Final Report

A Potential Restoration Approach for Sandy Beaches Impacted by Oil Spill and Cleanup Activities

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January 2009

Introduction

Exposed sandy beaches comprise three-quarters of the world's open coast shorelines (Bascom 1980) and are valued for human recreation and as habitat and resources for wildlife (Schlacher et al 2008, Hubbard and Dugan 2003). This prevalence means beaches are often the primary coastal habitats affected by oil spills and cleanup activities. Agencies, such as the California Department of Fish and Game's Office of Spill Prevention and Response (OSPR) and the National Oceanic and Atmospheric Administration (NOAA), are under increasing pressure to develop environmentally sensitive, cost-effective strategies to respond to, clean up and restore beaches impacted by an oil spill.

Macroinvertebrate communities inhabiting sandy beaches depend almost entirely upon allochthonous inputs of carbon and organic material (Brown and McLachlan 1990). For California beaches, stranded marine macrophytes (macroalgae, seagrasses) from rocky reefs represent a major subsidy that supports a diverse and productive portion of beach food webs (Dugan et al 2003). Changes in the supply and accumulation of macrophyte wrack have significant bottom-up effects on this ecosystem, altering the biodiversity, structure, composition and dynamics of the macroinvertebrate community, and consequently the availability of prey to higher trophic levels, such as shorebirds and fishes (Dugan et al. 2003). Our results from groomed beaches suggest that removal of wrack significantly reduces not only wrack cover, but the species richness, abundance and biomass of intertidal macroinvertebrates, prey availability to shorebirds and the cover of dune vegetation on sandy beaches (Dugan et al. 2000, 2003). Wrack-associated animals, such as amphipods, isopods, and insects, made up an average of >37% of the invertebrate species on ungroomed beaches (Dugan et al. 2003). The wintering abundance of two shorebirds, Black-bellied Plovers and Western Snowy Plovers, that forage using visual cues, were positively correlated with the standing crop of wrack and with the abundance of wrack-associated invertebrate prey (Dugan et al. 2003). The density and distribution of snowy plover nests and chicks was also correlated with wrack availability and prey diversity and abundance (Dugan et al 2008). Hence, the ecological costs of the disturbance and removal of organic material, food resources and habitat associated with the removal of wrack during an oil spill appear to be great.

The ability of damaged beach ecosystems to recover their function and ecological integrity after an oil spill is unknown, as is the time course for recovery. The recovery of full ecological function of sandy beach ecosystems impacted by an oil spill should include the support of 1) populations of organisms that consume stranded macrophyte wrack, 2) a full range of trophic levels including shorebirds and 3) a diverse community that includes direct-developing crustaceans and flightless insects.

We investigated hypotheses concerning approaches that could be useful in the ecological restoration and recovery of sandy beaches from an oil spill and cleanup activities. We experimentally enhanced the allochthonous subsidy of organic material to beaches in the form of macrophyte wrack additions and measured the responses of: the diversity, abundance and composition of the wrack-associated invertebrate community. Specifically, we tested predictions concerning the responses of species richness, abundance, biomass, and composition of the wrack-associated invertebrate community with regard to the overall recovery and to the dispersal capabilities of different wrack-associated taxa to wrack additions.

Methods

We conducted manipulative field experiments at two locations to investigate aspects of the recovery of exposed sandy beaches from oil spill/ wrack removal. We investigated whether experimental plots diverge from control sites over different time periods using a modified Before-After-Control-Impact (BACI) design (e.g. Schroeter et al. 1993) to examine changes in a number of response variables before and after wrack is added to experimental treatments, using un-manipulated plots as controls. Response variables included the wrack cover and type, and abundance, biomass, and species richness of the wrack-associated invertebrates, of the experimental treatments and controls or references. We measured these response variables before or soon after wrack additions and at regularly spaced intervals the experimental period. To assess our hypotheses, we statistically tested for divergence in the response variables between the experimental and control treatments.

Experimental Designs

1) Santa Claus Lane Short Term Wrack Addition Invertebrate Study 2006

The treatment was designed to double the standing crop of wrack in the experimental plots on a weekly basis by adding 15 kg of fresh kelp to each treatment plot. We randomly selected 4 treatment plots (wrack addition) and 4 control plots (no addition) on ~200 m of shoreline of an ungroomed beach in southern Santa Barbara County (Figure 1). Each plot was ~25 m of shoreline length. Plots were delineated by lineups with houses and riprap features. Pre-treatment sampling of all 8 plots was conducted on July 13th 2006 using cores and sticky traps on 3 replicate transects per plot. The first wrack addition to the treatment plots was July 24th 2006.

For the additions, fresh *Macrocystis pyrifera* was collected from the swash zone at a nearby beach, rinsed clean, weighed into 5 kg portions, bagged and transported immediately to the treatment plots. Long fronds with a good number of blades were selected and no holdfasts or bare stipes were used. Each plot addition treatment consisted of 3 replicate 5 kg portions of fresh *M. pyrifera* for a total of 15 kg per plot. The wrack was added on the high tide strand line in ~ 1m diameter piles at the center of the plot and 1 m east and west of the center line. Wrack was added to the treatment plots weekly for 8 weeks, from July 24, 2006 to September 12, 2006 for a total addition of 120 kg per plot. The experimental and treatment plots were sampled 4 times after wrack addition was initiated, at 1 week, 2 weeks, 4 weeks and 8 weeks.

Figure 1. Location of short term wrack addition experiment west of Santa Claus Lane beach in Carpinteria, CA in summer 2006. Arrows indicate the extent of the area where the experimental plots were located.

2) Oceano Dunes Wrack Addition Invertebrate Study 2007

To investigate responses of wrack-associated invertebrates to wrack additions in seasonally closed area compared to reference and control areas during the 6 month closure period for Snowy plover nesting (March 1 to October 1). The study design consisted of five study areas: two treatments (T1, T2), two reference (R1, R2), and one control (C) (Table 1, Figure 2).

Table 1. Description of study areas for long term wrack addition experiment at Oceano Dunes.

Treatments:	Snowy Plover Seasonal ORV Exclosure (March 1 to Oct 1)
	T1-Wrack Addition (Pole 6-7)
	T2-Wrack Accumulation (Pole 8 – Cable Fence)
Reference:	Year-round ORV closures
	R1-North Oso Flaco (Cable Fence and south)
	R2-North of Grand Avenue Ramp
Control:	Year-round ORV use (Riding Area)
	C-Pole 5-6

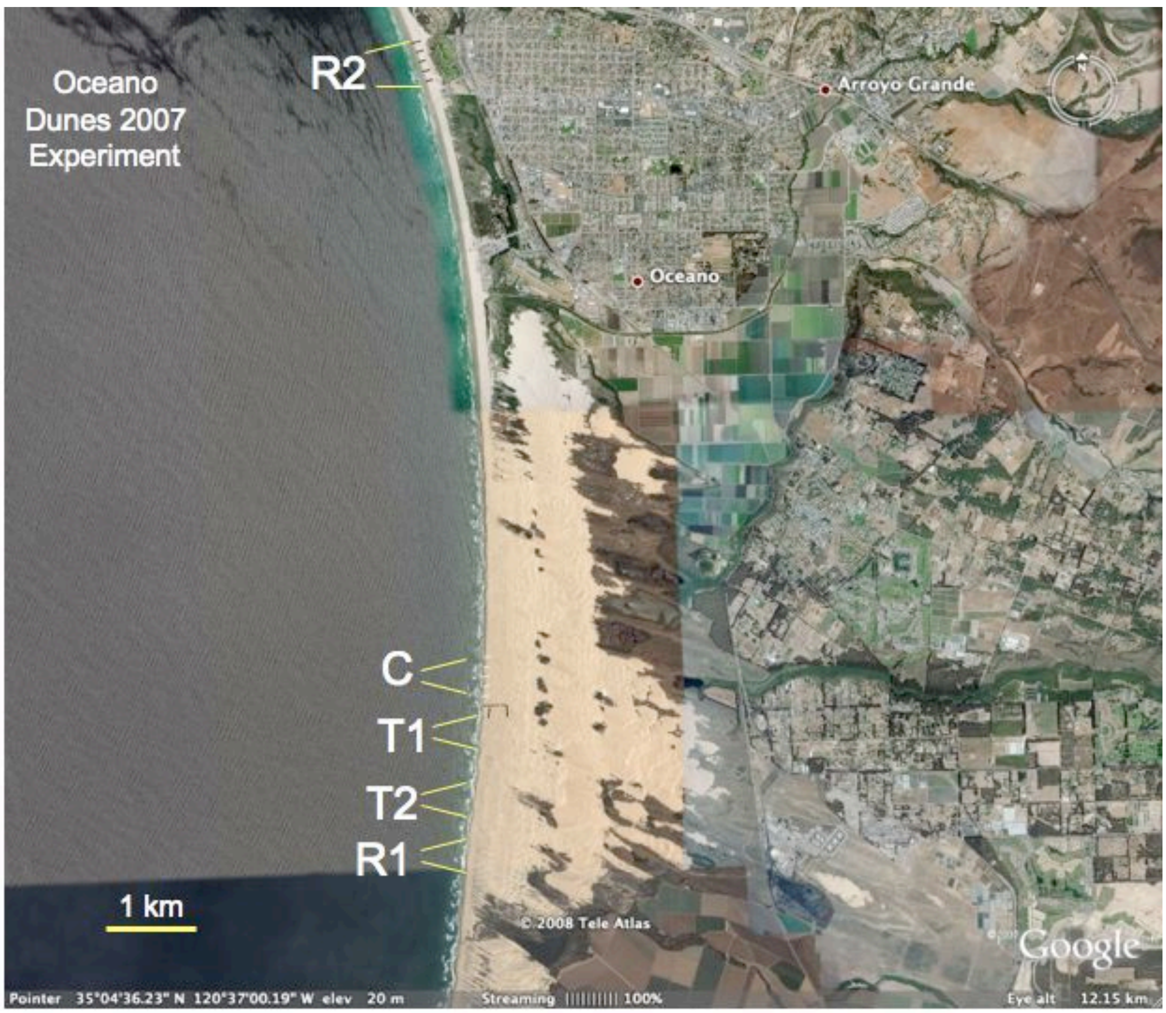

Figure 2. Approximate locations of treatment (**T1, T2**), reference (**R1, R2**) and control (**C**) areas for the 2007 experiment at Oceano Dunes. Each area indicated spanned ~ 500 m of shoreline and contained 5 replicate transects.

