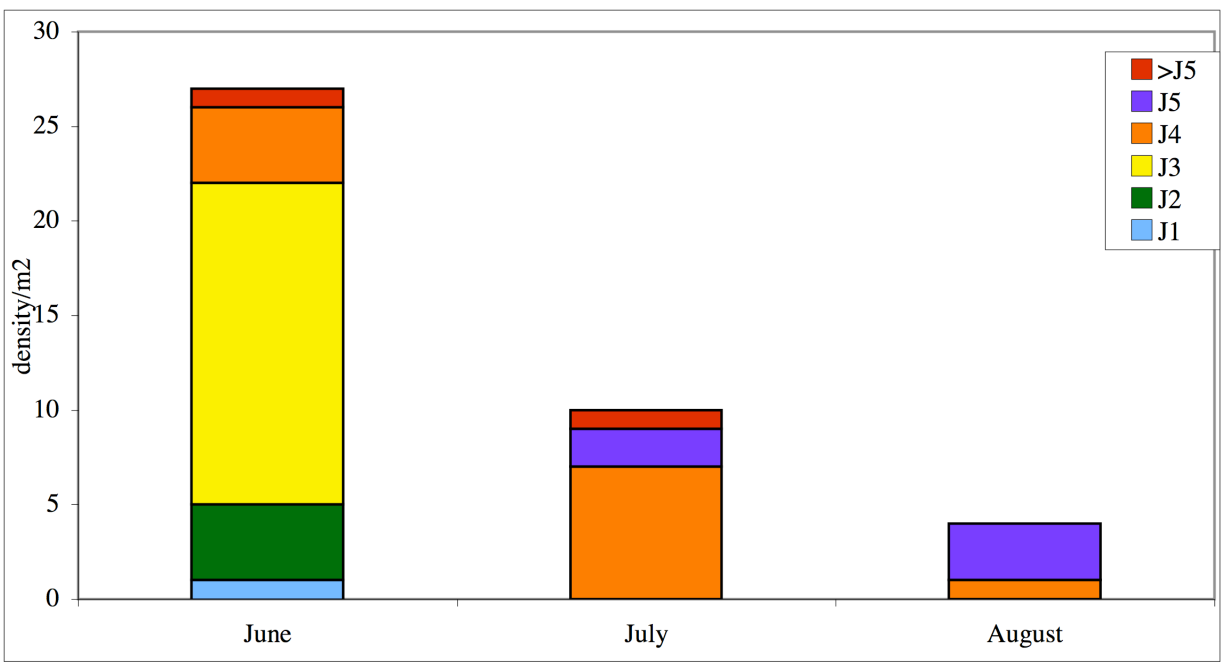
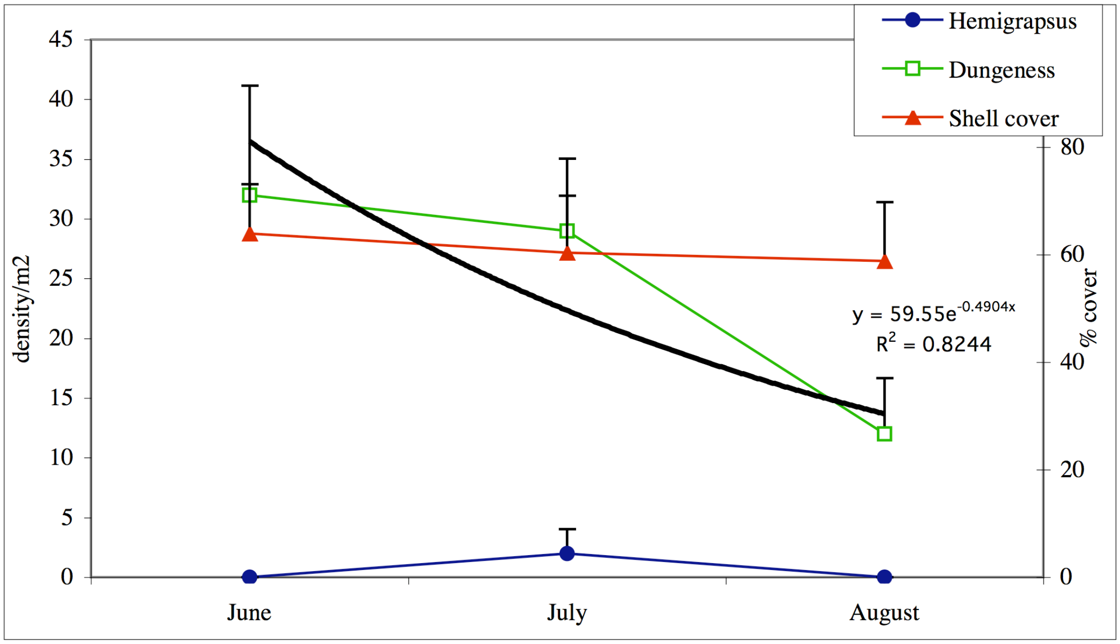


