Mouth of the Columbia River: Beneficial Sediment Deposition Project

Benthic Impact Study 2014

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Executive Summary

A primary goal of the *Regional Sediment Management Plan for the Mouth of the Columbia River* is to increase beneficial uses of sediment dredged from the navigation channel. One such use is to mitigate for eroding outer coast beaches through deposition of coarse sand onto select nearshore zones. Concerns over impacts to benthic fauna, and especially Dungeness crab, have led to dispersive deposition strategies and a research and monitoring program to assess impacts to the benthos.

The research program we developed employs several linked techniques to understand and monitor the effects of sediment disposal on the benthic community. These techniques include

1) Epibenthic faunal surveys using a benthic video sled
2) Video monitoring of deposition events
3) Acoustic telemetry to investigate acute and chronic effects of deposition on Dungeness crabs

In 2014, we built, tested, and deployed a benthic video sled; developed a video lander (CamPod) system to observe deposition effects on organisms; and deployed acoustic telemetry arrays to track individually tagged Dungeness crabs over time.

We also monitored environmental data pertinent to dredge disposal operations and to aid data analysis. We spent 16 days at sea across the three deposition areas and conducted 9 sled surveys, 5 CamPod deployments, and 3 tagging experiments. We monitored 60 tagged crabs and collected over 1 terabyte of video data. Experiments were conducted using a before-after/impact-control (BACI) statistical design and a theoretical framework developed to interpret results.

Our system of video sled, CamPod, and acoustic sampling equipment and techniques has been vetted, and each element appeared to function as designed. However, continued refinement of these systems will be needed for optimal performance.

During 2014, experiments were concentrated at the South Jetty site, with additional measurements made at the Deep and Shallow Water sites. At the South Jetty site, sediment deposition events primarily occurred immediately after the area was available in early September. Disposal frequency was relatively low in the middle of the deposition program and tapered to a single event in the last week of September. In contrast, there was a more consistent and heavy deposition pattern at the Deep Water Site from late August to mid-October.

Adverse weather and low water visibility were the biggest obstacles to data collection. Storm systems limited deployment opportunities for both the benthic sled and CamPod. We encountered an anomalously high phytoplankton bloom during early September that resulted in low visibility in the bottom layers at nearshore locations.

To improve data acquisition in 2015, we plan to deploy an instrument buoy at the South Jetty site that will provide real-time telemetry of near-bottom turbidity conditions. The buoy will afford flexibility for surveys by avoiding periods of low visibility.

Data from the 2014 experiments are reported here, but our conclusions are preliminary pending further study. This report provides a progress update and initial analysis for the 2014 *Benthic Impact Study* along with recommendations for adaptive management of the 2015 science program.

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Introduction

The *Benthic Impact Study* was designed to provide needed scientific information for adaptive management of sediment disposal practices for the Columbia River mouth under the *Regional Sediment Management Plan*. The plan is detailed in a report by the Lower Columbia Solutions Group (Greenwood et al. 2011) and in an environmental assessment of proposed nearshore disposal sites (USACE 2012). A main goal of the plan is to

> …increase the beneficial use of dredged sediment at the MCR [Mouth of the Columbia River] to help protect shipping channel jetties, coastal beaches and nearshore habitats from erosion while avoiding and minimizing adverse environmental, resource and navigational safety effects (Greenwood et al. 2011).

This process requires research and monitoring to "ensure that disposal practices will not result in unacceptable adverse effects on the nearshore ocean ecosystem" (Greenwood et al. 2011). Of specific concern are populations of Dungeness crab *Cancer magister*, deemed among the most susceptible of local fisheries to deposition events.

The research program we developed employs several linked techniques to understand and monitor the effects of sediment disposal on the benthic community at the Mouth of the Columbia River. These techniques include:

1. Epibenthic faunal surveys using a benthic video sled
2. Video monitoring of deposition event
3. Acoustic telemetry to investigate acute and chronic effects of deposition on Dungeness crabs

These monitoring surveys and experiments will aid in evaluating the effects of dredge material deposits on benthic habitats and will provide information to guide the position, timing, and magnitude of deposition activities. The intent of this report is to collate results to date for the 2014 sampling effort. Formal analysis is contingent on data acquisition during the 2015 field season.

The overall goal of this project is to assess the response of benthic macrofaunal populations to channel sediment deposition in the nearshore zone (RSMP 2011, USACE 2012). Study objectives were twofold:

1. Survey benthic environments for macrofaunal distribution and density utilizing a benthic video sled in a modified before-after/control-impact (BACI) statistical design.
2. Assess acute and chronic impacts of dredge spoil deposits on Dungeness crab and other macrofauna with video monitoring and acoustic telemetry techniques.

Study Sites and Experimental Design

Three sites have been identified for study: 1) South Jetty nearshore site; 2) Deep Water site; and 3) North Head nearshore site. Additional sediment deposition sites include the Shallow Water and North Jetty sites. Detailed descriptions of these sites, including the location and depth of each, were reported by the U.S. Army Corps of Engineers (USACE 2012), along with a summary of previous studies on sediment grain size, faunal composition, and other characteristics (USACE 2007). During 2014, experiments were concentrated at the South Jetty site, with additional measurements made at the Deep and Shallow Water sites. All 2014 monitoring was conducted aboard the R/V *Forerunner* chartered from the Clatsop County Community College.

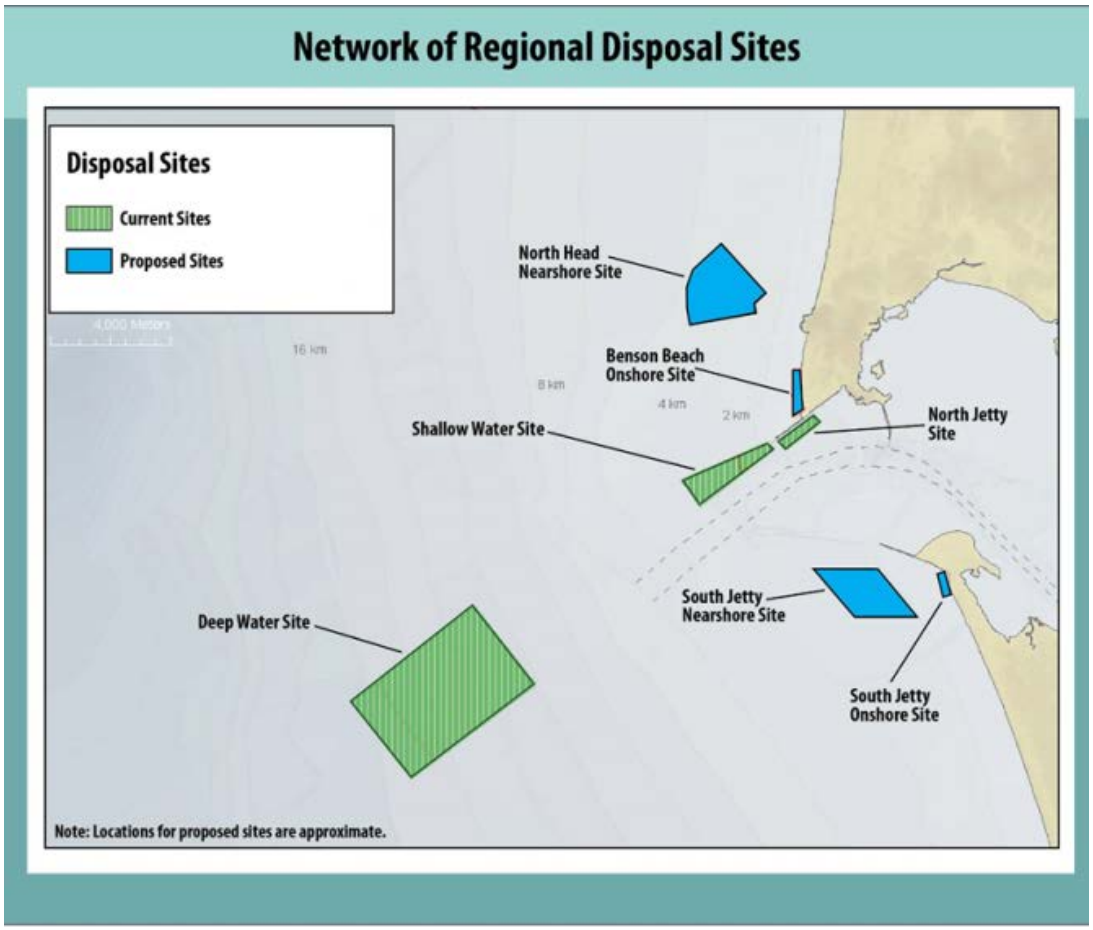


Figure 1. Locations of current and proposed dredged material disposal sites (USACE 2012).

The Benthic Impact Study was designed to assess both chronic (cumulative) and acute (immediate) effects of sediment deposition on benthic macrofauna. The overall experimental framework was a before-after/control-impact (BACI) design. This design calls for a comparison of two separate areas: a control site, where no sediment deposition occurs, and an impact site, where the effects of deposition events are monitored. The before-after component of the design refers to the time element (before and after impact).

However, for our evaluation, the "impact" was not a single event, but repeated deposits of sediment that may have a cumulative effect on the benthos. Therefore, we modified the design to include a "during" phase to measure sequential deposition events (Figure 2). Similarly, the "after" phase may capture recovery of the benthos to possible impact effects. Thus, the experimental design entailed sampling over the course of the deposition period, both before any deposition had occurred, during repeated deposits, and continuing after deposition had ceased.

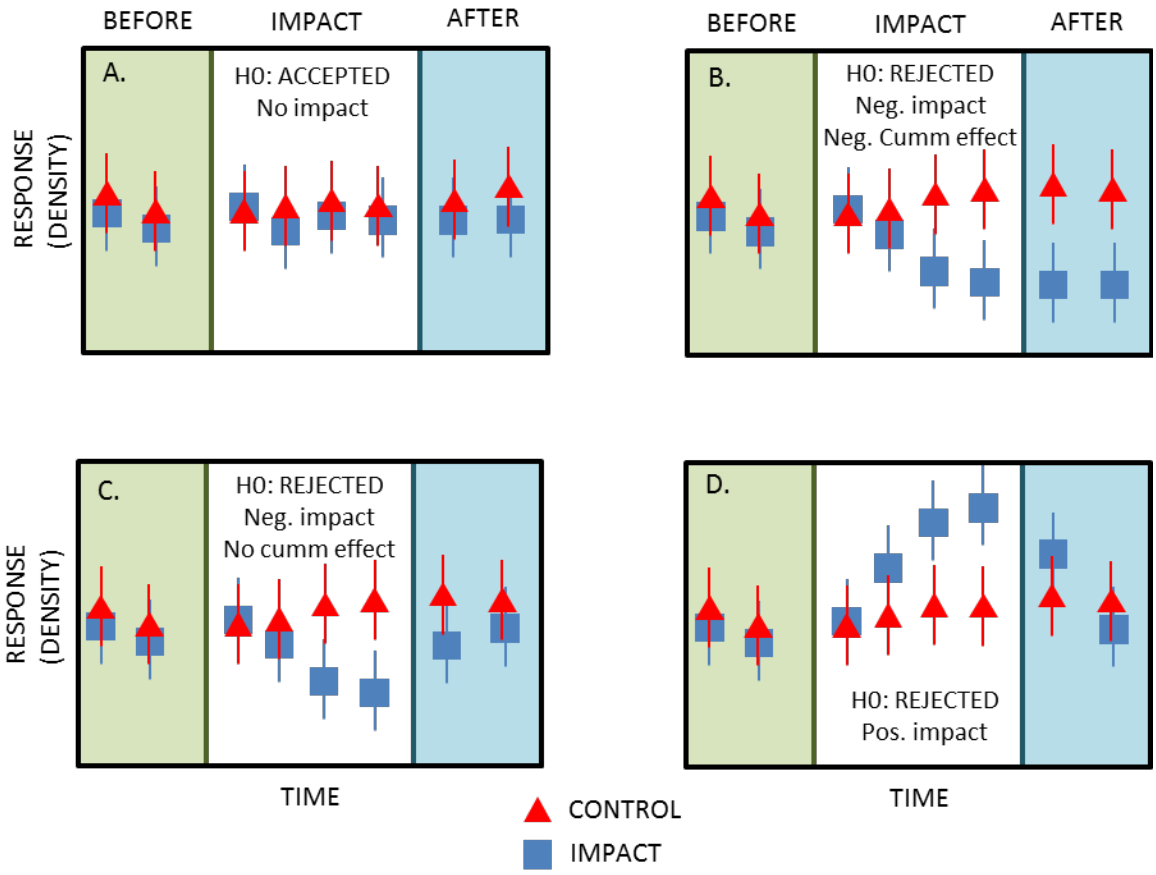


Figure 2. Hypothetical scenarios to evaluate responses of fauna to sediment deposition events.

During each sample date, surveys were made at both control and impact sites. Acute effects are of shorter duration (hours) and we used underwater video to investigate fauna distributions and abundances immediately before and after a deposition event. This experimental format is applicable to projected experiments at other benthic locales where a disturbance may occur.

We developed a conceptual framework of scenarios to evaluate the results from hypothesis testing (Figure 2). In scenario A., the response variable exhibits no significant difference between before, impact, or after time periods, leading to acceptance of the null hypothesis, that deposition does not affect the response variable. In scenario B, there is a decrease in the response variable during the impact phase that continues into the after phase. This result would lead to rejection of the null hypothesis and to a conclusion that significant and cumulative negative effect had occurred.

In scenario C, the response decreases during the impact phase but rebounds during recovery. In this scenario, the null hypothesis would also be rejected with the conclusion that deposition had a temporary effect on the benthos. It is also possible to observe the pattern in scenario D, where the response variable increases during the impact phase. This might occur, for example, if organisms were attracted to some stimulus in the deposited sediment such as entrained organic matter. Other patterns are also possible, for instance the control response variable may vary over time, due to seasonal trends in abundance.

The proposed schedule for dredge operations extended from 15 August to 30 September at the South Jetty site and from 15 August to 31 October at the Deep Water site. To meet specifications of our study design, we planned for 2 "before," 4 "during," and 2 "after" surveys to be conducted between 15 July and 1 November.

Sampling Times and Deposition Events

In 2014, we were unable to complete the full matrix of surveys due to a combination of inclement weather and environmental issues (as described below) and logistical delays. However at the South Jetty site, we did complete a limited BACI framework of surveys within a condensed, 4-week operational window from 1 to 30 September. At the Deep Water site, we monitored before and during the deposition perids. Overall, we spent 16 days at sea across the Deep Water, South Jetty, and Shallow Water deposition areas. During this time we conducted 9 sled surveys, 5 CamPod deployments, and 3 tagging experiments (Figure 3). Over 1 terabyte of video data was collected.

At the South Jetty site, sediment deposition events by *Essayons* were not consistent over time, with most occurring in the first week of dredge operations (Figure 27). As a consequence, the cumulative impacts experienced by benthic fauna also varied across the experimental period. We performed sled surveys at the South Jetty site during pre-impact; early, middle, and late impact periods; and after 1 month of recovery (Table 1).

