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Dungeness Crab & Fish Baseline Study

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The purpose of this project was to collect baseline data, the "before" component for a Before-After-Control-Impact (BACI) study, of the effects of a wave energy conversion project planned for the coastal waters off of Reedsport, Oregon on the local benthic ecology. A BACI study controls for inevitable spatial and temporal environmental variation and provides an objective, scientific means of addressing the question "Does this project result in significant environmental change?" The specific changes are determined in part by what variables are measured. In this study, the focus was on Dungeness crab (*Cancer magister*) and other substrate-associated marine organisms. These baseline data are contained in the electronic files that accompany this document.

In addition to collecting the data, digitizing those data and checking for quality and input errors, and providing basic summary statistics (below), we evaluated the statistical power of the sampling program to detect a real change in the abundance of crab and other benthic organisms as manifest by the CPUE (catch-per-unit-effort). We used these power analyses to evaluate the current sampling program, and to determine the sampling effort necessary to detect a range of project impacts from a 10-100% reduction in the starting abundance. These results should be considered when planning and funding on-going efforts to monitor the benthic ecology at the wave energy conversion project site. Our analyses are predicated on the assumption that a BACI sampling/analytical approach will be used to test the hypothesis that the deployment and operation of wave energy conversion (WEC) technology will be deployed at the site referred to hereafter in this document as the WEC project site.

Methods

Traps

Sampling using standard commercial crab pots was conducted from the *FV Delma Ann* (September) and the *FV Apache* (October). Three sites were sampled: the Ocean Power Technology wave energy conversion (WEC) project site off Reedsport, Oregon (see FERC filing P-12713; centered at 43° 45.30'N, 124° 14.11'W), and control sites north and south of the WEC project site (centered at 43° 42.00'N, 124° 15.00'W; and 43° 48.00'N, 124° 13.80' W). We placed and retrieved gear during two periods, 3-10 September and 19-24 October 2009, deploying 40 pots at each site (Table 1). Half of these pots were modified by sewing closed the escape ports with nylon cable ties (or 'zip' ties; 'zip traps' hereafter). The pots were baited with squid and either sardines or herring. Soak times varied, as the conditions during both sampling efforts deteriorated and prevented running the traps (retrieving the traps, removing and enumerating the crab caught, re-baiting and re-deploying the traps) at regular intervals.

Table 1. Dungeness crab sampling off Reedsport, Oregon, September-November 2009.

Site	Pull date	Soak (days)	Bait
North control	Sep 8	4	Sardine & squid
North control	Sep 10	1	Sardine & squid
North control	Oct 25	6	Squid & herring
WEC project	Sep 8	4	Sardine & squid
WEC project	Sep 9	1	Sardine & squid
WEC project	Sep 10	1	Sardine & squid

WEC project	Oct 25	6	Squid & herring
South control	Sep 8	4	Sardine & squid
South control	Sep 9	1	Sardine & squid
South control	Sep 10	1	Sardine & squid
South control	Oct 25	6	Squid & herring

When the traps were retrieved, all organisms captured were identified and counted. Dungeness crab (*Cancer magister*) were sexed and measured. On occasion, notes were taken on crab exoskeleton condition (e.g., softness, biofouling). Captures from each trap on each day were treated as a sample unit. No single bycatch species (non-crab) was sufficiently numerous to warrant collecting size data.

Tagging

A subset of crab captured was tagged for a movement study, which is currently being conducted by Oregon Sea Grant (OSG). Nearly 2800 crabs were tagged with a pink, fluorescent tag, imprinted with a four-digit code, and reward and contact information. All were tagged on the right rear appendage with a constrictor knot (Smith 1971) tied at the joint closest to the carapace. Crab captured and released at the south control site were tagged with numbers 0000-0999; those from the WEC project site were tagged with numbers 1000-1999; those from the north control site were tagged with numbers 2000-3000.

Trawling

To complement the trap sampling, we used a skate trawl from Innovative Net Systems (Milton, Louisiana). The trawl had a 7 m foot rope, a net opening of approximately 4 m across, and 38 mm stretch (knot to knot) mesh. A coated, knotless, fine mesh (12 mm) liner was sewn into the cod end to retain smaller organisms. We targeted the 64 m (35 fathom) contour at all three sites. The trawl provided an effective means to sample a wide size range of Dungeness crab, including females, as well as a means of sampling benthic fishes.

During the October sampling effort, inconsistent weather conditions and technical difficulties prevented effective trawling and all trawl data presented here were completed on 4 November 2009 (Table 2). Trawl samples were conducted as follows: The trawl was deployed using a 277 m towline; this gave us a scope of >4:1. We towed for approximately 10 minutes before retrieving the trawl, and completed nine trawls:

Table 2. Trawl samples conducted off Reedsport, Oregon, November, 2009.

Site	Depth (m)	Area (m^2)
North Control	62	11,484
North Control	68	9,396
North Control	60	8,874
North Control	68	9,396
WEC Project	64	13,050
WEC Project	60	11,484
WEC Project	69	8,874
South Control	71	9,396

South Control	57	10,962
Average	*64*	*10,324*

All trawls were conducted within 1000 m of the pot strings (pot string: line of pots with uniform spacing). Captures from each tow were emptied into a dedicated container and the catch recorded as a single sample unit. All organisms (e.g., fishes, crabs and other invertebrates) captured in the trawl were identified to the lowest taxonomic level feasible in the field, counted and recorded. The top three to five most abundant fish species were subsampled; these were measured (TL to the nearest mm).

Analyses of Trap Data

Descriptive Statistics

We summarized the October 2009 trapping data by calculating the means, standard deviations and sample sizes for CPUE (i.e., catch or number of crab per trap) of legal-sized male crab, sub-legal male crab and female crab by location and trap type (i.e., zip or standard traps). In addition, summary statistics for size data from male crab captured during the October 2009 trapping effort and female crab captured during the September 2009 effort were calculated from the zip trap data. These data were used because zip traps reduce the escape opportunities for smaller sub-legal size males or females, and hence were more representative of existing sizes.

Graphical Comparisons and T-Tests

Graphical comparisons of CPUE were conducted across locations (north control, south control and WEC project site), sample efforts (September and October 2009), and soak times. Two-sample t-tests were used to make pairwise comparisons of the catch across locations. Graphical techniques included kernel smoothing and boxplots; non-parametric analyses based on kernel smoothing techniques (from R library “sm”, Bowman and Azzalini 1997) were conducted to evaluate differences between the distributions of CPUE between locations. Kernel smoothing is typically a more accurate alternative to histograms. Comparisons were conducted separately for legal-sized male crab, sub-legal male crab and female crab. Legal-sized male crab were analyzed using catch data from standard, zip trap types or both, but sub-legal male and female crab were analyzed based on zip trap data only as standard trap catches were heavily biased towards large male crab.

Comparisons of male and female sizes were also conducted using kernel smoothing techniques to graph the distributions of sizes for each sex. Data for these graphs were taken from the October zip trap samples for male crab, and from the September zip trap samples for female crab.

Generalized Linear Model (GLM) Analyses

Generalized linear models were fit to the October 2009 data to determine the effects of trap type, location, soak time, and sampling effort on crab CPUE. We assumed a negative binomial distribution, which is appropriate for use with count data (Crawley 2002). We removed one variable at a time, following likelihood ratio tests comparing successive models. A variable was removed when likelihood ratio tests resulted in $p>0.10$; otherwise, it was retained. Variables leading to a likelihood ratio test result of $p<0.05$ were considered significant, and >0.10 not significant. Results were considered to be inconclusive when $0.05<p<0.10$.

The initial composition of the first model, prior to removing any explanatory variables, included the CPUE (the number of crab for an individual crab pot) as the dependent variable and can be expressed as:

```
CPUE ~ trap_type + soak_time + effort + location
```

Trap type was either zip or standard trap. Soak time was the number of days that traps were operational. Effort was either September or October 2009. Location was the north control, south control or WEC project site.

Power Analyses

The statistical power of the current sampling program to detect a change in crab abundance as manifest by CPUE was evaluated, assuming the future use of a "beyond BACI" (before-after-control-impact) analysis (Underwood 1991; Underwood 1992; Underwood 1994). We used data from the two sampling efforts described here, in September and October 2009, prior to the installation of WEC technology at the project site ('impact'), and assumed post-impact annual sampling efforts from 2010 to 2012. Power was estimated for varying sample and effect sizes to evaluate alternatives to the original level of effort, given varying levels of impact.

Legal-sized and sub-legal male crab data from the September and October 2009 trapping efforts were used as the basis for the power analysis; capture of female crab was inconsistent and too infrequent to enable the adequate estimation of power for females. Standard trap data were used for legal-sized males because this gear type specifically targets legal-sized males. Zip trap data were more appropriate for sub-legal males, however, due to their reduced ability to escape this type of trap.

Linear Mixed-Effects Models

We used linear mixed-effects modeling to determine if there was a significant impact. Mixed-effects models allow for modeling variation due to random effects (i.e., associated with sampling units drawn randomly from a population) (Pinheiro and Bates 2004) that potentially interfere with interpretation of the effects of greatest interest to the experiment (i.e., fixed effects). If random effects are not adequately accounted for, the coefficients and standard errors estimated for fixed effects may be biased (Mullen and Birkeland 2008). Linear mixed-effects models have been used by other researchers within the context of a BACI design on projects with similar objectives to this one, for example determining the impact of disturbance on coral reef communities (Lewis 1997) or the impact of trawling on seabed biota (Pitcher et al. 2009). All mixed-effects modeling was conducted using program R (R Development Core Team 2009) and the R-specific statistical package "lme4" (Bates and Maechler 2009). The fixed effects part of the model can be expressed as:

```
log(CPUE+1) ~ B + C + B:C
```

Log is natural logarithm, CPUE is catch-per-unit effort (number of crab per trap), B is either Before or After, and C is either Control or Impact. Catch-per-unit effort was log-transformed since the residuals of the linear model tended to increase with increasing values of CPUE.

Random effects were modeled for the intercept term conditional on location and sampling effort. The model specified in R was:

```
log(CPUE+1)~ B + C + B:C + (1|Location)+(1|Effort)
```

"Location" was north control, south control or WEC project site, and "Effort" was the sampling effort (as a factor). A term such as "(1|Location)" is interpreted as a random effect on the intercept conditional on "Location." The model essentially predicts a different intercept for each location. Random effects were considered to be cross-classified (i.e., each level of one variable co-occurs with each level of the other variable) as opposed to nested.

We estimated power based on the ability to detect a significant interaction between the before/after and control/impact terms (i.e., for the fixed effect, B:C). If the environmental impact is sustained, the interaction term indicates an overall impact effect (Underwood 1994; Pitcher et al. 2009). For the purposes of our power analyses, we assumed sustained impacts, and so were only concerned with the significance of this interaction term.

Monte Carlo Simulations

We used a Monte Carlo approach (i.e., repeated random sampling) to simulate trapping efforts and calculate power. Monte Carlo methods are frequently employed in situations where mathematical solutions are not possible and where random variation needs to be accurately incorporated into a simulation process. Both "before" and "after" sampling efforts were simulated, using a truncated random normal distribution (truncated at zero, since negative values for catch are not possible) to select a true mean CPUE and to model the catch for each simulated crab trap deployed. The process involved several steps and is described in detail in the following text.

First, to simulate stochasticity in the true mean CPUE for a given location, sampling was simulated in the "before" phase of the project by drawing a mean CPUE from a distribution of true means centered around the mean observed trap catch from a given site during the September and October efforts (using 4 and 6 d soak times only). The standard deviation was based on the variance among observed means across all locations and efforts (i.e., 6 values, one for each combination of effort and location). We suggest simulating the variation in the true mean from effort to effort provides a more realistic model because the population is not static. (The use of 4 and 6 d soak times allowed us to use data from both efforts and ensured that the data were somewhat comparable. GLM analyses suggested that there was an effect due to soak time; data based on 1 d soak time appeared to be substantially different from either a 4 d or 6 d soak time (see Results, Figures 4a-d).) Once the simulated true mean was selected, trap catch was simulated using a truncated normal distribution with a standard deviation represented by the highest standard deviation in trap catch observed at any of the locations during either effort (using 4 and 6 d soak times only). The use of the highest standard deviation in trap catch by location and effort was considered to be conservative with respect to estimating power (i.e., potentially underestimating power). The same process of drawing a true mean CPUE and subsequently generating a random sample of catch was applied at all three locations. Each "before" sampling effort was simulated in the same way.

"After" sampling efforts assumed some constant level of change compared to the "before" efforts. The process for generating random "after" CPUE values was identical to the "before" sampling, except that, for the impact location, the simulated mean of the truncated normal distribution from which the true mean was selected was the observed value adjusted by a range of assumed reductions in CPUE. The reduction in CPUE was arbitrarily specified by us as in the following example: If we assumed an 80% reduction in CPUE, the true mean was drawn from a truncated normal distribution with a mean of , where is the mean CPUE at a given location *L*. The standard deviation used was the maximum standard deviation of any location and effort, as was used previously for the "before" simulated sampling efforts. Values for control locations were selected as they were for "before" sampling efforts. A linear mixed-effects model, was then fit to the simulated "before" and "after" data. The significance of the interaction term B:C was calculated using F-tests. Conditional F-tests and t-tests for the coefficients of fixed effects are preferred over the likelihood ratio tests we used for evaluating GLMs, because, in this case, they tend to yield more realistic p-values (Pinheiro and Bates 2004). The determination of degrees of freedom for these tests followed the recommendations of Pinheiro and Bates (2004) and Zuur et al. (2009).

This entire process was then repeated 5,000 times to determine how frequently a significant interaction term B:C was identified. The percent of iterations that yielded a significant interaction term is equivalent to power. We then evaluated the relationship between power and sample size (using 5,000 iterations per sample size), as well as for power and varying effect sizes (using 1,000 iterations per effect size); we targeted greater precision for evaluating changes in power with sample size, since this is a controllable aspect of our study. Sample sizes were kept constant across locations during these simulations.