The experimental treatments consisted of wrack addition (T1) and no wrack addition (T2) in the area that is seasonally closed to recreational and ORV use (March 1 to October 1) (Table 1, Figure 2). Wrack was added to T1 by California State Parks biologists and staff as part of the enhancement program for snowy plover breeding beginning in March 2007. Amounts of wrack added to the T1 treatment area varied over time depending on availability of fresh wrack and staff resources. A total of 3441 cubic feet of wrack was added to T1 and vicinity between March 1 and August 5th 2007. Wrack was allowed to accumulate naturally in T2. The reference areas were areas closed to ORV use year round but subject to other recreational use at least seasonally (R1: North Oso Flaco) or year round (R2 North of Grand Avenue). The control area (C) was open to ORV use year round. Wrack associated invertebrates were sampled in April, May, June, and in Aug/Sept. on 5 replicate transects in each of the 5 study areas. No samples were collected in July to avoid nesting least terns and snowy plover broods.

Sampling methods

Beach zone widths (dry and damp sand zones) were estimated from distance measurements. On each shore-normal transect, we measured the distance from the vegetation, fence or rock line to two points 1) the high tide strand line (HTS) or drift line and 2) the water table outcrop (WTO) or effluent line. Beach slope was measured in degrees with an electronic level at these two points.

The cover and composition of macrophyte wrack, driftwood, rocks, animal material, and terrestrial vegetation were measured between the lowest strand vegetation line and the swash zone along each shore-normal transect using a line intercept approach. The distance covered and depth of all material (wrack or other) $\geq$1 cm intersecting the transect line was recorded

Core, sticky trap, and standard net sweep samples to estimate the composition and availability of macroinvertebrates. Flying invertebrates were collected with standard insect net sweeps along for a 1 m wide swath from the HTS to the swash zone on each transect prior to collection of cores at Oceano only. To collect flying and crawling invertebrates, 2 sticky traps (commercial fly paper strips, Aeroxon®) were deployed on fresh brown algal wrack located below the HTS on each transect for 15 minutes. After 15 minutes, the strips were collected and placed in labeled 1 gallon ziplock bags for later analysis. Infaunal macroinvertebrates were sampled between the upper shore and the lowest wrack line with a series of ten equally spaced cores (10 cm diameter to a depth of 20 cm). All cores were placed in a mesh bag (1.5 mm opening) and sieved in the swash zone retaining the animals and coarse sediments. The contents of the mesh bag were then transferred to a labeled 1 gallon ziplock bag that was returned to the lab and frozen for later processing and analyses. At Oceano, we also collected cores of 3 wrack piles in each area.

Laboratory processing

In the laboratory, all prey species in each sample were identified, enumerated, blotted dry and weighed to the nearest 0.001g. Wrack and coarse sediments retained in each sample were dried and weighed to the nearest 0.01g. The number, higher taxonomic group and size of animals were counted on both sides of each sticky trap. We calculated basic statistics by species and for total abundance, biomass and species richness of prey for each transect. Macrofauna species richness (total species in samples) was compiled for each transect. Mean faunal abundance and wet biomass for each meter wide strip of beach were calculated for selected target species and the total prey assemblage for each transect using the core spacing.

Results

1) Small scale short term wrack addition Santa Claus Lane

A diversity of wrack associated invertebrates including an oniscoid isopod, 4 species of talitrid amphipods, a wide variety of beetles from 6 families, mites, pseudoscorpions and several species of flies were found in the core samples suggesting the beach at Santa Claus Lane supports a rich upper beach fauna. The core samples also contained eggs of the California grunion, *Leuresthes tenuis* on two sample dates (July 31 and August 9, 2006).

Three response variables for wrack associated invertebrates, species richness, abundance and biomass, were compared in the small scale 8 week experiment on wrack addition at Santa Claus Lane in 2006. Initial conditions for species richness varied from 7 to 11 species per plot among plots. Initial abundance varied from 6858 to 19083 individuals m^{-1} and biomass from 88 to 524 g m^{-1} among the 8 plots. Species richness responded positively to the addition of wrack (Figure 3). In the addition plots species richness nearly doubled in 8 weeks from a mean of 8.8 species to 16 species per plot. In the control plots species richness declined from 8.0 species to 5.8 species per plot over 8 weeks.

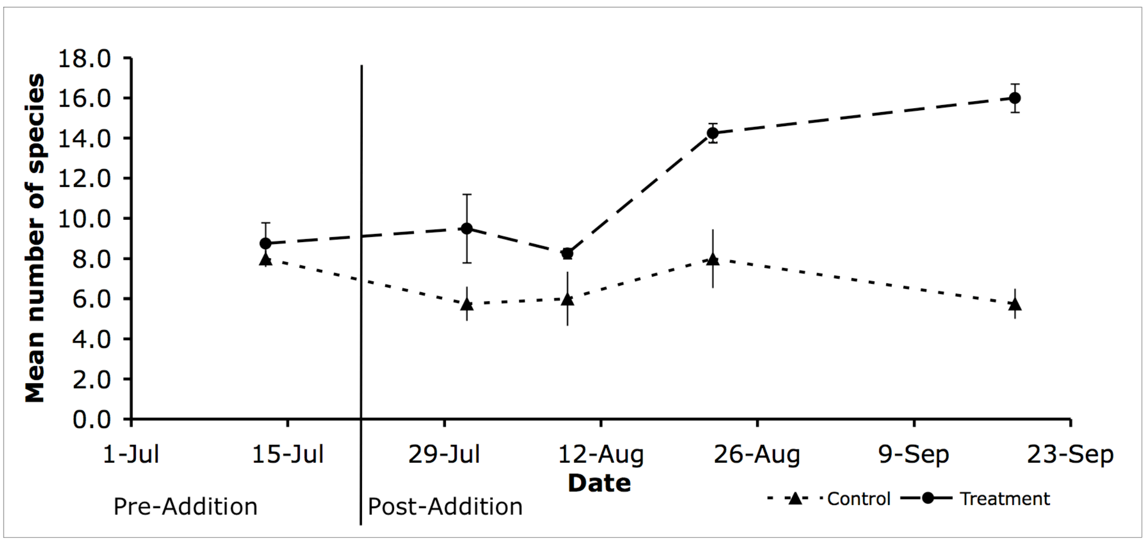

Figure 3. Mean species richness of wrack invertebrates in control and treatment plots of the wrack addition experiment at Santa Claus Lane in 2006. Error bars = +/- 1 standard error.

The mean abundance and biomass of the treatment plots were also higher than the controls after 8 weeks of wrack addition. However, the responses of abundance and biomass to the weekly wrack addition treatments were less clear-cut than species richness (Figures 4, 5) due to higher variability among plots, as indicated by the large standard errors. Much of this variation was driven by taxa, such as talitrids and oniscoid isopods, that could potentially move across the relatively small (25 m wide) plots.

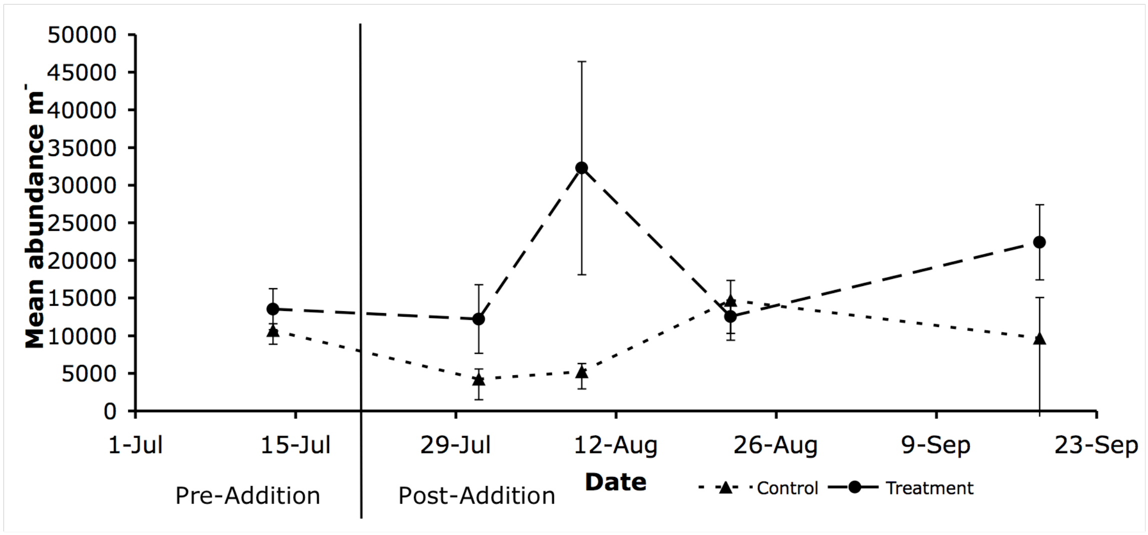

Figure 4. Mean abundance of wrack invertebrates in control and treatment plots of the wrack addition experiment at Santa Claus Lane in 2006. Error bars = +/- 1 standard error.