Figure 14. 2000 Up data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



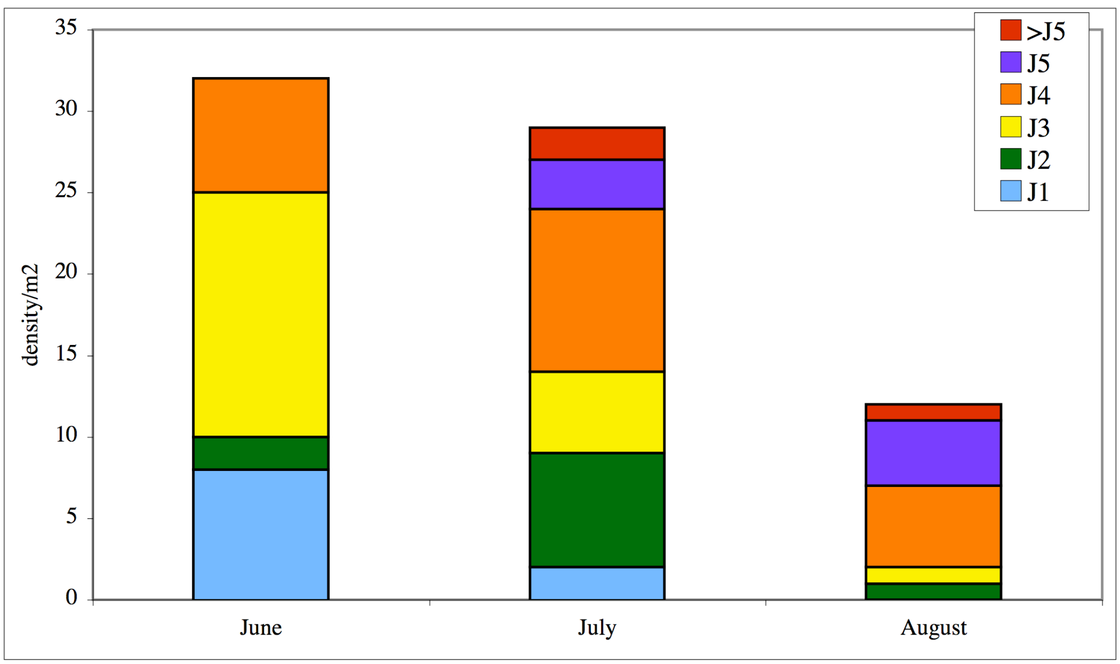
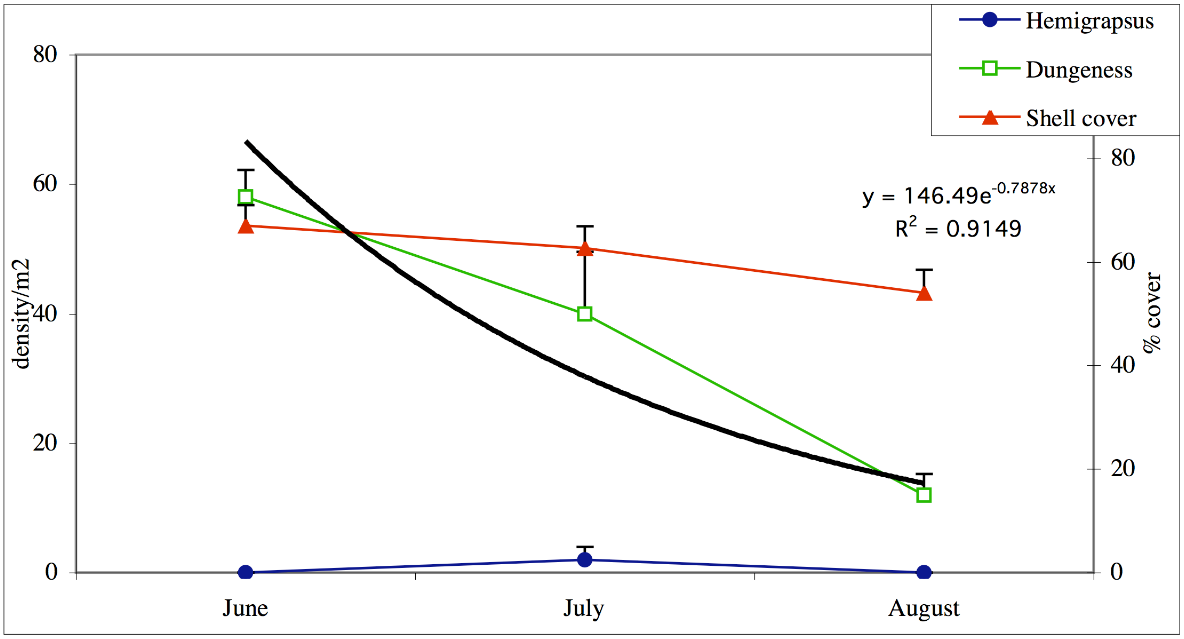