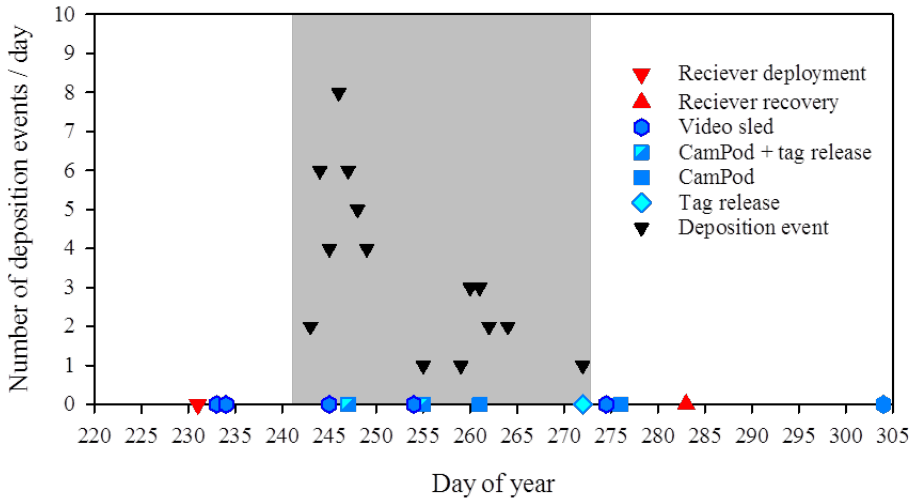


Figure 3. Deposition events and survey dates at the Shallow Water site.

For tagging experiments, the first release coincided with heavy deposition, the middle release with moderate deposition, and the final release with light deposition (Table 3). We deployed CamPods strings during the first two tag releases, during a deposition event within the moderate deposition period, and during early recovery (no deposition).

In addition to our main site at South Jetty, we completed two sled surveys at the Deep Water site, with one during the pre-impact period and the other during ongoing disposal activities (Figure 4). Inclement weather prevented the post-deposition sample. At the Shallow Water site we performed one sled survey and one CamPod deployment, but conditions were marginal during both these samples.

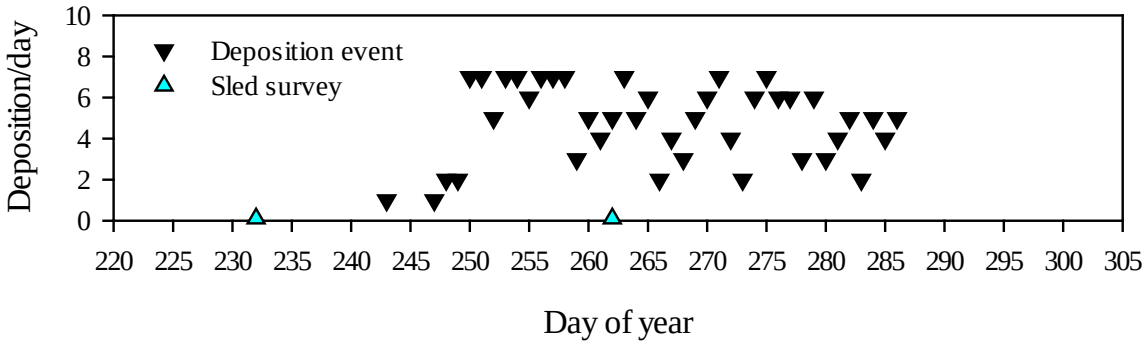


Figure 4. Deposition events and survey dates at the Deep Water site.

Environmental Data

Methods

To place biological observations in context, we collated environmental data from several sources during the study period:

1. Wind velocity, average wave height, and sea surface temperature data measured at the Columbia River Bar buoy (Station 46029). Wind vectors were converted to mean daily alongshore wind stress (N/m^2) from hourly observations. Positive (northward) wind stress induces downwelling, while negative (southward) wind stress drives upwelling conditions. These conditions in turn control phytoplankton production and incidents of low dissolved oxygen (DO).

2. Bottom temperature and light intensity were recorded with Onset Hobo data loggers attached to the base of one acoustic mooring in each array and set to record at 5-min intervals. These were deployed in addition to loggers deployed on CamPods during deposition events.

3. Vertical profiles of water quality constituents were made during cruises with a conductivity-temperature-depth (CTD) profiler equipped with a dissolved oxygen sensor (Sea Bird Electronics 19 plus and SBE 43) and fluorometer (WetLabs WS3S). Data were recorded at 2 Hz and binned into 0.5-m depth intervals, typically yielding 5 measurements per bin. We averaged data from the bottom 2 m to document conditions affecting benthic organisms (dissolved oxygen) and visibility of our optical sensors (chlorophyll).

Results and Discussion

Summer/autumn 2014 exhibited relatively low-intensity upwelling conditions and moderate wave heights from the end of August through the last week in September, when a strong downwelling period (storm) prevented operations (Figure 5, days 265-270). A weather window opened in early October, but conditions then deteriorated for the bulk of October with a second prolonged downwelling event.

Offshore surface temperatures were relatively warm, and we monitored a strong warming event in bottom water at the South Jetty site associated with downwelling winds, when temperatures increased 6°C over a 7-d period. These warm conditions are likely associated with the “warm blob” of anomalous temperatures occurring off the coast during 2014 (Milstein 2014).

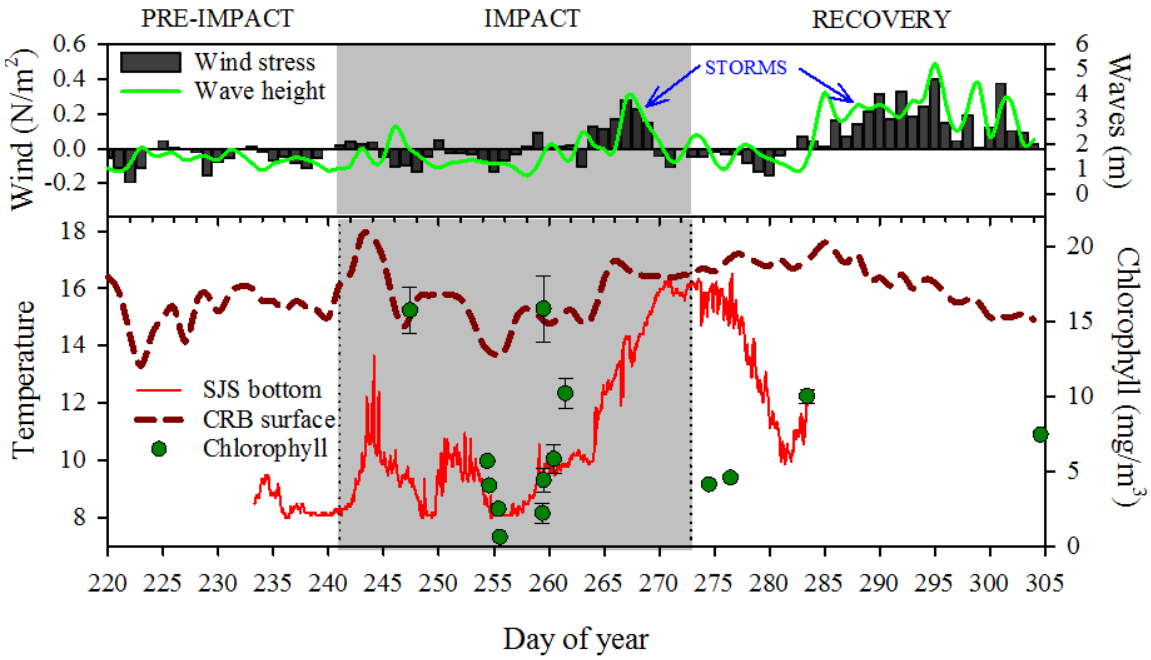


Figure 5. Environmental conditions and sediment deposition events at the South Jetty site during the 2014 field experiments. Gray bars indicate 2014 disposal season. Upper plot shows northward wind stress and mean wave height, which indicate periods of inclement weather. Lower plot shows sea surface temperatures at Buoy Station 46029, bottom temperature at the South Jetty site, and mean bottom chlorophyll from CTD casts (green circles).

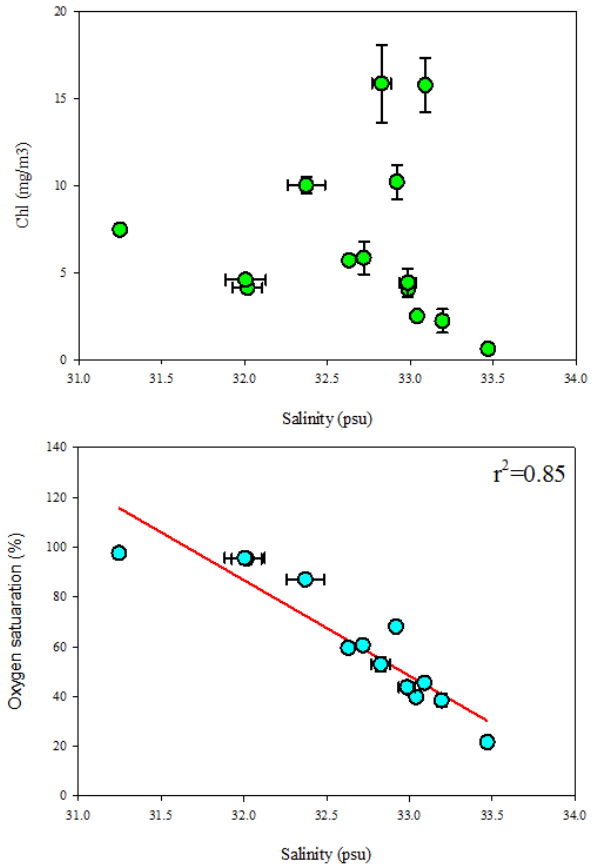


Figure 6. Water quality correlations at the South Jetty site. Upper panel shows chlorophyll × salinity; lower panel shows dissolved oxygen saturation × salinity.

Aside from waves and stormy periods, there were also several low-visibility events that limited data analysis during video sled and CamPod measurements (Tables 1 and 3). Reduced visibility was primarily due to high phytoplankton concentrations (up to 40 mg/m^3), although at the Shallow Water site it was apparently associated with dredged sediment deposition events. Mean bottom concentration of chlorophyll at the South Jetty site ranged from more than 1 to 17 mg/m^3, and visibility was reduced at concentrations exceeding about 10 mg/m^3. Chlorophyll concentration was unrelated to salinity (Figure 6). We also measured low dissolved oxygen (DO) events associated with upwelling wind stress. There was a strong negative correlation between DO and salinity. Minimum mean DO was below 20% saturation, which may have deleterious effects on benthic organisms including crabs (Roegner et al. 2010).

Objective 1: Epibenthic Faunal Surveys

Methods

Benthic Video Sleds

For benthic surveys, we used two video sleds that were similar in design and capability except for depth of operation. A sled operated by Oregon Department of Fish and Wildlife (ODFW) was used at the Deep Water site, where depths exceeded 70 m. This sled and its operation are described by ODFW (2015). In shallower water, we used a sled constructed specifically for this project (Figure 7). This sled had an instrument configuration consisting of a high-resolution data camera (Canon Vixia HF R20 camcorder)[1] enclosed in a waterproof housing, two intensity-adjustable floodlights, and a navigation camera with (Deepsea Power & Light Sealite Sphere and multi-SeaCam 2060).

Additionally, two laser pointers (Deepsea P & L SeaLaser 100) were situated to provide a 10-cm measurement scale on the video. Except for the data camera, which was internally powered, electrical and data transmission to the surface were enabled through an umbilical coaxial cable. Data transmitted from the navigation camera were also recorded to a DVD at the surface. The data camera was set to a fixed focus and oriented to image a ~2 m^2 area directly in front of the sled, with the laser points positioned near the center of the camera view field. The data camera recorded with progressive framing at 24 MB/s.

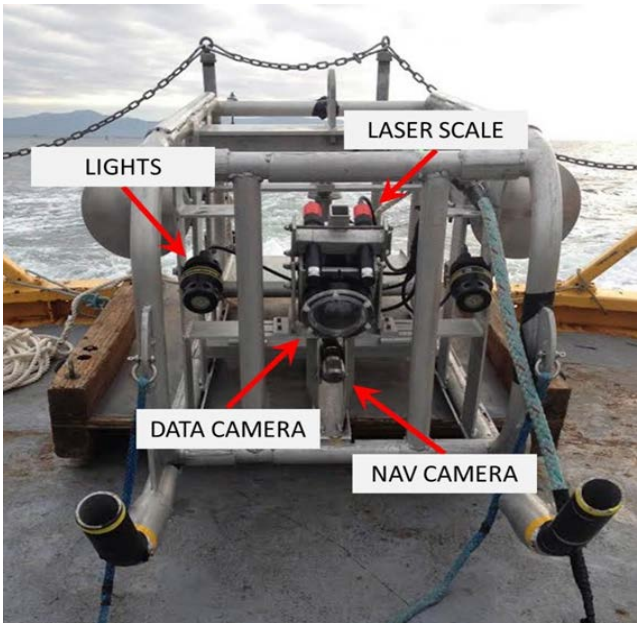


Figure 7. Components of the benthic video sled.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Video sled sample methodology followed Sheehan et al. (2010), as modified for benthic deployment and particulars of our sites. The sampling design entailed three replicate ~500-m transects at each control and impact site.

Target velocity of the sled over the bottom was 0.25 to 0.50 m/s (0.49 to 0.97 knot) to provide adequate image resolution. Transect orientation and vessel speed depended on ambient current velocities, which could be considerable (>1.5 m/s at both the South Jetty and Shallow Water sites. Each 500-m transect resulted in a surveyed area of 375 m^2 and required ~30 min for full deployment. Sled position was estimated from ship position and cable deployment length and was recorded continuously by shipboard instruments for each transect (data not yet available).

Analyses of Faunal Densities

Video analysis consisted of counts of organisms observed in each transect and identified to the lowest possible taxon. During processing, organisms were enumerated within a standardized window delineated as the area below the laser points and between the sled arms (Figure 8, yellow box). Counts were only made when the sled was appropriately positioned on the bottom (laser points visibly on the seafloor) and as visibility allowed (ODFW protocol, Keith Matteson, pers. comm.).

Counts were transformed to densities (D; individuals/100 m^2) by dividing counts by distance traveled (d) × sled width (w), and then standardizing to a 100-m^2 area, where D = (individuals × 100)/d × 0.75 m. For this initial analysis, the distance traveled (d) was determined by calculating the length of usable video footage (minutes) and multiplying by an assumed average tow speed of 1 knot (30.87 m/minute). Actual distances determined from ship GPS readings will be used when available.

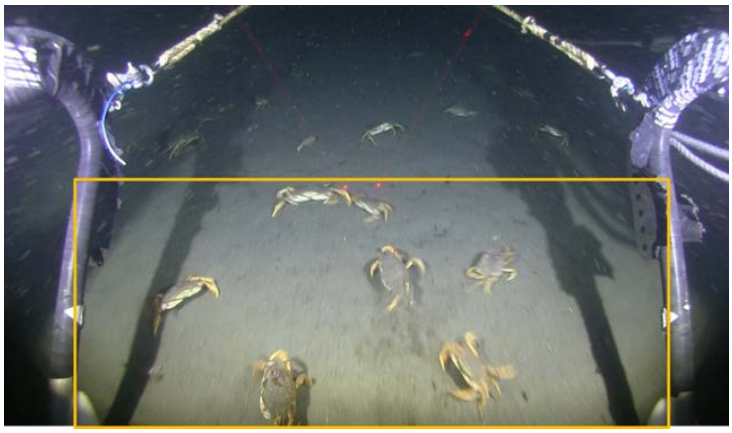


Figure 8. Video sled sample window (yellow box) used to standardize counts/interval. Image shows Dungeness crab at the Deep Water site.

For each sample day and treatment, mean density and variance were computed from replicate transects for statistical tests. Target taxa included Dungeness crab, demersal fishes, hermit crabs, gastropods, echinoderms, and cnidarians. In addition to organism density, aspects of the benthic topography, such as sediment bedforms, presence of organic debris, etc., were noted.

