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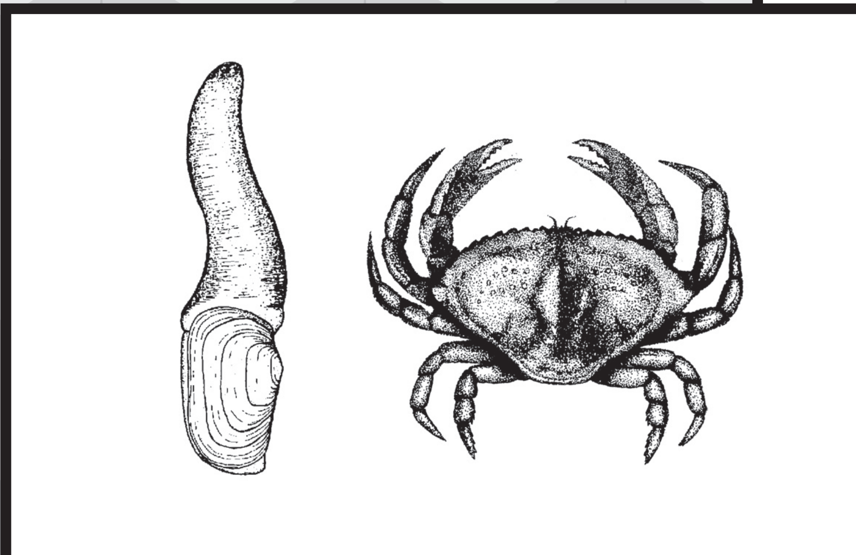
The Effect of Commercial Geoduck (*Panopea abrupta*) Fishing on Dungeness Crab (*Cancer magister*) Catch Per Unit Effort in Hood Canal, Washington



by Therese Armetta Cain & Alex Bradbury

Washington Department of
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The Effect of Commercial Geoduck (*Panopea abrupta*) Fishing on Dungeness Crab (*Cancer magister*) Catch Per Unit Effort in Hood Canal, Washington

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Abstract

Recreational crab pot fishers in Hood Canal, Washington sometimes complain that their catch rates for Dungeness crab, *Cancer magister* (Dana 1852) decline drastically following commercial geoduck clam *Panopea abrupta* (Conrad, 1849) harvest by divers. To test this assertion, we sampled crabs during a 4.6-year period with baited pots before, during, and after commercial geoduck fishing at a treatment site in Hood Canal. We also sampled crabs at a nearby unfished control site during the same time period. We tested whether significant changes in crab catch-per-unit-effort (CPUE) occurred following geoduck fishing in the treatment site, and if such changes could be attributed to geoduck fishing. Mean CPUE at the treatment site increased from 1.70 crabs/pot prior to fishing to 2.96 crabs/pot after geoduck fishing began. CPUE at the nearby unfished site during the same two time periods was 4.79 and 4.85 crabs/pot. Based on the results of an unpaired t-test of CPUE before and after geoduck fishing at the treatment site, we concluded that there were no significant effects on crab CPUE that could be attributed to geoduck fishing. A high level of natural variability in crab CPUE reduced the statistical power of the experiment, but such variability would likely affect the recreational pot fishery to an even greater degree. We therefore conclude that anecdotal reports which allege drastic declines in crab catch rates following geoduck fishing cannot be given much credence.

Key Words: *Cancer magister, Panopea abrupta,* recreational crab catch per unit effort

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Table of Contents

List of Figures ii

List of Tables iii

Introduction 1

Methods 2
- Experimental Design 2
- Site Description 4
- Crab Sampling Methods 5

Results 7

Discussion 12

Literature Cited 14

List of Figures

Figure 1. Thorndyke Bay (treatment) and South Point (control) sampling sites in Hood Canal, Washington, United States 4

Figure 2. CPUE (crabs/pot) of all Dungeness crabs at the control and treatment sites. Shaded areas indicate the two periods of commercial geoduck fishing 9

Figure 3. CPUE (crabs/pot) of all legal Dungeness crabs (>151 mm carapace width) at the control and treatment sites. Shaded areas indicate the two periods of commercial geoduck fishing. Note: The legal size of Dungeness crabs in Hood Canal was increased to >158 mm in 2002 9

List of Tables

Table 1. Results of Dungeness crab sampling at the control and treatment sites in Hood Canal. 8

Introduction

Geoduck clams (*Panopea abrupta*) dominate the biomass of benthic infaunal communities in many parts of Puget Sound, Washington, and support an important commercial fishery (Goodwin and Pease 1989). Since 1971, divers have commercially fished geoducks in Washington by individually extracting them from the substrate with high-pressure water jets. Various crab species, including the large and commercially important Dungeness crab (*Cancer magister*) are common on many geoduck beds north of Vashon Island in Puget Sound (unpublished Washington Department of Fish and Wildlife [WDFW] dive survey data). Recreational crab pot fishing also occurs on some of these geoduck beds, and some crab fishers have complained that their crab fishing success declines drastically following commercial geoduck harvest.