Figure 15. 2000 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



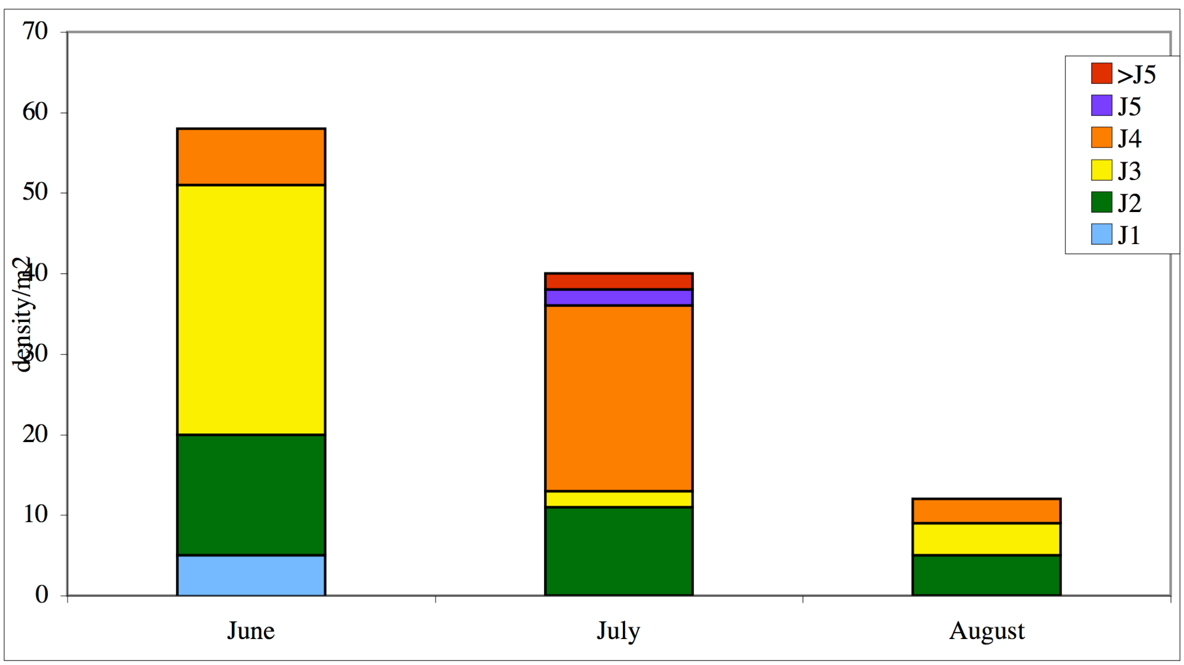
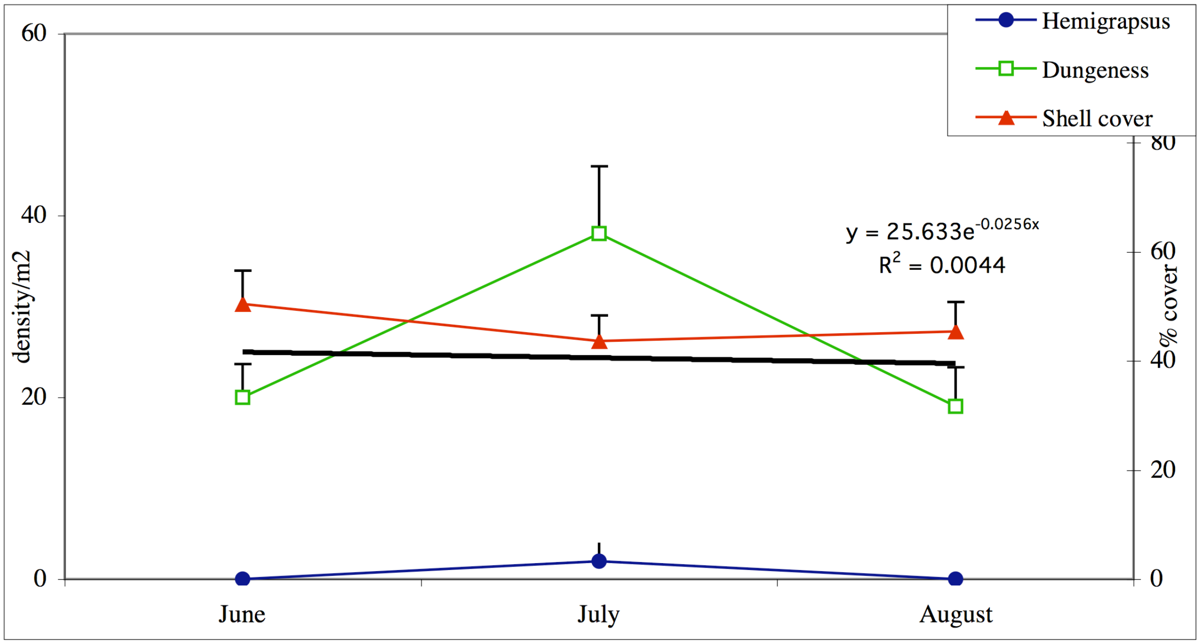