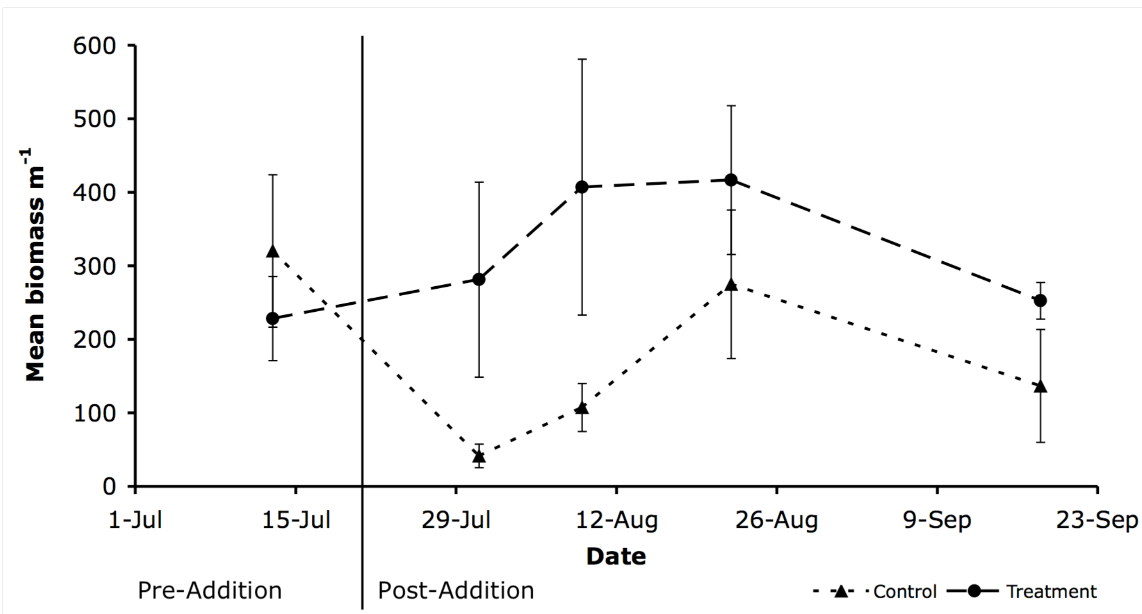

Figure 5. Mean wet biomass of wrack invertebrates in control and treatment plots of the wrack addition experiment at Santa Claus Lane in 2006. Error bars = +/- 1 standard error.

The experimental results were analyzed with a non- parametric multivariate approach (PRIMER) designed to analyze matrices of species by sample abundance (or biomass). The results of the MDS (multi-dimensional scaling) and the ANOSIM (analysis of similarity) for abundance indicated that although the treatment and control plots did not differ at the beginning of the experiment (Figure 6), they diverged over time (Figures 7, 8, 9, 10).

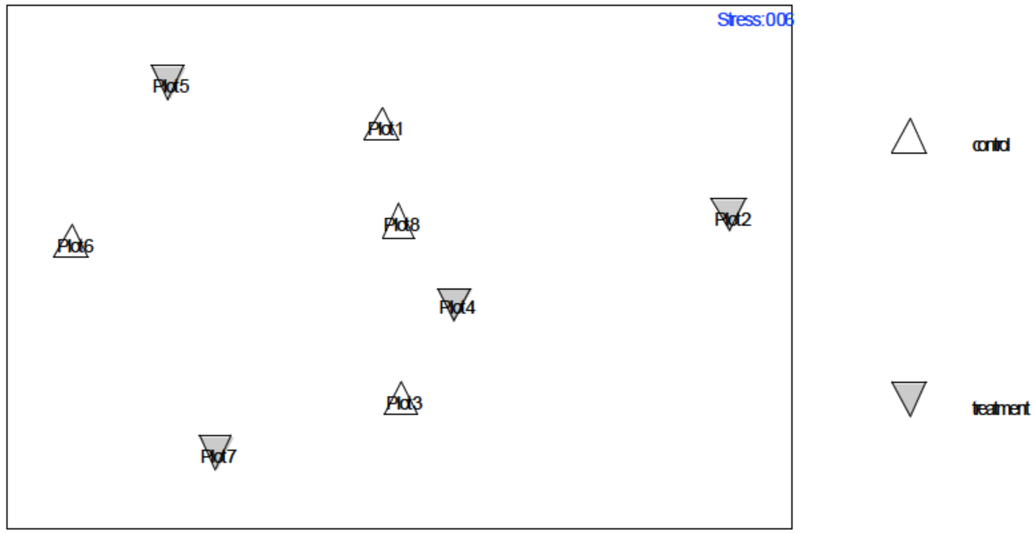

Figure 6. MDS plot of wrack invertebrate community in control and treatment plots on July 13, 2006, 11 days before experimental manipulation (wrack addition) was initiated (square root transformed data). Treatment plots are grey triangles and control plots are open triangles and plot numbers appear in each symbol

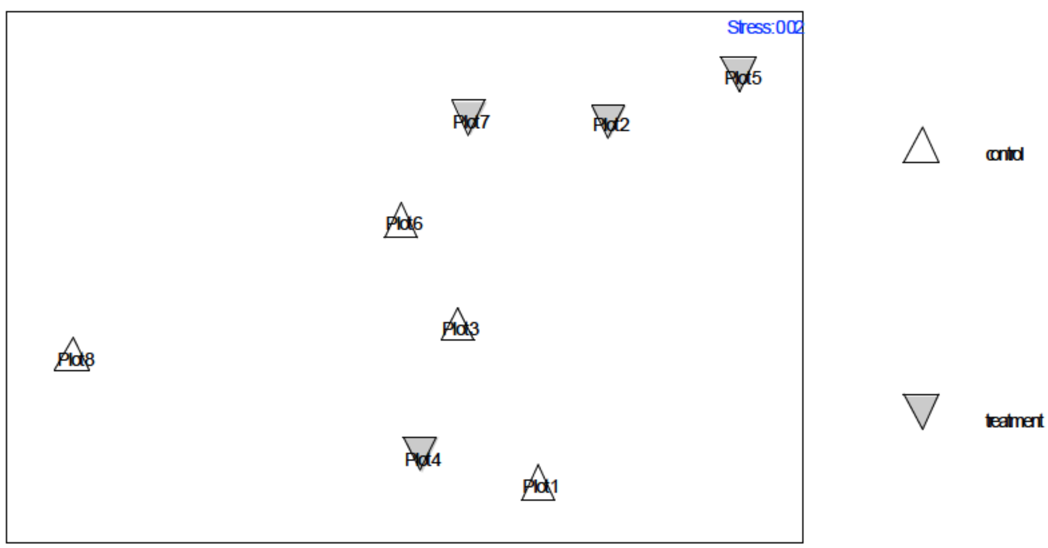

Figure 7. MDS plot of wrack invertebrate community in control and treatment plots on July 31, 2006, one week after experimental manipulation (wrack addition) was initiated (square root transformed data). Treatment plots are grey triangles and control plots are open triangles and plot numbers appear in each symbol.

MDS analysis showed the invertebrate assemblages in the treatment and controls did not differ significantly before the experimental wrack addition (Figure 6). Some separation in the assemblages by treatment was evident even after 1 week of addition (Figure 7) where 3 of the 4 treatment (addition) plots (7, 2 and 5) are in the upper right portion of the MDS plot. After two weeks of wrack additions, invertebrate assemblages of the treatments and controls continued to diverge (Figure 8) with most of the treatment points on the left side of the MDS plot. After four weeks, divergence in the assemblages of the controls and treatments was quite evident in the MDS plot (Figure 9). At eight weeks, controls and treatments had clearly diverged further, indicated by the separation and relative distances between the two groups of points (Figure 10).

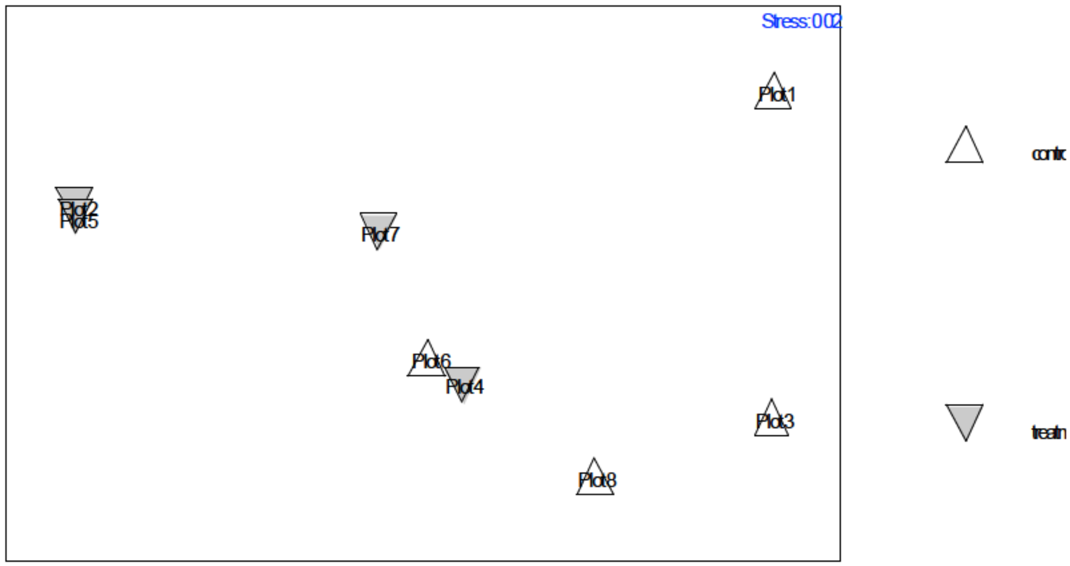

Figure 8. MDS plot of wrack invertebrate community in control and treatment plots on August 9, 2006, two weeks after experimental manipulation (wrack addition) was initiated (square root transformed data). Treatment plots are grey triangles and control plots are open triangles and plot numbers appear in each symbol.

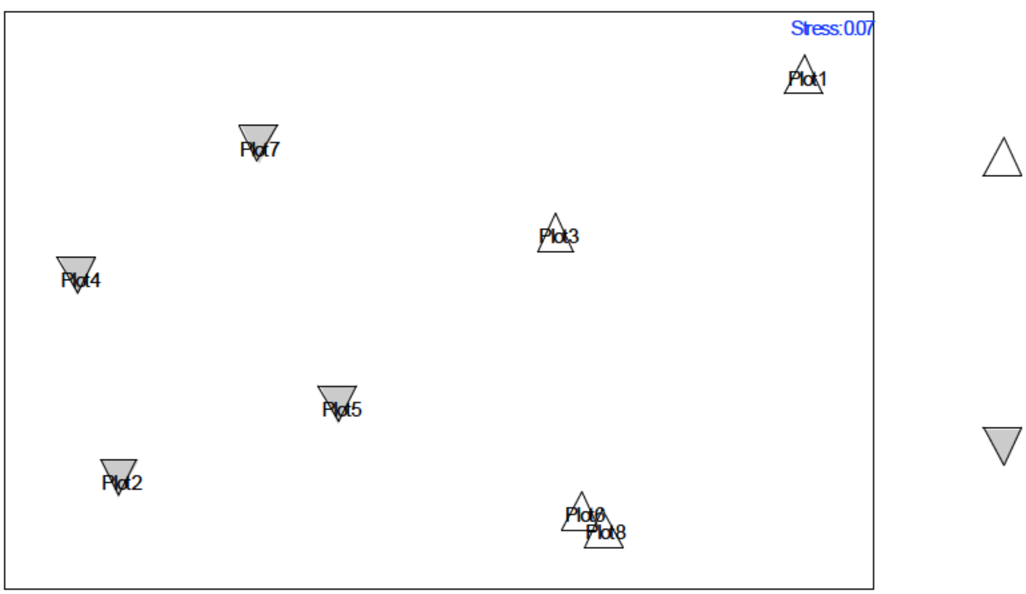

Figure 9. MDS plot of wrack invertebrate community in control and treatment plots on August 22, 2006, four weeks after experimental manipulation (wrack addition) was initiated (square root transformed data). Treatment plots are grey triangles and control plots are open triangles and plot numbers appear in each symbol.