Analyses of Trawl Data

Trawl surveys were used to measure the diversity of benthic organisms, and to provide an assessment of Dungeness crab abundance using a technique that samples a broader range of sizes, and females as effectively as it does males.

Species Richness and Diversity Measures

Species richness and diversity indices were quantified for individual locations using trawl surveys; these metrics could be derived from the trawl data because this net gear, unlike the crab traps, captured benthic organisms in a broad range of sizes, from those large enough to be retained by the 12 mm mesh liner to those swift and agile enough to avoid the net (generally larger species of fish). In addition to presenting the number of species by location and the relative abundance by species, we used the "EstimateS" software application (Colwell 2005) to estimate both species richness and species diversity indices. We presented the following measures in our results:

- Abundance-based Coverage Estimator of species richness (ACE) (see Chazdon et al. 1998; Chao et al. 2000)
- Chao 1 richness estimator (see Chao 1984)
- Exponential Shannon diversity index (Magurran 2003)
- Simpson (inverse) diversity index (Magurran 1988)

The ACE and Chao 1 richness estimators are non-parametric species richness estimators that attempt to account for missing species based on information about rare species detected in the sample. The ACE consists of two components, an abundant and a rare species component, and incorporates an estimation of sample coverage to estimate the number of rare species (Chao 2005) (for equation see Colwell 2005). The Chao 1 estimator is based on the concept that the number of rare species can be used to estimate the number of missing species in the sample (for bias-corrected equation see Chao 1984; Colwell 2005).

The Exponential Shannon and Simpson diversity indices are widely accepted species diversity indices that incorporate information about abundance (Magurran 2003). These indices give an easily interpretable statistic, the number of equally common species, which is critical for evaluating the meaning of differences between index values (Jost 2006). The Shannon diversity index is based on information theory, and is commonly expressed as:

where p_i is the proportion of individuals in the ith species (Magurran 1988).

The Exponential Shannon diversity index is calculated simply as *exp(H')*.

The Simpson diversity index is weighted heavily towards abundance of the most common species (Magurran 1988), and is based on:

The Simpson diversity index presented in this paper is the inverse form, calculated as $1/D$. The Simpson diversity index is the least sensitive to rare species, in contrast to richness estimators (most sensitive) and the Shannon Diversity Index (intermediate) (Colwell 2005)).

Another benefit of using “EstimateS” was the ability to estimate variance via bootstrapping methods. We used 1,000 runs (via sampling with replacement) to estimate variance for each location, for the ACE, Exponential Shannon diversity index, and Simpson (inverse) diversity index; the standard deviation for the Chao estimator was calculated directly using analytical methods (see Appendix B Colwell 2005).

The Exponential Shannon diversity index was selected for comparison between locations. This index has also been argued by some to be equivalent to an estimate of species diversity, not just an index, and to have more stable mathematical properties than the Shannon diversity index (Jost 2006). We fit the following linear model to evaluate potential differences by location:

```
log(EXP.Shannon+1) ~ Location,
```

Log is natural logarithm, EXP.Shannon is the Exponential Shannon diversity index, and "Location" is north control, south control or WEC project site.

Catch-Per-Unit Effort

Catch-per-unit effort (CPUE) was calculated for the 3 most abundant species and Dungeness crab (the 5th most abundant species) due to its commercial and biological importance, and also to allow for qualitative comparisons with results based on analyses of the trapping data. Effort was defined in terms of trawling distance covered, estimated as the rate of travel multiplied by the duration of the trawl (when the trawl was on the bottom, as judged by temperature records). Summary statistics (i.e., mean, standard deviation) for CPUE were presented. Comparisons were also made graphically (using scatterplots) and via linear modeling to compare CPUE among locations, using the model:

```
log(CPUE+1) ~ Location,
```

Log is natural logarithm, and "Location" is as previously defined.

Dungeness Crab Size

We measured all Dungeness crab sampled during the September effort, those from the first two pots in each string during the October effort, and all crab collected in the trawl. Size was measured as carapace width, measured immediately anterior to the 10th anterolateral spine using a measuring board to the nearest 0.5 cm. The large number of crab measured precluded the use of vernier calipers for these measurements; the same sampler measured every crab to eliminate potential bias introduced by different samplers, and these data were checked against a limited number of crab (size range: 97-172 mm, n=23) measured using calipers. We used graphical comparisons to assess the size frequency distribution of crab from each of the sampling sites.

Power Analyses

We evaluated the power gained by adding one more sampling effort (for a total of two) to the "before" sampling. For this analysis, we assumed a 50% reduction in CPUE at the impact site (WEC project). Power analyses were also conducted for each of the four species where CPUE was estimated, using the same methods described previously for the trapping data (see Methods – Analyses of trap data – Power analyses). The relationship between power and sample size was evaluated, as it was for power and effect size.

Results

Analyses of Trap Data

Descriptive Statistics

There were substantially higher CPUEs for legal-sized male crab compared with sub-legal male or female crab, regardless of trap type (Table 3). Female crab CPUE never exceeded 1 crab per trap during the October 2009 sampling effort.

Table 3. Trap effort and CPUE

Location	Group	Trap Type	Number of traps	CPUE (# per trap)		
				Mean	SD	Range
North Control	Legal-Sized Male	Standard	20	21.9	2.90	17-28
South Control	Legal-Sized Male	Standard	20	18.0	6.43	2-27
WEC Project	Legal-Sized Male	Standard	19	19.2	3.93	13-26
North Control	Legal-Sized Male	Zip	20	24.7	3.85	18-33
South Control	Legal-Sized Male	Zip	27	17.9	5.63	2-30
WEC Project	Legal-Sized Male	Zip	19	20.8	5.35	12-31
North Control	Sub-Legal Male	Standard	20	1.6	1.85	0-5
South Control	Sub-Legal Male	Standard	20	0.8	1.29	0-5
WEC Project	Sub-Legal Male	Standard	19	1.8	2.27	0-7
North Control	Sub-Legal Male	Zip	20	6.3	7.03	0-19
South Control	Sub-Legal Male	Zip	27	2.4	2.73	0-9
WEC Project	Sub-Legal Male	Zip	19	3.6	4.25	0-17
North Control	Female	Standard	20	0.1	0.31	0-1
South Control	Female	Standard	20	0.0	0.00	0-0
WEC Project	Female	Standard	19	0.0	0.00	0-0
North Control	Female	Zip	20	0.1	0.31	0-1
South Control	Female	Zip	27	0.0	0.19	0-1
WEC Project	Female	Zip	19	0.1	0.23	0-1

Summary data for Dungeness crab sizes captured in the zip traps are given in Table 4.

Table 4. Crab sizes (carapace width) from zip traps by sex and location

Sex	Location	Sample Size	Mean (mm)	SD
Male	North Control	51	174.0	12.61
	South Control	82	172.9	12.02
	WEC Project	31	173.7	11.90
Female	North Control	372	141.5	9.74
	South Control	330	142.2	9.44
	WEC Project	477	143.1	9.52

Graphical Comparisons and T-Tests

Graphical Comparisons of CPUE Among Locations

There were modest differences in CPUE of a given group of crab (i.e., legal-sized males, sub-legal males and females) across locations (Figures 1 a, b). The CPUE of legal-sized males from the WEC project site was intermediate between north control and south control sites, for both standard trap and zip trap data. In the standard traps, there was greater variation in the south control site; from the zip traps, the WEC project site yielded the greatest variation in CPUE. For sub-legal males in the zip traps, the distributions were generally similar, though there was greater variation and higher mean CPUE in the north control site. Distributions for legal-sized males appeared to be approximately normal for most locations, whereas distributions for sub-legal-sized males appeared to be strongly skewed. Catches for females were consistently low across all locations.

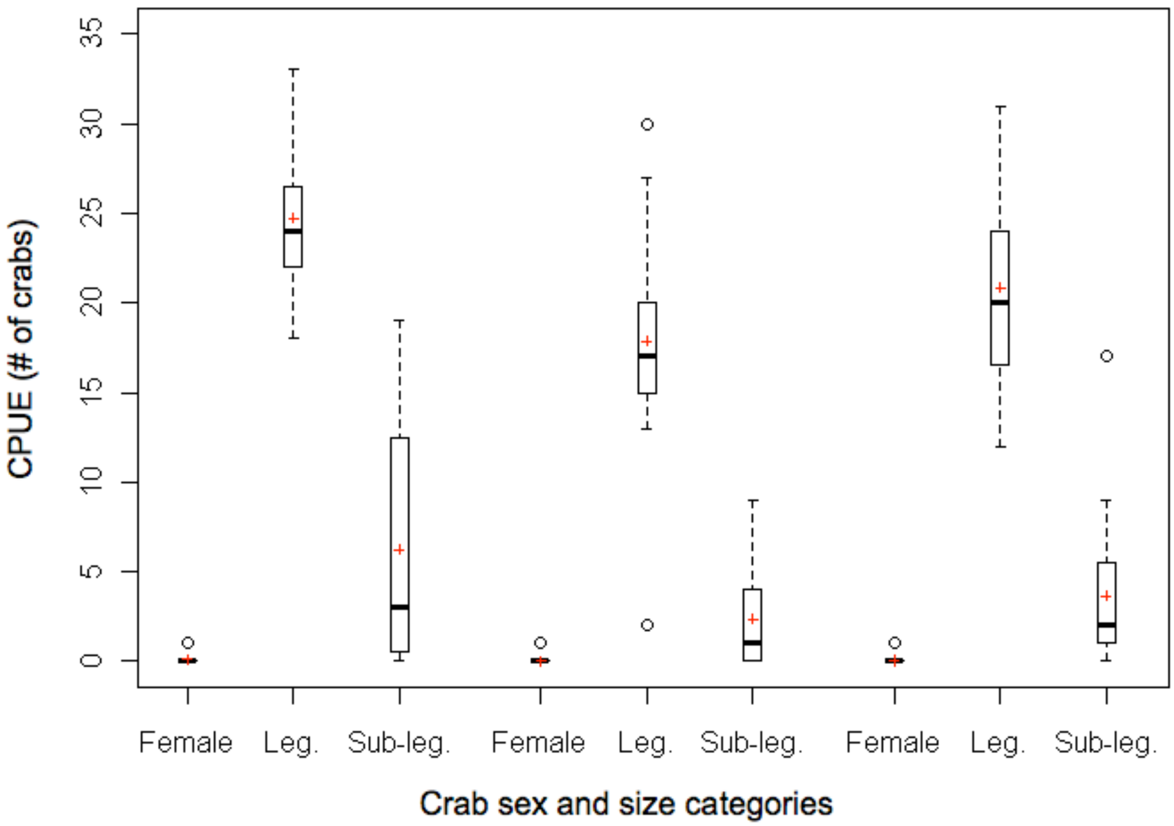

Figure 1a. Boxplot of Dungeness crab zip trap CPUE; red crosses indicate means.

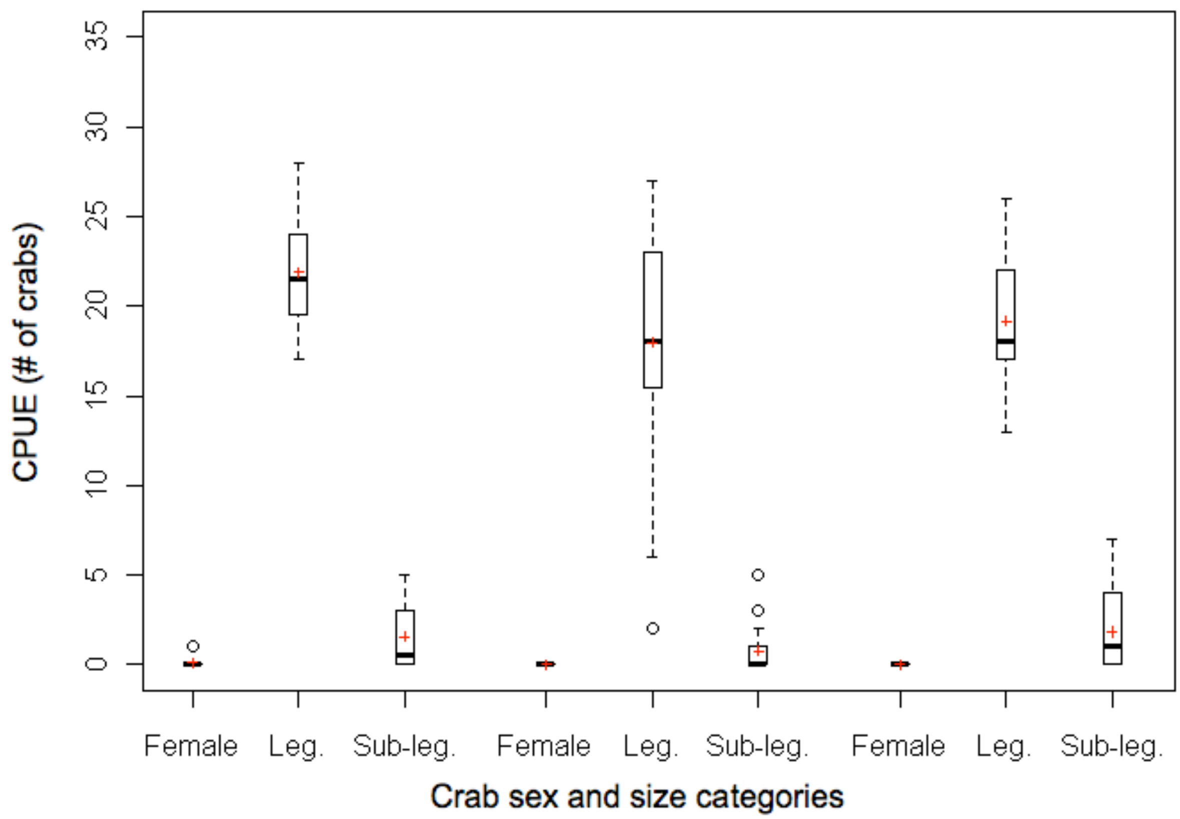

Figure 1b. Boxplot of Dungeness crab standard trap CPUE; red crosses indicate means.