Figure 16. 2003 Up data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



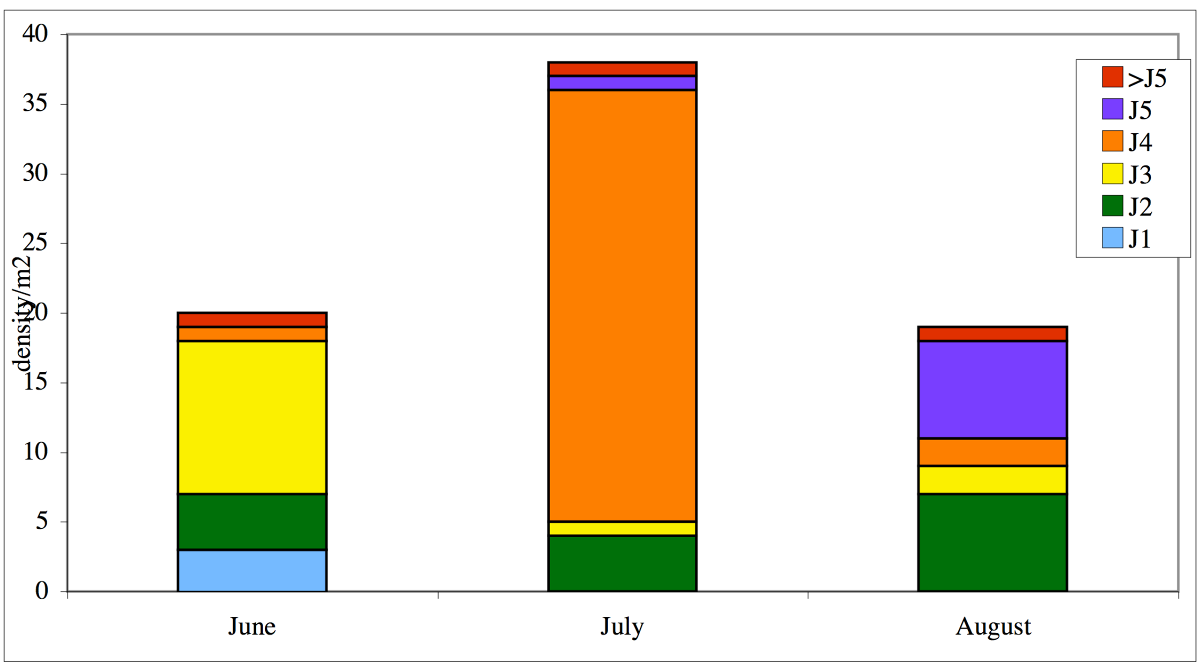
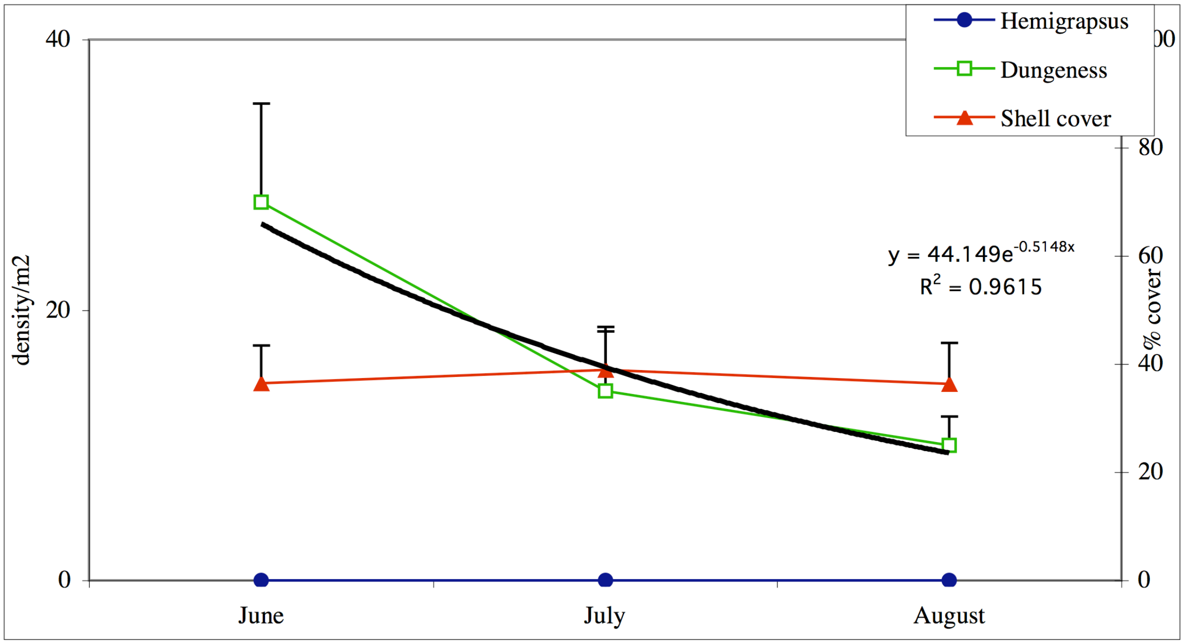