Figure 10. MDS plot of wrack invertebrate community in control and treatment plots on September 18, 2006, eight weeks after experimental manipulation (wrack addition) was initiated (square root transformed data). Treatment plots are grey triangles and control plots are open triangles and plot numbers appear in each symbol.

The global correlation coefficient estimate of similarity (R) values from the ANOSIM analyses for each sample date were used to evaluate change in similarity between the treatment and control plots over time (Figure 11). The decrease observed in this estimate over time indicates that the treatment and control plots diverged strongly during the course of the experiment. By 4 weeks, a statistically significant difference in community composition was observed between control and treatment plots ($p < 0.03$). A significant difference ($p < 0.03$) in community composition between treatment and control plots was also present at 8 weeks.

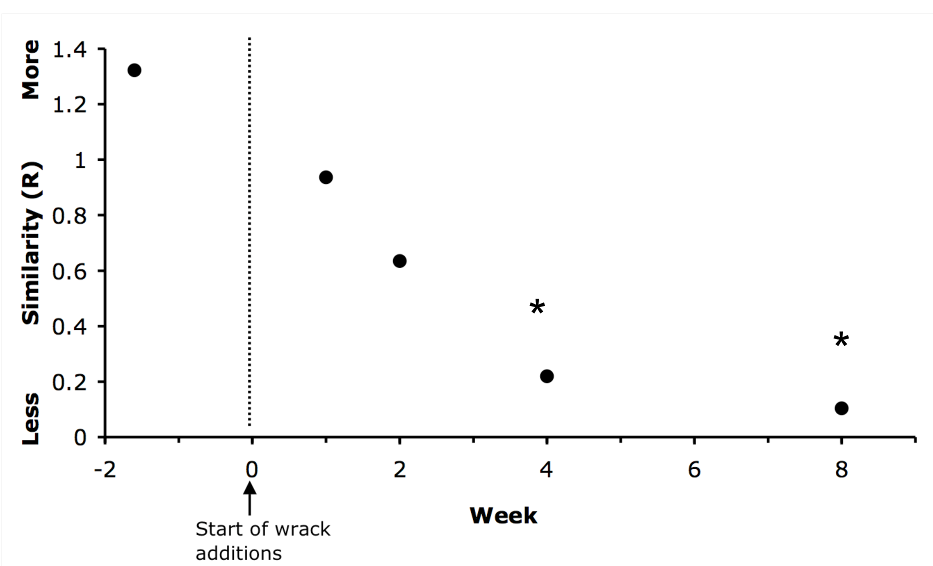

Figure 11. Global correlation coefficient (R) estimate of similarity in the wrack invertebrate community (abundance) between the treatment (wrack addition) and control plots in the short-term wrack addition experiment at Santa Claus Lane (* denotes significant difference between treatments and controls, $p < 0.05$) (square root transformed data).

The results of our small scale experiment on the effects of enhancing wrack resources for an undisturbed beach with an intact wrack invertebrate community suggest that addition of wrack to a beach ecosystem can result in significant changes in the structure this community on a relatively short time span, in particular, increased species richness and changes in composition. The proportion of the observed changes that are a result of invertebrate responses to increased food, habitat or both needs to be further explored. The mechanism of response to the manipulation of wrack resources could be related to aggregation in the short term and/or increased production of the invertebrate community.

2) Large scale wrack addition-Oceano Dunes

Starting conditions for the large scale, longer term (6 month) wrack addition experiment at Oceano Dunes State Vehicular Recreation Area (ODSVRA) were dramatically different to those for the short-term experiment at Santa Claus Lane. At Oceano Dunes, the wrack invertebrate community is subject to regular disturbance by ORV use in the treatment and control plots from October 1 to March 1. On March 1 the area containing the treatment plots is closed to ORV use until September 30th for snowy plover and least tern nesting, leaving a 7 month window that we used to evaluate recovery of the wrack-associated invertebrate community from disturbance.

Initial samples of the treatment, control and reference areas at Oceano Dunes were collected in mid April 2007, ~1.5 months after the area was closed to vehicle use. The April samples indicated that the wrack invertebrate community was absent or extremely low in abundance (<2500 ind. m^{-1}) and diversity (1 species) at all treatment plots after >1.5 months of recovery time (Figures 12, 13). In contrast, the reference areas to the north and south of the vehicular use area supported a diverse and relatively abundant wrack invertebrate community in mid-April. Samples from the control area (C) contained zero to very few animals for all transects in all months of the study and are not included in most of the graphs.

Samples from the reference areas (R1, R2) contained a high diversity of animals throughout the study with mean species richness of 3-5 species (Figure 12). Strong temporal patterns in species richness were not apparent in the reference areas. For the treatment areas (T1, T2) mean species richness increased from 1 to ~3 species over time, suggesting that some recovery occurred.

In comparison to the control area (C), where very few animals occurred and most samples contained no animals, a moderate abundance of invertebrates developed over time in the two treatments (T1, T2) in the seasonally closed area, although variation was high among samples (Figure 13). Total abundance in the T1 treatment area was close to that of the reference area in June. High variability was particularly apparent in the treatment area (T1) where the wrack additions were spatially and temporally variable. Peak abundance occurred in the June samples.

A different pattern of response or recovery was observed in the biomass of wrack-associated invertebrates over time among the treatment and reference areas. Total biomass was always much greater in the reference areas than in the treatment areas (Figure 14). In the reference areas mean total biomass ranged from 50 g m^{-1} to 160 g m^{-1}, while in the treatment areas it ranged from 10 g m^{-1} to 40 g m^{-1}. A temporal pattern was evident with peak biomass in the June samples at the reference areas.

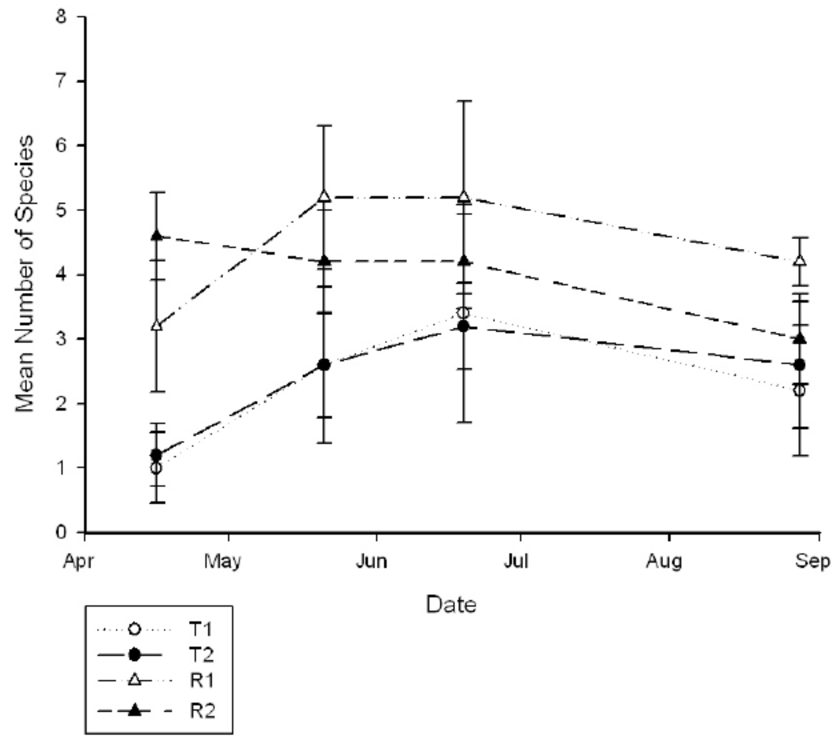

Figure 12. Mean species richness of wrack invertebrates in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

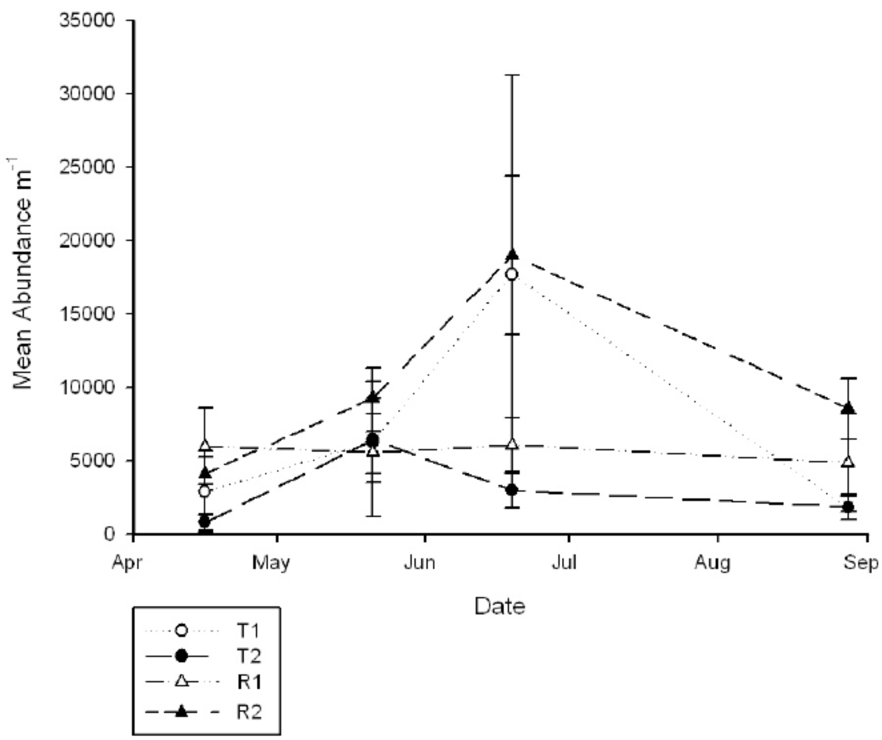

Figure 13. Mean abundance of wrack invertebrates in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