The graphical comparisons of smoothed distributions show greater detail than the boxplots regarding the nature of the distribution and whether there were multiple peaks in the data. Analyzed data included 4 d soak times (September effort) and 6 d soak times (October effort); data based on these soak times were deemed to be comparable based on graphical analyses of CPUE with soak time (see Figures 4a-d and section Results – Analyses of trap data – *Graphical comparison of CPUE by soak time*). Smoothed distributions showed some apparent differences in distributions between locations, though most differences appeared to be subtle and not likely to be something beyond what can be explained by variation in the data (Figures 2 a-d. There were notable differences between north control and south control sites for CPUE of legal-sized male crab, based on both zip and standard trap data (Figures 2 a,b). The shaded region represents a reference band of equality, based on the standard error of differences between the two curves (Bowman and Young 1996); if a curve falls outside of the shaded region, this suggests that the distributions differ. This graphical approach allows for an assessment of how and where two distributions may differ. There is a clear difference in the CPUE at the north control versus the south control sites based on zip trap data, and marginal differences between the control sites and the project site (also based on zip trap data, Figure 2b).

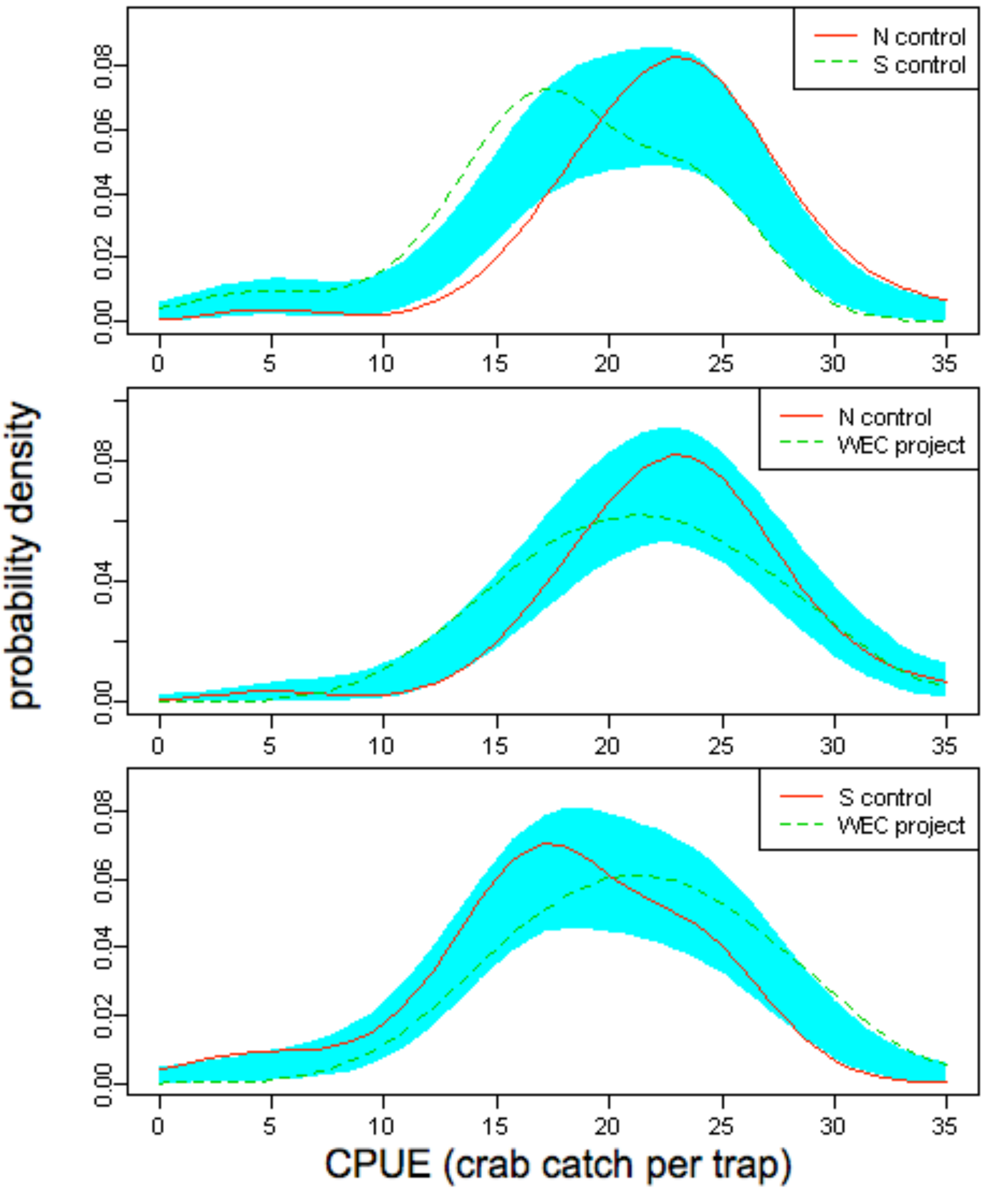

Figure 2a. Smoothed probability density distribution curves by location for legal-sized male Dungeness crab, standard traps

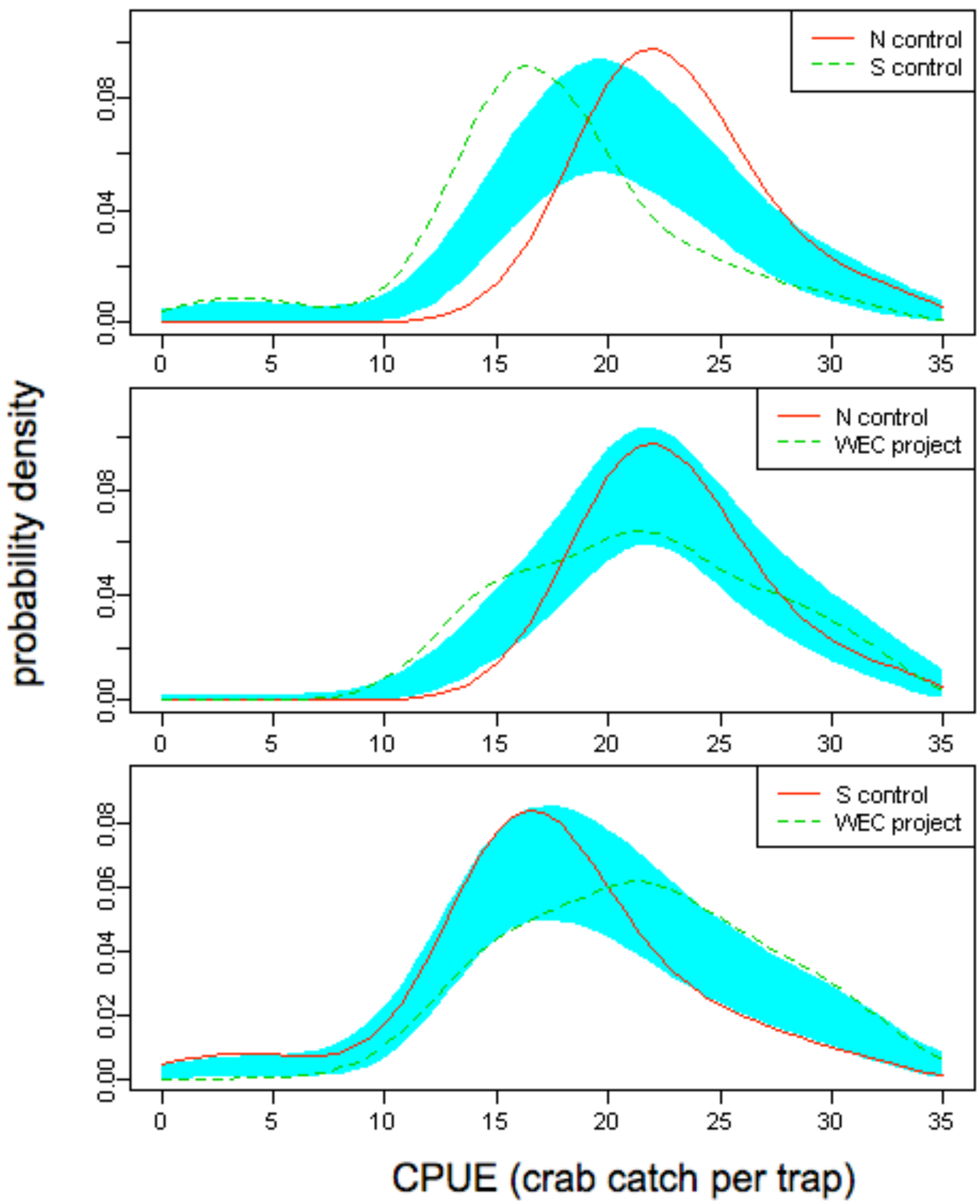

Figure 2b. Smoothed probability density distribution curves by location for legal-sized male Dungeness crab, zip traps.

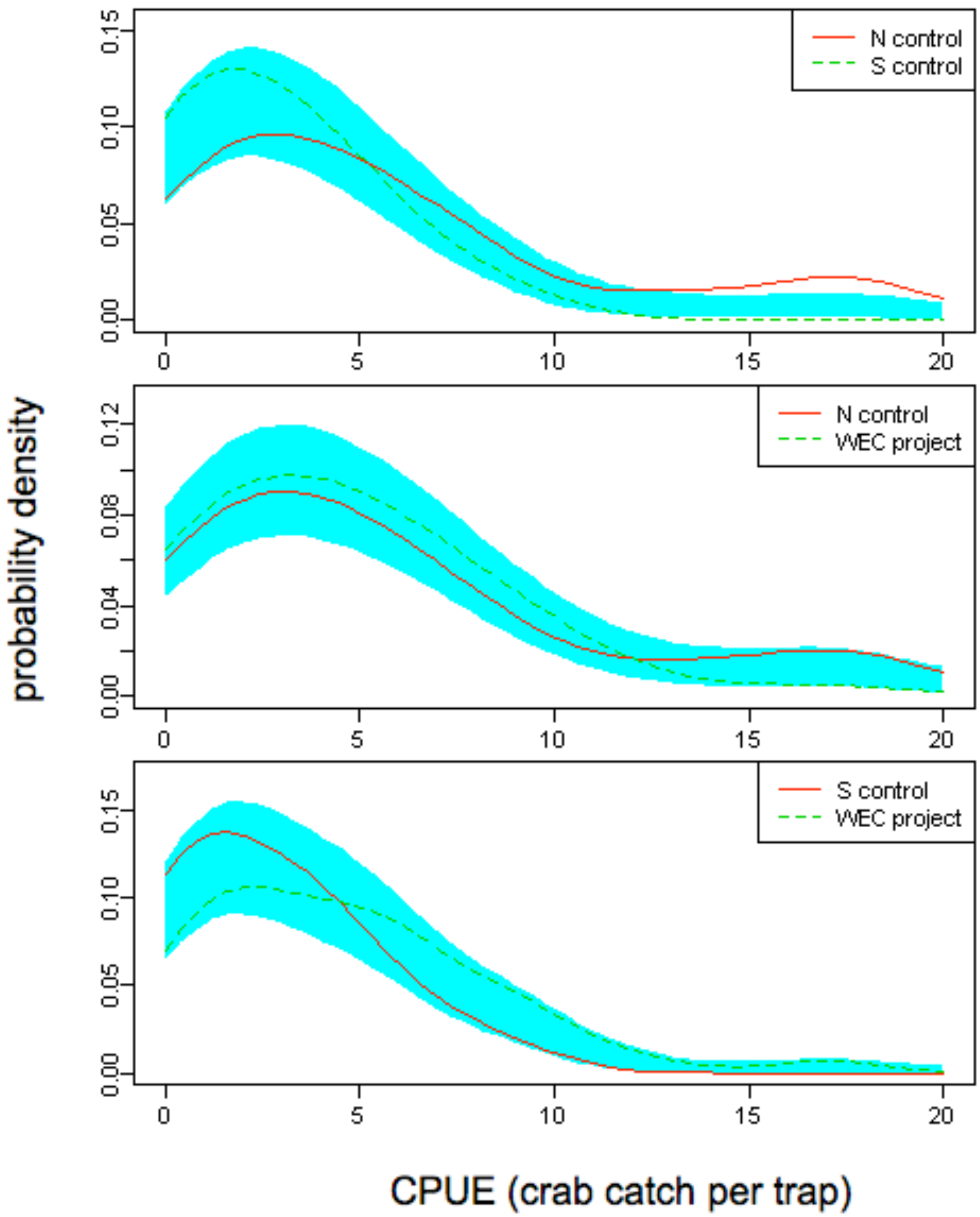

Figure 2c. Smoothed probability density distribution curves by location for sub-legal male Dungeness crab, zip traps.