Results and Discussion

Despite logistical restrictions, we completed nine survey days across three disposal sites (Table 1). Water visibility turned out to be a major limitation to the video sled. Even when weather and sea state allowed for deployment of the sled, water clarity near the seafloor was variable. At the South Jetty site, there were four days of low visibility that did not allow for count data to be extracted. In contrast, visibility at the Deep Water site was clear during both days of surveys. As a result, two survey days from the South Jetty site and Deep Water site were processed for data extraction.

Table 1. Schedule and visibility of video sled surveys.

Location/Survey date	Period	Visibility
South Jetty		
21 Aug	Pre-impact	Low
22 Aug	Pre-impact	Low
2 Sep	Early impact	Low
11 Sep	Mid-impact	Clear
1 Oct	Late-impact	Clear
30 Oct	Recovery	Low
Deep Water		
20 Aug	Early impact	Clear
19 Sep	Mid-impact	Clear
Shallow Water		
16 Sep	Mid-impact	Variable

Overall Community Analysis

Initial multivariate analysis involved exploring the similarity between overall benthic communities across all surveys at the Deep Water and South Jetty sites. Benthic communities were evaluated based on number of taxa and density of both demersal fish

and epibenthic invertebrates. A cluster analysis based on the Bray-Curtis dissimilarity matrix was conducted on square-root transformed organism densities. The resulting cluster dendrogram revealed three groups with a 0.5 dissimilarity cut-off (Figure 9 colored boxes): 1) all South Jetty transects (including control and impact from both dates), 2) the three Deep Water impact transects from September, and 3) the remaining Deep Water transects.

Results indicated that from an overall community perspective South Jetty transects were more than 50% similar, with no distinction between control and impact communities. The same was true for the Deep Water site, except for the three transects from the impact location in September. These three transects appeared to be less than 50% similar, and the difference seems to have been driven by the high density of spoon worms that were unique to these surveys.

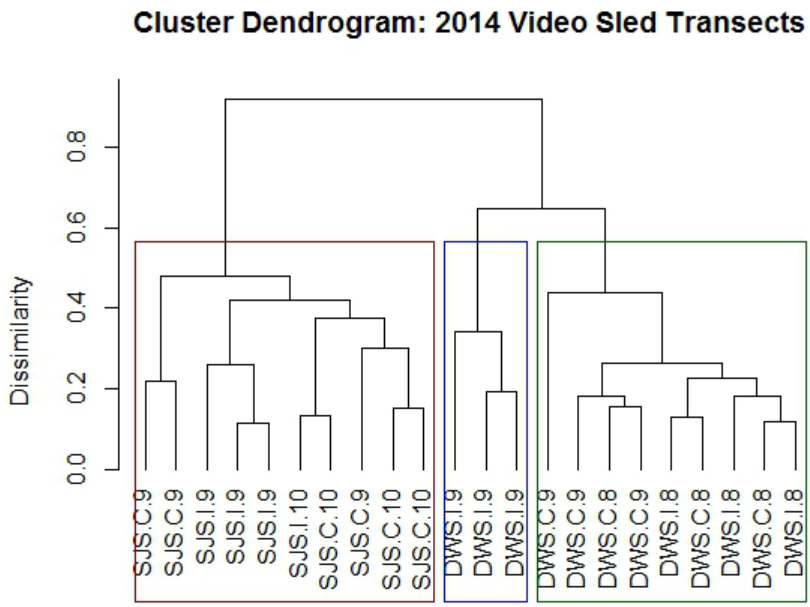


Figure 9. Cluster analysis dendrogram of species density (individuals/m^2) across all sled surveys. Abbreviations: SJS, South Jetty site; DWS, Deep Water site; C, control; I, impact. Number associated with location indicates month of survey.

Benthic Invertebrate Community

Identification was more successful for invertebrate species than for fish (Table 2). Identifying Dungeness crab and sea stars to species was possible for every individual. For some of the less-conspicuous invertebrates, identification was only possible to a higher taxonomic level.

Table 2. Mean density (individuals/100 m^2) of benthic invertebrates at South Jetty and Deep Water deposition sites based on data from video sled.

		South Jetty				Deep Water			
		11 September 2014		1 October 2014		20 August 2014		19 September 2014	
Common Name	Scientific Name	Control	Impact	Control	Impact*	Control	Impact	Control	Impact
Dungeness crab	*Cancer magister*	1.89	1.84	0.75	0.88	1.79	1.52	4.88	34.68
Giant anemone	*Metridium giganteum*	0.00	0.00	0.00	0.00	0.31	0.24	1.37	0.00
Hermit crab	Paguridea *spp.*	3.09	6.81	3.41	3.83	0.09	0.00	0.00	0.00
Nudibranch	--	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
Red octopus	*Octopus rubescens*	0.00	0.00	0.09	0.29	0.00	0.00	0.00	0.00
Orange sea pen	*Ptilosarcus gurneyi*	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Giant pink sea star	*Pisaster brevispinus*	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Ribbon worm	*Nemeretea*	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Sand star	*Luidia foliolata*	0.00	0.00	0.00	0.00	1.78	1.53	1.95	1.65
Sea anemone	Cnidaria	0.00	0.00	0.00	0.00	0.09	0.00	0.24	0.00
Sea whip	Cnidaria	0.00	0.00	0.00	0.00	0.10	0.09	0.16	0.00
Snail	Gastropoda	0.17	0.57	0.41	1.47	0.00	0.00	0.00	0.00
Sunflower star	*Pycnopodia helianthoides*	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.07
Spoon worm	Echiura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	115.98
Weathervane scallop	*Patinopecten caurinus*	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00

* Density at the South Jetty impact site on 1 October 2014 was based on images from a single sled transect.

Deep Water site—At the Deep Water site, a total of 156 invertebrates were counted in the control and 1,910 in the impact locations, with 13 taxa categories identified. At control and impact locations in August and at the control location in September, respectively, the dominant species were Dungeness crab (43, 42, and 52%) and sand star *Luidia foliolata* (41, 42, and 23%). In contrast, impact locations in September were dominated by a spoon worm (Phylum Echiura) (75%) and Dungeness crab (25%). Spoon worms were detected at extraordinarily high densities only during September in the impact transects. Interestingly, these normally infaunal worms were mainly laying on the surface, a presumably undesirable position for a soft-bodied, burrowing worm. Many appeared to be attempting to re-enter the sediment (Appendix Figure 1).

South Jetty site—At the South Jetty site, a total of 115 invertebrates in the control and 139 in the impact locations were observed. A total of four taxa categories were determined. In September, the respective control and impact locations had the same dominant species: hermit crab (60 and 74%) and Dungeness crab (37 and 21%). In September, the control location was again dominated by hermit (73%) and Dungeness crab (16%), while the impact locations were dominated by hermit crab (60%) and snails (23%). With only four taxa categories and low overall counts at the South Jetty site, discussion of dominant species becomes less biologically meaningful.

Demersal Fish Community

Fish identification to species level was a major challenge. For flatfish, positive confirmation of species was extremely difficult, but determination of left-eye or right-eye orientation was done when possible to distinguish between Bothidae and Pleuronectidae families. When a fish could not be confidently determined to be a sculpin or eelpout, it was assigned to the "unidentified roundfish" category. Due to the unspecific measure of fish identification, diversity analysis will not be pursued.

Deep Water site—At the Deep Water site, a total of 1,191 fish in the control and 1,521 in the impact locations were counted and identified to lowest taxonomic level. From these data, eight taxa categories were determined (Table 3). In the August pre-impact survey, dominant species were similar between sites: at the respective control and impact sites, flatfish were 67 and 64% of the counts and eelpout were 17 and 24%.

In September (active deposition), the control site was again dominated by flatfish (81%) and eelpout (13%), but the impact site was dominated by flatfish (95%) and sculpin (4%), with no eelpouts present. Again, the September impact transects contained a large number of spoon worms, which may have affected fish distributions.

South Jetty site—At the South Jetty site, a total of 30 fish in the control and 25 in the impact locations were recorded. Four taxa categories were determined (Table 3). In September, flatfish were dominant at the control and impact locations (93 and 100%, respectively). In October, the control site was dominated by flatfish (60%) and sculpin (40%), and the impact site by flatfish (100%) (the same as the control in September). Again, with only four taxa categories and low overall counts, the dominant species was less meaningful, biologically.

Table 3. Mean density (individuals/100 m^2) of demersal fish at South Jetty and Deep Water deposition sites based on data from video sled.

		South Jetty				Deep Water			
		11 September 2014		1 October 2014		20 August 2014		19 September 2014	
Common Name	Scientific Name	Control	Impact	Control	Impact*	Control	Impact	Control	Impact
Lingcod	*Ophidon elongatus*	0.00	0.00	0.00	0.00	0.52	0.00	0.24	0.07
Eelpout	Zoarcidae	0.00	0.00	0.00	0.00	7.62	14.05	5.10	0.00
Total flatfish		1.07	1.22	0.61	0.88	31.01	35.08	34.14	21.04
Left-eye flatfish	Bothidae	0.09	0.00	0.09	0.30	0.05	0.38	0.00	0.65
Right-eye flatfish	Pleuronectidae	0.00	0.40	0.09	0.30	1.71	2.09	0.99	0.46
Roundfish		0.00	0.00	0.00	0.00	1.32	1.14	0.80	0.30
Sculpin		0.09	0.00	0.53	0.00	6.20	6.25	1.35	1.00
Starryskate	*Raja stellulata*	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00

* Density at the South Jetty impact site on 1 October 2014 was based on images from a single sled transect.

Comparison of Faunal Densities

As discussed above, we could only complete a partial BACI design due to environmental and logistical constraints on sampling. We have data from mid- and late-impact periods at the South Jetty site and from pre-impact and mid-impact surveys at the Deep Water site. We used these data in an analyses of variance to investigate differences in fish and invertebrate densities.

We first examined sediment impact effects by testing the null hypothesis that mean densities were not different between impact and control locations (Figure 2, scenario A). To test this hypothesis, we ran two-way ANOVAs on density data from control and impact locations for each survey date.

The second hypothesis examined temporal effects and tested the null hypothesis that density of organisms within a control or impact location was the same between surveys over time. The two deposition sites were analyzed separately, and we looked only at the most abundant organisms. Dungeness crab, sculpin, and total flatfish were abundant at both sites. Densities were log $D + 0.001$ transformed prior to analysis. Overall, few significant differences were found.

Comparative invertebrate densities at the South Jetty site are shown in . Dungeness crabs were at about equal density at control and impact treatments during both mid- and late-impact periods, although there were more crabs early in the season. Hermit crabs were about twice as abundant in the mid-impact period as during other times. Snails tended to be more abundant in the impact than control period.

Flatfish and sculpin densities are shown in Figure 11. Fish densities overall were comparatively low. Flatfish were at similar densities in each array during the mid-impact phase, and fell to low densities at both locations during late impact. Sculpin increased in density over time in the control location but were not observed in the impact location. Note only one replicate was available for the impact survey on 1 October, hampering analysis. None of these comparisons were significant, due to low density and high variance.

At the Deep Water site, a greater number of species at higher densities were observed. Comparative invertebrate densities at the Deep Water site are shown in . Sand stars exhibited stable density throughout the region and times sampled. *Metridium* sea anemones were at equal densities in the pre-impact period, but were at higher density and more variable in the control location and not observed in the impact location during the mid-impact period.

Some of this variance may have been due to differences in the availability of preferred substrate type. Both Dungeness crab and spoon worms exhibited greatly enhanced (but variable) density in the impact location during the mid-impact period compared to other surveys. The wide surface distribution and high density of infaunal spoon worms was remarkable, and the high density of Dungeness crab overlapped that of the worms, suggesting the worms served as an attractant (Figure 2, scenario D). We have not ascertained mechanisms explaining the spoon worm abundance, but possibilities include effects of dredging or oceanographic processes such as low dissolved oxygen or increased bottom temperatures (unfortunately, benthic oceanographic measurements are not available).

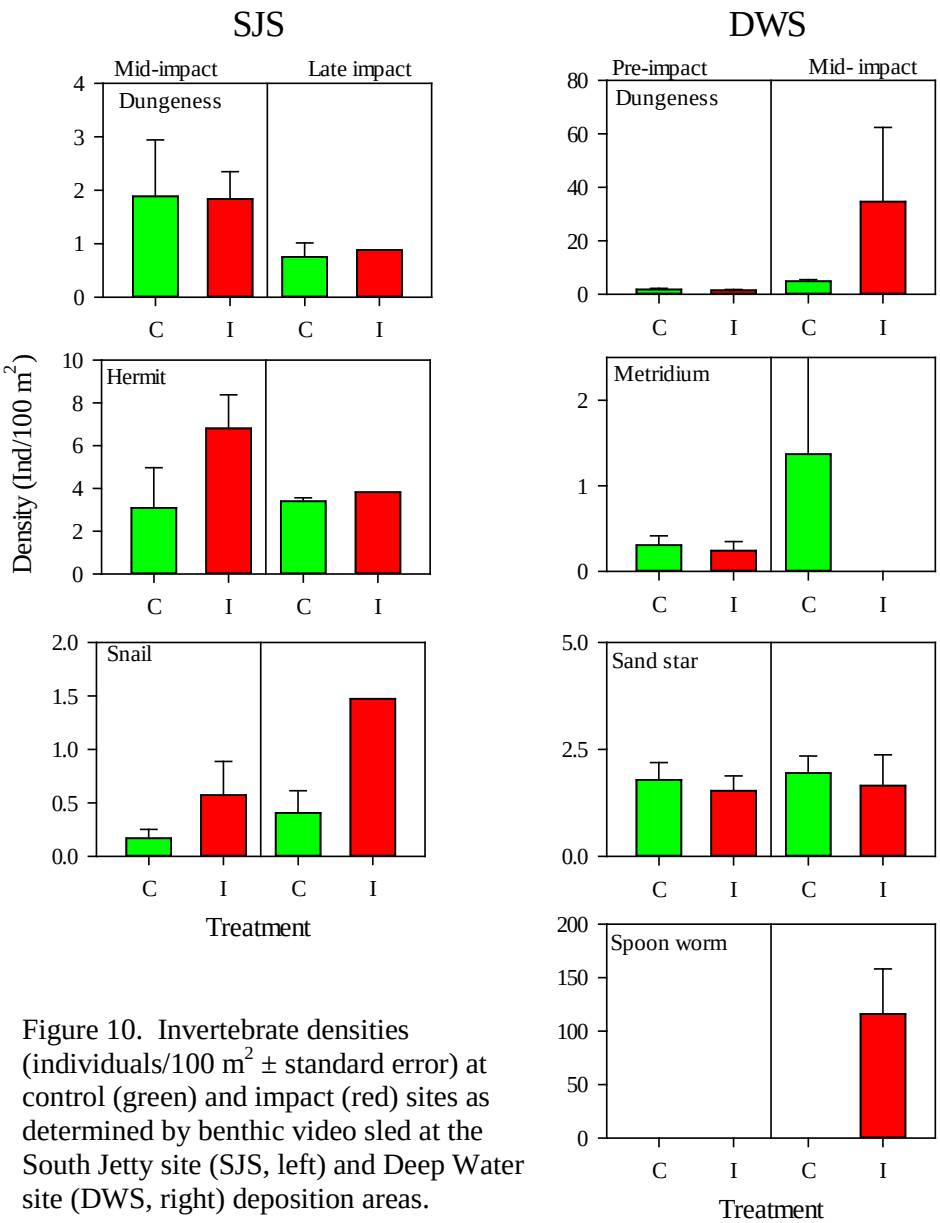


Figure 10. Invertebrate densities (individuals/100 m^2 ± standard error) at control (green) and impact (red) sites as determined by benthic video sled at the South Jetty site (SJS, left) and Deep Water site (DWS, right) deposition areas.