The objective of this study was to determine if there was a significant effect of commercial geoduck fishing on Dungeness crab fishing catch-per-unit-effort (CPUE). We sampled crabs using baited pots at one site before, during, and after commercial geoduck fishing. Concurrently, we sampled crabs at a nearby unfished site. Both sites were sampled 20 times over a period of 4.6 years. Specifically, we wanted to determine if significant changes in crab CPUE occurred following geoduck fishing in the treatment site, and if any such changes could be attributed to geoduck fishing.

Methods

Experimental Design

Two sites, a treatment site and a control site, were experimentally fished with crab pots in order to determine if geoduck fishing had an effect on Dungeness crab fishing success. The observed random variable was crab CPUE, the number of crabs caught per pot. The treatment site was sampled both before and after commercial geoduck fishing in order to test the primary null hypothesis: H_0: $\mu_{before} = \mu_{after}$, where μ_{before} = mean CPUE of all pre-fishing samples, and μ_{after} = mean CPUE of all post-fishing samples.

Crab CPUE at the treatment site could be affected both by fishing effects (the direct or indirect consequences of geoduck fishing) and non-fishing effects (environmental, seasonal, or crab behavioral effects not related to geoduck fishing). Non-fishing effects at the treatment site might mask the effects of geoduck fishing, causing acceptance of H_0 and a Type II error. Conversely, non-fishing effects at the treatment site might be mistaken for fishing effects, causing rejection of H_0 and a Type I error. Thus, an unfished control site was sampled concurrently with the treatment site in order to account for non-fishing effects affecting crab CPUE.

This comparison between control and treatment sites assumed that crab CPUE at both sites was equally affected by non-fishing effects. This assumption and other hypotheses had to be tested prior to a test of H_0 at the treatment site, as outlined in the sequence below:

Step 1. Test the assumption that crab CPUE at the control site and treatment site are equally affected by non-fishing effects.

This assumption was tested with a test on the correlation coefficient ρ (Sokal and Rohlf 1981). Specifically, we tested the hypothesis that $\rho > 0$, with the variables x_i = estimated CPUE at the control site for the i = 1-10 pre-fishing samples, and y_i = estimated CPUE at the treatment site for the i = 1-10 pre-fishing samples. If $\rho \leq 0$, then correlation was either nonexistent or negative, implying that the control site was not a reliable analog of the treatment site in terms of non-fishing effects. Without being able to "tease out" non-fishing effects at the treatment site, we would be unable to determine if fishing effects had occurred, and the experiment would be terminated. If, on the other hand, $\rho > 0$, we could conclude that the two sites were positively correlated, and that therefore the control site was a reliable estimator of non-fishing effects at the treatment site. However, $\rho > 0$ does not necessarily imply strong correlation. Therefore we established an arbitrary guideline for “strong" correlation and tested the hypothesis that $\rho \geq 0.70$. If we failed to reject this hypothesis, we continued to Step 2.

Step 2. Test whether non-fishing effects differed during the pre-fishing and post-fishing periods.

Following acceptance of the assumption that the control and treatment sites are equally affected by non-fishing effects (Step 1), the control site provides a basis for this test, since no fishing occurred there during either period. We can test the hypothesis H_0: $\mu_{pre\text{-}fishing} = \mu_{post\text{-}fishing}$, where μ is mean crab CPUE at the control site. If H_0 is not rejected, no significant changes occurred, and we proceed to Step 3. If, on the other hand, H_0 is rejected, then a significant change due to non-fishing effects occurred at the control site between the two time periods which must be taken into account at the treatment site, and we proceed to Step 4.

Step 3. Failing to reject H_0 in Step 2, we would conclude that there are no changes in non-fishing effects between the pre- and post-fishing time periods. In this step we can then proceed to directly test whether CPUE changed in the treatment area following geoduck fishing, and significance will imply an effect due to geoduck fishing rather than environmental, seasonal, or behavioral effects. We test the primary hypothesis, H_0: $\mu_{pre\text{-}fishing} = \mu_{post\text{-}fishing}$, where μ is the mean crab CPUE at the treatment site. Rejection of H_0 would imply an effect due to geoduck fishing.