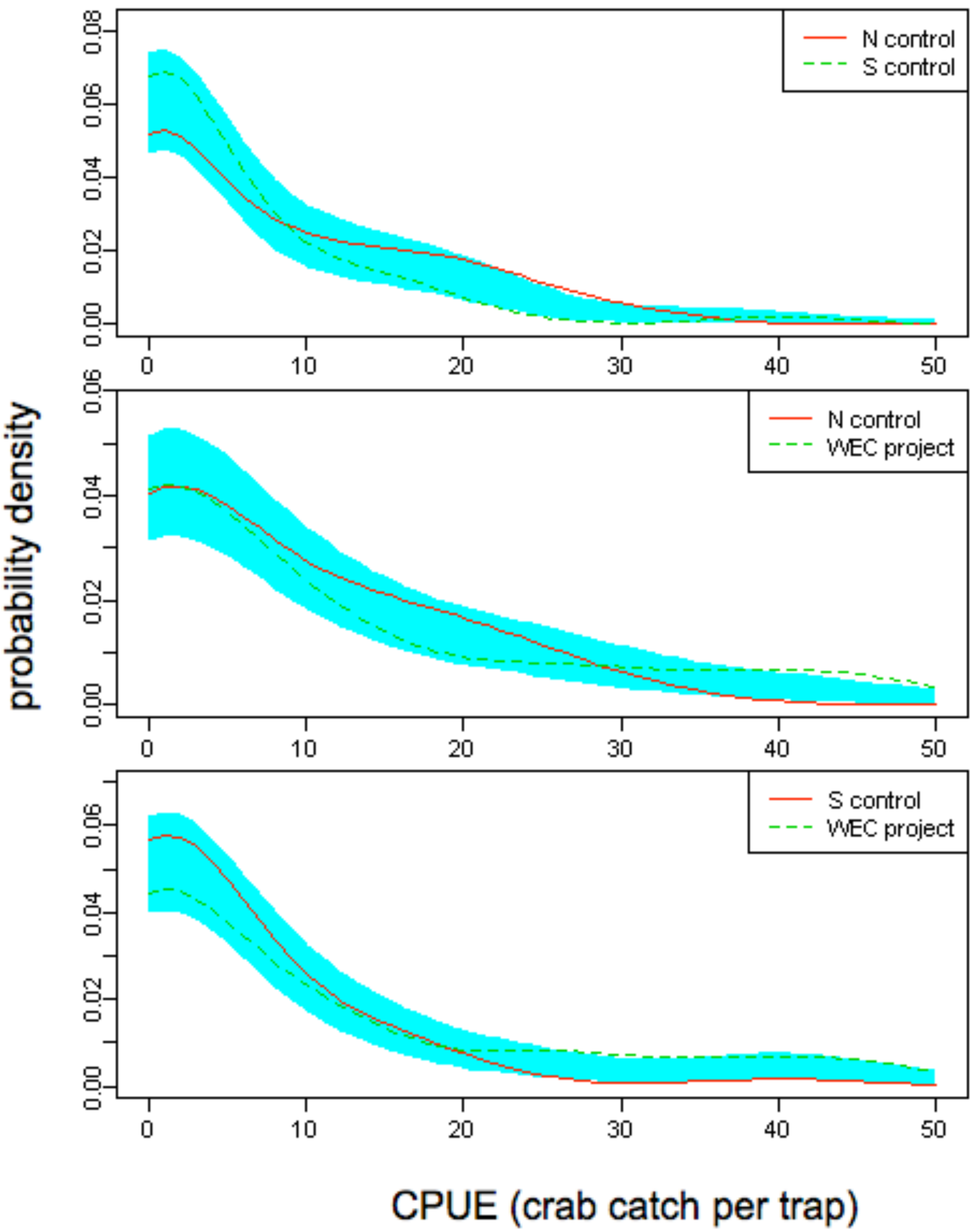

Figure 2d. Smoothed probability density distribution curves by location for female Dungeness crab, zip traps.

For sub-legal males, there appeared to be differences between the north control and south control sites, particularly for larger values of CPUE (Figure 2c), whereas for females, there appeared to be greater CPUE in the WEC site as compared to either the north or south control sites (Figure

2d). The differences in the distribution of CPUE between locations did not appear to be significant for females.

T-Tests Comparing Locations

T-test results generally supported the observations based on the graphical approaches, showing significant differences between the north and south control sites for legal-sized male crab (p=0.0187 based on standard trap data, and p<0.0001 based on zip trap data, Table 5). There were also significant differences (p=0.0148 based on zip trap data and 0.0190 based on standard trap data) in legal-sized male crab CPUE at the north control and WEC project sites. Catch-per-unit-effort of legal-sized male crab did not differ significantly between south control and WEC project sites, although the comparison based on the zip trap data was inconclusive (p=0.0752, Table 5).

Comparisons of CPUE for sub-legal male and female crab based on zip trap data only revealed one significant difference between the north and south control sites for sub-legal males (p=0.0281) (Table 5). All other comparisons resulted in non-significant results.

Table 5. Comparisons of crab CPUE between locations; t-tests based on Welch approximation

Group	**Trap Type**	**p-value (df)**		
		S Control vs. WEC	**N Control vs. WEC**	**S Control vs. N Control**
Legal-Sized Male	Standard	0.4818 (32)	0.0190 (33)	0.0187 (26)
	Zip	0.0752 (40)	0.0148 (33)	<0.0001 (45)
Sub-Legal Male	Zip	0.2641 (28)	0.1664 (32)	0.0281 (23)
Female	Zip	0.8100 (34)	0.5880 (35)	0.4269 (30)

Graphical Comparison of CPUE of Legal-Sized Male Crab Between Sampling Efforts

Graphical comparison of CPUE of legal-sized male crab based on standard trap data (4 and 6 d soak times only) between efforts revealed that although the shapes of the curves were somewhat different, differences were no greater than what could be expected due to sampling variation (Figure 3). The one exception was for the WEC site, where it appeared that the CPUE was greater in September than it was in October (Figure 3).

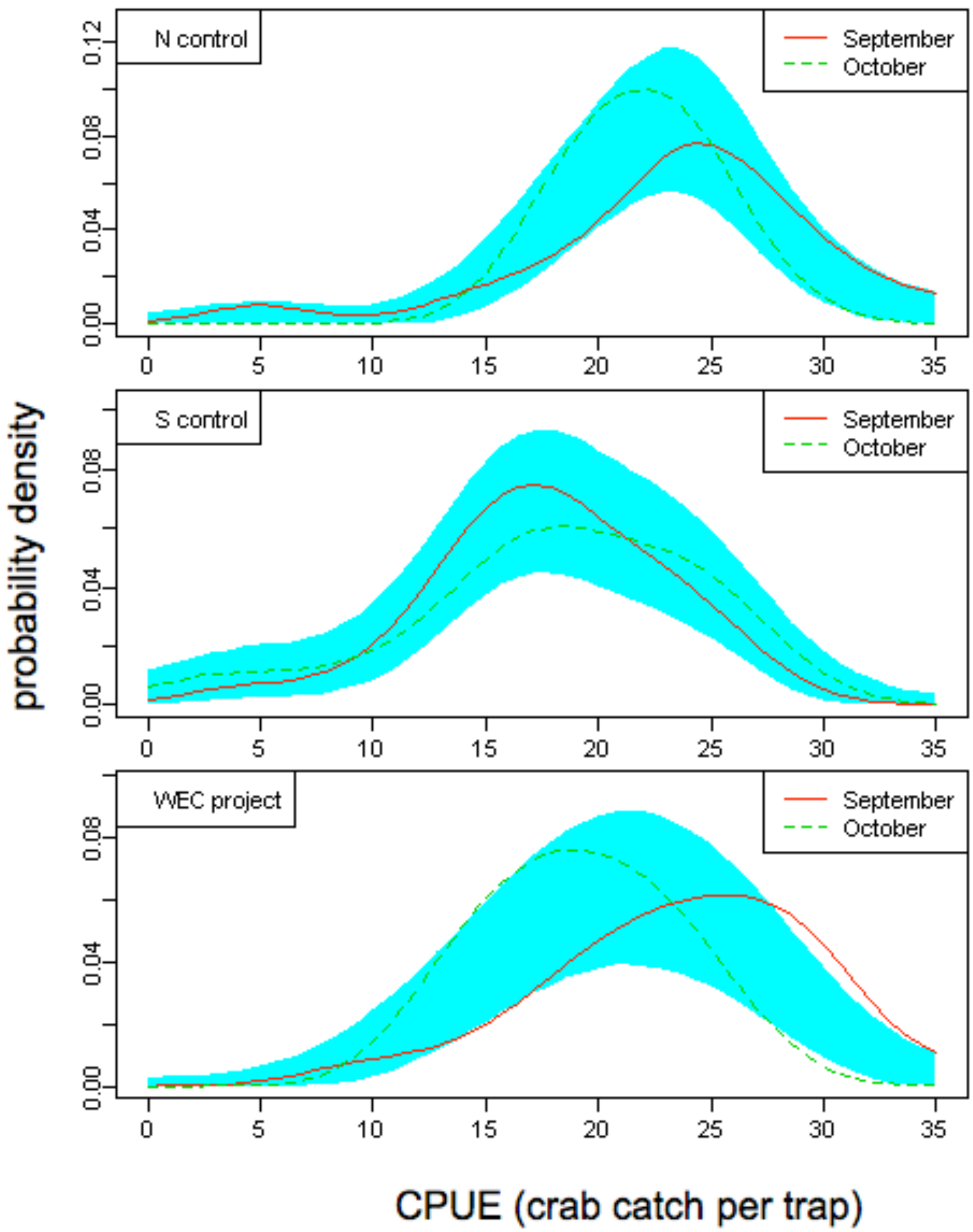

Figure 3. Comparison of smoothed distributions of CPUE for legal-sized male crab based on standard trap data (4 and 6 d soak times) by sampling effort.

Graphical Comparison of CPUE by Soak Time

Soak time had an effect on crab CPUE, with the strongest differences between 1 and 4 or 6 d soaks for legal-sized males (Figure 4a and 4b). Differences between the CPUE for 4 and 6 d soaks were subtler, with sub-legal males and females showing a decline in CPUE with the longer soak duration (Figures 4c and 4d). This pattern was less obvious for sub-legal males.

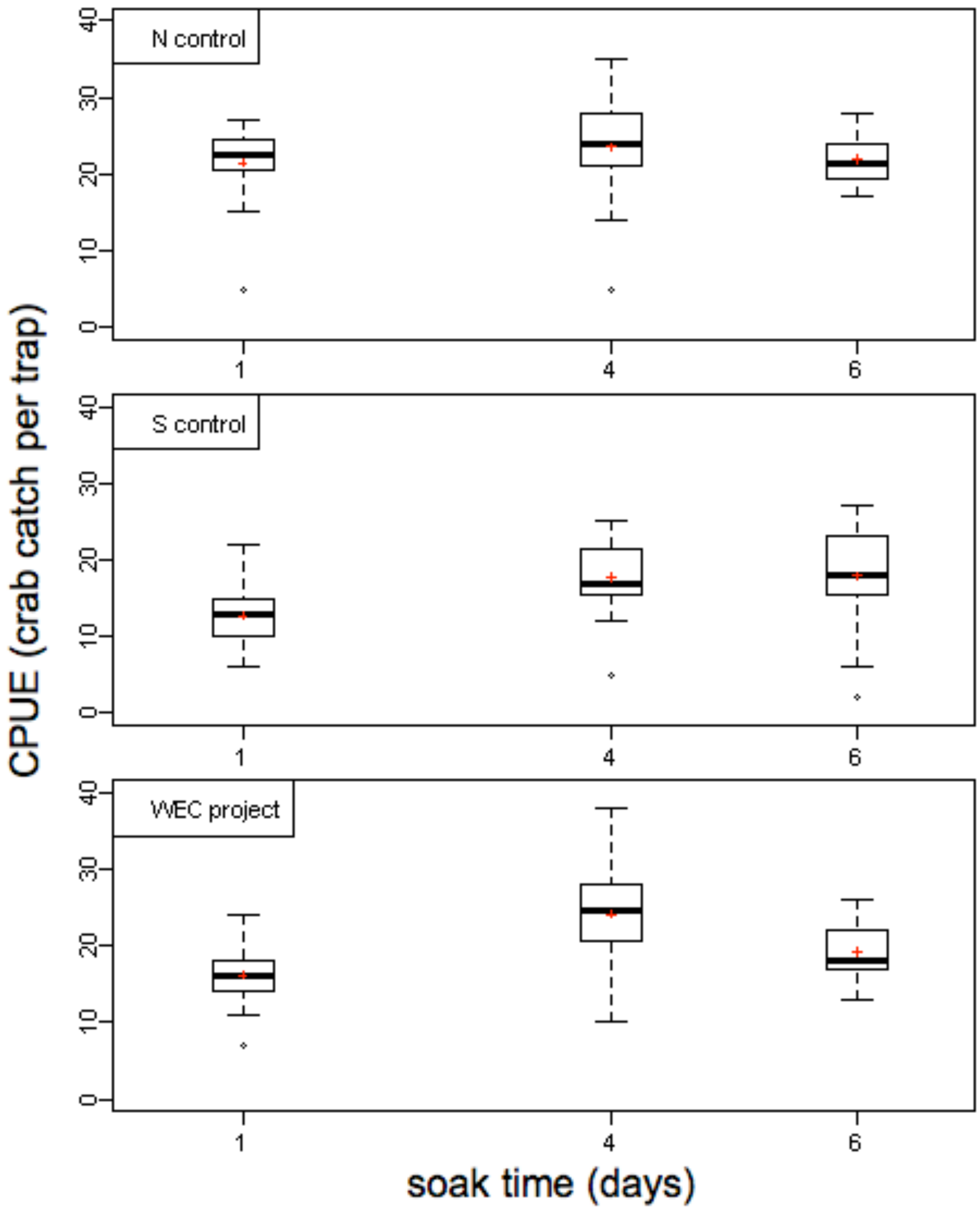

Figure 4a. Boxplots of CPUE for legal-sized male Dungeness crab based on standard trap data.