Four fish groups were abundant at the Deep Water site (Figure 11). There was a relatively high mean density of total flatfish which did not vary significantly across surveys. Sculpin were at equal densities within a survey date but declined significantly ($P < 0.005$) between dates. Eelpout densities declined significantly ($P = 0.026$) in the impact area over time. Unidentified roundfish were at low density and exhibited no significant differences over time or between treatments.

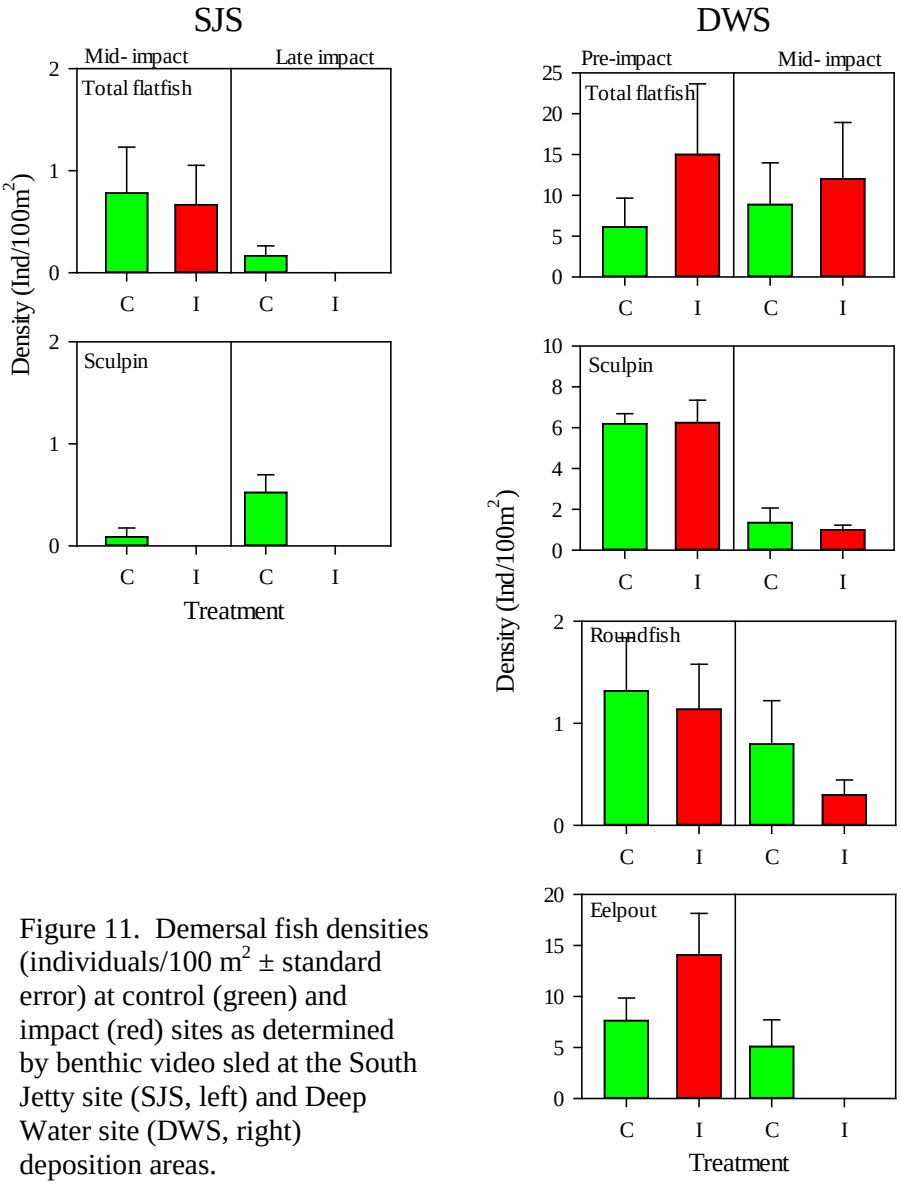


Figure 11. Demersal fish densities (individuals/100 m^2 ± standard error) at control (green) and impact (red) sites as determined by benthic video sled at the South Jetty site (SJS, left) and Deep Water site (DWS, right) deposition areas.

Objective 2a: Video Monitoring of Acute Effects

Methods

We designed and built a series of baited video landers termed "CamPods" (Figure 12). These platforms were deployed immediately before disposal events and performed two functions: First, they measured sedimentation levels, and second they recorded imagery showing the direct effects of sediment plumes on organisms. Each CamPod had a base consisting of a 0.5-m^2 circular rim made from 15-mm stainless steel and slatted with a series of flat metal strips to prevent burial in the substrate. Welded to the base was a central 110-cm pole with four curved support ribs. The central pole held a camera and underwater light source (Intova IFL-WA-ZOOM) and was topped with a crab trap float to aid orientation during deployment. A second camera was mounted to one of the support ribs, and a bait container was secured to the base. To gauge sediment levels, a 1-mm ruler was place on each central pole and on a graduated frame for side and downward views, respectively. Weights were attached to the rim of the base as necessary.

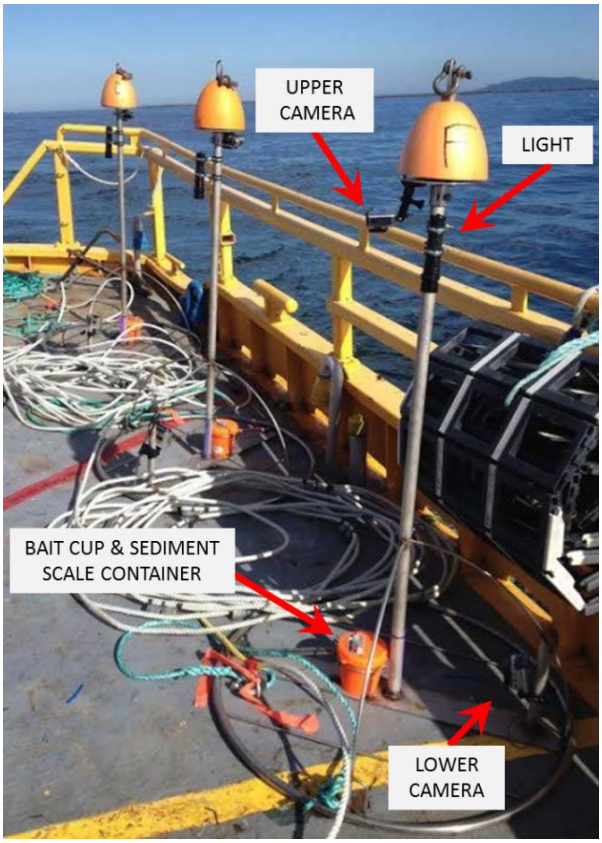


Figure 12. Components of the CamPod benthic video lander.

Thus, each CamPod was equipped with two cameras (GoPro Hero, models 2 and 3). The downward-viewing cameras situated 100-cm from the base of the central poles were used to capture images of the 0.5-m^2 base area to determine time series of faunal density. The side-viewing cameras attached to the support ribs near the sediment surface were used to measure sediment deposition levels and to aid in behavioral

observations. Video data were recorded at a standard high-definition resolution of 1,920 × 1,080 pixels at 30 frames/s on the "wide" setting (1080p-30 wide). This setting provided the best balance between resolution, field of view, and battery life.

CamPods were deployed to measure sediment deposition levels and to compare faunal densities at control and impact location. For deposition events, individual CamPods were joined in a "daisy chain" configuration, with 30 m between pods (Figure 13). The center CamPod of the chain was aligned on the center-line of the dredge deposition track to measure primary vertical deposition effects. Peripheral pods were arranged perpendicular to the axis of the deposition track to measure proximal effects. Solo CamPods were also deployed as conditions warranted (e.g., no deposition events).

CamPods were baited with diced northern anchovy *Engraulis mordax* placed in a perforated plastic container. CamPods were deployed ~0.75 h prior to deposition events to attract organisms to the bait and were retrieved after a total of ~2.5 h (the limit of camera battery life). A light/temperature sensor was attached to a CamPod in each array to record ambient conditions during sediment depositions (Onset Hobo pendant set to record at 1-s intervals).

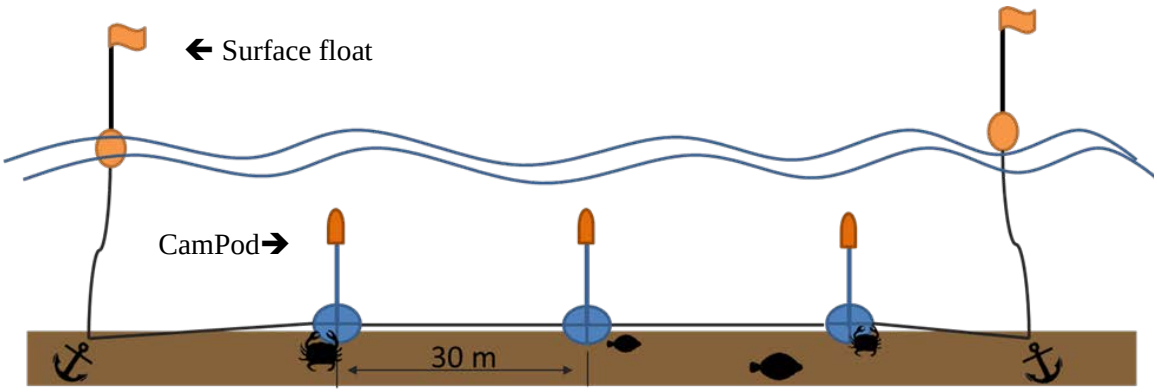


Figure 13. Design of CamPod daisy chain for sediment deposition experiments.

CamPod experiments were designed to test the null hypothesis of no acute effect of sediment deposition on selected taxa. Crabs, gastropods, and demersal fish were the primary target for CamPod observations. These organisms have differential motility and orientation to the bait, as well as differential susceptibility to forces exerted by the sediment plume. Therefore, analysis of the video data entailed quantifying organism density at discrete time intervals (5 min) before and after the deposition event. No counts were possible during sediment blackout periods (usually < 5 min).

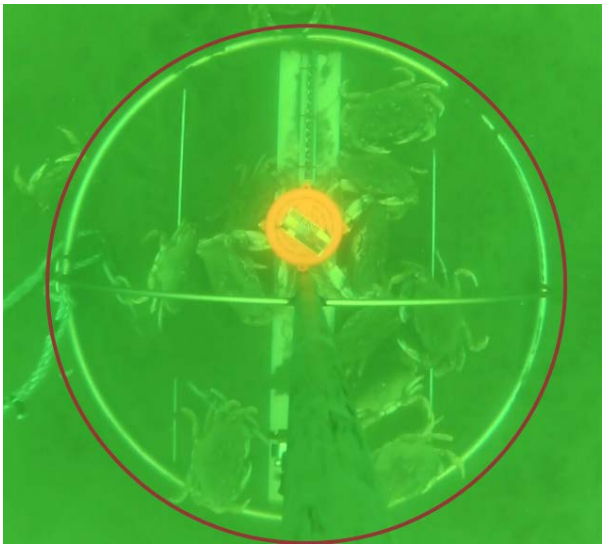


Figure 14. CamPod sample area (red circle) used to standardized counts from the upper camera view. Image shows Dungeness accumulating at orange bait box.

Organisms were counted if they were visible and in contact with or within the base ring (Figure 14). Upper camera images were was used in these analyses since they provided a defined area for standardized counts. Based on experiments conducted in 2011 comparing crabs and whelks, we expected differential susceptibility by taxon (Figure 15). The plot illustrates rapid accumulation at the bait by crabs, and slower aggregation by gastropods. Post deposition, gastropods recover and continue to accumulate while crabs are dispersed.

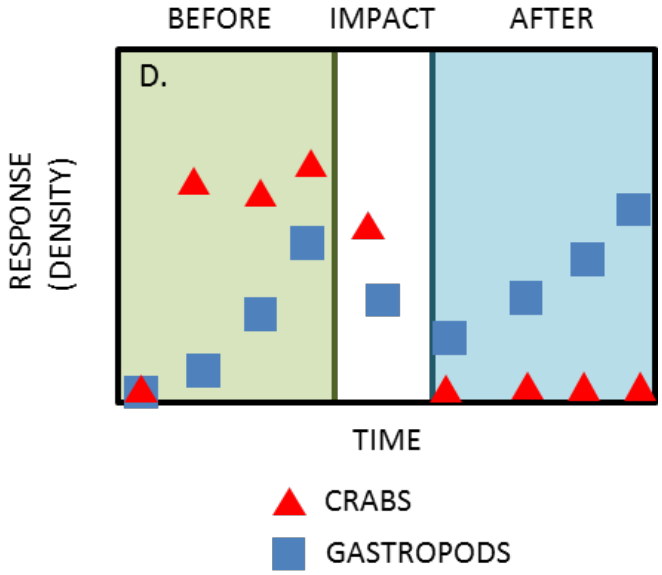


Figure 15. Hypothetical scenario depicting taxon-specific responses of fauna to sediment deposition events.

Results and Discussion

At the South Jetty site, we deployed CamPods three times during sedimentation deposition events and one time during the recovery period (Table 4). Results from CamPod deployments at the Shallow Water site will be discussed in a later report. The main organisms quantified from CamPod deployments were Dungeness crab, whelk, hermit crab, and several species of benthic fishes (Table 5). Here we concentrate on Dungeness crab *Cancer magister* and whelks *Nucella* spp.

Table 4. Schedule and visibility of CamPod deployments, 2014.

Site/period	Experiment	Date	Day of year	Visibility	Comment
South Jetty					
Impact	CP01	4 Sep	247	Medium	Tag01
Impact	CP02	12 Sep	255	Clear	Tag02
Impact	CP03	18 Sep	261	Medium	>Tag03
Recovery	CP04	1 Oct	274	Clear	No dump
Shallow Water					
Impact	CP01	17 Sep	260	Medium-low	Odd

Table 5. Species identified at the South Jetty site from CamPod data, 2014.

Common name	Scientific name	Impact	Control
Dungeness crab	*Cancer magister*	*x*	*x*
Whelk/snail	*Nucella* spp	*x*	*x*
Hermit crab	Paguridea	*x*	*x*
Red octopus	*Octopus rubescens*	*x*	
Total flatfish		*x*	*x*
Left-eye flatfish	Bothidae	*x*	*x*
Right-eye flatfish	Pleuronectidae	*x*	*x*
Sculpin		*x*	*x*

Sediment Deposition Levels

Deposition events resulted in a rapidly moving sediment plume that enveloped the CamPods. Video feeds went black during deposition events, an indication of high levels of suspended sediment. Relatively high current velocities and sediment loads were observed to pass the CamPod (based on particle trajectories viewed with the underwater lights). However, the impact period was relatively brief. Based on clarity of the image from the downward-looking camera, the impact of the sediment plume did not exceed 5 minutes. Deposition levels observed on the CamPods were also relatively low and did not exceed 2 cm (usually < 1 cm). Future work will aim to quantify these observations.

Abundance

Results from CamPod deployment supported our earlier observations and the hypothesis that fish and crabs are affected by, but recover quickly from acute dredging effects (Figure 2, scenario C). Relative mean relative density of Dungeness crabs was similar between control and impact locations during the pre-impact period (Figure 16) and tended to increase to a maximum at 0.75-1.0 h into the deployment. Fluctuations in the mean number occurred because crabs actively moved around the CamPod base rather than accumulate as they would in a standard crab trap.