Figure 17. 2003 Down data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.



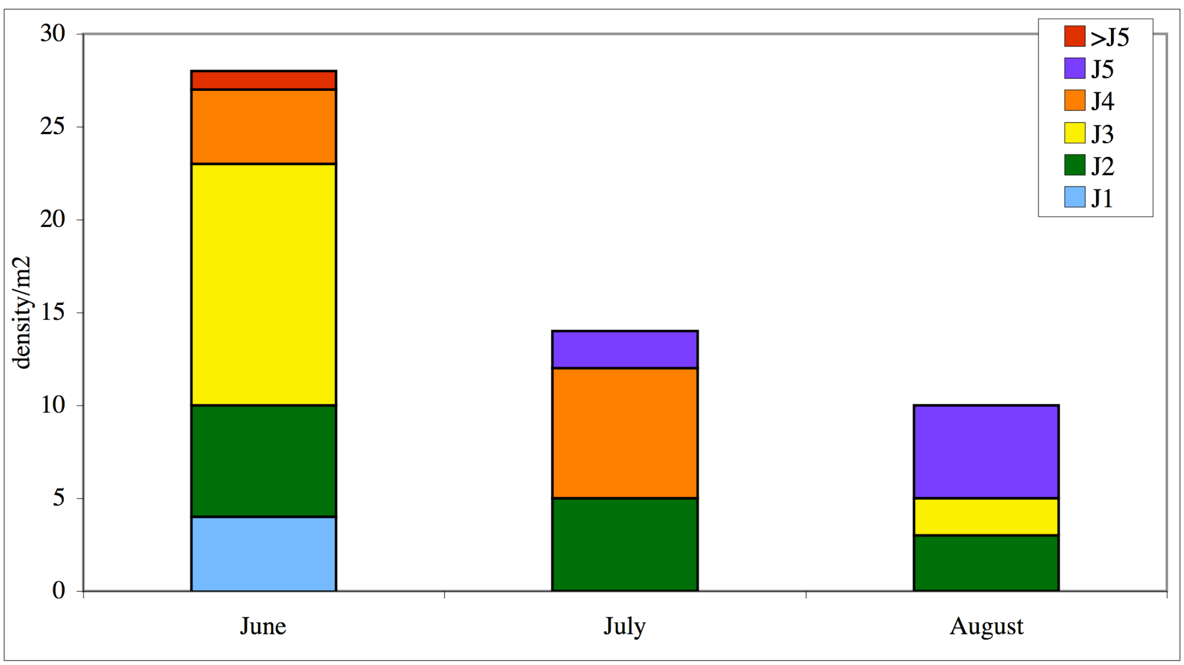


Figure 18. 2003 East data: Dungeness and *Hemigrapsus* densities (crabs per m^2), percent shell cover, and Dungeness crab instar composition for June through August 2004. Trendline is the exponential mortality function fit to juvenile Dungeness crab density curve.

Hemigrapsus oregonensis densities for the 2004 summer show that the apparent recruitment failure for this population to Grays Harbor that began in 1998 continues to hold. The blue line representing *Hemigrapsus* density is close to zero for all nine plots and all four months sampled in 2004 (Figures 10-18). Thus 2002 - 2004 sampling years fit into the post-*Hemigrapsus* chapter of mitigation ecology (Visser et al. 2004).