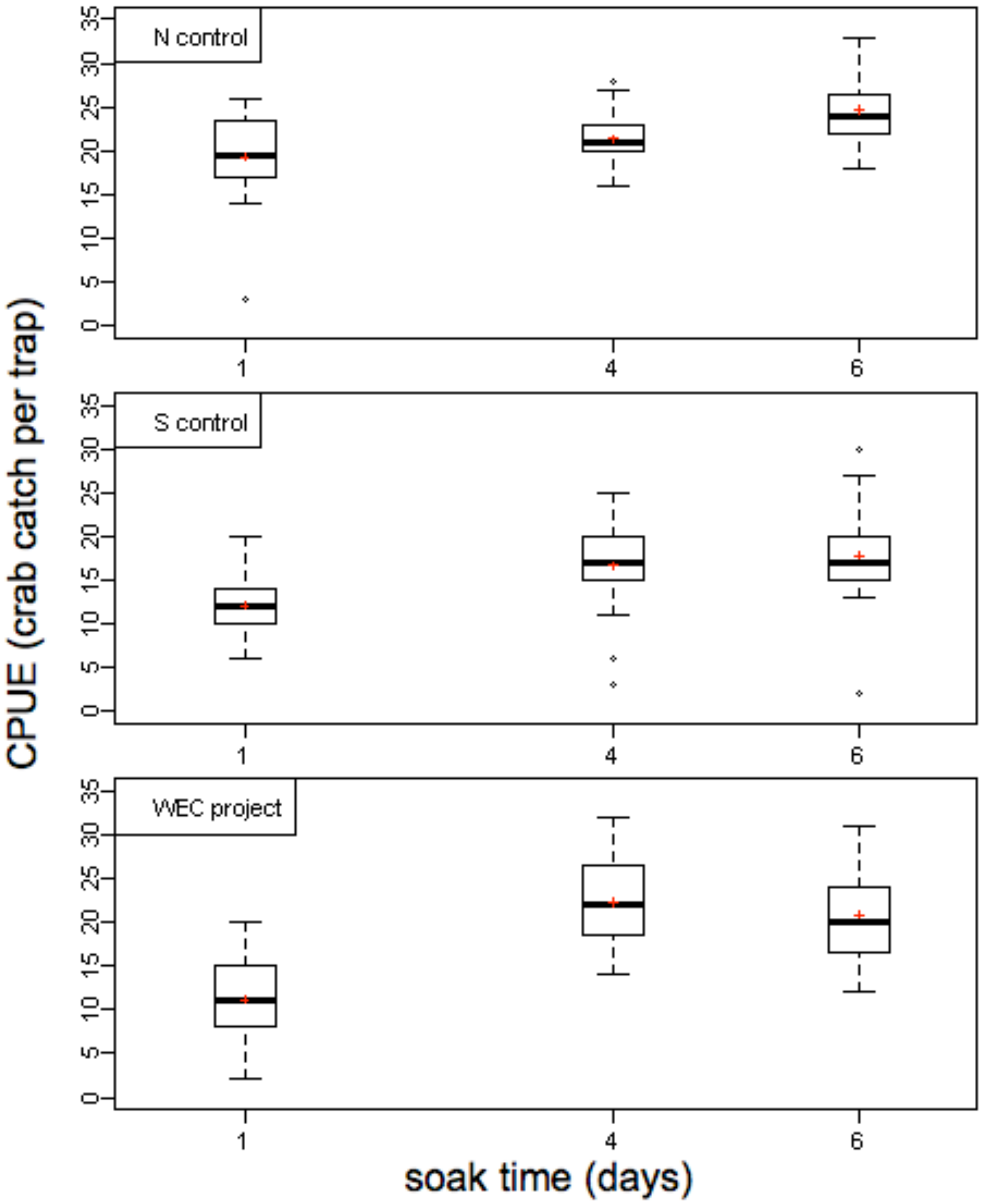

Figure 4b. Boxplots of CPUE for legal-sized male Dungeness crab based on zip trap data.

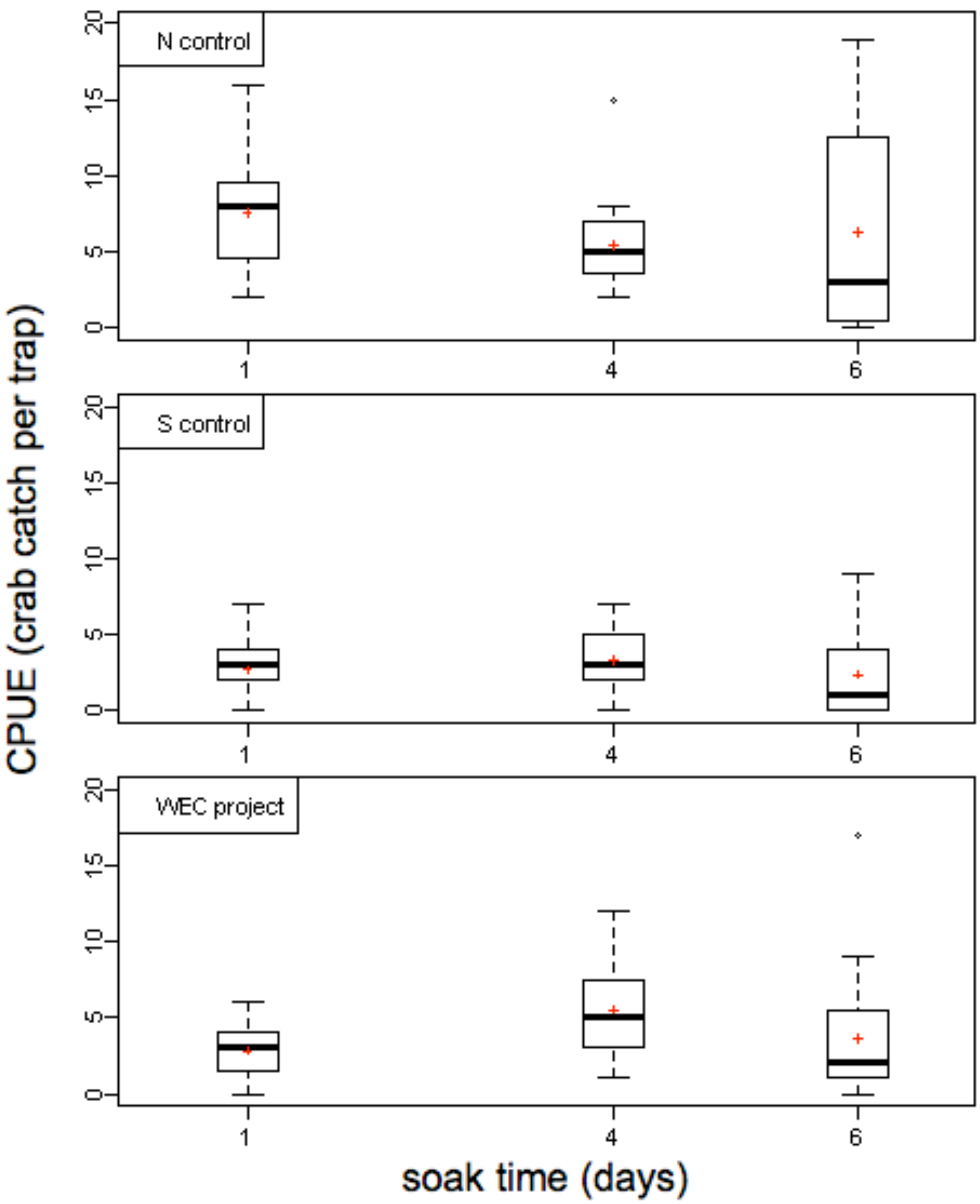

Figure 4c. Boxplots of CPUE for sub-legal male Dungeness crab based on zip trap data.

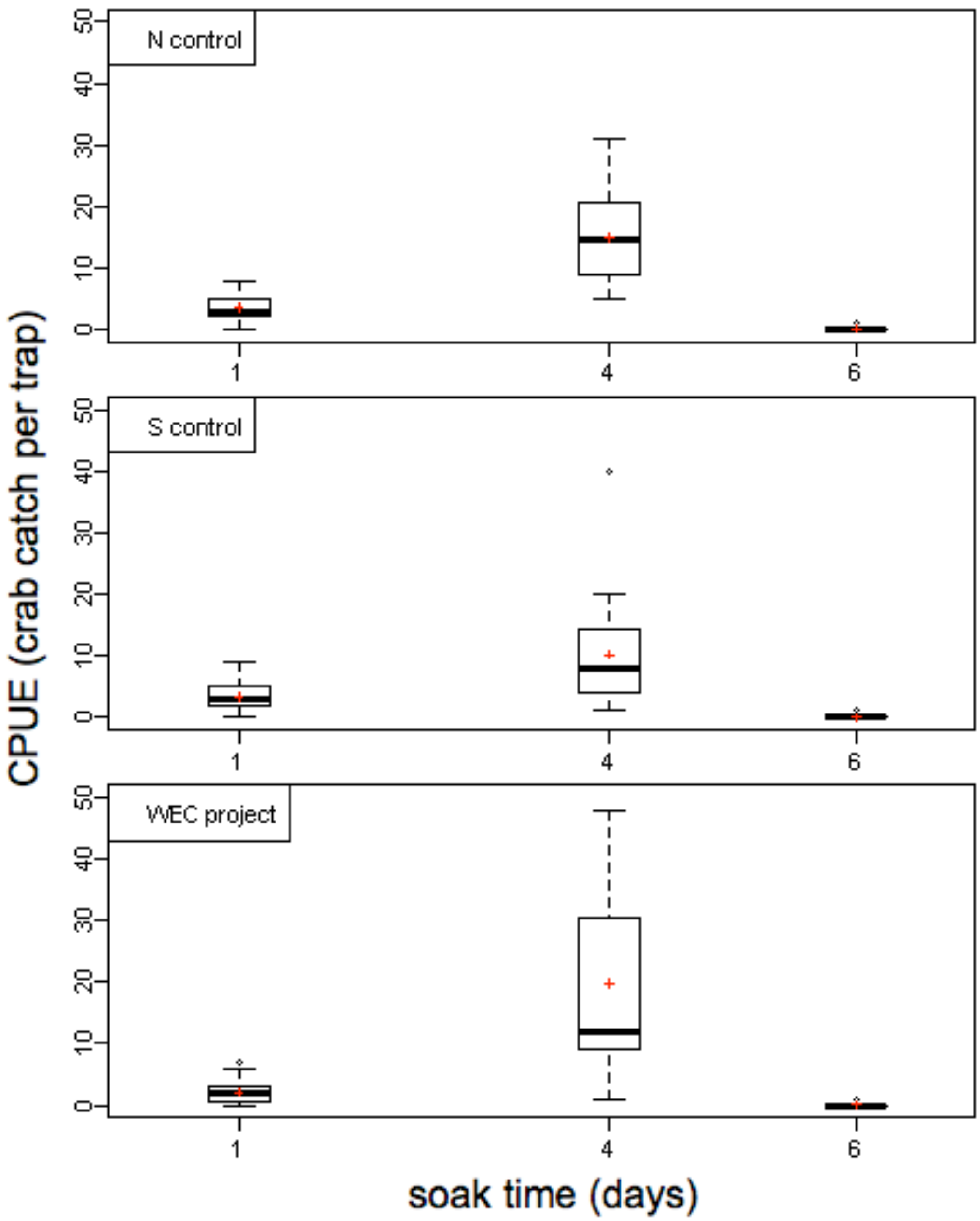

Figure 4d. Boxplots of CPUE for female Dungeness crab based on zip trap data.

Graphical Comparisons of Size by Sex and Location

Graphical comparisons of size distributions based on kernel smoothing techniques showed dramatic differences between males and females for every location (Figure 5). The north control site appeared to have a peak of smaller males near 140 mm, in contrast to the other sites, which appeared to have peaks in size at approximately 160 and 180 mm. The largest peak for each location appeared to be at 180 mm, though the WEC project site had a substantial peak at about 165 mm. Females peaked at about 140 mm for each location and did not appear to have any secondary peaks in their size distributions.

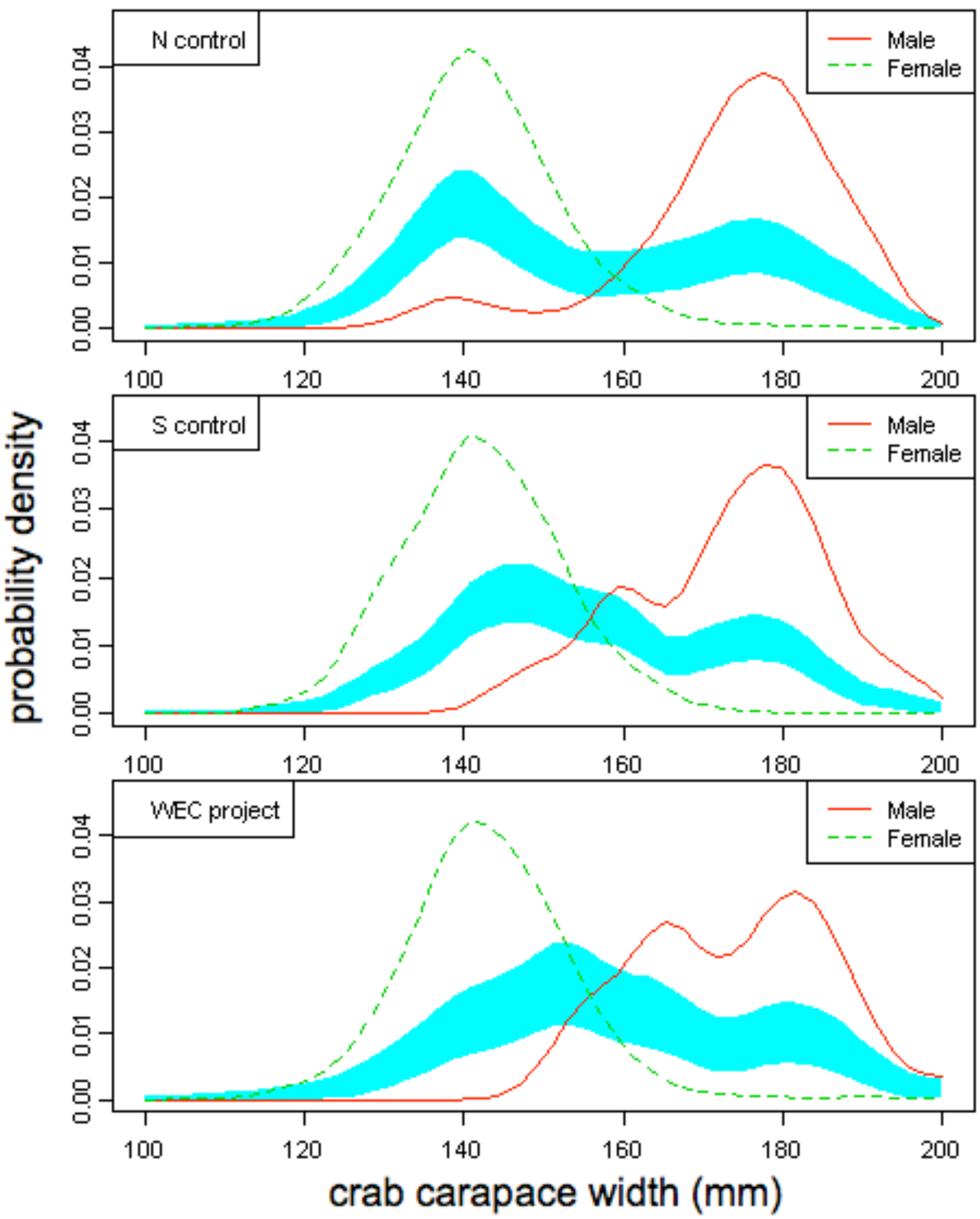

Figure 5. Smoothed distributions of size (carapace width) for Dungeness crab by sex.

