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SHOREBIRD, WATERFOWL AND BIRDS OF PREY USAGE IN WILLAPA BAY IN RESPONSE TO *SPARTINA* CONTROL EFFORTS[1]

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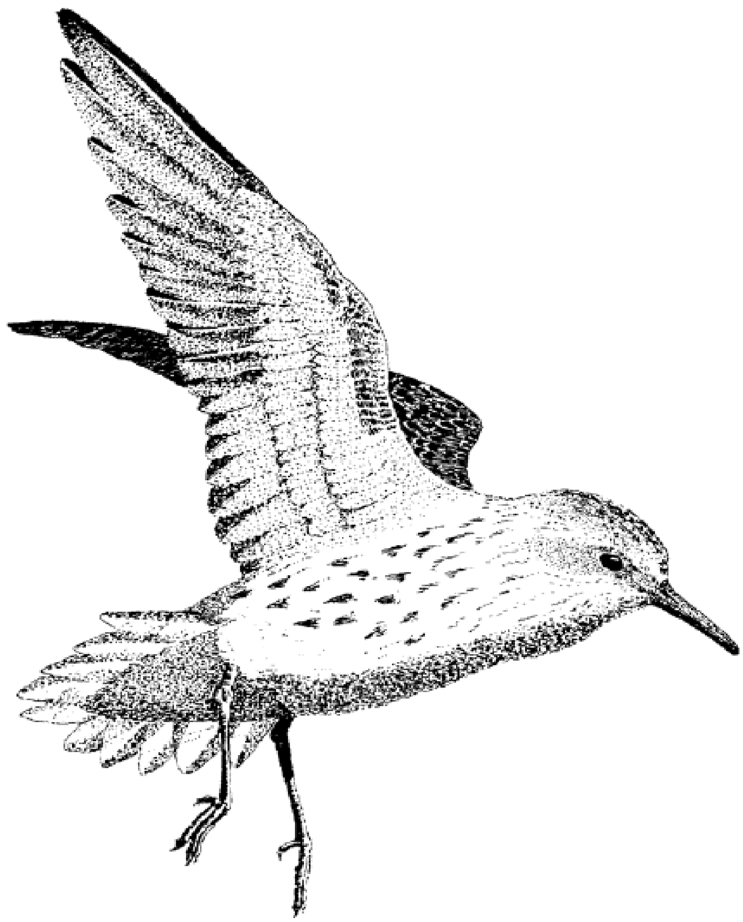

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Introduction

Spartina is a perennial, deep-rooted saltmarsh grass, which re-sprouts each year from a dense, persistent root mass. It has colonized and eliminated much of the upper part of the wide expansive intertidal mudflats of Willapa. The long-term ecological impacts of this colonization include major declines in shorebird and waterfowl species, biodiversity, eelgrass beds (*Zostera marina* L.), macroalgae beds, native saltmarsh habitat, and commercial shellfish beds (Daehler and Strong 1996; Dumbauld et al. 1997; Goss-Custard and Moser 1988; Gray et al. 1997; Kriwoken and Hedge 2000; Millard and Evans 1984; Jaques 2002). Species most threatened by *Spartina* are likely to be the 30 species of shorebirds that rely upon Willapa Bay's 47,000 acres of tideland for food and shelter during annual migrations to and from the Arctic (Paulson 1993; USFW 1997; Gray 1997). Much of the most-preferred shorebird habitat of Willapa Bay, sheltered upper tidal mudflats in the south part of the bay, has been displaced by *Spartina*. Peak winter and spring shorebird usage in sections of the bay has declined over 60% in the past decade as *Spartina* meadows have replaced the tidal mudflats (Jaques 2002). Census studies on shorebird abundance in Willapa Bay in 1991-1995, prior to the major increases in *Spartina growth*, found that 44% of the total bird usage was within two areas, the Bear River/Lewis Unit – South Willapa Bay region and the Willapa River area (Buchana and Evenson 1997). These two areas have become almost contiguous *Spartina* meadows.

Long term ecological impacts of invasive *Spartina* marshes on shorebirds have been most studied in England (Gray 1997). During *Spartina* expansion, the benthic fauna of the mudflat becomes generally depleted compared with nearby tidal mudflats (Millard & Evans 1984). Following that depletion, there is a decline in tide-edge-feeding species, like dunlin, oystercatchers, ringed plover, and sanderling (Goss-Custard & Moser 1988). Eelgrass beds (*Zostera*) also get displaced, affecting waterfowl, notably the wigeon, and the Brant goose (Gray 1997). Not only are food sources for birds degraded by *Spartina*, but shorebirds are also reluctant to feed in or near *Spartina* clones because it impairs their ability to detect potential mammalian and avian predators (Smith and Evans 1973).