When the sediment plume reached the impact site, all crabs and fish were displaced. Displacement occurred both by escape behavior, where crabs and fish attempted to avoid the approaching sediment plume, and by entrainment, where crabs were engulfed and swept away by the plume. No crab or fish remained at the CamPod post-impact, but crabs did return within 0.5 to 1 h. Battery power on the cameras was not always sufficiently long to observe crabs returning, but we suspect crabs continued foraging relatively soon after a single deposition event.

During the recovery period in October, abundance time series for the two CamPod arrays exhibited similar patterns of asymptotic increase (3 Oct in Figure 16). These data lend support to the hypothesis there are acute effects on crab and fish distributions, but that recovery is likely (Figure 2, scenario C). However, the experience of individual crabs entrained in the plume remains unclear, as do the effects of multiple depositions events on benthic populations. The contrast between crabs and whelks was significant in two ways:

1) Whelk density during the impact phase was much higher at the impact than at the control location, in part due to visibility issues on 4 September.
2) Whelks were displaced less by the sediment plume than crabs (as previous data had suggested).

Differences in whelk density between control and impact arrays are not yet understood, but may be related to enhanced organic deposition in the impact zone (Figure 2, scenario D). These results are in agreement with video sled observations of fewer whelks in control than impact locations (Figure 10).

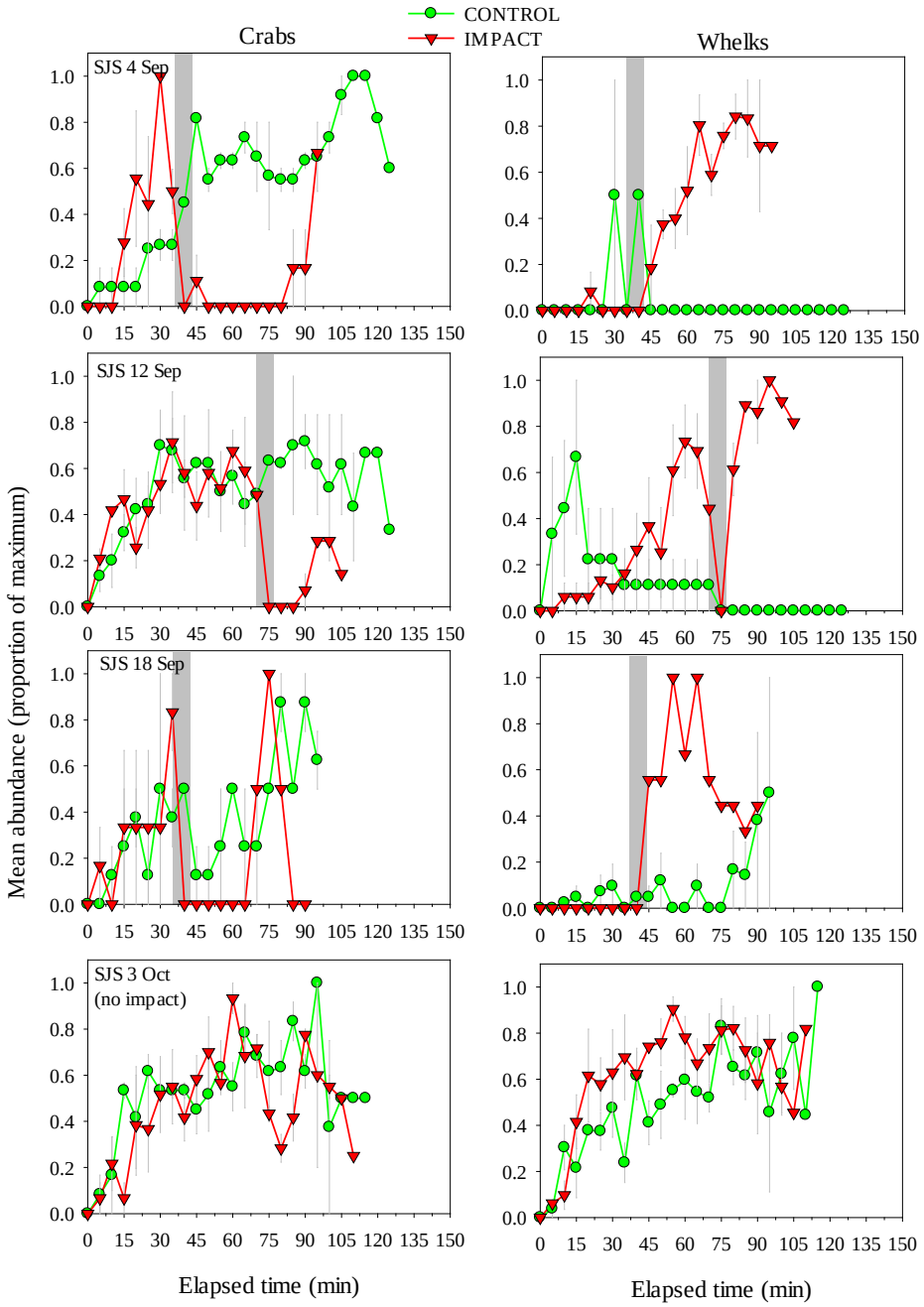


Figure 16. Time series of mean abundance (± standard error) of Dungeness crab (left) and whelks (right) from CamPod images at control and impact locations. Grey bar marks the time of sediment deposition at the impact location.

Objective 2b: Acoustic Telemetry to Monitor Acute and Chronic Effects

Methods

Acoustic telemetry was used to measure both the immediate displacement of crabs, if any, in the impact zone and also the behavior of tagged crabs in the intervening period (chronic effects). These data were used to compare behavior of crabs in the impact zone with that of crabs from the control area.

Metrics to examine acute effects included: 1) displacement distance; 2) recovery time (quiescence). Metrics for chronic effects include: 1) residence (departure from release area); 2) home range.

Set up of moorings and arrays followed Webber (2009). Acoustic receivers (Vemco VR2W 69 kHz) were deployed in an array of four moorings arranged orthogonally (N-S) and separated by 300 m (Figure 17). Receivers were positioned 5 m from the bottom of each mooring line and vertically stabilized by a subsurface float at 7 m. A reference "synch" tag was attached to the mooring line 1 m above each receiver, and a final reference tag was deployed randomly within each array on a small weight. The synch and reference tags were used to coordinate node positioning and as transmitter controls, respectively.

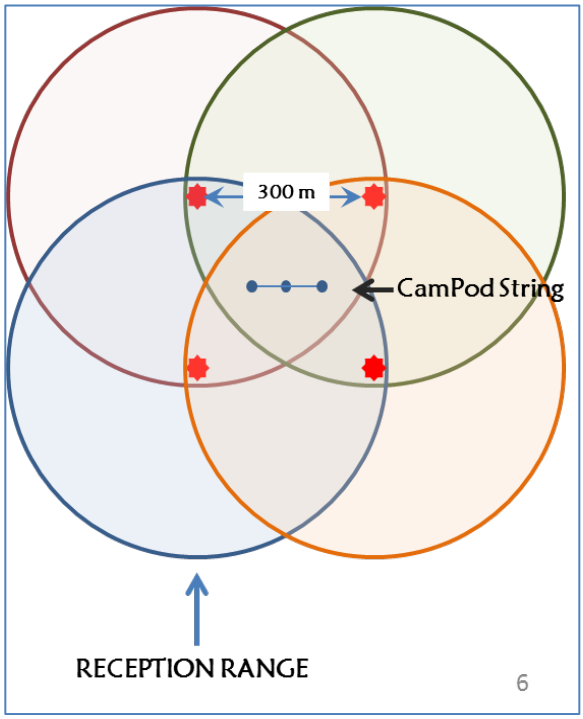


Figure 17. Acoustic array design showing interacting reception ranges. Simultaneous detection by 3 or more receivers yields a 3D position.

One array was deployed in the control area and the other in the impact area, and the two arrays were separated by 1.7 km (Figure 18). Within an array, high-resolution tracking of acoustic signals (3 or more nodes receiving signals) was estimated to occur in a central area (~9×10^4 m^2). Circles in Figure 18 designate the area wherein signals were received by a minimum of one node (~8.1×10^5 m^2).

Dungeness crabs were captured with baited crab traps the morning before the experiment. Crabs were graded by size and sex into the two treatment groups. Individually coded acoustic transponders were affixed to the dorsal carapace of crabs with fast-curing epoxy glue (Figure 19). Acoustic tags were 9 mm long with a variable ping rate of 150-250/s and an estimated battery life of 296 d (Vemco V9A). Size (carapace width), sex, and limb loss were recorded for each tagged crab.

During a tagging experiment, ~10 tagged crabs (range 9-11 individuals) were released in the center of each acoustic array. Crabs were

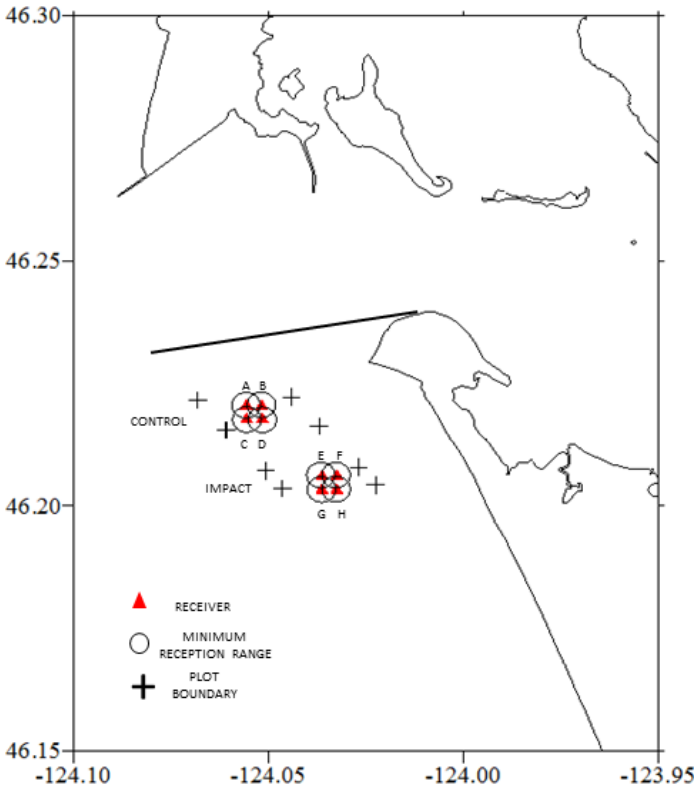


Figure 18. Position of control and impact acoustic arrays at the South Jetty site. Circles indicate reception ranges, the "+" symbols denote the South Jetty site boundaries.

Figure 19. Tagged Dungeness crabs ready for deployment.

allowed 0.75-1.5 h to acclimate before a sediment load was deposited in the impact array by the USACE hopper dredge *Essayons*. As the sediment was being deposited, the R/V *Forerunner* was stationed ~200 m off the center of the array to monitor current velocities using a bottom-mounted acoustic Doppler current profiler (RDI Workhorse ADCP). A CamPod string (Figure 13) was deployed within the center of the arrays when possible.

The acoustic array was in operation from 19 August to 10 October 2014 (52 d), and we performed three tagging experiments using a total of 60 tagged crabs. These experiments occurred during the beginning, middle, and end of the dredge disposal season. Upon recovery of the arrays in October, acoustic data were downloaded from the receiver nodes for processing by Vemco (VW2 positioning system). In addition to known tags, we noted and identified (where possible) acoustic signals from additional targets utilizing Vemco tags.

Results and Discussion

Crab Size

We conducted three tag release experiments in 2014 (Table 6). Dungeness crabs in the first and third release groups were of similar size and age, and were mostly 2- to 3-year-old sublegal crabs (Figure 18). The second release group had a relatively high proportion of legal-sized crabs (143-mm carapace width). The first release group was composed of 20 males and 1 female; the second and third releases were composed of 20 and 19 individuals, respectively and were relatively evenly split between males and females.

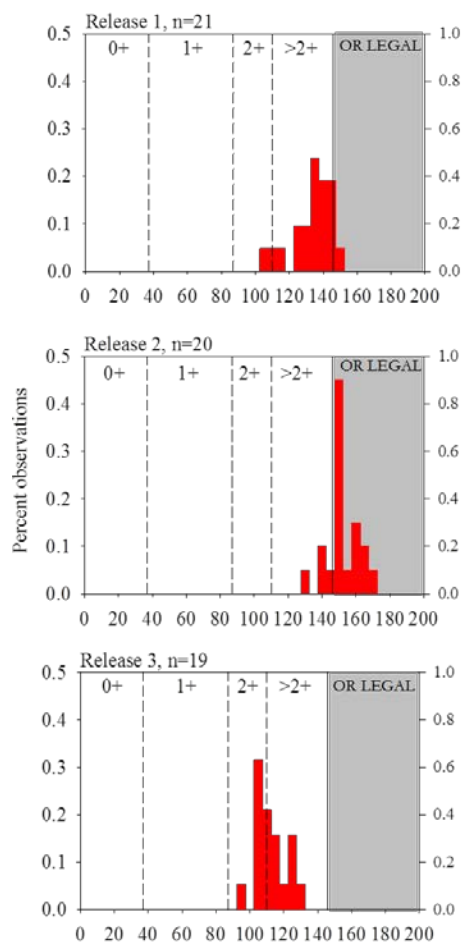


Figure 18. Size frequency of tagged crabs for each release experiment. Legal size for crabs in Oregon is indicated by grey shaded area.

The timing of sediment deposition events by *Essayons* was not consistent over time. Therefore, our first tagged releases experienced a total possible cumulative effect from 28 deposition events, while the final tagged release group experienced only a single deposition event (Table 6).

Table 6. Dates of acoustic mooring deployment/retrieval and tag releases, and cumulative number of sediment deposition events.

Activity	Date	Day of year	Days deployed	Deposition events (n)
Deploy arrays	19 Aug	231	--	
Tag release 01	4 Sep	247	36	28
Tag release 02	17 Sep	260	23	13
Tag release 03	29 Sep	272	11	1
Retrieve arrays	10 Oct	283	52	48

Acoustic Data

During retrieval of the acoustic array on 10 October, one control receiver was found vandalized (at 16:08 on 29 September), and one impact mooring was not recovered. Further attempts to retrieve the mooring were unsuccessful. Loss of these receivers reduced the detectible area by 25%, but did not negate the experimental design.

Data from acoustic transmitters (tags) were downloaded from the receivers, and all tags were accounted for. Synch tags had near-continuous detection within their respective arrays, and control tags were likewise recorded throughout the deployment period. Control tags were used to evaluate transmitter effects, such as failing batteries, and results indicated that undetected tags were likely those from crabs that moved out of receiver range. Receivers recorded a total of 77,901 detections from the 60 tagged crabs. We also recorded over 5,000 unidentified detections, include those suspected to be from tagged green sturgeon (see below).

Analysis of acoustic transmission data will yield position information that we can interpret to identify both acute (single deposition event) and chronic effects (multiple events) from deposition. From these data, we can determine behaviors that include directed vs. passive movement, periods of activity and quiescence, aggregation or dispersal, and nighttime vs. daytime movement, etc. Position data will also substantiate possible tag loss or mortality. Until that analysis is complete, we report acoustic data in terms of the presence/absence of tagged individuals in relation to release sites (Figure 20).