Generalized Linear Model (GLM) Analyses

Generalized linear model analyses revealed that for all groups modeled (i.e., legal-sized male, sub-legal male and female Dungeness crab), at least one of the variables in the initial model (i.e., trap type, location, effort, and soak time) significantly affected CPUE. Trap type significantly influenced CPUE for legal-sized male crab ($p=0.0059$), sub-legal male crab ($p<0.0001$) and females ($p<0.0001$) (Table 6). There was significantly greater CPUE for legal-sized males in standard traps than zip traps, as compared to sub-legal males and females, where there was greater CPUE in zip traps than standard traps (Table 6).

Legal-sized male crab was also significantly affected by site, effort and soak time, with greater CPUE associated with the north control site, the September sampling effort and increasing soak time (Table 6). Sub-legal males were also affected by site, with the greatest CPUE occurring in the north control site; no other variables were identified as significant for sub-legal males. Female CPUE was positively associated with soak time and the September sampling effort.

Table 6. Coefficients of GLM's (negative binomial family) fit to Dungeness crab trap data. The reference categories were: Trap (Standard), Effort (Oct), and Site (N control).

Group	Model Term	Estimate	SE	Z Value	Pr(>|Z|)
Legal-Sized Male	Intercept	2.5471	0.0755	33.7314	<0.0001
	Trap (Zip)	-0.0740	0.0269	-2.7545	0.0059
	Soak time	0.1121	0.0109	10.2619	<0.0001
	Effort (Sept)	0.2465	0.0494	4.9884	<0.0001
	Site (S Control)	-0.3358	0.0336	-9.9996	<0.0001
	Site (WEC)	-0.1782	0.0332	-5.3698	<0.0001
Sub-Legal Male	Intercept	0.8120	0.0916	8.8650	<0.0001
	Trap (Zip)	0.9249	0.0877	10.5495	<0.0001
	Site (S Control)	-0.6964	0.1067	-6.5271	<0.0001
	Site (WEC)	-0.3439	0.1033	-3.3283	0.0009
Female	Intercept	-7.1033	0.4705	-15.0977	<0.0001
	Trap (Zip)	1.5609	0.1048	14.8886	<0.0001
	Soak time	0.4961	0.0331	15.0018	<0.0001
	Effort (Sept)	6.1840	0.4314	14.3363	<0.0001

Power Analyses

Analyses show generally increasing statistical power with both sample and effect size. While this was expected, the results provide insight into what effect sizes might reasonably be detected, given practical limits to effort and cost, and where the relationship between power and sample size changes.

Power Versus Effect Size

We analyzed the relationship of power to effect size, given a reduction in CPUE ranging from 10 to 100%. Power was relatively low for small reductions in CPUE of legal-sized male crab using standard traps (i.e., 10 and 20% reduction), but was very strong for reductions ≥40% (Figure 6). Even a reduction of 30% resulted in a reasonably good level of power (77%). Power was not strong for any effect size with respect to sub-legal male crab using zip trap data. Power did not exceed 10% until there was at least 50% reduction in CPUE and never exceeded 30% for any effect size.

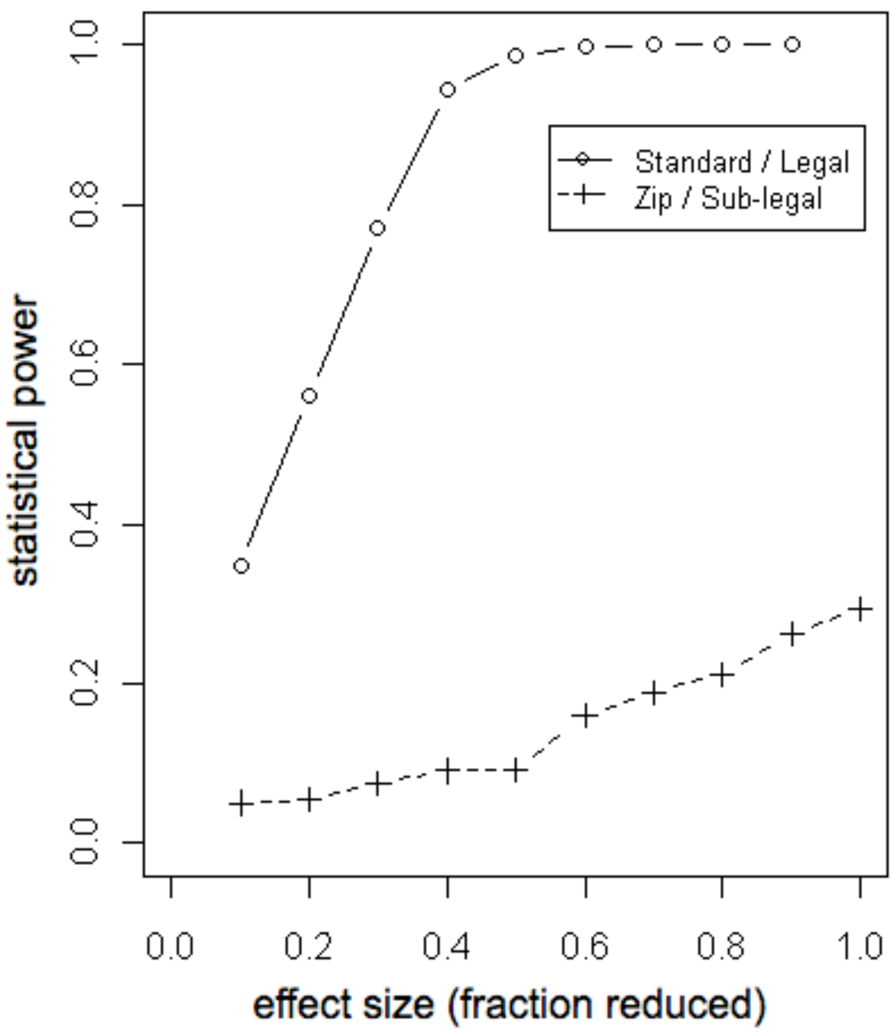

Figure 6. Power vs. effect size for legal-sized male and sub-legal male Dungeness crab, based on standard trap and zip trap data, respectively

Power Versus Sample Size.

We analyzed power over sample sizes ranging from 10 to 60 traps per site, and assumed 20 and 30% reduction for power analyses of standard trap data for legal-sized male crab and 50 and 90% reduction for power analyses for sub-legal male crab. These levels of reduction were chosen to help us improve power based on selection of appropriate sample size. Power increased with larger sample sizes, though the rate of increase seemed to change at different sizes, depending on the magnitude of the effect analyzed. Using the standard trap data for legal-sized male crab and assuming a 30% reduction in CPUE, power increased rapidly with an increase in sampling effort from 10 to 15 traps; thereafter, improvements in power with greater effort were more modest (Figure 7). In contrast, assuming a lower, 20% reduction in CPUE, statistical power rose steadily with increasing sampling effort until effort reached 40 traps per site; increased effort beyond this level appears to offer little to no improvement in power (Figure 7).

For sub-legal male crab, power was extremely limited for all sample sizes analyzed, however the overall rate of increase in power with sample size differed substantially when comparing effects of 50% reduction vs. 90% reduction in CPUE (Figure 7). With a 90% reduction, increasing sample sizes resulted in much greater gains in power when compared to the 50% reduction. There was a change in the rate of increase in power at a sample size of 35 at 90% reduction, whereas the rate of increase in power did not appear to change at any of the modeled sample sizes for the 50% reduction. Though the peak in CPUE appeared to be at n=55 for the 50% reduction, the variation in power at sample sizes ranging from 40 to 60 indicated that power at any of these sample sizes is comparable. Power did not exceed 35% for any of the sample sizes modeled for sub-legal male crab at 50% or 90% reduction.

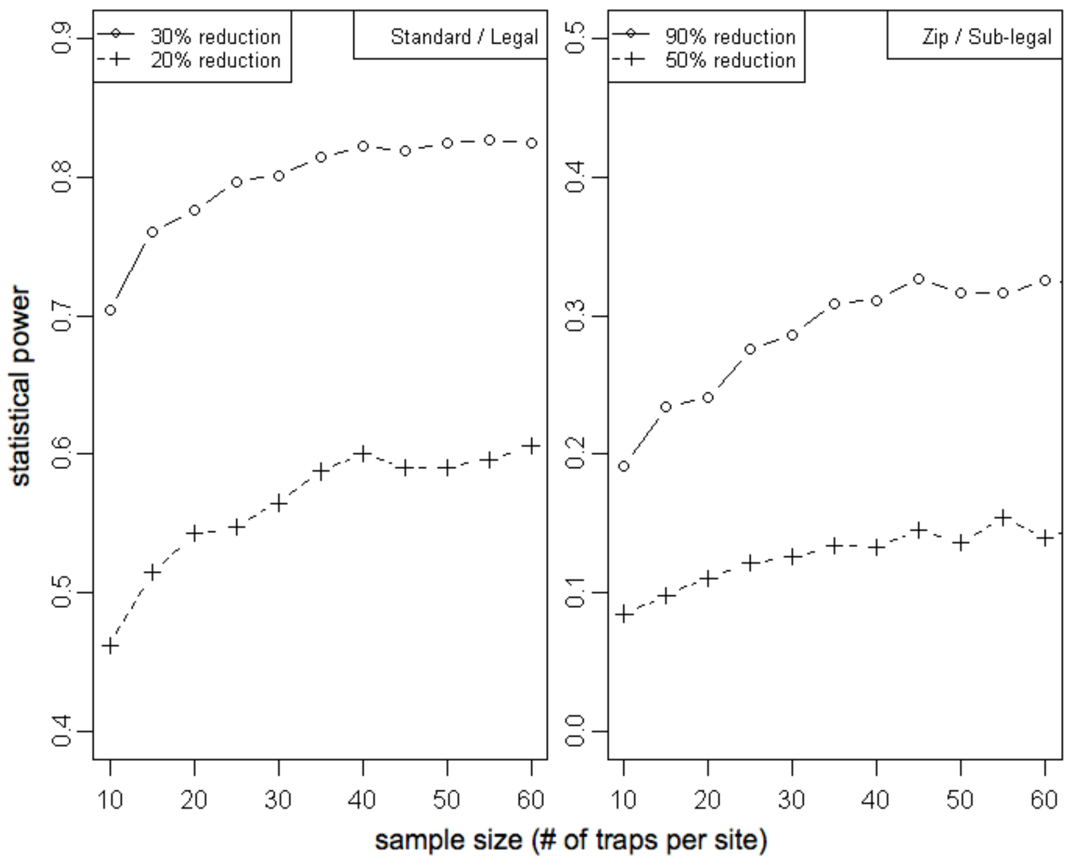

Figure 7. Power vs. sample size for legal-sized male and sub-legal male Dungeness crab, based on standard trap and zip trap data, respectively.

Analyses of Trawl Data

Species Richness and Diversity Measures

English sole, Pacific sanddab, butter sole, tomcod and Dungeness crab were the 5 most abundant species (in order, with English sole being most abundant) captured during trawling efforts (Table 7). These 5 species represented 89% of the total catch by number. The number of species captured ranged from 13 to 21 per trawl and from 22 to 25 per location (Table 8). Though the greatest number of individuals was captured in the north control site (3,415), the most species were detected in the south control site (25) (Table 8).

Table 7. The number of individuals per species and percent of total individuals captured during trawling efforts at the south control, WEC project and north control sites in November 2009.

Species	**Total**	**% of Total**
English sole	2693	35.8
Pacific sanddab	2216	29.4
butter sole	989	13.1
tomcod	520	6.9
Dungeness crab	258	3.4
anenomes	132	1.8
poachers	125	1.7
rex sole	101	1.3
slender sole	93	1.2
leather seastar	74	1.0
petrale sole	56	0.7
night smelt	53	0.7
shiner perch	53	0.7
staghorn sculpin	46	0.6
sand sole	42	0.6
sunstar	34	0.5
snubnose pipefish	11	0.1
kelp greenling	7	0.1
UI sculpin	6	0.1
lingcod	4	0.1
arrowtooth	3	<0.1
buffalo sculpin	2	<0.1
clams	2	<0.1
coonstripe	2	<0.1
dover sole	2	<0.1
bay pipefish	1	<0.1
blacktail snailfish	1	<0.1
pacific halibut	1	<0.1
showy snailfish	1	<0.1
Pisaster sp	1	<0.1

Table 8. The number of species captured per trawl and location during trawling efforts in November 2009.