Many thousands of acres of habitat critical for shorebirds have been negatively impacted by *Spartina*. The ongoing chemical and mechanical control effort is the first step in recovering that habitat. The ultimate goal of a control effort should not be limited to control, but also needs to consider restoration of the affected habitat for maximal ecological value. Unfortunately, little information exists to date on how the numerous chemical and mechanical control methods being used to manage *Spartina* have expedited the restoration of native habitat. This can best be done over a time course that allows that ecosystem to respond. For example, several years after the control of *S. anglica* in certain English saltmarshes there was an increase in infauna (Evans 1986) and a dramatic rise in shorebird populations (Gray *et al.* 1997). Studies in Pacific Coast estuaries on eelgrass (Major and Grue 1997, Patten and Stenvall 2002), native marsh plants (Patten and Stenvall 2002, Patten 2002b, Patten 2003), benthic infauna (Zipperer 1996, Norman and Patten 1995), shorebirds and waterfowl (Jaques 2002; Patten and Stenvall 2002) and aquatic invertebrates (Zipperer 1996) have not extended past one to two years and/or have been on a micro-site. Where there have been long-term control efforts by agencies, there has been limited concurrent efforts to record if any particular control method or conditions has expedited the restoration of native habitat. The one exception was the enhanced shorebird and waterfowl usage recorded following a large-scale (>30ha) winter tilling project (Jacques 2002; Patten and Stenvall 2002). The value of these data, however, is also limited, in that the monitoring was limited in scope and scale, and did not evaluate a full range of alternative control methods.

The objectives of this study were to 1) quantify shorebird usage of *Spartina*-affected mudflats as a function of *Spartina* control methods, 2) develop assessment methods for monitoring shorebirds' response to *Spartina*- affected mudflats, and 3) make recommendations for enhancing restoration efficacy for shorebird usage of *Spartina*-affected mudflats.

Methods

Direct and indirect assessments of shorebird, waterfowl and birds of prey usage of *Spartina* meadows (treated and untreated) in comparison to bare mudflats were made. These assessments were made for five sites: bare mudflat, tilled *Spartina* meadow, sprayed *Spartina* meadow, spray-mowed *Spartina* meadow and an untreated *Spartina* meadow. Data collected included beak probe density, footprint density, fecal dropping density, visual counts during peak migration in spring 2003 and winter of 2003/2004, remote monitoring with video cameras in winter/spring 2003, prey (food) density, and prey availability (% bare ground available for foraging and sediment resistance to beak probing).

The study site was on Willapa National Wildlife Refuge property at the south end of Willapa Bay. That site has been previously described (Patten 2004). The *Spartina* infestation is 10 to 14 years old. Treatment sites are adjacent to each other and large enough to be considered ecologically significant units (>200 acres). This part of the bay supported abundant bird population prior to infestation by *Spartina* (Jacques, 2002). Although the sites had similar bathymetry prior to *Spartina* infestation, their current elevations are >0.5 feet above the adjacent mudflats. The bare mudflat site is and has been *Spartina*-free. The tilled site has been treated since 2000/2001 with mowing, tilling, and spraying for cleanup. It has been relatively free of *Spartina* since 2002. The sprayed and spray-mowed sites were treated with 2 gallons/acre of Rodeo in summer of 2002 and had follow-up spraying in summer of 2003. The spray-mowed site was mowed to the 4" to 6" level during the spring of 2003 to remove dead stubble and encourage bird usage. The untreated *Spartina* meadow is a large >500 acre meadow at the southwest end of the bay.

Beak probe density, footprint density, and fecal dropping density were collected at several time periods during peak use. Counts per $0.25m^2$ quadrant were taken along transects in each treatment site. Data represent means of at least 20 quadrants/transect and 3 to 4 transects per site. Data collection at the bare mudflat site was less than at the other sites due to the difficulty of taking quadrant data. Data were collected at low tides several days after no significant rain events had occurred (heavy rains removed prints and fecal droppings). Resistance (grams of force to penetrate 3 cm depth) to beak probing was measured by using an artificial dunlin beak attached to a penetrometer. Additional beak probe, footprint and fecal dropping density data were collected at several sites in the Porter's Point area in May 2003 as a function of the type of canopy coverage over the mudflat (live canopy, dead stubble, bare mudflat).

Remote monitoring of all five sites was done using video cameras in winter/spring 2003. A Mitsubishi Time Lapse Security Recorder, Model #HS-1280U, was used to record the black and white image from a Super Circuits PC23C camera w/12mm 1/3"CS TV lens. Power was provided using three 12V Deep Cycle Marine Batteries and a 16W Solar Pane with a DC to AC, 12V, 150Watt Inverter. Cameras were mounted in weatherproof camera housing on 20' poles 400' from the native marsh. Feed from the camera to the recorder was done using standard TV coaxial cable with an image recorded every three seconds. A schematic is shown in figure 1. Recording was programmed to occur from dawn to dusk. The cameras were focused on a representative area within each site. The focal area for each site varied slightly, ranging from ~90 to 180 m^2. Total bird usage (shorebird and waterfowl) from each tape was recorded every 30 seconds and the data was converted to mean daily flux densities (#/m^2/hour). For shorebirds, daily flux densities were based only for time periods during the day when the tideflats were exposed. For ducks, daily flux densities were based only for time periods during the day when the tideflats were exposed or had <~12" water on them. Species separation within shorebirds was not feasible. Based on size and profiles, it was determined that all ducks observed in the video were most likely to be mallards. Due to the need for battery recharging every three to eight days and other technical difficulties, images for all sites were not recorded the entire four months of this experiment. The total number of days of complete data collection, from February 18 to May 14, ranged from 20 to 40 depending on the site (see Figure 2).