Step 4. Rejecting H_0 in Step 2, we would conclude that there are significant changes in non-fishing effects between the pre- and post-fishing time periods which must be accounted for in hypothesis tests of the treatment site. As in Step 3, we again test the primary hypothesis, H_0: $\mu_{pre\text{-}fishing} = \mu_{post\text{-}fishing}$, where μ is the mean crab CPUE at the treatment site, but we now require a modification of the means test in order to "tease out" the significant changes due to non-fishing effects.

We first followed the above testing sequence using the estimated CPUE of all Dungeness crabs. Then we performed the sequence again, using only the estimated CPUE of Dungeness crabs which may be legally taken by sport and commercial crabbers (i.e., male Dungeness crabs with a carapace width > 151 mm). (Note: The legal size of Dungeness crabs in Hood Canal was increased to >158 mm in 2002).

Site Description

Two sites along the western shore of northern Hood Canal were chosen for the experiment (Figure 1). Thorndyke Bay, located at 47º 48' 22" N 122º 44' 15" W, was chosen as the treatment site because a commercial geoduck harvest was scheduled to start there in August 1992. Commercial divers landed 1.8 million pounds of geoducks from the treatment site during the period of this experiment. South Point, located at 47º 49' 27" N 122º 41' 57" W, was chosen as the unfished control site because of its proximity to Thorndyke Bay, which lies about 1.8 km to the south. South Point was surveyed by WDFW divers in 1986, but has never been fished commercially for geoducks.

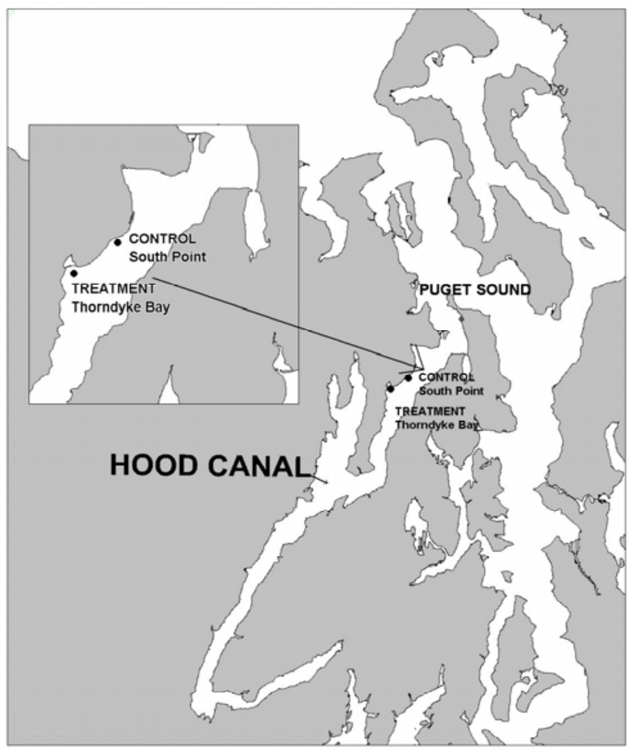

Figure 1. Thorndyke Bay (treatment) and South Point (control) sampling sites in Hood Canal, Washington, United States.

WDFW geoduck dive surveys in 1986 and 1990 indicated that Dungeness crab occurred at both sites. During these surveys, divers at the treatment site (Thorndyke Bay) sighted Dungeness crabs on 12% of all transects. At the control site (South Point), divers sighted Dungeness crabs on 17% of the transects. Neither site was fished commercially for crabs during the course of this experiment. Both sites are open for recreational crab fishing, and recreational crab pots were observed at both sites during portions of the study. Substrate at both sites is comparable, a mix of roughly equal parts sand and mud, and is typical of commercial geoduck beds.

Each of the two sites was divided into a northern half and a southern half to facilitate the use of 30 crab pots over a two-day sampling period as described below. Distance between the northern and southern portions of each site was approximately 30 m. Total area of the control site (northern and southern halves combined) was roughly 16,700 m^2. Total area of the treatment site (northern and southern halves combined) was roughly 33,400 m^2. The difference between the areas of the two sites was due to differences in bottom contours; the length of each site (i.e., the distance along the shoreline) was identical, but because crab pots were placed along depth contours (see below), the more gently sloping bottom contour at the treatment site increased its width (i.e., distance from the shoreline) relative to the control site.

Crab Sampling Methods

Both the control and treatment sites were sampled for crab CPUE over a period of 4.6 years, from December 1990 through July 1995. During this period, each of the two sites was sampled on 20 occasions, and both of the two sites were sampled on the same days. Sampling dates are shown in Table 1.

The first ten samples at both sites were taken prior to any geoduck fishing. Commercial geoduck fishing began at the treatment site in August 1992. No geoduck fishing occurred at the control site, either before or during this experiment.