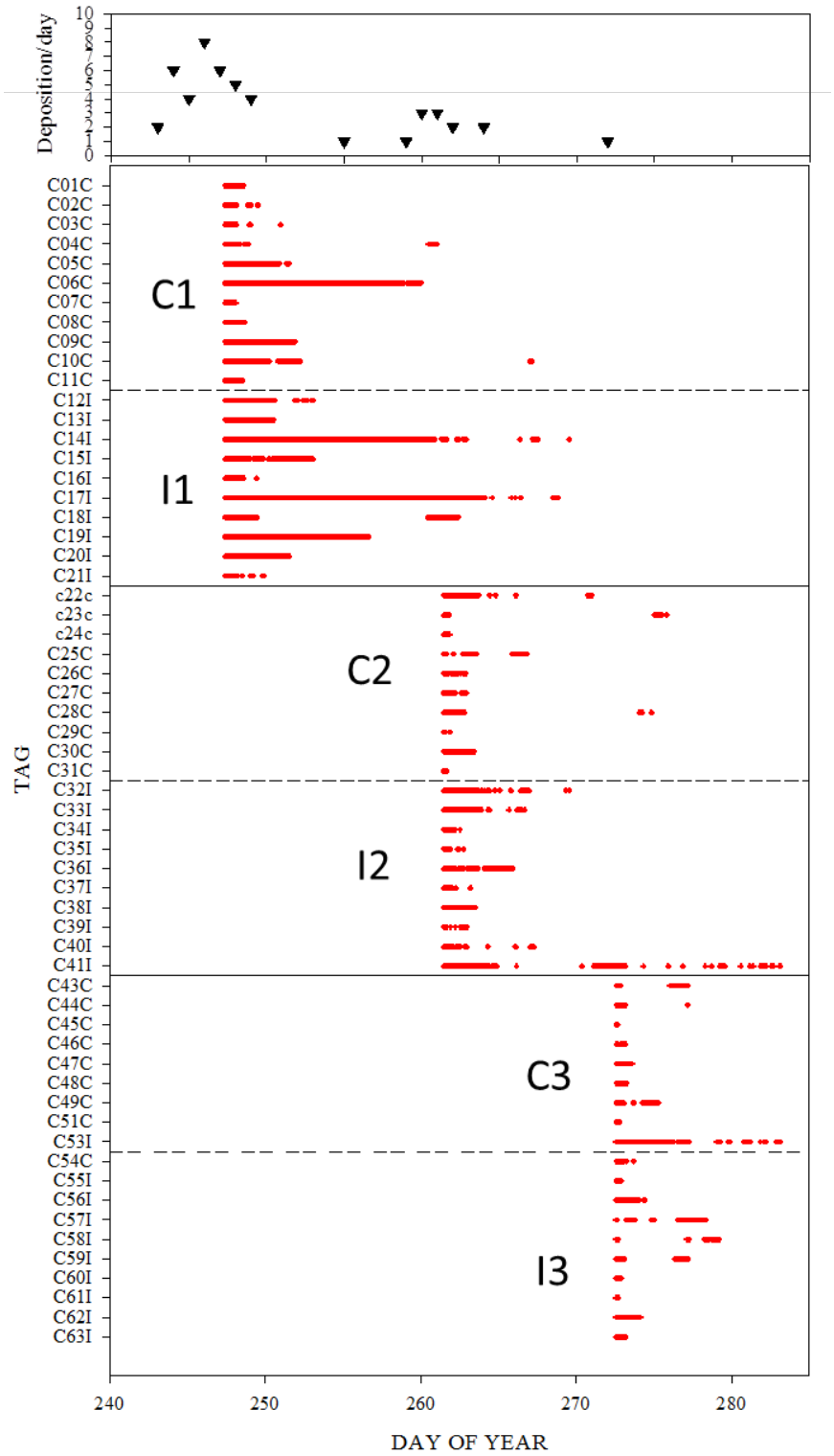


Figure 20. Detections of individual crabs during the three tagging experiments C, Control. I, Impact. Upper plot shows deposition events.

Overall, no signals from any group of tagged crabs were detected in the arrays for more than 25 d, and most crabs apparently migrated from the release site array after about 1 week. We identified four categories of movement behavior (Table 7):

1) Same array: presence in only one array
2) Other array: movement from one array to the other
3) Back and forth: movement from one array to the other and then back
4) Left and returned: presence in an array after absence longer than 3 d

Table 7. Observed crab movement patterns based on presence/absence of acoustic tag detections.

Trial	Release array	Tags detected (n)	Same array (n)	Other array (n)	Back and forth (n)	Left and returned (n)
Release 1	Control	11	8	0	0	3
	Impact	10	7	1	1	1
Release 2	Control	10	4	3	1	2
	Impact	10	5	4	1	0
Release 3	Control	9	3	5	1	0
	Impact	10	6	1	1	2

The most common observation was tag detections exclusively in the release array (50.0% of control and 60.0% of impact crabs). Of these, there was a wide range of residency time within the detection area, varying from a few hours to ~25 d (Figure 21).

The second most common observation included crabs that migrated from one array to the other (Figure 22). Eight control crabs moved to the impact array vs. six doing the reverse. Most of these migrations occurred during medium and light deposition periods.

In the third pattern, the tag signal disappeared for a variable period before becoming reestablished (5 in the control array and 3 in the impact array (Figure 23). The period of signal loss ranged from a few days to several weeks. We interpret this "left and returned" behavior as localized movement out of the detection area (~8.1×10^5 m^2) before subsequent return. Crabs were not always detected by the full array upon return, likely because they were on the edge of the array.

The final migration pattern included crabs that traveled back to the release array after being detected in the other array (2 crabs from control releases and 3 from impact releases; Figure 24).

Figure 21. Examples of "same array" behavior for individually tagged crabs. Plots depict time series of detections over a forty day period. Receivers 1-4 comprise the control array, and 5-8 are the impact array.

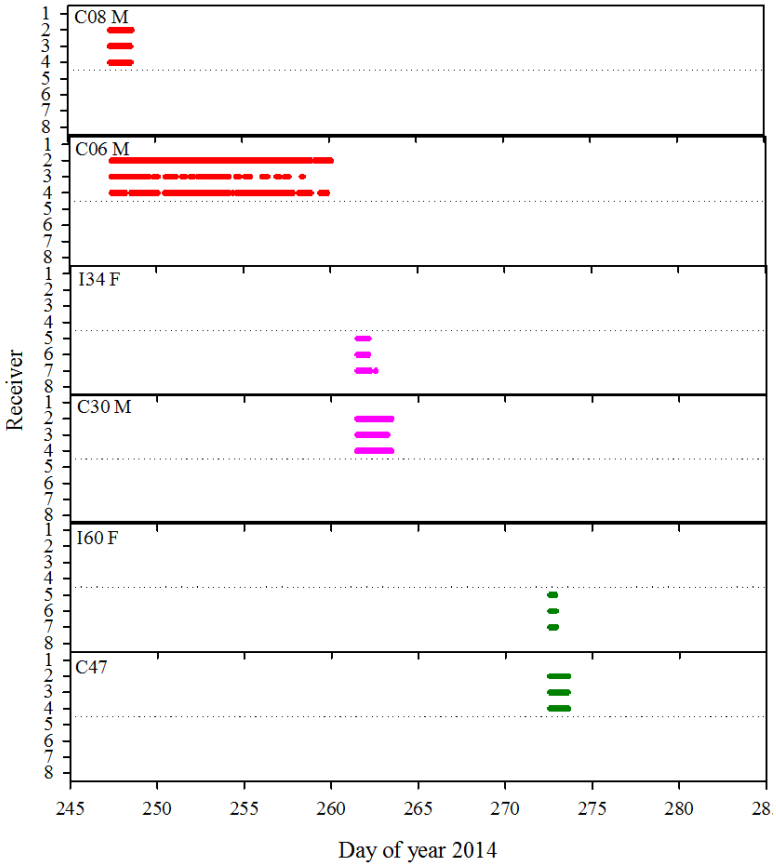


Figure 22. Examples of "other array" behavior for individually tagged crabs. Plots depict time series of detections over a forty day period. Receivers 1-4 comprise the control array, and 5-8 are the impact array.

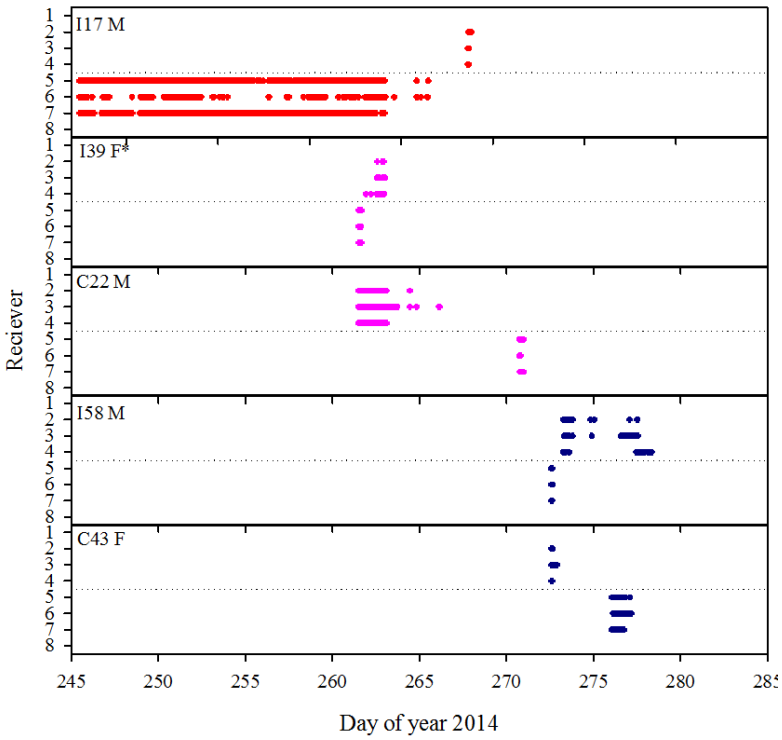


Figure 23. Examples of "left and returned" behavior for individually tagged crabs. Plots depict time series of detections over a forty day period. Receivers 1-4 comprise the control array, and 5-8 are the impact array.

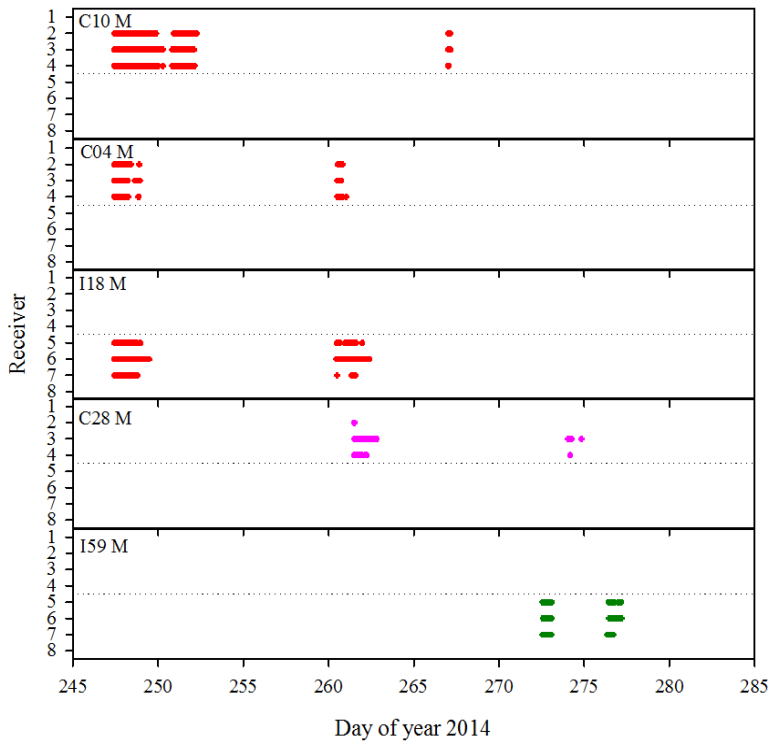
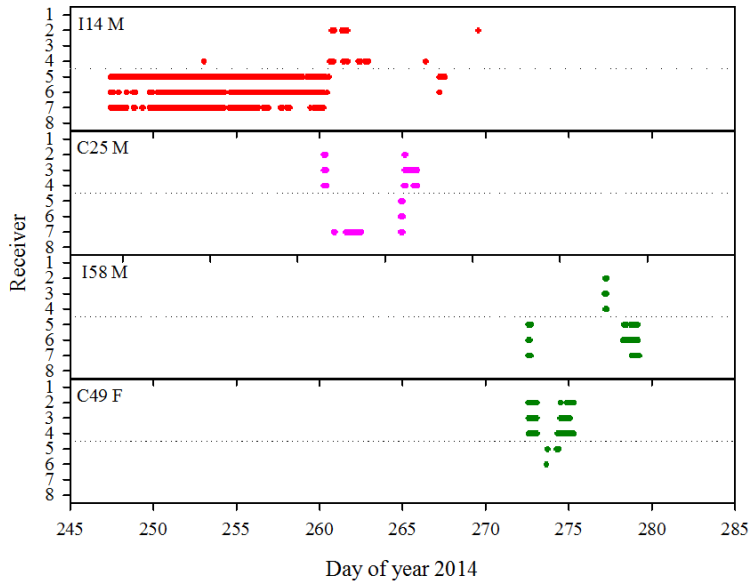


Figure 24. Examples of "back and forth behavior for individually tagged crabs. Plots depict time series of detections over a forty day period. Receivers 1-4 comprise the control array, and 5-8 are the impact array.



For these observations from presence/absence data, the “other array” and “back and forth” categories depict evidence of directed crab movement. For these crabs, movement away from an array occurred over periods ranging from a few hours to a week or more after release. In some cases there was relatively direct movement from one array

to another (over several hours), while in other cases tagged crabs were undetected for days or weeks during movement between arrays.

Crabs could move quickly from one array to the other, traveling a distance of about 1.7 km within several hours (Figure 25). For crab C44, minimum travel speed was estimated at 0.15 m/s. More movement data will be available with complete analysis of the acoustic data.

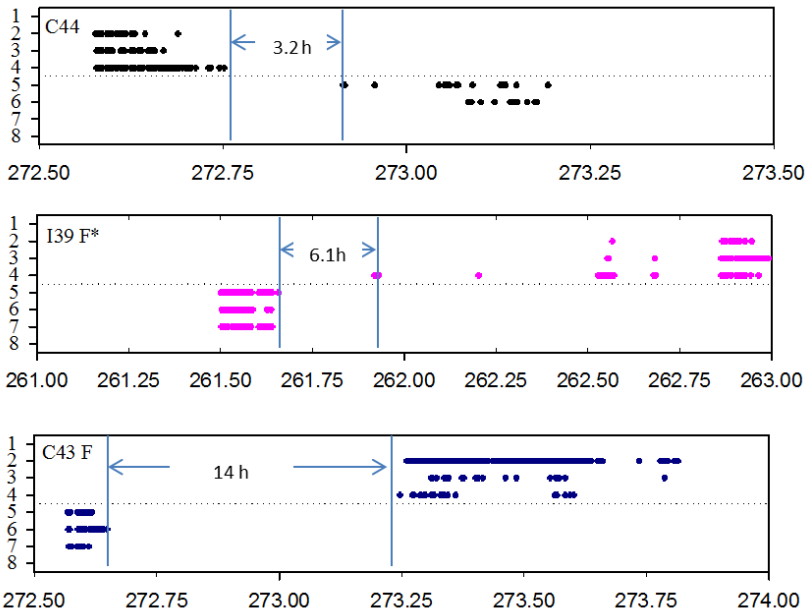


Figure 25. Examples of travel time between acoustic arrays. Plots depict time series of detections on receivers 1-8. Control array was composed of receivers 1-4, and the impact array was receivers 5-8. Note variation in x-axis scaling.