Eelgrass data

Eelgrass cover stayed very constant for all plots over the 2004 summer and remains an excellent predictor for productivity. Average difference in rank of shell cover and rank of productivity is only 1.78. Average eelgrass cover was always lower than shell cover for all shell plots (Figures 20-22). All plots had between 0 and 4% eelgrass cover, except for the 1995 Island plot, which averaged 6% eelgrass (Figure 20). The three years of complete and replicated eelgrass data do not show dramatic changes in eelgrass density or abundance trends, nor in distribution of patches, but rather constant low densities. The possibility that shell placement stabilizes sediment, making establishment and propagation of eelgrass beds easier should be evaluated by testing nearby areas outside mitigation habitats.

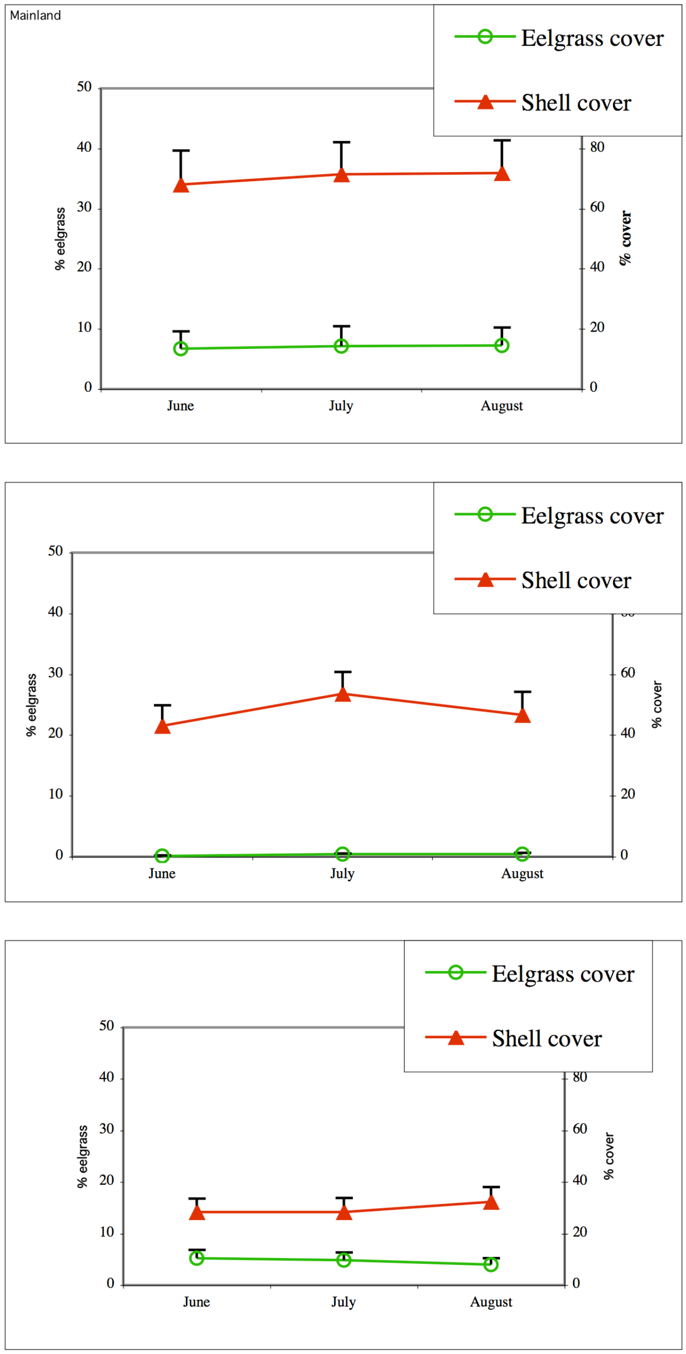


Figure 19. Eelgrass and shell cover data for the 1995 Island, Mainland and 1996/1997 shell plots during summer 2004.