At the treatment site, the commercial geoduck fishery took place during two distinct seasons, from August 1992 through December 1992, and from June 1993 through December 1994. During the five-month period from January 1993 through May 1993, geoduck fishing was closed in the treatment site. For purposes of this analysis, we considered all samples taken after the commercial geoduck fishing began in August 1992 to be “post-fishing” samples. Thus, “post-fishing” samples included three samples taken during the first fishing season, two during the five-month hiatus between fishing seasons, and two during the second fishing season. Thus, there were ten pre-fishing samples spanning 1.6 years, and ten post-fishing samples spanning 3.0 years. Note that we use the term "post-fishing samples" for simplicity's sake when referring to both the treatment and control sites, although no fishing took place in the control site.

Each sample consisted of three consecutive days during which crab pots were set and retrieved. On the first day, 15 commercial crab pots were set in the northern half of each site and allowed to soak overnight for an average of 22 hrs. At each site, five of the 15 pots were set at 6.1 m MLLW, five were set at 12.2 m MLLW, and five were set at 16.8 m MLLW. This depth range was chosen because the commercial geoduck fishery takes place between 5.5 m MLLW and 21.4 m MLLW. Along each of these depth contours, the five pots were positioned roughly 30 m apart. Each pot was baited with about 0.7 kg of frozen geoduck meat. On the second day of each sample, the pots were pulled at each site and the crabs caught were sampled and released. Pots were then re-baited and reset in the southern half of each site, along the same depth contours and with the same approximate spacing. Following a second overnight soak that averaged 22 hours, the pots were again recovered, and the crabs sampled and released. Bait removed from pots following fishing was always kept aboard and discarded well away from the test sites.

During some of the sampling, stormy weather or equipment problems prevented timely collection of some crab pots. This resulted in some pots soaking for a longer time than others. In such cases, we eliminated these pots from data analysis.

To avoid conflicts with the commercial geoduck fishing fleet, all samples taken during the two fishing seasons were made during the weekends, when the fishery was closed.

The crab species, sex, carapace width, and shell condition (new molt, soft shell, hard shell, old shell) were noted for each crab caught. In addition, the presence or absence of external embryos was recorded for all female crabs. Individual crab weights were taken during eight of the samples.

Results

Table 1 and Figures 2 and 3 show how the estimates of Dungeness crab CPUE varied at the control and treatment sites during the 4.6 years of the experiment. Estimated CPUE for total Dungeness crab was higher at the control site than at the treatment site throughout the pre-fishing period (unpaired t-test of equality of means assuming equal variance, $t = 3.86$, $\alpha = 0.05$, $df = 18$, $P = 0.0012$, two-tailed test; F-test of equality of variances, $F = 3.179$, $\alpha = 0.05$, $df = 9,9$). Estimated CPUE for total Dungeness crab was not significantly higher at the control site than at the treatment site throughout the post-fishing period, however (unpaired t-test of equality of means assuming equal variance, $t = 1.81$, $\alpha = 0.05$, $df = 18$, $P = 0.0867$, two-tailed test; F-test of equality of variances, $F = 1.807$, $\alpha = 0.05$, $df = 9,9$).

Mean estimated CPUE at the treatment site prior to geoduck fishing was 1.70 Dungeness crabs/pot, and was 2.96 crabs/pot during the post-fishing period. At the control site, mean estimated CPUE prior to fishing was 4.79 crabs/pot, and post-fishing estimated CPUE was 4.85 crabs/pot. When only legal crabs (males > 151mm carapace width) were considered, mean pre-fishing and post-fishing estimated CPUEs at the treatment site were 1.24 and 2.31 crabs/pot, respectively. At the control site, mean pre-fishing and post-fishing estimated CPUEs for legal crabs were 3.20 and 3.53 crabs/pot, respectively.

The first assumption to be tested in Step 1 of the experimental design was that the control and treatment sites were equally affected by seasonal and environmental variables. This assumption was examined with a test on the correlation coefficient ρ (Sokal and Rohlf 1981). Specifically, we tested the null hypothesis H_0: $\rho = 0$, where x_i = estimated Dungeness crab CPUE at the control site for the i = 1-10 pre-fishing samples, and y_i = estimated Dungeness crab CPUE at the treatment site for the i = 1-10 pre-fishing samples. The null hypothesis of no correlation was rejected ($r = 0.8339$, $\alpha = 0.05$, $df = 8$, $P = 0.0010$). A non-parametric correlation test also demonstrated a statistically significant correlation between control and treatment sites during the pre-fishing period (Spearman rank test, $r_s = 0.806$, $\alpha = 0.05$, $n = 8$, $P = 0.0032$). We performed the same two tests on CPUE data for legal Dungeness crabs and got similar results ($r = 0.8738$, $\alpha = 0.05$, $df = 8$, $P = 0.0003$; $r_s = 0.818$, $\alpha = 0.05$, $n = 8$, $P = 0.0023$). We used Fisher's transformation (Zar 1984) to set confidence limits on the estimate of for total Dungeness crab at the control and treatment sites. The asymmetric 95% confidence bounds on the estimate r (= 0.8339) were $0.4301 < r < 0.9595$. Based on the rejection of H_0 in these correlation tests and a lower confidence bound on ρ that is not unreasonably low, we were willing to accept the first assumption of equal non-fishing effects in the control and treatment sites.