Of interest was the recovery of two tagged female crabs (C23 F and I39 F), both from the second release group. Crab C23 F was released into the control array and quickly left but was re-detected in the same array after 15 d (left and returned). She was recovered around 13 May 2015 after 255 d at liberty. Crab I39 F was released into the impact array but moved quickly to the control array (Figure 25). She was captured on 29 December 2014 after 105 d. Both crabs were recovered at locations south of the impact zone (N46.193, W124.006 and N46.194, W124.042, respectively).

A code was retrieved from crab I39 F to confirm identity, but the battery on crab C23 F was drained (ID number was visible on the tag). These crabs likely moved out of the detection zone of the arrays but remained in the local area.

Green Sturgeon

In 2013, our acoustic receiver arrays detected green sturgeon *Acipenser medirostris* migrating through and residing around the South Jetty site (Figure 26). In 2014 we also detected signals that we suspected were sturgeon (Figure 27), but the tag codes have not been verified.

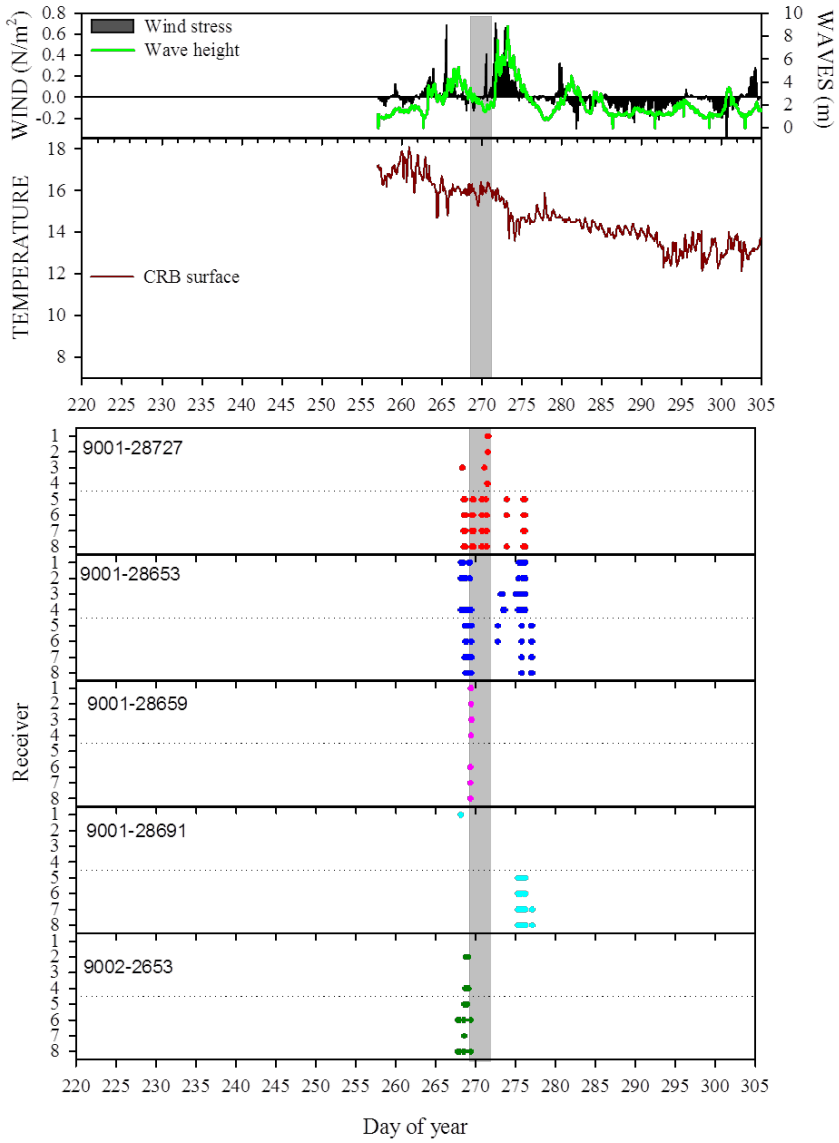


Figure 26. Environmental variables and movement of green sturgeon around receiver arrays in 2013. Gray bar indicates the brief 2013 disposal period. Plot A shows northward wind stress and mean wave height. Plot B shows sea surface temperatures at Buoy Station 46029. Plot C shows detections of green sturgeon at receiver arrays.

In both years, sturgeon detections occurred during a relatively narrow time frame during late September-early October. In 2014, sturgeon tended to move rapidly through the arrays, while data from 2013 indicated patterns of longer residency. During 2014, suspected sturgeon were present mainly during periods of low sediment deposition. In 2013, the *Essayons* made limited sediment deposition events, but these events were within the sturgeon migration/residency window.

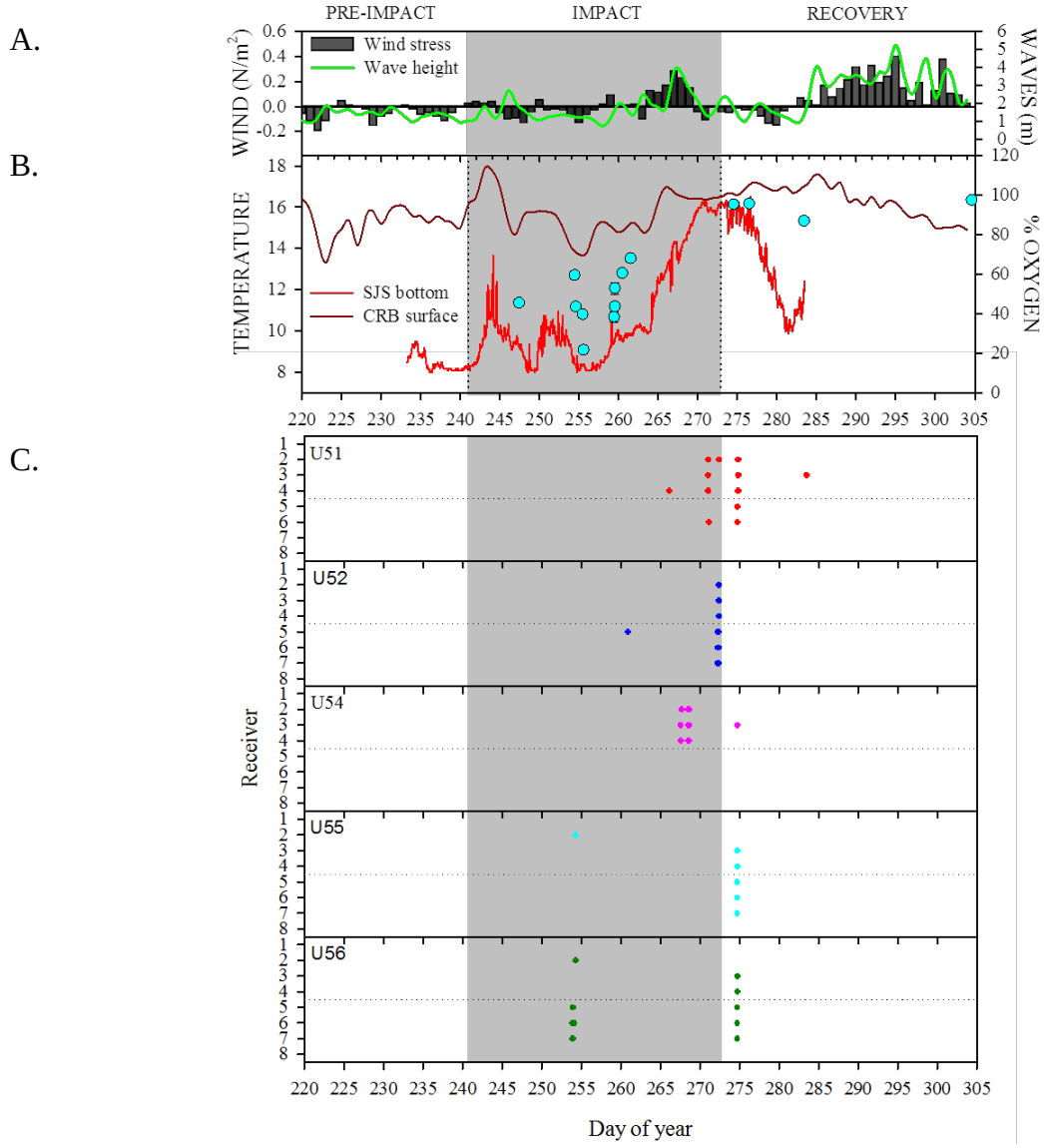


Figure 27. Environmental variables and movements green sturgeon around the receiver arrays in 2014. Gray bar indicates the 2014 disposal period. Plot A shows northward wind stress and mean wave height. Plot B shows sea surface temperatures at Buoy Station 46029, bottom temperature at the South Jetty site, and mean bottom oxygen saturation from CTD casts (blue circles). Plot C shows detections of suspected green sturgeon at receiver arrays.

Conclusions and Recommendations

This report provides a progress update and initial analysis for the 2014 Benthic Impact Study and allows for adaptive management of the science program. Pending further study, our overall preliminary conclusions are enumerated below.

Preliminary Overall Conclusions

1. Our system of using the video sled, CamPod, and acoustic sampling techniques has been vetted, and each element appears to function as designed. However, we will continue to refine the systems for optimal performance. The sled in particular was constructed to be "hefty," and we plan to build a smaller and lighter unit to reduce individual deployment times.

2. Adverse weather and low visibility were our biggest obstacles. Storm systems limited deployment opportunities for both benthic sled and CamPods. Significant wave heights greater ~3 m and periods less than ~ 10 s were unsafe for these deployments. Northwest (upwelling) winds of moderate velocity and relatively benign sea states are common for the August-September period in this region. However, the fall transition to predominately southerly (downwelling) winds during October or November usually leads to stormy conditions unsuitable for sampling. In 2014, this fall transition occurred in late September and affected some of our late impact and post-impact surveys (Figure 5).

3. The other major problem we encountered was an anomalously high phytoplankton bloom during early September. This resulted in low visibility in the bottom layers at the South Jetty and Shallow Water sites but not at the Deep Water site. CTD measurements of chlorophyll concentration exceeded 40 mg/m^3 at the South Jetty site, well above typical maximum nearshore or estuarine levels of ~ 15 mg/m^3 during September (Roegner et al. 2010). This condition appears to be the result of unusual warming and reduced mixing in the Northeast Pacific during 2014, resulting in a mass of warm water termed "the warm blob" (Milstein 2014). Our bottom-mounted temperature probes recorded this warm water mass impinging on the coast coincident with a strong downwelling episode in late September (Figure 5).

   To improve data acquisition in 2015, we plan to deploy an instrument buoy at the South Jetty site that will provide real-time telemetry of near-bottom turbidity conditions to our lab. This data will allow an avenue for adaptive management of the sled and CamPod deployments, permitting flexibility for surveys by avoiding periods of low visibility. Other sensors on the mooring (dissolved oxygen, temperature, salinity, etc.) will provide useful contextual data for explaining possible correlates with faunal abundance and behavior.

4. At the South Jetty site, deposition events by *Essayons* primarily occurred immediately after the site was available for research activity (Figure 3). The frequency of impacts decreased by the middle of the deposition program, and there was a single deposition event in the last week of the study period. In contrast, there was a more consistent and heavy deposition pattern at the Deep Water site (Figure 4). To fully explore impacts from heavy vs. light deposition frequencies at the South Jetty site, we hope to coordinate our observations more closely with the dredge deposition schedule in 2015.

Preliminary assessment of video and acoustic data has revealed varied effects from sediment deposition at the South Jetty and Deep Water sites. We strongly emphasize these are preliminary observations requiring further sampling and analysis. Nevertheless, we offer some general observations and preliminary conclusions from progress to date under each objective.

Epibenthic Faunal Surveys using the Benthic Video Sled

1. Too few images from video sled transects were of sufficient quality to provide firm conclusions concerning the effects of disposal on benthic populations.

2. There were relatively large differences in topography between the South Jetty, Deep Water, and Shallow Water sites.

    a. Although we made only trial surveys at the Shallow Water site, we found it to be composed of large sand mounds that were difficult for the sled to traverse. These may be a consequence of the bulk deposition practiced there compared to the dispersed deposition conducted at the South Jetty site.

    b. The South Jetty site was relatively flat and lacked large topographic features.

    c. The Deep Water site was also predominately flat, but during some control sled transects we encountered rocky outcrops and rubble fields, which we did not expect and will endeavor to avoid in future surveys.

3. In terms of faunal densities, we observed interesting differences between the South Jetty and Deep Water locations. Diversity and abundance were much higher, and benthic fishes tended to be larger at the Deep Water than at the South Jetty site. Dungeness crab were common at both sites, but were found at extremely high density at the Deep Water impact site in association with echiuroid worms.

At the South Jetty site, we found few differences in density among treatments, but we reiterate there were few deposition events between the two surveys. In general, variance between replicates tended to be high, reducing the ability to detect differences between treatments. Additional replicates may be possible with our redesigned sled, and a greater number of replicates would help reduce variance.

Video Monitoring for Acute Effects (CamPod)

1. General conclusions from deposition experiments at the South Jetty site indicate sediment layers were thin and rarely exceeded 2 cm. However, the sediment plume from the deposition events was energetic and sufficient to cause both behavioral responses (escape) and physical entrainment.

2. An acute or immediate effect of deposition was that crabs and fishes were always displaced by the sediment plume. Whelks had a more muted response, and many were not displaced during deposition events.

3. In post-deposition video (when CamPod recordings were sufficiently long), crabs and fish were observed to return to the site soon after deposition events.

We concluded that the sediment plume exerts taxon-specific acute effects on organisms, with unknown consequences to individual crab and fish entrained by the plume.

Acoustic Telemetry to Monitor Acute and Chronic Effects

1. We released 60 tagged Dungeness crab in three batches each separated by about 2 weeks. Again, deposition events by *Essayons* varied widely over this period and did not conform to the envisioned cumulative impact exemplified by the deposition pattern at the Deep Water site.

2. Despite the variation in deposition events, behavioral interpretations based on presence/absence data did not indicate striking differences between crabs released at control and impact sites or across the three release dates. Crabs appeared to be relatively mobile at both sites: they did tend to move away from the impact array at a higher rate than at the control array. When the positional data is analyzed, we will have a better understanding of possible acute and long-term effects.

Adaptive Management Tasks for 2015

1. Deploy coastal monitoring instrument buoy to identify and avoid low visibility periods and provide environmental context.

2. Rebuild lighter sled and acquire longer umbilical cable to reach deeper sites.

3. Conduct spatial analysis of sled transect data using ship track and topographic survey information.

4. Complete 2014 telemetry analysis, and evaluate acoustic array geometry with considerations for additional receiver deployments to expand coverage in 2015.

5. Coordinate CamPod and tagging experiments to closely coincide with dredge disposal schedule at the South Jetty site in 2015.

6. Conduct sled surveys at the South Jetty site, Deep Water site, and the North Head Site, with schedule determined by the LCSG.

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We are grateful to the captains and crew of *Essayons* for coordinating deposition runs through the acoustic arrays and over CamPod strings. We keenly thank our field crew, “Briny” Brian Kelly and “Droney” Joe Aga of Ocean Associates, as well as Captain Tim Stentz and crew of the F/V *Forerunner* for their assistance at sea. Deepwater sled work was accomplished under direction of Keith Matteson and Scott Marion of the Oregon Department of Fish and Wildlife. Major funding for this research was provided by US Army Corps of Engineers, U.S. Environmental Protection Agency, and NOAA Fisheries.