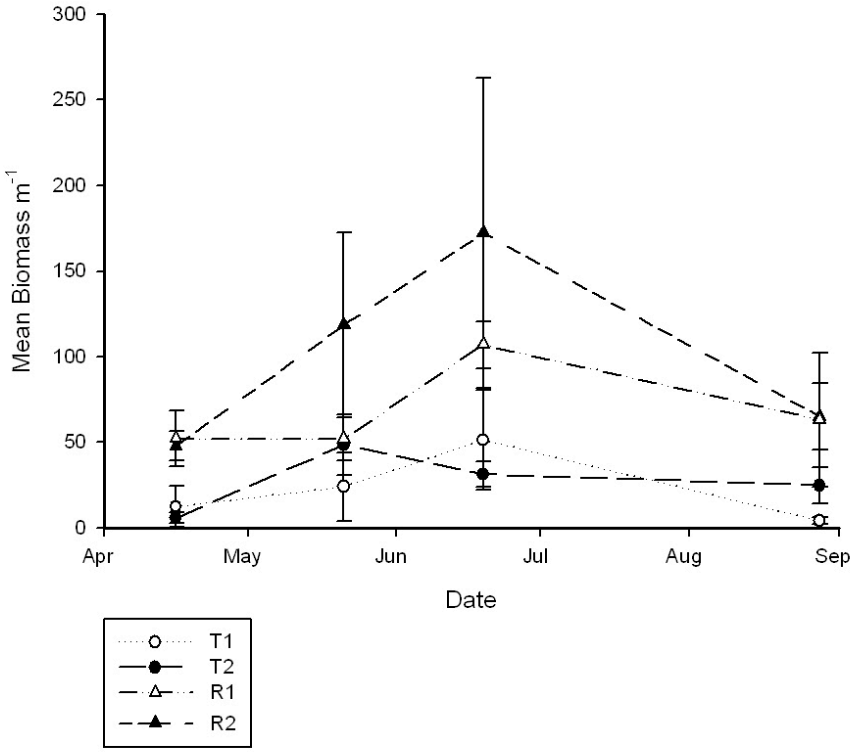

Figure 14. Mean biomass of wrack invertebrates in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

The response of wrack-associated invertebrates to the treatments varied strongly with the type of animal (e.g. talitrid amphipod, beetle, kelp fly). In the reference areas the mean abundance of talitrid amphipods was >1000 individual m^{-1} for all sample dates and exceeded 11,000 individuals m^{-1} in R2 in June. In the treatment areas the peak abundance of talitrid amphipods observed was <1000 individuals m^{-1} and abundance was much lower in T1 than in T2 after 6 months of closure (Figure 15). This suggests that recovery of these taxa was very limited even 6 months after disturbance ceased. A similar pattern was observed for beetles (Figure 16). Overall, beetles responded more clearly to the treatments and more than doubled in abundance in treatment areas after 6 months. However, beetle abundance was much greater in the reference areas in all but the August/September samples. The abundance of kelp flies was highly variable over time and among treatment and reference areas, peaking in May and June and declining by the August/September samples (Figure 17). The abundance of flies (primarily larvae/pupae) in core samples appeared to respond most rapidly to the reduction of disturbance reaching high mean abundance (5000 individuals m^{-1}) in treatment areas by May, then declining to low abundance in all areas by August/September. Notably the abundance of fly larvae/pupae in the both treatment areas exceeded the abundance in both reference areas in May. The abundance of adult flies on sticky traps peaked in May and declined by June for all treatment and reference areas (Figure 18).

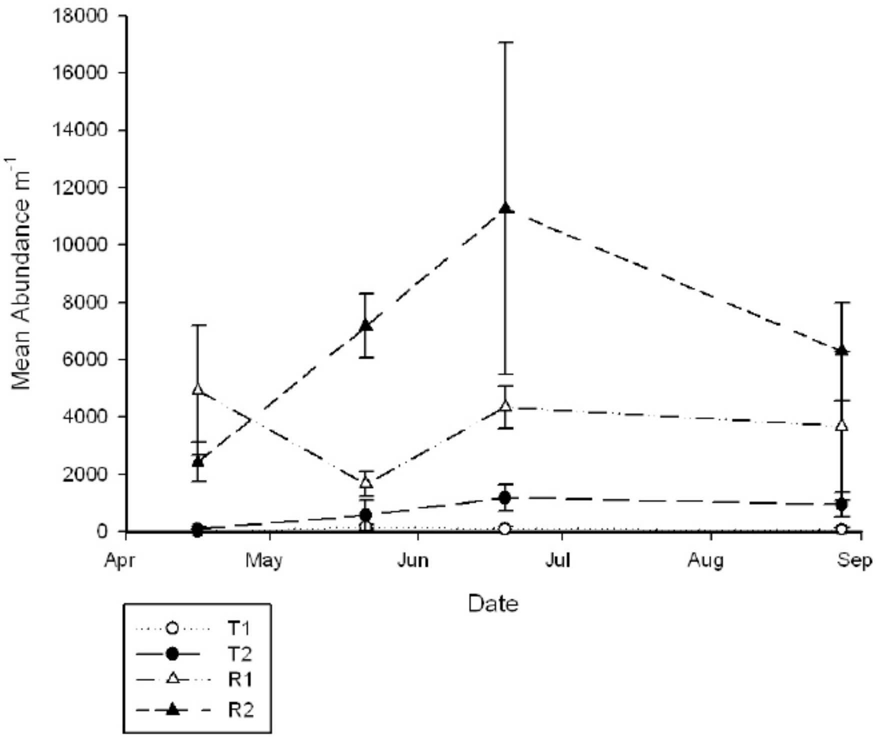

Figure 15. Mean abundance of talitrid amphipods in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

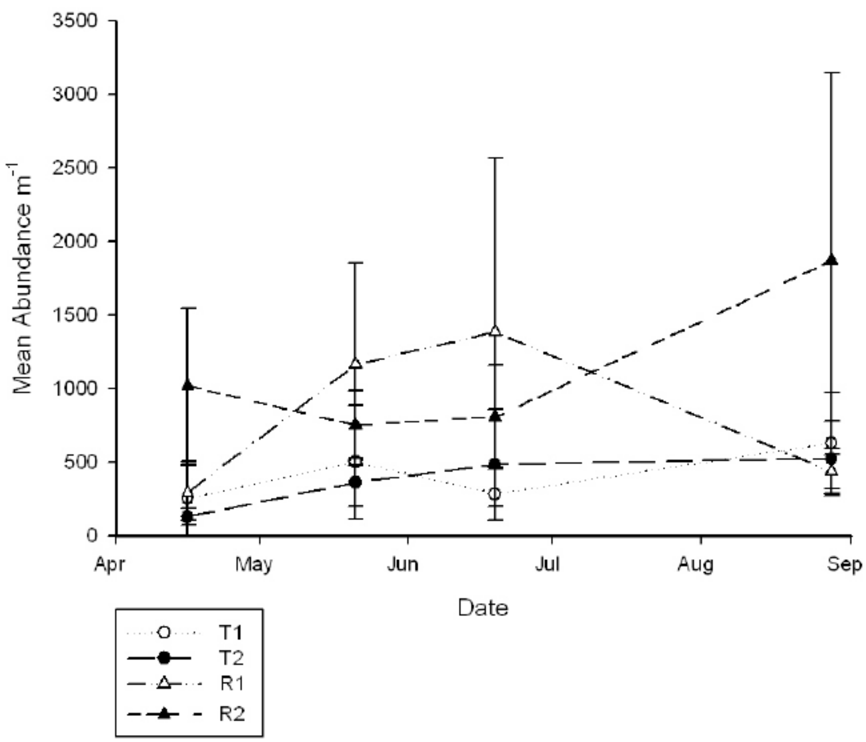

Figure 16. Mean abundance of beetles in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

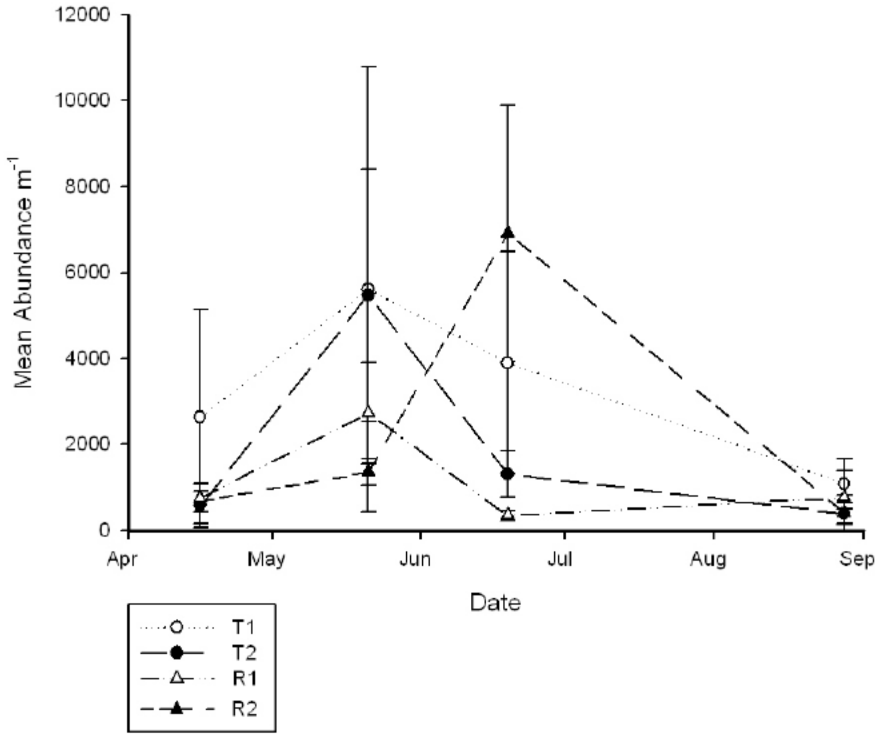

Figure 17. Mean abundance of flies (larvae/pupae) in core samples of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