Table 1. Results of Dungeness crab sampling at the control and treatment sites in Hood Canal. "Pre-fishing" refers to sample numbers 1-10; "post-fishing" refers to sample numbers 11-20. Legal crab refers to males > 151 mm carapace width. Note: The legal size of Dungeness crabs in Hood Canal was increased to >158 mm in 2002.

			Control					Treatment				
Sample	Date	Time (days)	Catch	Effort		CPUE (Number Crab/Pot)		Catch	Effort		CPUE (Number Crab/Pot)	
			Total Crab	Legal Crab	Number of Pots	Total Crab	Legal Crab	Total Crab	Legal Crab	Number of Pots	Total Crab	Legal Crab
1	12/12/90	0	44	26	24	1.83	1.08	17	8	24	0.71	0.33
2	03/15/91	93	148	121	24	6.17	5.04	62	49	24	2.58	2.04
3	04/19/91	128	153	116	24	6.38	4.83	69	57	24	2.88	2.38
4	07/03/91	203	257	185	30	8.57	6.17	113	74	30	3.77	2.47
5	08/22/91	253	74	20	30	2.47	0.67	22	12	30	0.73	0.40
6	10/17/91	309	188	93	30	6.27	3.10	36	18	30	1.20	0.60
7	12/13/91	366	106	64	30	3.53	2.13	20	17	30	0.67	0.57
8	02/28/92	443	157	113	30	5.23	3.77	92	75	30	3.07	2.50
9	06/11/92	547	160	117	30	5.33	3.90	33	29	30	1.10	0.97
10	07/30/92	596	58	34	27	2.15	1.26	9	3	30	0.30	0.10
11	09/27/92	655	63	40	15	4.20	2.67	9	4	15	0.60	0.27
12	11/15/92	704	148	108	30	4.93	3.60	31	21	29	1.07	0.72
13	12/13/92	732	114	90	30	3.80	3.00	46	38	30	1.53	1.27
14	02/25/93	806	202	140	30	6.73	4.67	138	121	30	4.60	4.03
15	05/07/93	877	176	111	30	5.87	3.70	77	68	30	2.57	2.27
16	06/26/93	927	263	195	30	8.77	6.50	51	43	30	1.70	1.43
17	06/19/94	1285	162	130	30	5.40	4.33	281	191	30	9.37	6.37
18	02/28/95	1539	124	98	30	4.13	3.27	143	120	30	4.77	4.00
19	05/03/95	1603	65	51	30	2.17	1.70	45	37	30	1.50	1.23
20	07/12/95	1673	75	56	30	2.50	1.87	56	46	30	1.87	1.53
Mean (Pre-Fishing)			**134.50**	**88.90**		**4.79**	**3.20**	**47.30**	**34.20**		**1.70**	**1.24**
Mean (Post-Fishing)			**139.20**	**101.90**		**4.85**	**3.53**	**87.70**	**68.90**		**2.96**	**2.31**