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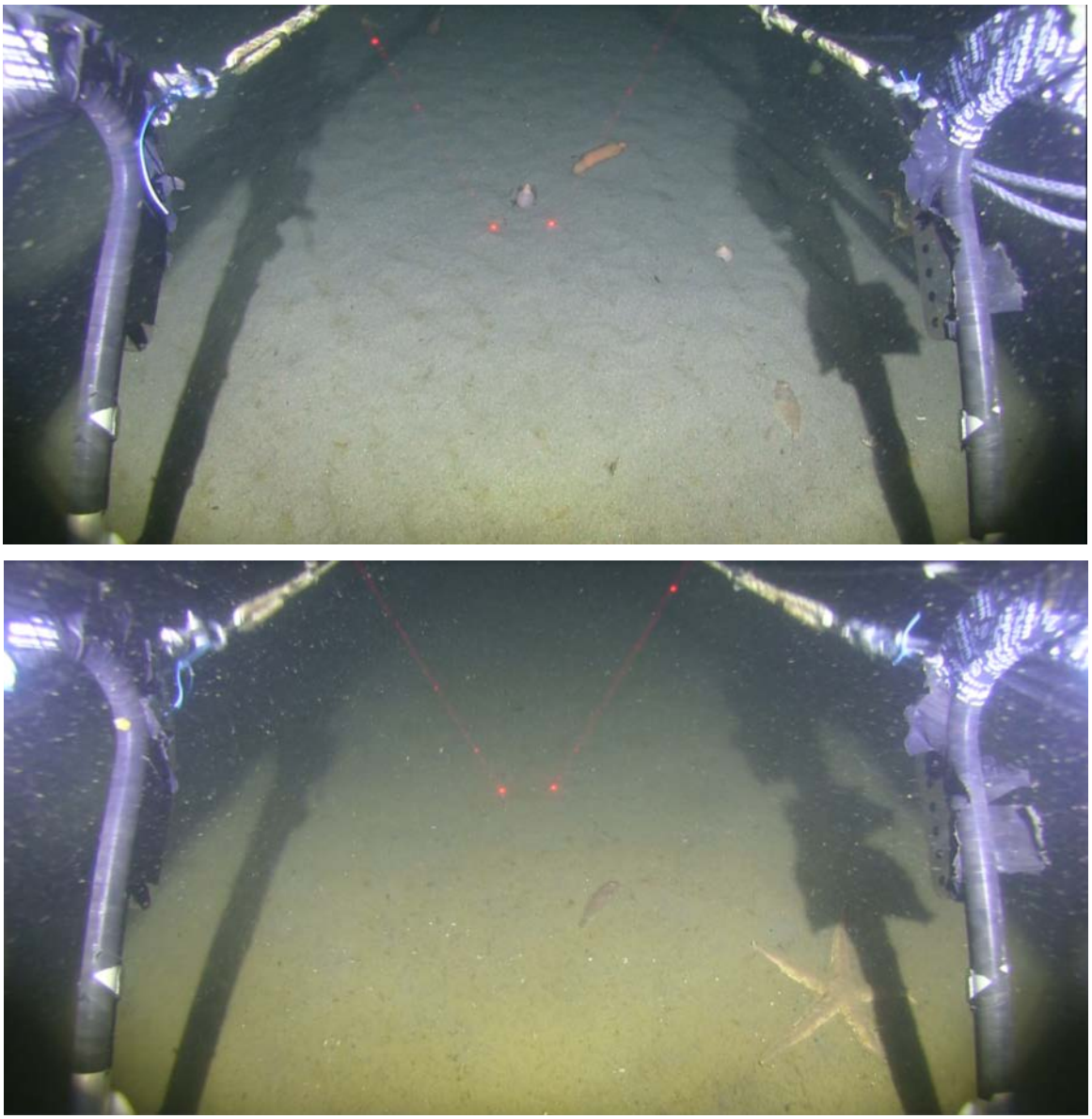
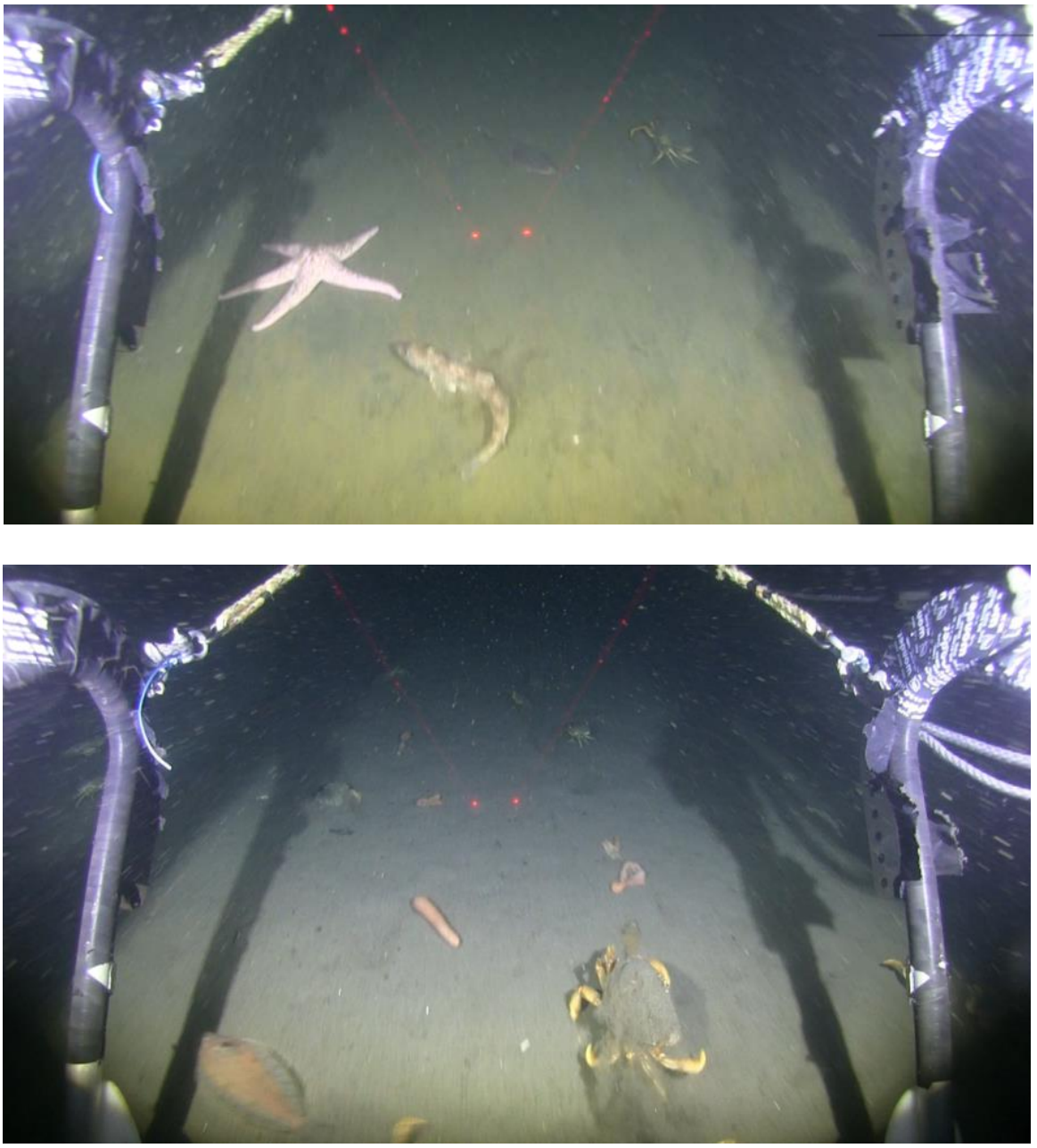
Appendix: Benthic Images

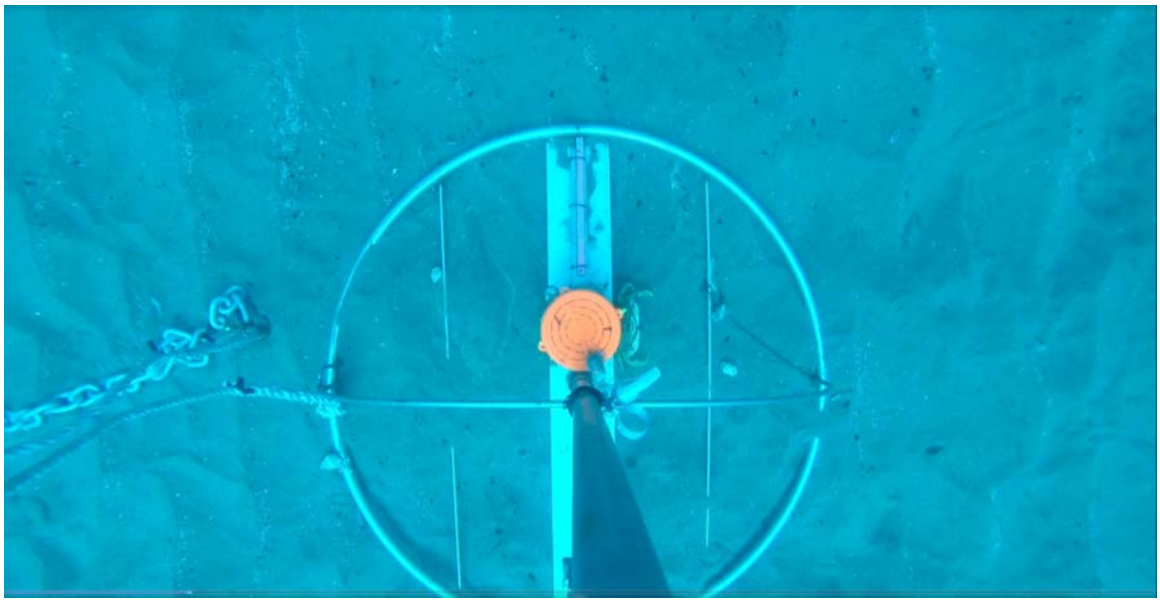
Shown here are selected images from deployments of the benthic sled and CamPods at the South Jetty and Deep Water sites. Additional video clips from sled and CamPod deployments are available online (Roegner 2015).



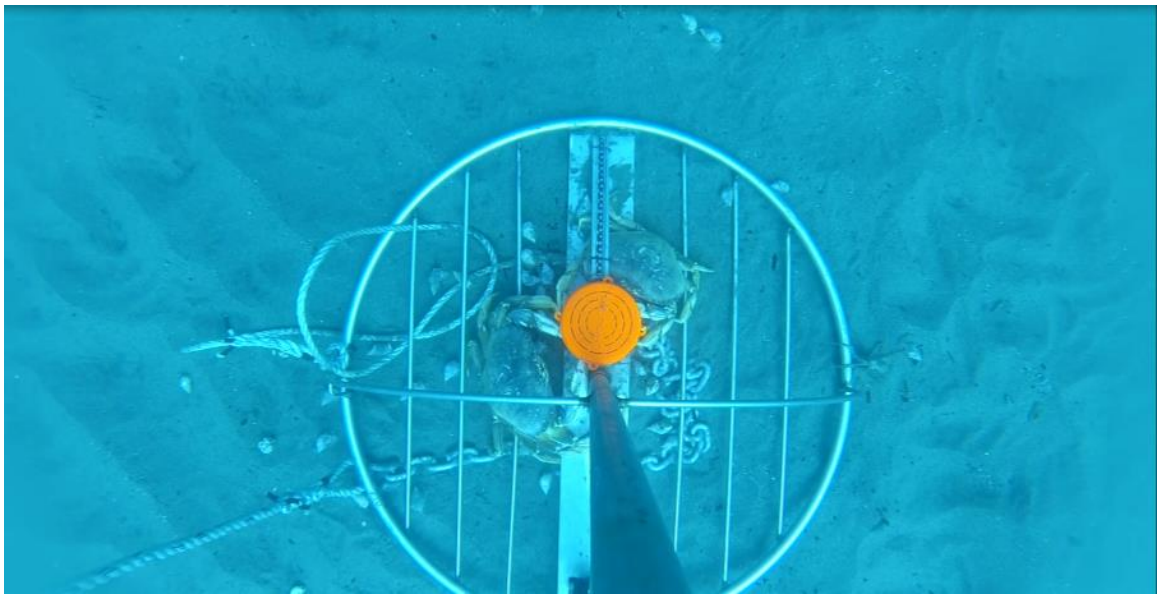
Appendix Figure 1. Benthic sled images from the Deep Water site. Upper photo shows a spoon worm laying on the surface and another reburrowing. Lower photos shows sand star and right-eyed flatfish. See Table 2 for species names.

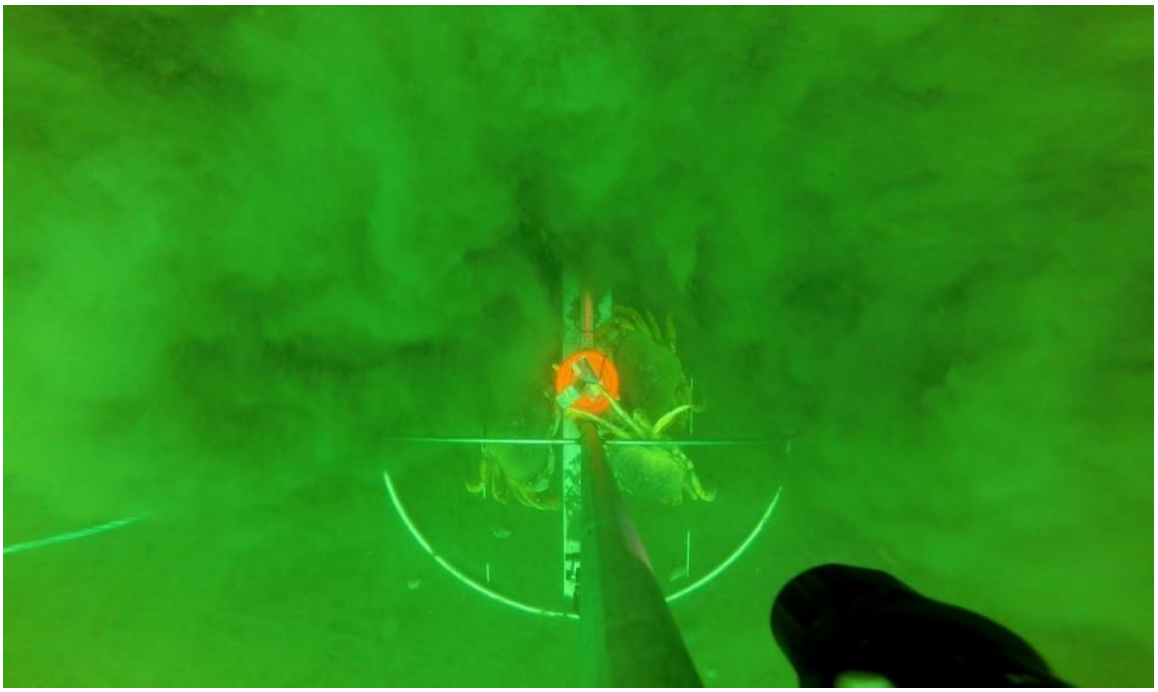


Appendix Figure 2. Benthic sled images from the Deep Water site. Upper photo shows ling cod, pink sea star, flatfish, and Dungeness crab. Lower photo shows flatfish, spoon worms, and Dungeness crab emerging from sediment. See Table 2 for species names



Appendix Figure 3. Video images from the South Jetty site. Upper image from video sled shows Dungeness crab. Lower image from CamPod shows sand sole, crab, and whelks. See Table 2 for species names





Appendix Figure 4. Video images from the South Jetty site. Upper image from CamPod shows crabs and whelks accumulating at the bait. Lower image shows impact of sediment plume at baited CamPod.