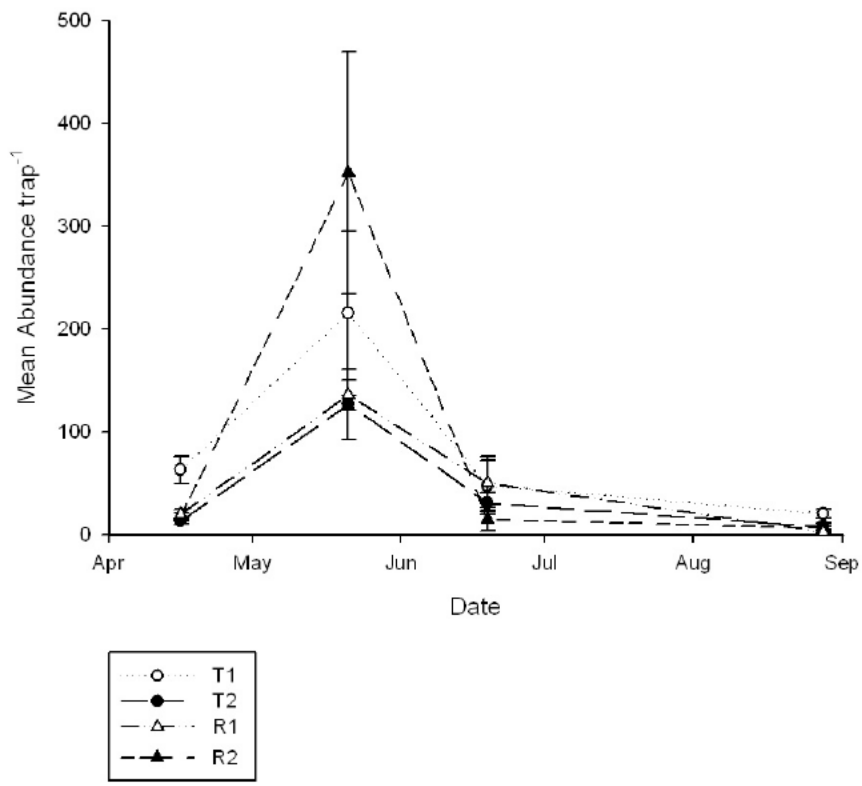

Figure 18. Mean abundance of invertebrates in sticky trap samples (primarily adult flies Anthomyiidae, Empididae) of reference and treatment areas at Oceano Dunes in 2007. Error bars = +/- 1 standard error.

Overall the composition of the wrack-associated invertebrate community differed among treatment and reference areas for the entire study period (Figure 19). The invertebrate communities of the treatment areas were dominated by insects (flies and beetles) and those of the reference areas by crustaceans (primarily talitrid amphipods, congeners of several species). The talitrid amphipods had not recovered to comparable numbers or proportions in the treatment areas 6 months after disturbance ceased. In addition, some crustacean taxa, such as the oniscoid isopod, *Alloniscus perconvexus*, were never observed in the treatment areas.

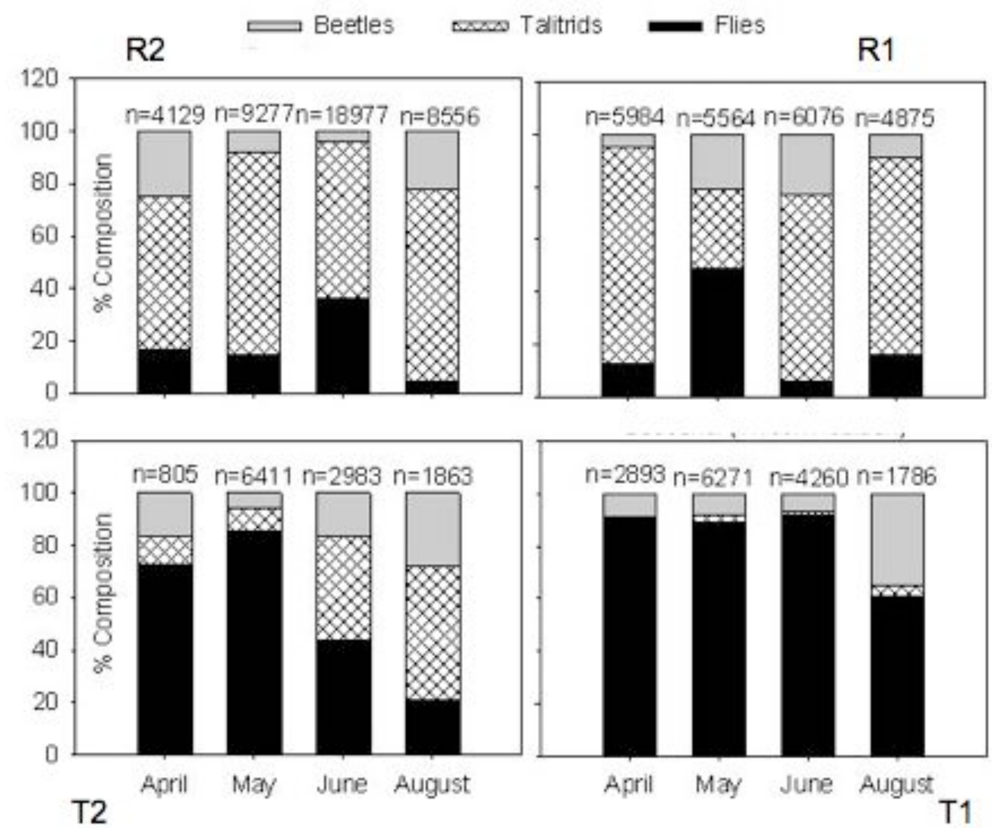

Figure 19. Composition of the wrack-associated invertebrate community in core samples from the reference and treatment areas at Oceano in 2007.

Spatial patterns also appeared to be important to results of our experiment at Oceano Dunes. In April, what appeared to be an edge effect, where abundance increased with distance from the boundary of the disturbed area, was evident at the southern reference site, (R1) North Oso Flaco which bounds the ORV area. The proximity of treatment areas relative to a source area appeared to affect the degree of response observed for talitrid amphipods. Our results indicate that by August/September 2007, limited numbers of talitrids moved north from the North Oso Flaco reference into the nearby treatment (T2) where no wrack was added. In contrast, our results indicated that talitrids did not return to the more distant treatment (T1) area in that same time period even though wrack was added regularly.

The experimental results from Oceano were analyzed with a non-parametric multivariate approach (PRIMER) designed to analyze matrices of species by sample abundance (or biomass). The results of the MDS (multi-dimensional scaling) and the ANOSIM (analysis of similarity) for abundance indicated that the treatments and reference areas differed at the beginning of the experiment (Figure 20) and converged somewhat but not completely over time (Figures 20-23). This approach provides a somewhat inflated estimate of the convergence between treatment and reference sites as an estimate of recovery of the wrack invertebrate community because it only compares samples that contained at least one animal. Any samples that lacked animals were excluded from the analyses as noted in the figure legends. Samples that lacked animals were found only in the treatment areas (or in the control area).

Clear separation between the wrack invertebrate assemblages in the treatment and reference areas was seen in April (Figure 20) where the majority of the treatment area samples are on the left side of the graph. After another month of wrack additions, the invertebrate assemblages of the treatment and reference areas were still fairly separated in the MDS plot for May (Figure 21) with most of the treatment samples on one half of the MDS plot. In June, limited convergence in assemblages was evident from the overlap of some of the reference and treatment samples in the MDS plot (Figure 22). By August/September, the control and treatment samples were again more distinct, as indicated by the relative distances and separation between the two groups of samples in the MDS plot (Figure 23).

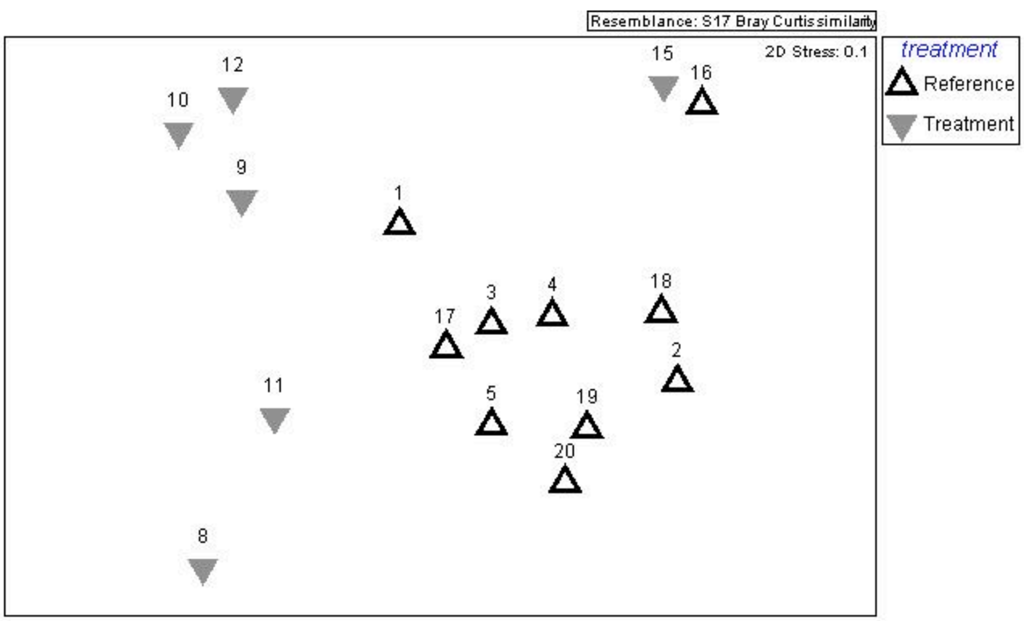

Figure 20. MDS plot of wrack invertebrate community in reference and treatment areas in April 2007, eight weeks after disturbance ended (seasonal closure) and as experimental manipulation (wrack addition) was initiated. Note four transects from the treatment areas with no animals in the samples are excluded (6,7, 13, 14). Transect identification: R1= 1-5, R2= 16-20, T1= 6-10, T2=11-15.