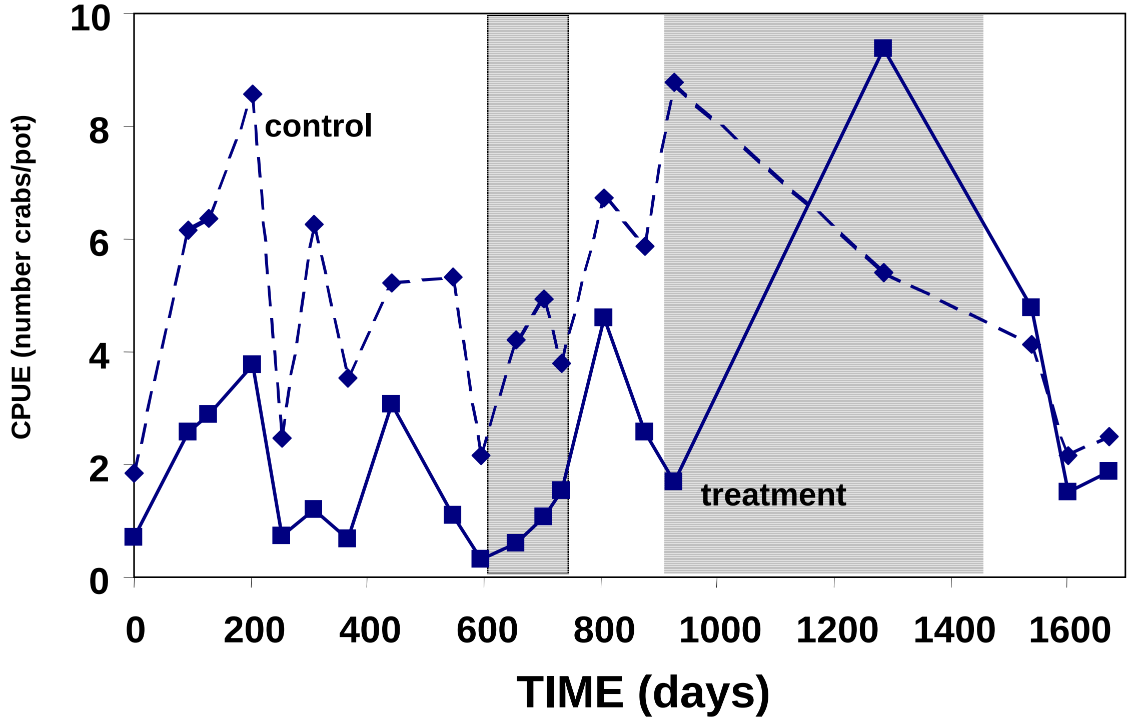

Figure 2. CPUE (crabs/pot) of all Dungeness crabs at the control and treatment sites. Shaded areas indicate the two periods of commercial geoduck fishing.

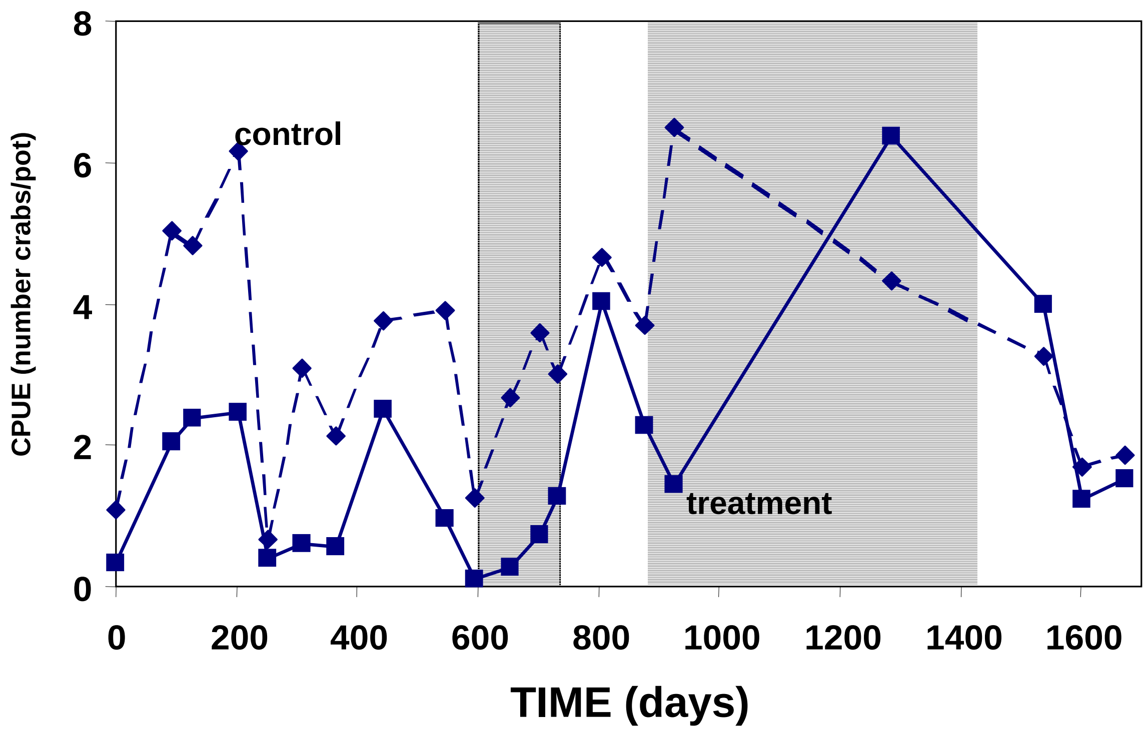

Figure 3. CPUE (crabs/pot) of all legal Dungeness crabs (>151 mm carapace width) at the control and treatment sites. Shaded areas indicate the two periods of commercial geoduck fishing. Note: The legal size of Dungeness crabs in Hood Canal was increased to >158 mm in 2002.