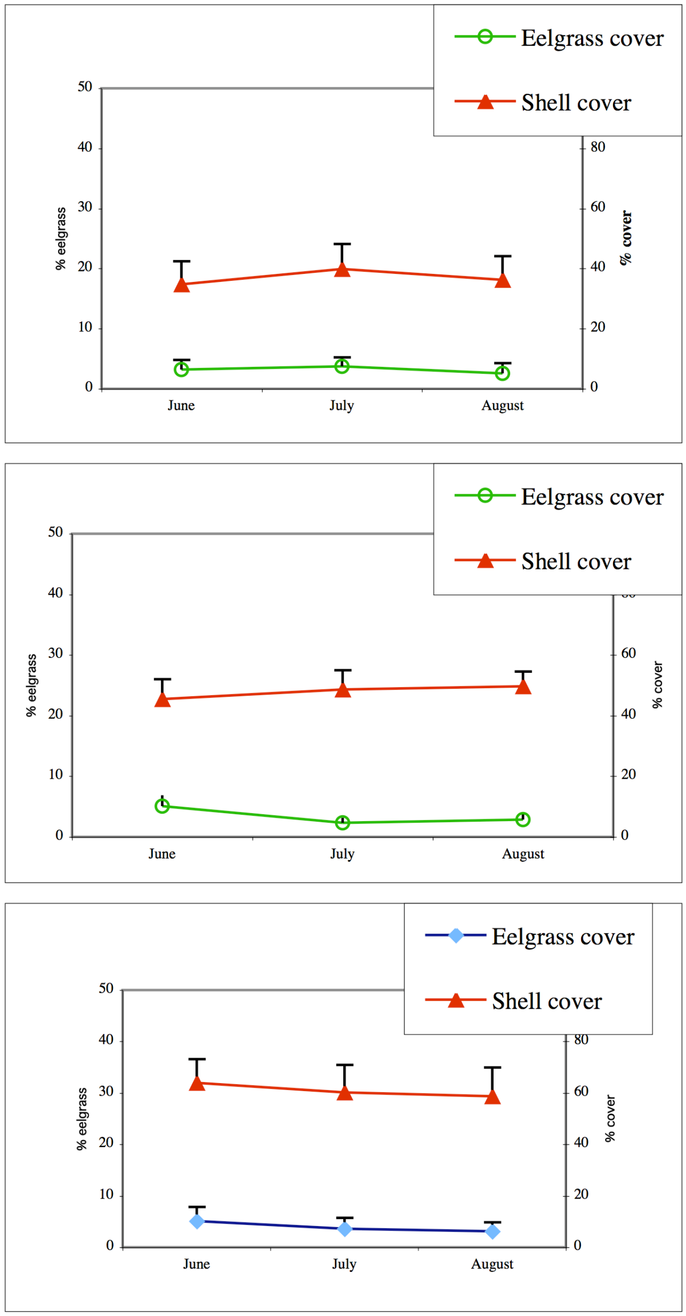


Figure 20. Eelgrass and shell cover data for the 1997 East, 2000Up, and 2000 East shell plots during summer 2004.

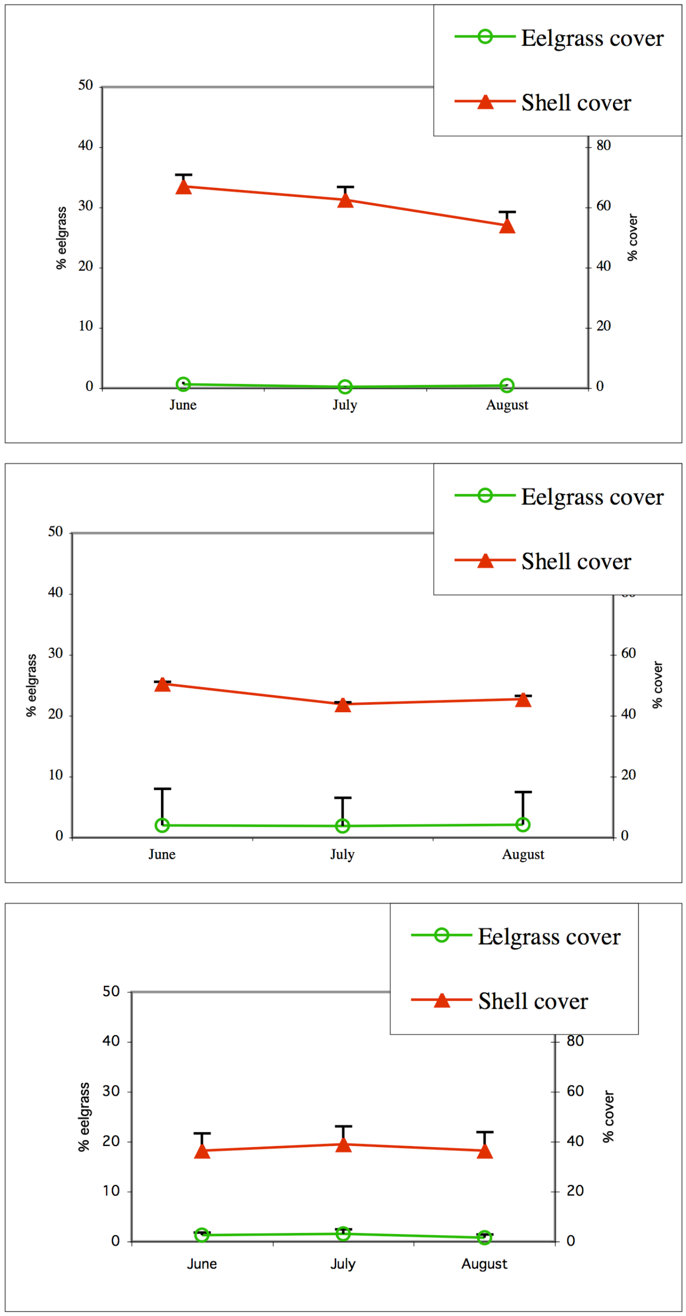


Figure 21. Eelgrass and shell cover data for the new 2003 shell plots: Up, Down, and East during summer 2004.