Location	**Trawl**	**Number of Species**	**Number of Individuals**
South Control	0705	21	393
South Control	0846	18	1413
South Control	*Total*	*25*	*1806*
WEC Project	0940	16	917
WEC Project	1042	13	760
WEC Project	1231	19	632
WEC Project	*Total*	*22*	*2309*
North Control	1312	14	1025
North Control	1401	15	652
North Control	1444	14	900
North Control	1534	18	838
North Control	*Total*	*22*	*3415*
All	*Total*	*30*	*7530*

The south control site appeared to have greater species richness and diversity than the north control or WEC project sites, based on the ACE and Chao species richness estimators, and the Exponential Shannon and Simpson (inverse) diversity indices (Table 9). The north control and WEC project sites had comparable species richness and diversity indices. These results should be interpreted with caution however, due to the small sample size in the south control site (n = 2). The south control site typically had the greatest variation in all species richness and diversity indices.

Table 9. Species richness and diversity indices by location, based on trawling data from November 2009.

Location	Emphasis	Estimator	Mean	SD
South Control	Richness	ACE	25.8	6.18
		Chao1	23.6	1.64
	Diversity	Exponential Shannon	7.1	1.13
		Simpson (inverse)	4.8	1.06
North Control	Richness	ACE	22.0	2.9
		Chao1	21.4	1.79
	Diversity	Exponential Shannon	5.1	0.3
		Simpson (inverse)	3.6	0.13
WEC Project	Richness	ACE	21.3	3.54
		Chao1	20.3	0.91
	Diversity	Exponential Shannon	5.9	0.19
		Simpson (inverse)	4.2	0.11

Comparisons of the Shannon Exponential diversity indices among locations revealed significantly greater species diversity in the south control site than the north control site (Table 10). However, there was no statistically significant difference between the south control and the WEC project site. Inclusion of location in the model significantly improved model likelihood ($p=0.0221$; $X^2=7.6219$, $df=2$).

Table 10. Coefficients for linear model relating the Exponential Shannon diversity index to location; reference "Location" is the South control site.

Model term	Estimate	SE	t-Value	Pr(>|t|)
Intercept	1.9264	0.1084	17.7682	<0.0001
Location (North Control)	-0.3690	0.1328	-2.7786	0.0321
Location (WEC Project)	-0.1892	0.1400	-1.3520	0.2251

Catch-Per-Unit Effort

There was a wide range of values for CPUE among locations and species, usually with greater variation within the south control site than the other sites (Table 11 and Figure 8). However, these observations were based on limited sample sizes, ranging from 2 to 4 trawls per location.

Table 11. Mean CPUE (# of fish per m distance trawled) from trawl data, November 2009.

Location	Species	Mean	SD
North Control	English sole	0.1945	0.0426
South Control	English sole	0.2045	0.1845
WEC Project	English sole	0.1311	0.0311
North Control	Pacific sanddab	0.1836	0.0417
South Control	Pacific sanddab	0.0763	0.0596
WEC Project	Pacific sanddab	0.1363	0.0342
North Control	butter sole	0.0420	0.0242
South Control	butter sole	0.1135	0.1398
WEC Project	butter sole	0.0591	0.0137
North Control	Dungeness crab	0.0106	0.0100
South Control	Dungeness crab	0.0203	0.0024
WEC Project	Dungeness crab	0.0216	0.0015

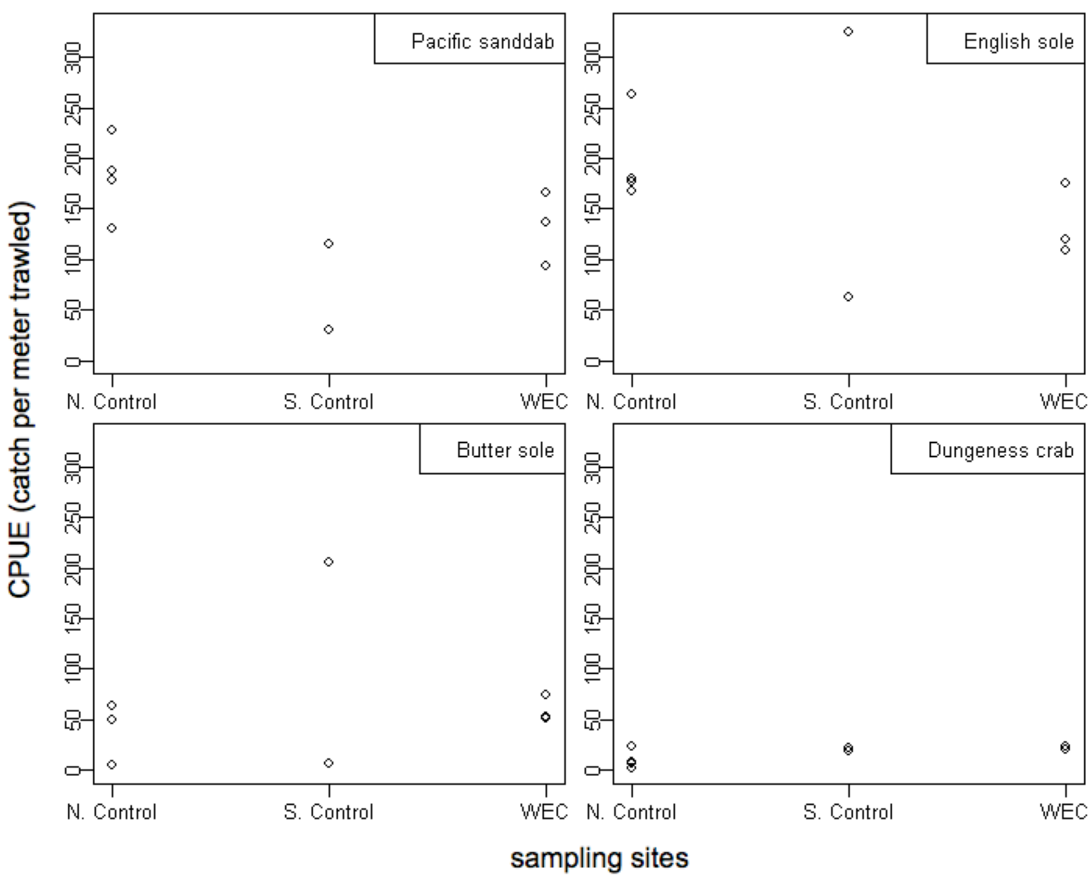

Figure 8. CPUE by location and species, based on trawling data from November 2009.

Linear models relating `log(CPUE + 1)` to location indicated relatively few differences in CPUE among locations. Location was not significant in the model for either English sole or butter sole, based on likelihood ratio tests, but was significant for both Pacific sanddab and Dungeness crab (Table 12). For Pacific sanddab, the north control site had significantly greater CPUE than the south control site, though the north control site was not significantly different from the WEC project site (Table 13). For Dungeness crab, even though location significantly improved model likelihood (Table 12), the north control site did not differ significantly from either the south control site (p=0.1202) or the WEC project site (p=0.0616; inconclusive result).

Table 12. Likelihood ratio tests comparing linear models with location included vs. models without location, based on trawl data from November 2009.

Species	Degrees of Freedom	X^2	Pr(>X^2)
English sole	2	1.4129	0.4934
Pacific sanddab	2	8.1160	0.0173
butter sole	2	1.8325	0.4000
Dungeness crab	2	6.4631	0.0395

Table 13. Coefficients for linear models relating `log(CPUE + 1)` to location, based on trawl data from November 2009.

Species	Model term	Estimate	SE	t value	Pr(>|t|)
	Intercept	0.1793	0.0356	5.0419	0.0024
English sole	siteSC	-0.0077	0.0616	-0.1244	0.9051
	siteWEC	-0.0529	0.0543	-0.9749	0.3673
	Intercept	0.1660	0.0189	8.7733	0.0001
Pacific sanddab	siteSC	-0.0963	0.0328	-2.9375	0.0260
	siteWEC	-0.0426	0.0289	-1.4745	0.1908
	Intercept	0.0408	0.0277	1.4737	0.1910
butter sole	siteSC	0.0557	0.0479	1.1627	0.2891
	siteWEC	0.0164	0.0423	0.3886	0.7110
	Intercept	0.0097	0.0033	2.9390	0.0260
Dungeness crab	siteSC	0.0103	0.0057	1.8107	0.1202
	siteWEC	0.0115	0.0050	2.2945	0.0616

Sizes of Dungeness Crab

Male Dungeness crab ranged in size from 80 to 200 mm carapace width within the north control site, 65 to 200 mm within the south control site, and 80 to 195 mm within the WEC project site based on trawl data (Table 14 and Figure 9). These ranges were much wider than those based on trapping, where size ranged from 135 to 190 mm for the north control site, 145 to 195 mm for the south control site, and 155 to 200 mm for the WEC project site. Based on inspection of smoothed distributions of size, it appeared that there were more peaks in size for the trawl data than the trapping data (Figure 9). This could potentially reflect a greater number of age classes captured by trawling than trapping. In addition, trawling typically captured more crab in the 90 to 130 mm range than trapping. There was a peak in the size distributions of Dungeness crab captured by trawling for all locations and sexes between 100 and 120 mm. Females were only captured in substantial numbers within the south control site; only one female was captured anywhere else (WEC project site). In addition, one juvenile was captured in the south control site (50 mm). Whereas trawling captured males up to 200 mm in size at all sites, no females >130 mm were captured during trawling. This was in contrast to trapping with respect to females, where sizes up to 190 mm were captured.

Table 14. Sizes of Dungeness crab captured during November 2009 trawling efforts; na=not available, due to sample size of 0 or 1.

Sex	Location	Sample Size	Mean (mm)	SD	Range
Male	North Control	58	114.8	28.91	80-200
	South Control	41	131.5	33.66	65-200
	WEC Project	119	119.5	24.99	80-195
Female	North Control	0	na	na	na
	South Control	27	112.8	11.38	90-130
	WEC Project	1	110.0	na	na

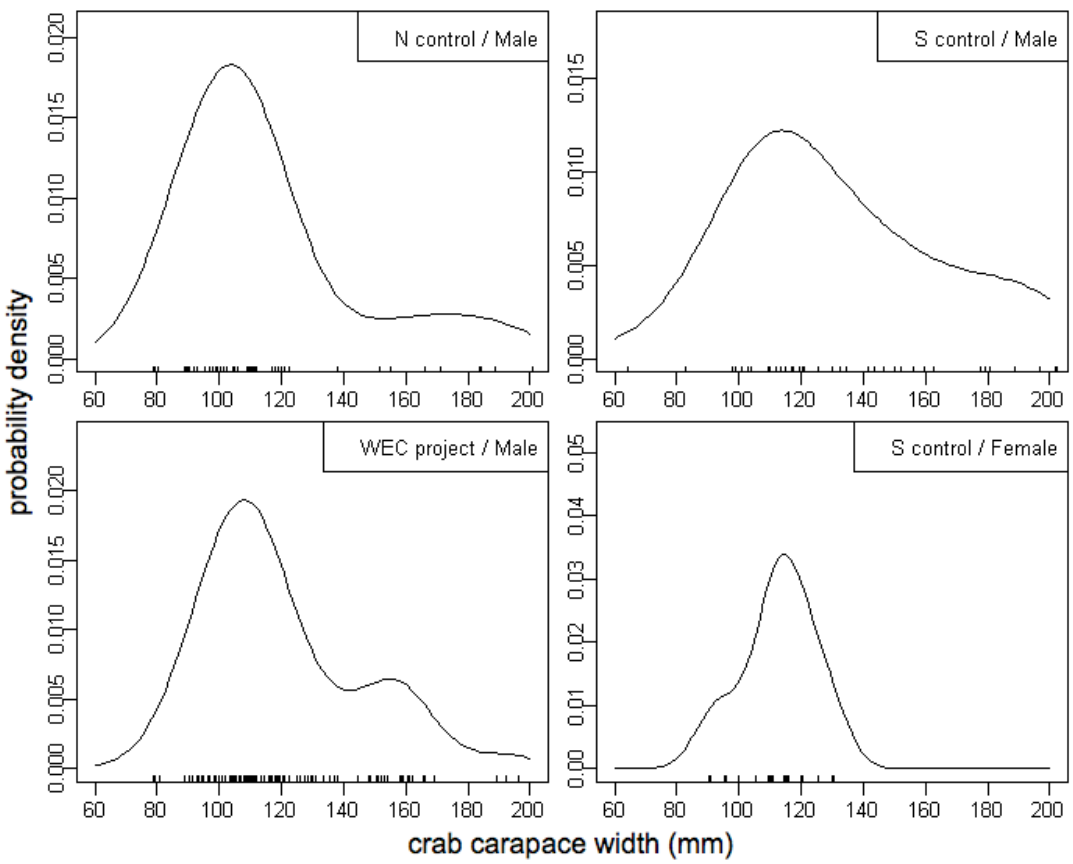

Figure 9. Dungeness crab size frequency / probability density by location, based on trawl data from November 2009.

Power Analyses

Power analyses based on trawl data revealed similar patterns in the relation between power and effect size for all species, though there were differences in the magnitude of power predicted. For all species, there were substantial gains in power when comparing the "two sampling efforts before impact" sampling design ("2 before" design) to the "one sampling effort before impact "sampling design ("1 before" design), once reaching >30% reduction in CPUE (Figure 10). This difference in power between the two sampling designs increased with increasing effect size.

Power increased with increasing sample size, though much more so for the "2 before" sampling design than for the "1 before" design (Figure 10). Note that sample size could not change for the before sampling efforts in the "1 before" design, because these sample sizes are limited to those already implemented (i.e., 4 trawls in north control site, 3 trawls in WEC project site, and 2 trawls in south control site). Therefore, increases in sample size for the "1 before" design were only reflected in the "after" portion of the design. The relationship between power and sample size was similar among species, with differences mostly reflected in the magnitude of power, and only subtle changes in the rate of increase in power. There may have been slight curvilinear relationships seen, potentially with a change in the rate occurring near a sample size of 10, with minor differences among species. Of course, this is open somewhat to interpretation. The magnitude of power differed somewhat among species, with the lowest magnitude for butter sole and Dungeness crab. There was greater power for all sample sizes and sampling designs for Pacific sanddab and English sole than for either butter sole or Dungeness crab.