Next, we proceeded to Step 2 and tested whether crab CPUE differed in the control site before and after geoduck fishing in the treatment site. Specifically, we tested the null hypothesis H_0: $\mu_{pre\text{-}fishing} = \mu_{post\text{-}fishing}$, where $\mu_{pre\text{-}fishing}$ is the mean crab CPUE (number of total Dungeness crab/pot) during the pre-fishing period at the control site, and $\mu_{post\text{-}fishing}$ is the mean CPUE during the post-fishing period at the control site. Variances about the two estimated mean CPUEs were not significantly different (*F*-test, $F = 1.258$, $\alpha = 0.05$, df = 9,9), so an unpaired t-test assuming equal variance was used to test the equality of the two means. There was no statistically significant difference between pre- and post-fishing periods (unpaired t-test with equal variance, t = -0.06, $\alpha = 0.05$, df = 18, P = 0.95, two-tailed test). We performed the same test with CPUE data for legal Dungeness crabs and got a similar result (*F*-test, $F = 1.749$, $\alpha = 0.05$, df = 9,9; unpaired t-test with equal variance, t = -0.45, $\alpha = 0.05$, df = 18, P = 0.66, two-tailed test). These results suggest that there were no non-fishing effects occurring in the control area which would have to be “teased out” of the treatment area in the post-fishing period. In other words, we could assume that statistically significant changes following fishing in the treatment area, if any, could be attributed to geoduck fishing and not environmental “noise.”

Thus, we proceeded to Step 3 and tested the primary hypothesis, whether crab CPUE in the treatment site differed following geoduck fishing. Specifically, we tested the null hypothesis H_0: $\mu_{pre\text{-}fishing} = \mu_{post\text{-}fishing}$, where $\mu_{pre\text{-}fishing}$ is the mean crab CPUE (total Dungeness crab/pot) during the pre-fishing period at the treatment site, and $\mu_{post\text{-}fishing}$ is the mean CPUE during the post-fishing period at the treatment site. Variances about the two mean CPUEs were significantly different (*F*-test, $F = 4.560$, $\alpha = 0.05$, df = 9,9), so an unpaired t-test assuming unequal variance was used to test the equality of the two means. There was no statistically significant difference in crab CPUE between pre- and post-fishing periods at the treatment site (unpaired t-test with unequal variance, t = -1.36, $\alpha = 0.05$, approximate df = 12, P = 0.20, two-tailed test). The same tests were performed using CPUE data for legal Dungeness crab with similar results (*F*-test, $F = 3.709$, $\alpha = 0.05$, df = 9,9; unpaired t-test with equal variance, t = -1.59, $\alpha = 0.05$, df = 18, P = 0.13, two-tailed test).

By failing to reject H_0 in Step 3, we concluded that there were no significant effects on crab CPUE which could be attributed to geoduck fishing at the treatment site in Thorndyke Bay.
We estimated the statistical power ($1-\beta$) of the experiment using CPUE data for total Dungeness crabs at both the control and treatment sites. First, we estimated the power of the two-sample t-test at the control site to detect a change in mean CPUE of ± 50%. We assumed sample sizes $n_1 = n_2 = 10$ as in our experiment, and $\alpha = 0.05$ (two-tailed), and used the power test outlined in Zar (1984). Since mean CPUE at the control site throughout the experiment was 4.82 crabs/pot, we were therefore estimating the probability of detecting a true difference of ± 2.41 crabs/pot

from this mean level. A value of $\varphi = 1.82$ and $v = (n_1 + n_2) - 2 = 18$ was associated with a power $(1-\beta)$ of about 0.65. Thus, our experiment had only a 65% chance of detecting a 50% change (either an increase or a decrease) in total Dungeness crab CPUE at the control site.

Similarly, we estimated the minimum difference in mean CPUEs at the control site which we would detect with a power of 0.90, given the sample sizes above and $\alpha = 0.05$. The minimum difference which we would have a 90% chance of detecting was 3.22 crabs/pot. Since the mean CPUE at the control site during the entire experiment was 4.82 crabs/pot, CPUE would have to increase or decrease at least 67% before we would have a 90% chance of detecting it with our experimental methods.

We also estimated power of the two-sample t-test at the treatment site. The power of the test to detect a change in mean CPUE of ±50% was almost zero at the $\alpha = 0.05$ significance level. The minimum difference in mean CPUE that would be detected with a power of 0.90 was 3.00 crabs/pot. Mean CPUE at the treatment site prior to geoduck fishing was 1.70 crabs/pot, so the minimum detectable difference amounts to 176% of the average CPUE.