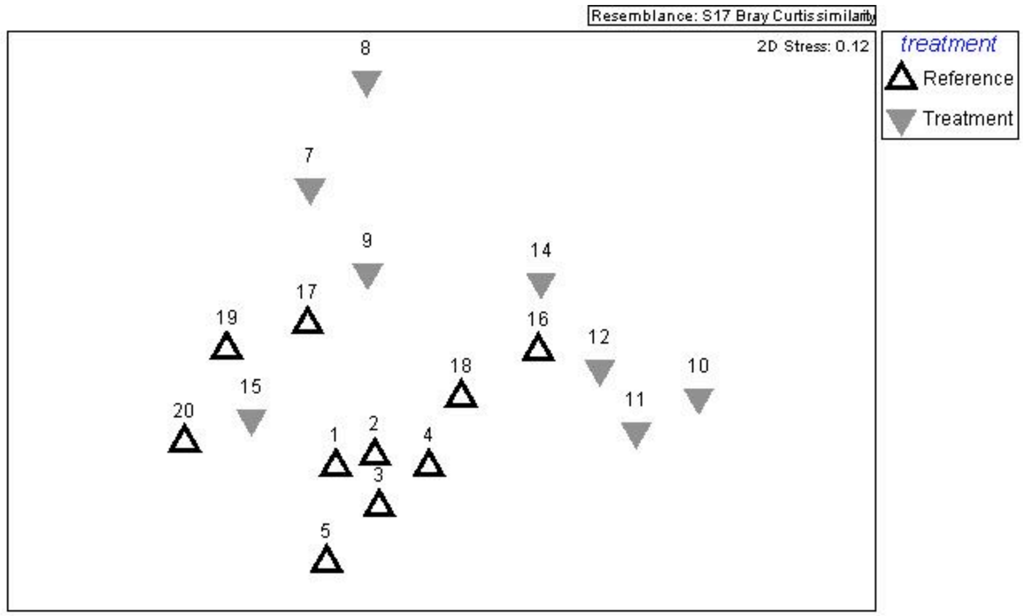

Figure 21. MDS plot of wrack invertebrate community in reference and treatment areas in May 2007, 11 weeks after disturbance ended (March 1 seasonal closure) and after experimental manipulation (wrack addition) was initiated. Note two transects from the treatment areas with no animals in the samples are excluded (6, 13). Transect identification: R1= 1-5, R2= 16-20, T1= 6-10, T2=11-15.

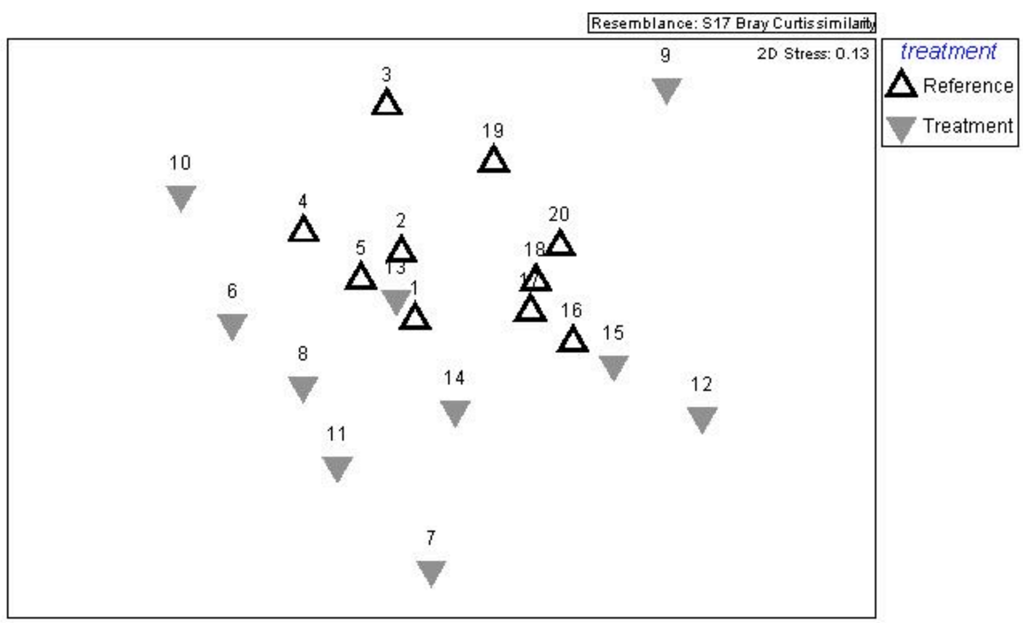

Figure 22. MDS plot of wrack invertebrate community in reference and treatment areas in June 2007, more than 3.5 months after disturbance ended (March 1 seasonal closure) and after experimental manipulation (wrack addition) was initiated. Note, all transects from the treatment areas had at least 1 animal in the samples. Transect identification: R1= 1-5, R2= 16-20, T1= 6-10, T2=11-15.

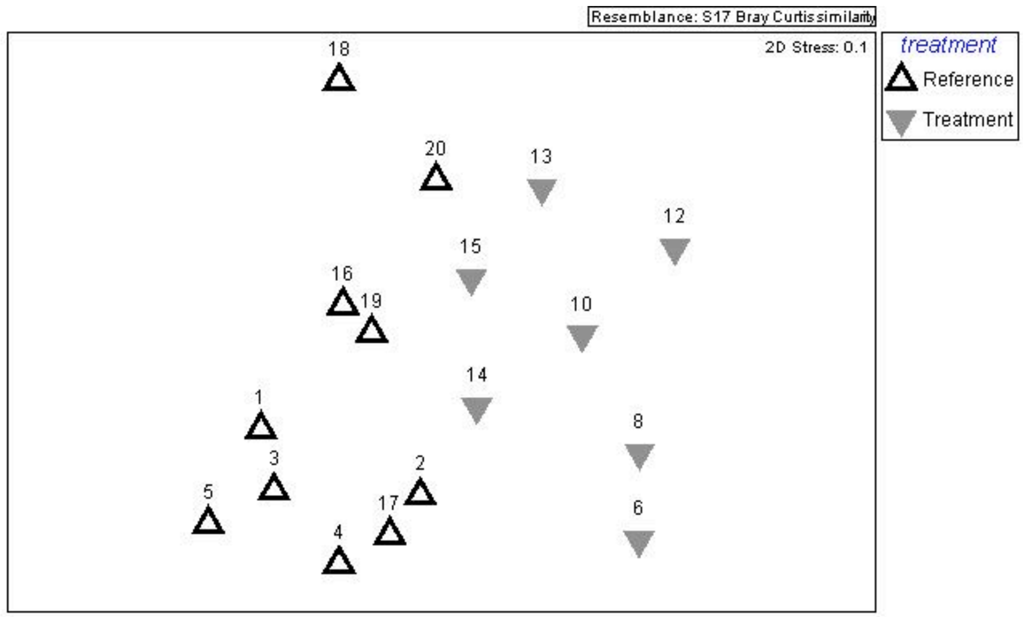

Figure 23. MDS plot of wrack invertebrate community in reference and treatment areas in August/September 2007, ~6 months after disturbance ended (March 1 seasonal closure) and after experimental manipulation (wrack addition) was initiated. Note three transects from the treatment areas with no animals in the samples are excluded (7, 9, 11). Transect identification: R1= 1-5, R2= 16-20, T1= 6-10, T2=11-15.

The global correlation coefficient estimate of similarity (R) values from the ANOSIM analyses for each sample date were used to evaluate change in similarity between the treatment and reference areas over time (Figure 24) for abundance and composition. A comparable pattern was found for biomass of the wrack invertebrate samples. The wrack invertebrate community of treatment and reference areas differed significantly in every comparison ($p<0.02$) indicating that community recovery was not achieved during the closed season at Oceano Dunes State Vehicular Recreation Area. Note this estimate of the amount of recovery is optimistic as the MDS analyses did not excluded all the samples in which no animals were found. Samples lacking animals were observed for at least 1 transect in the treatment area on every sampling date and in the majority of samples on all dates in the control area.

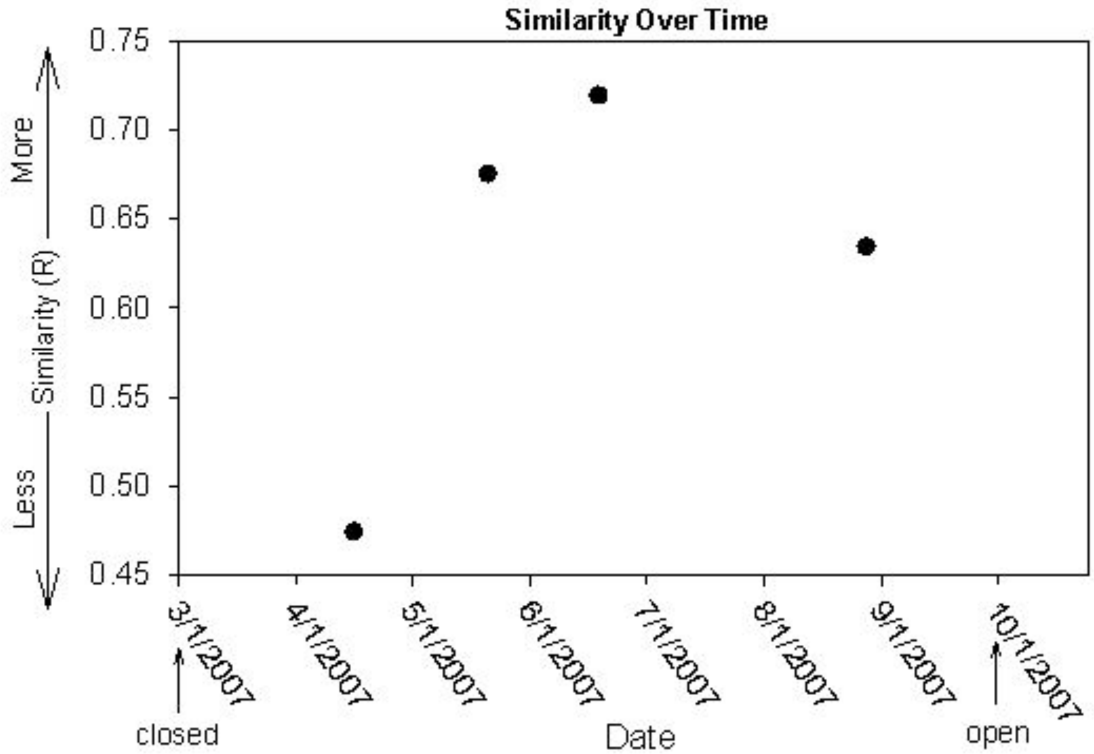

Figure 24. Global correlation coefficient estimate of similarity in the wrack invertebrate community (abundance) between treatment and reference areas over the experiment from ANOSIM analyses. All R values shown were statistically significant at the $p < 0.02$ level indicating that wrack-associated community composition differed significantly between the treatment and reference areas in every comparison over 6 months of closure.