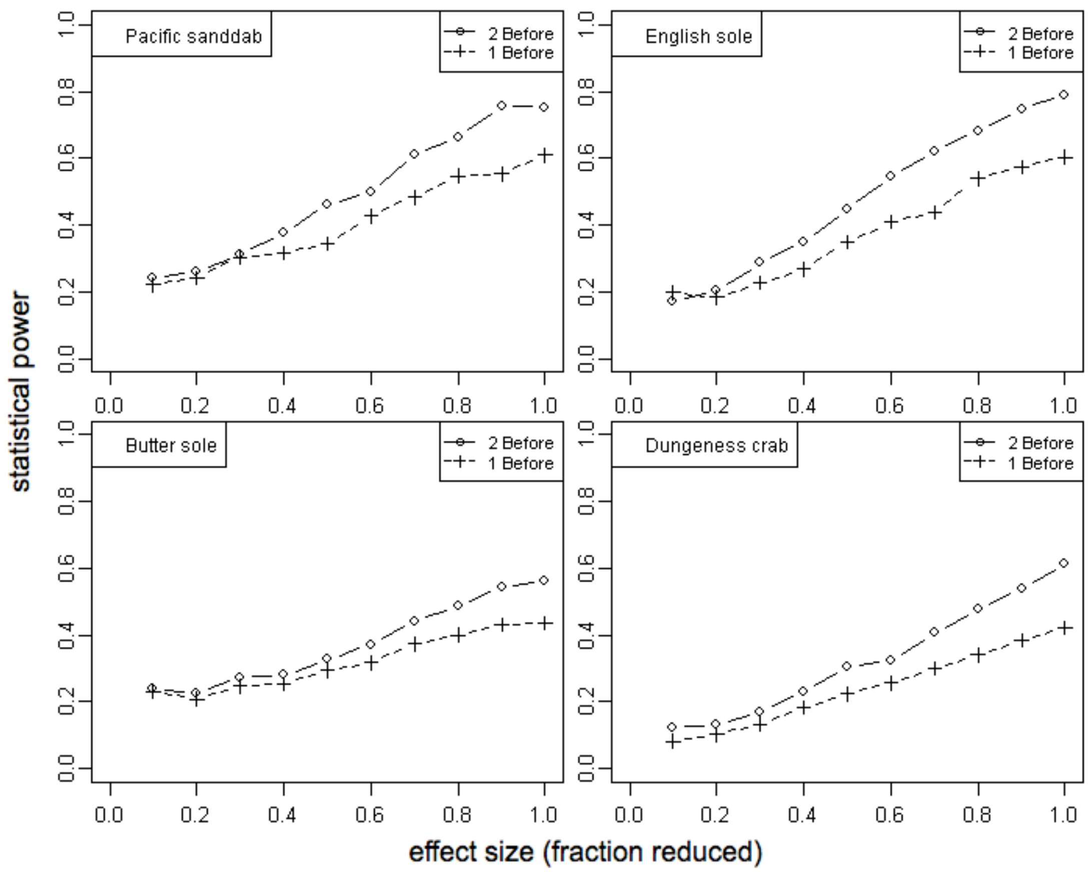

Figure 10. Power vs. effect size for Pacific sanddab, English sole, butter sole, and Dungeness crab, based on trawl data from November 2009. “2 Before” refers to two sampling efforts before impact, and “1 Before” refers to one sampling effort before impact.

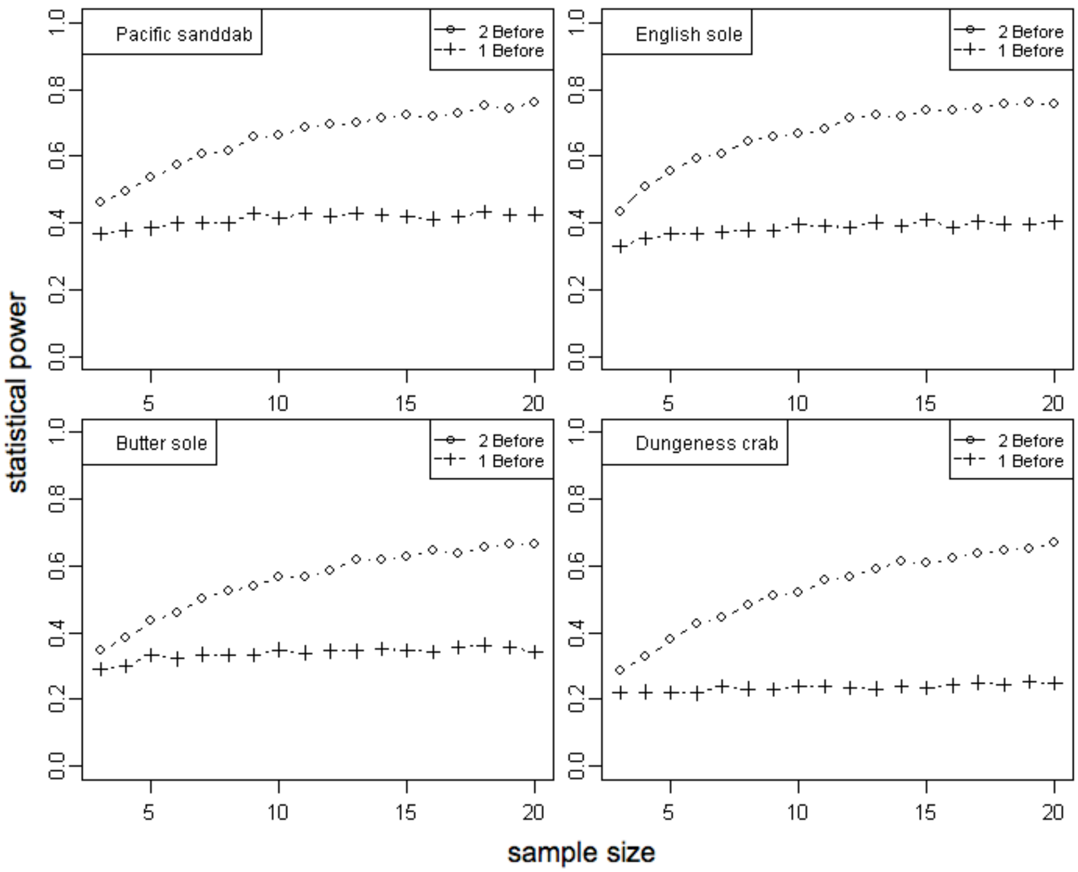

Figure 11. Power vs. sample size for Pacific sanddab, English sole, butter sole, and Dungeness crab, based on trawl data from November 2009. “2 Before” refers to two sampling efforts before impact, and “1 Before” refers to one sampling effort before impact.

Discussion

CPUE (Trawling and Trapping)

There were substantial sex-specific differences in Dungeness crab CPUE that may reflect differential habitat uses by males and females. Trapping CPUE was substantially higher for male (both legal-sized and sub-legal) than for female Dungeness crab (Table 3). Females were captured at every location, but in very low numbers. Trawl samples produced no females from the north control site (Table 14), though this is likely a reflection of the low sampling effort and not an indication that they were actually absent from this site. Because the sampling plan did not encompass a wide range of depths, it is possible that females may be under-represented in our samples.

Trapping CPUE of legal-sized male Dungeness crab varied by location, with greater CPUE in the north control than the south control or WEC project site (Figures 2a-d and Table 5).

Similarly, the sub-legal male crab CPUE was greater in the north control than south control site. There were no differences in CPUE of female crab between locations. The trawl CPUE for sub-legal male Dungeness crab at the three sites were probably not significantly different: Linear model analyses showed no significant effect of location on CPUE (Table 13), and trawl captures were dominated by sub-legal males (Figure 8). The differences in CPUE by location could easily change from year-to-year or more frequently, and may not reflect a meaningful biological difference in abundance between locations. It is unlikely, however, that the power of the statistical design would be compromised, because the BACI design allows for variation due to location. In fact, our estimation of power incorporates the pre-treatment data as is (with statistical differences among locations), and power did not appear to suffer from these differences.

Species Richness and Diversity

The location with the lowest CPUE of legal-sized and sub-legal male crab, the south control site, had the greatest species richness and diversity of the sites (Table 9). Though there were only two trawls conducted in the south control site, 25 species were captured here, compared to 22 species in the north control site (4 trawls) and 22 in the WEC project site (3 trawls). These differences could however be attributed to sampling variation, as sample sizes by location were small. It is unlikely that there are meaningful biological differences between locations, though there may be some differences in habitat utilization. A BACI design accounts for differences among locations, so this would not compromise the power of the design if the apparent differences were, in fact, real.

Differences in Sizes of Dungeness Crab

The range in sizes of captured crab indicated a wide range of age classes and, presumably, a healthy and stable population structure. Crab ranged in size from 50 to 200 mm, and their size frequency distributions were comparable among locations (Tables 4 and 14; Figures 5 and 9). Most females captured were sexually mature, exceeding 90 – 100 mm (Figures 5 and 9), the size at 2 years of age (Hankin et al. 1989 and references therein).

Interestingly, the peak of size distributions based on trapping (Figure 5) was much larger than that based on trawl data (Figure 9). The difference in Dungeness crab size by gear type supports the expectation that crab traps target larger crab, and that trawling samples a wider range of sizes, likely representing all post-larval age classes present.

Effects Due to Effort, Soak Time, and Trap Type on Trap Catch

Effects due to effort, soak time and trap type on trap catch of Dungeness crab were investigated; while arguably not of direct interest to this study, these effects are important should the sampling program be subject to alterations (deliberate or otherwise!). Though there were differences in CPUE between sampling efforts for legal-sized males and females, the differences did not appear to be large for legal-sized males (Table 6). For legal-sized males captured by standard traps, it appears that the difference may be primarily attributable to more traps with high values of CPUE in the WEC project site during September as compared to October (Figure 3). However, the implications for the power analysis are minor, since the BACI design allows for variation in CPUE by location and sampling effort.

Soak time affected the CPUE of legal-sized males and females, based on GLM analyses (Table 6) and graphical analyses (Figure 4). CPUE was positively related to soak time, though it appeared for females that the 4 d (rather than the 6 d) soak time yielded the highest CPUE (Figure 4). These results are confounded by sampling effort, as the 4 d soak was conducted only during the September sampling effort and the 6 d soak was conducted only during the October sampling effort. (These soak times were not chosen deliberately but were a consequence of ocean conditions.) For legal-sized males and sub-legal males, there was typically little difference between CPUE for 4 and 6 d soak times. There were, however, large differences between 1 and 4 d soak times, particularly for legal-sized males (Figure 4). For this reason, our analyses relied primarily on data from sampling efforts with 4 and 6 d soak times.

Not surprisingly, trap type was a critical variable affecting legal-sized males, sub-legal males, and females. Legal-sized males had higher CPUE in standard traps, whereas sub-legal males and females had higher CPUE in zip traps (Table 6). Data were primarily analyzed for these combinations of sex/legal (size) status and trap type. Power analyses focused on data for legal-sized males captured by standard traps and sub-legal males captured by zip traps. The Hafer traps proved impractical because they had to be run on long-line gear, which was comparatively difficult to run, and the species they captured were more effectively sampled using the trawl gear.

Power

The statistical power was strong for detecting differences in CPUE of legal-sized male Dungeness crab when using standard trap data, exceeding 80% power at 30 to 40% reduction in CPUE (and assuming minimal sample sizes of 20 traps per location for each sampling effort, Figure 7). Assuming a 30% reduction in CPUE, there is only a slight increase in power when increasing sample size beyond 25 traps per location (Figure 8). We do not recommend reducing sampling effort—the potential for reduced effort due to inclement weather, lost gear and other factors is too great.

The power to detect differences in sub-legal male Dungeness crab CPUE was much lower than for legal-sized males, and not adequate for our purposes. Although increasing the sample size provided relatively large gains in power, it appeared that an asymptote was reached at a low level of power (i.e., <35%) even with substantial reductions in CPUE (i.e., 90%, Figure 8).

Varying the sampling design could dramatically increase statistical power for detecting differences in CPUE based on trawling data. The inclusion of another “before” impact sampling effort (e.g., spring or summer, 2010) would have the greatest effect on increasing power. In addition, there were relatively large gains in power by increasing sample sizes from 3 to 15 trawls per location.

Recommendations for Sampling Design

The metrics analyzed here, CPUE for Dungeness crab, Pacific sanddab, English sole and butter sole, and the diversity measures, are all potentially robust indicators of the local benthic ecology. We recommend maintaining the current sample sizes for the trapping efforts (i.e., 20 traps per location per effort for 3 more sampling efforts after impact), as power is reasonably good with this design even for relatively small reductions (i.e., 30%) in CPUE. If there is a desire to detect differences as small as 20% reduction in CPUE, larger sample sizes will have to be considered. We recommend at least one additional set of trawl samples conducted before project installation, and at least ten trawl samples per site per effort.

A narrow window of opportunity, adverse weather conditions and technical difficulties prevented completion of a second trawling effort or the planned number of trawls per effort. However, the data collected allowed us to model several sampling alternatives. There appears to be a strong need for a second "before impact" trawling effort, if there is to be adequate power to detect differences in CPUE and adding a third may be advisable although we did not model this scenario. Otherwise, power will remain low even with a moderate reduction in CPUE (i.e., 50%), regardless of attempts to increase sample size. With a moderate reduction in CPUE, power is reasonably good (>60% for all 4 species analyzed) if sample size is increased to n=15 trawls per location. The power gained when increasing beyond this sample size is small.

Other Concerns

The relationship between CPUE and actual abundance could change for trapping data, particularly if CPUE increases over time. There is a space limitation and a maximum density to the crab traps, and, if these were exceeded, the relationship between CPUE and crab abundance would break down. We do not think this likely, but it would put additional importance on the trawl surveys.

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