The same power tests were performed using CPUE data for legal Dungeness crab with similar results. The power $(1-\beta)$ of the two-sample t-test to detect changes in mean CPUE for legal Dungeness crabs of ±50% at the control site was 0.55. The minimum difference in mean CPUEs at the control site which we would have a 90% chance of detecting was 2.54 legal crabs. Since the mean CPUE at the control site during the entire experiment was 3.36 legal crabs/pot, CPUE would have to increase or decrease at least 76% before we would have a 90% chance of detecting it with our methods. At the treatment site, power of the test to detect changes of ±50% in legal Dungeness CPUE was almost zero, and the minimum detectable difference with a power of 0.90 was 189% of the average pre-fishing CPUE.

Discussion

This study tested the effects of geoduck fishing on crab CPUE (i.e., the number of crab per pot), not on the absolute abundance or density of crabs. Although crab CPUE may be a valid estimator of crab abundance or density, we did not make this assumption nor test it. Confining our results to crab CPUE in this way is appropriate, because the impetus for this experiment was the frequent complaint of recreational crabbers that their catch rate (i.e., the number of crabs per pot) declines following commercial geoduck fishing. Estimating CPUE with crab pots as we did is perhaps more relevant to the question posed by recreational crabbers than attempting to directly estimate crab abundance or density. Indeed, we can construct plausible scenarios whereby crab CPUE could be altered by geoduck fishing due to crab feeding behavior changes, even as abundance or absolute density of crabs in the area remains stable. Our results, however, suggest that there is no statistically significant change in CPUE following geoduck fishing.

Implicit in our experimental design were several assumptions which could not be statistically tested. The first of these assumptions was that crabs caught during each sample represented a random sample of the crab population, and were independent of previous samples. The average time between two samples was 88 days, and the minimum time between samples was 28 days. Crabs are highly mobile, moving in search of food and migrating due to reproductive and molting cues. Cleaver (1949) reported that tagged crabs released at Grays Harbor, Washington, traveled an average of 14 km in three months, which was the average time between samples in this study. The combination of crab motility and a lengthy period between samples tends to support our assumption that crabs randomly mixed in the population between sampling occasions.

A second related assumption is that handling mortality of crabs was negligible during the experiment, or else equal at both sites. Dungeness crabs, except when soft-shelled immediately following a molt, are not easily harmed by normal handling. In any case, since handling procedures were identical at both sites, it is likely that any mortality would have affected the results equally at both sites.

A third assumption is that crab catch during the first day of a sample (i.e., when the northern half of each site was sampled) did not affect crab CPUE during the second day, when the southern half was sampled. We do not know how far crabs move in order to feed, but it is likely that at least some crabs moved from one half of the plot to the other half during the two days of each sample period. We also do not know if crabs become "trap-shy" or, conversely, if they become dependent on pots for food. Such behavior would be of concern if we were attempting to estimate absolute abundance or density of crabs, but is of lesser concern in this experiment, which estimates CPUE. It is likely that such behavior, if it affected the experimental results at all, would have affected both sites equally.

The results of this test revealed a high level of natural variability in crab CPUE. Possible reasons include the migratory nature of crabs, which move onshore and offshore in response to molting and reproductive cues. Other possible factors include cyclic abundance patterns and behavioral changes related to food availability. Commercial catch rates of Dungeness crabs in Washington, Oregon, and California have historically been highly unstable, and have been correlated with a number of abiotic and biotic factors (Methot 1989). In addition, crab CPUE in our experiment could have been affected by recreational crabbing which occurred at both sites. During WDFW sport crab surveys, crab pots were observed at the treatment site in August and October 1991, and at the control site in October and November 1993, as well as in February and March 1994. This recreational crabbing may have been partly responsible for the apparent decline in estimated CPUE at the control site between samples 16 and 17, a period during which estimated CPUE at the treatment site increased.

This high natural variability in crab CPUE reduced the statistical power of the experiment. Although we detected no significant change in crab CPUE following geoduck fishing at the treatment site, power analysis revealed that CPUE would have to increase or decrease roughly 176% before we would have a 90% chance of detecting the change. Likewise, we failed to reject our first assumption (i.e., that the control and treatment sites were equally affected by non-fishing effects), but the low power of the test means that we would have detected only very large differences between the site-specific crab CPUE.

We sampled the site 20 times during 4.6 years with 30 crab pots on each occasion, so from a practical sampling standpoint, this low level of statistical power is probably unavoidable. We can expect that such natural variability in crab CPUE would also affect recreational crabbers, and probably to a much greater degree since they are limited in the number of "samples" they can take. Therefore, anecdotal reports which allege that commercial geoduck fishing drastically reduces crab catches cannot be given much credence.

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