Mortality rates

Surprisingly, rank of mortality rate is not at all consistent with plot location or site. Only one plot was in the top half of survival rates 2 years in a row. Three plots (1995 Mainland, 1996/1997, and 1997 East) showed extremely high survival rates (70%, 83%, and 69% respectively). These rates would be high even for new shell, and are impressive for plots seven or greater years after construction. Mortality rate differences do not explain the 2004 production trends, where the average rank difference between productivity rank (total number of crabs produced) and rank based on mortality rates was 3.8.

Table 4. Mortality rates and percent survival for Dungeness crab on the nine plots sampled during summer 2004.

Plot	z	% survival	2004 Rank	2003 Rank
1995 Island	0.0264	39.69	8	2
1995 Mainland	0.0101	70.21	2	3
1996/1997	0.0052	83.45	1	9
1997 East	0.0106	69.00	3	6
2000 Up	0.0318	32.83	9	8
2000 East	0.0163	56.43	4	7
2003 Up	0.0263	39.89	7	4
2003 Down	0.0200	53.29	6	1
2003 East	0.0172	54.85	5	5

Mortality rates for 2004 summer are slightly higher than average (in the highest 5/13 for old shell). As noted last year, variation among mortality rates on old shell plots is much greater than that new ones, which contrasts with variability in productivity, which is greatest on new shell plots.

Table 5. Annual mortality rates for new and old shell plots. Survival is the percent of crab juvenile J2 instars surviving through the 35 day interval to the J4 stage when exodus to subtidal areas occurs.

Year	New shell	% Survival	Old Shell	% Survival
1990	0.0195	50.54	N/A	
1991	0.0276	38.06	0.0216	46.95
1992	0.0179	53.45		
1993	N/A		0.0216	46.95
1994	0.0187	51.97	0.0216	46.95
1995	0.0136	62.13	0.0248	41.98
1996	0.0123	65.02	0.0096	71.46
1997	0.0158	57.52	0.0187	51.97
1998	0.0208	48.29	0.0343	30.10
1999	0.0168	55.54	0.0226	45.34
2000	0.0216	46.95	0.0197	50.18
2001	N/A		0.0321	32.51
2002	N/A		0.0098	70.96
2003	0.0220	46.32	0.0289	36.37
2004	N/A		.0180	53.26
Average	0.0188	52.34	0.0218	46.63
Std dev	0.0043	7.6408	0.0073	12.48

Summary and Conclusions

The 2003 Up shell plot performed quite well, yielding 0.41 million J4 crabs over the three month sampling period in summer 2004 and contributing 32% of the annual production. The 1995 Island, 2003 Down, and 1996/1997 plots had the next highest productivity with 0.21, 0.19, and 0.17 million crabs, respectively. Total production during the 2004 season, summed across all plots sampled, was 1.33 million, among the 10 highest in the 15 year history of the project, notable only because no new shell production is included in that number. This brings the cumulative sum of J4 individuals produced by Grays Harbor mitigation plots to 22.22 million since its inception in 1990.

Production rate per square meter of habitat created was average for plots sampled in 2004. The 1995 Island, 2003 and 2000East plots met the initial mitigation target of 10 crabs • m^{-2}. Shell cover values still correlate extremely well with production rate, with and average difference of only 1.78 between the ranks of these two parameters.

Hemigrapsus oregonensis densities were extremely low again this season, and ecology and thus interspecific competition for refuge spaces seems to be a minor factor among juvenile Dungeness crabs on the shell mitigation plots. Eelgrass distribution and coverage still does not explain the trends in production data but comparing nearby areas without shell may add helpful information as far as sediment stability and eelgrass ecology are concerned.

Plot-specific mortality rates do not explain the production variation among shell plots over 2004 sampling season. Shell plot age did not correlate with productivity, with one 1 year old plot dropping to rank 6 of 9 (2003 East) while 1995 Island, one of the two oldest plots still sampled (both 9 years old without any overlay) ranked 2 of 9 in productivity.

When a survey of mitigation habitat is performed, the elevation data will be evaluated to see if productivity differences are consistent with the hypothesis to test being that survival is greatest on plots of highest elevation. This information will be key as decisions about potential locations for placement of new 2006 shell are evaluated. Overlay as a strategy seems to give an improvement over placing new shell on bare mud, but there are too many factors and not enough replicates to obtain a statistically rigorous comparison. Overlay plots do occupy 3 of the top 4 ranks in terms of productivity and thus this strategy should certainly remain a strong consideration in placement decisions.

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