The increase observed in the R estimate of similarity over time indicates that the wrack invertebrate assemblages of the treatment and reference areas did become more similar over the course of the experiment (Figure 24). However the result of peak similarity in June followed by a decline in similarity in August/September suggests even this was not a robust recovery or that it depended on taxa with strong seasonal patterns, such as flies. Although the pattern of increasing similarity with reference areas over time as estimated by global R suggests that recovery of the community was occurring in the impacted treatment areas, the communities did not converge and still differed significantly 6 months after closure to ORV disturbance, even in areas where wrack was added. This result suggests that recovery of the wrack-associated community of a disturbed beach can be protracted, requiring more than 6 months, and that enhancement of recovery rates to provide invertebrate prey for shorebirds, including nesting snowy plovers, may require additional restoration actions for beaches impacted by oil spills and other human activities.

Discussion

Because of the prevalence of sandy beaches on our coastline and their importance as sites of human recreation, in coastal protection, and as wildlife habitat, it is critical to understand the potential for recovery of sandy beaches from oil spills in order to develop reasonable goals for restoration. Our study provides some of the first empirical information from experimental investigations of the potential ecological recovery of a beach affected by an oil spill and cleanup activities. The results of this study increases the understanding of the time required to restore damaged beach ecosystems to functional levels that could support higher trophic levels, such as shorebirds and fish.

The abundant and diverse invertebrate animals inhabiting sandy beaches depend almost entirely upon inputs of organic material from other sources, including ocean phytoplankton and marine macroalgae. Stranded marine macroalgal wrack (e.g. kelp) is important to beach food webs in California. Changes in the supply of wrack are known to have bottom-up effects on beach ecosystems, altering the abundance and composition of the invertebrate community, and consequently the abundance of prey for higher trophic levels, such as shorebirds and fishes. Thus, the wildlife support provided by beach ecosystems can be affected by the availability of macrophyte wrack and associated invertebrate prey.

Our results suggest that the potential of beach wrack macroinvertebrate communities to recover from disturbance and respond to enhancement activities such as increased wrack subsidies depends on the initial conditions, the degree of disturbance and the proximity of source populations. Both of the experiments were conducted in spring to summer months when the beach wrack invertebrate community is most productive. For a severely disturbed beach, recovery of the wrack invertebrate community was not achieved in >6 months time (March to September) even where wrack was added to enhance recovery. In contrast, for a relatively undisturbed beach, the wrack-associated community responded to wrack subsidies in one month.

Wrack-associated invertebrates include peracarid crustaceans and insects, both of which do not possess planktonic larvae. This life history attribute means in order to repopulate disturbed beaches that dispersal of adults from source beaches must occur. For some insects such as kelp flies, dispersal to disturbed beaches can be rapid once fresh wrack is available. For other taxa, including flightless insects, arachnids, talitrid amphipods and oniscoid isopods, dispersal ability appears to be much more limited. Disturbed beaches that are relatively isolated from other beaches are expected to have much slower recovery than beaches located in proximity to source populations on un- or less disturbed beaches. This would apply to pocket beaches surrounded by rocky headlands and to beaches that have higher background disturbance such as groomed beaches, nourished beaches or those subject to heavy vehicular use.

Information gained from our research project will help OSPR and other agencies develop policies and protocols that can potentially enhance the restoration of ecological function to sandy beach habitats as well as realistic goals for recovery. Agencies involved in endangered species management, and coastal habitat enhancement and restoration may also benefit from the results of this study by gaining information on potential enhancement of resources for endangered and threatened bird species, including the Western Snowy Plover.

Recommendations

Results of one of our recent studies of beach ecosystems suggest that impacts to macrophyte wrack availability negatively affect wrack-dependent invertebrates quite rapidly (Dugan et al. 2004). However, despite the general perception that beach invertebrates are adapted to high levels of disturbance hence capable of rapid recovery, the results of our experiments on recovery dynamics suggest that once damaged by heavy equipment and wrack removal, full ecological recovery of the wrack-associated components of beach ecosystems can require many months (>6), even when wrack supply is abundant and/or is enhanced by the addition of appropriate fresh macroalgal material, such as kelps. This finding has important implications for maintaining wildlife support on beaches, particularly the availability and diversity of prey resources for higher trophic levels, such as shorebirds and fishes, following anthropogenic disturbances.

In summary, our results from this and related studies indicate:

- Strong ecological impacts of wrack loss via beach cleaning, grooming, oil spill responses and mechanical disturbance are found for sandy beaches.
- Rapid ecological impacts from wrack removal (<2 months) are possible even without the use of heavy equipment.
- Slow ecological recovery (>6 months) of wrack-associated animals and the wildlife support they provide is expected for impacted beaches, note this time is expected to be longer in winter conditions and for isolated beaches

These findings suggest that avoiding widespread damage and disturbance to the wrack-associated community during oil spills, spill response and other beach management activities could be an effective approach to preservation of habitat value and function. Avoiding driving vehicles and heavy equipment over beach wrack and allowing as much wrack as possible to remain undisturbed in the habitat should be considered in oil spill response protocols. The possibility of moving wrack to a higher tidal level where it will not be oiled during oil spill response could potentially allow some fraction of the wrack-associated community to persist at oiled beaches and reduce recovery time. Our SSEP study found that the diversity and abundance of a relatively undisturbed intertidal wrack community responded positively to the additions of kelp wrack in a matter of a few weeks. If small populations of wrack-associated invertebrates are purposely allowed to persist at an oiled beach, the possibility of enhancing recovery time of this community by adding clean macroalgae, particularly kelps, to the intertidal zone may be a viable option.

Dispersal ability appears to play an important role in the recovery dynamics of wrack-associated invertebrates. While kelp flies and other seaweed flies can recolonize rapidly once macrophyte wrack is available, a number of taxa, particularly flightless crustaceans and insects, do not recover quickly, even in the summer months when conditions are optimal for production and growth of these animals. During fall or winter, when background abundance is low and conditions are less favorable for production of all wrack-associated taxa including flies, recovery times of the wrack-associated community are expected to be considerably longer.

If wrack disturbance and removal can not be avoided and the wrack community is impacted by oil spill and spill response activities, additional restoration activities beyond adding wrack could potentially be useful. To reduce the recovery time of the wrack-associated components of damaged beach ecosystems, augmentation of taxa that exhibit relatively low dispersal may be needed, particularly for beaches that are isolated from source populations by geography or other factors such as beach grooming or vehicular activity. The timing of any augmentation needs to be coordinated with favorable beach conditions for survival of the invertebrates and ideally the availability of fresh wrack. The availability of appropriate and sufficiently abundant local source populations and species that are compatible with the pre-impact assemblage is also an important consideration.

Our recent first study of experimental additions of talitrid amphipods at Oceano Dunes using a local source of animals indicated that we were successful in enhancing abundance at the treatment areas within a few months. We added about 15,000 animals, primarily juveniles, over 3 dates in March and April 2008. These animals were collected alive from around and under fresh wrack deposits at the driftline in the nearby North Grand Avenue area (R2, Figure 2) because there were abundant populations and the area is not generally used for nesting by snowy plovers. The adjacent North Oso Flaco area (R1, Figure 2) also supported abundant populations of talitrids but was not utilized as a source because of the use of this area by nesting snowy plovers and the need to avoid both disturbance of the birds and any reduction of prey resources in a nesting area. In the morning when talitrid amphipods are less active and burrowed in the sand, animals were collected by quickly placing shallow shovelfuls of sand containing animals into mesh dry cleaning bags (~1.5 mm maximum sieve aperture, 0.6 m x 0.9 m bag size), these bags were rinsed in the swash zone to remove sand and retain the animals. All animals retained in the mesh bags were placed in gallon ziplock bags (300-800 per bag), kept cool and released into freshly added piles of kelp wrack located on the driftline by noon on each date. Fresh kelp wrack (~1 30 gallon trashcan full) was added to the driftline in the animal addition treatments weekly. Samples collected in May, June and August indicated the added animals survived to disperse and reproduce in the area. Our results from this pilot study suggest that if appropriate sources are available, augmentation of wrack-associated invertebrates and wrack could potentially be used to restore and enhance prey resources for support of wildlife, including breeding Western Snowy Plovers, on beaches damaged by oil spills and response activities.

Acknowledgements

We thank R. Fisher, K. Johnston, I. Rodil, N. Schooler, and X. Shinbrot, for their dedication and enthusiastic assistance with all aspects of field and laboratory work. We especially thank D. George, D. Costello, J. Iwanicha, M. Przybylski and other ODSVRA staff for their expert assistance, patience and dedication in making the field experiment on beach recovery at ODSVRA possible. We extend special thanks to R. Glick, Resource Ecologist for California State Parks, for supporting and encouraging the experiment at Oceano Dunes State Vehicular Recreation Area. This study was supported by funding from OSPR, California State Parks and the Santa Barbara Coastal Long Term Ecological Research project (NSF #OCE-9982105). I.F. Rodil was supported by Universidad de Vigo and Xunta de Galicia (Predoctorales Xunta P.P. 0000 300S 140.08) during the first year of the study.

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