Visual observations of shorebird usage were made during peak migration in the late spring of 2003 using five simultaneous observers (one per site) perched on five observation towers(8' high) within 300 to 1000' of the observation plots. Data were collected for two minute intervals per plot. There were three 60x60 m plots per treatment site. Bird densities by species were recorded during five peak use events, just prior to tidal submergence or after tidal withdraw.

Visual observation of bird usage in the winter of 2003/04 was modified to remove variability due to the observer. A single observer was used. Three plots (1 hectare each) per site were observed for 10 minute intervals using a spotting scope. Observations were timed to coincide with peak usage at each site, just prior to tidal submergence or after tidal withdraw. Observation frequency was at least once a week. Bird species and behavior were noted. For shorebirds and waterfowl, usage was counted any time a landing occurred. For birds of prey, usage was counted when a bird flew over the plot. In all observations, the recorded data were for the total birds sighted within the plots during the time period. Bird behaviors were categorized as skittish flight (birds landing and immediately flying away), skittish feeding (nervous feeding with short probing duration), intense feeding (continuous sustained probing), and resting.

General prey density data were collected at each site from the surface two centimeters during the summer and winter. The summer samples did not include a *Spartina* meadow or the spray-mowed site and were collected at various distance points progressing from the native marsh. The winter samples were collected from the observation plots used for visual bird counts in winter 2004. There were five pooled cores, 4" in diameter and 1" in depth, taken per replication or site. Samples were refrigerated and screened within the following 24 to 96 hours using 0.25 mm mesh screen and fresh water. Samples were classified into bivalves, polychetes, nematodes, gastropods, amphipods and isopods, or dipteran larvae. Some sampling bias occurred because screening of prey from root masses was much more difficult and time-consuming than from pure mud.

Soil and plant data: Intact cores to the bottom of the root system (80+ cm) were collected by digging a 1 m wide and deep trench. Standard soil science methodology was used to determine porosity, bulk density, and the core sample composition. By washing the trench wall it was possible to identify all growing point meristems and record their points of origin (depth). The change in depth from the first occurring meristem to the current growing points over the 8 to 10 year period this meadow had been growing was assumed to be a change in tidal elevation resulting from *Spartina*-induced accretion. Data on vascular plant density (#/ m^2) by species were collected in June 2004 from multiple transects from the native marsh line out to 500 m through each treatment site.

Results and Discussions:

Shorebird foraging winter/spring 2003: Based on visual and remote observation data during the time course of this study, none of the *Spartina* control methods resulted in shorebird usage comparable to the bare mudflats (Figures 2, 3 & 4). Flux density of shorebirds during winter and spring of 2003 was repeatedly higher in the bare mudflat than in the tilled areas, often by orders of magnitude (Figure 2 & 3). Flux densities of shorebirds on the tilled site were higher than the sprayed or spray-mowed site. Only minor differences were observed between these latter two sites. During 480 hours of video recordings, no shorebirds were ever observed at the *Spartina* meadow site.

Remote sensing results always did agree with visual observation during the spring 2003. We observed few birds using the bare mud site, while the tilled, spray-mowed and sprayed sites were fairly comparable (Figure 4). Differences between observers at each of these sites could account for some of this difference in results between methods. Beak probing holes and fecal density results also did not always agree with remote sensing data (Figure 5). Few beak probes or fecal droppings were recorded at the bare mud site. This was mostly likely the result of tidal flushing removed these markings. This was not the case in the other more protected sites.

Shorebird foraging winter 2003/2004: Shorebird usage patterns in the winter were similar to the spring. The bare mudflat site had the greatest usage, followed by the tilled site (Figure 6 and 7). Western Sandpipers did not appear to have any real preference over the two sites, while Dunlin showed a higher usage of the bare mudflat. Usage of these sites by dowitchers and Black-bellied Plovers was too sporadic to make any inference about preference. The sprayed site was used by Western Sandpipers and Black-bellied Plovers, but in much lower numbers than the adjacent tilled site. The one observation of sandpipers in the *Spartina* meadow site was recorded as birds resting on an incoming floating mat of *Spartina* rack. From a behavioral perspective, it appeared that the tilled site had the lowest percentage of skittish feeding and the bare mudflat the lowest percentage of resting (Figure 8). However, there were little overall differences in shorebird behaviors noted between sites. Additional data is being gathered to break down behavior by species. An interesting pattern of bird usage that was noted was the preferred forage times for the different species (Figure 9). Western Sandpipers were observed more or less equally on the in-coming and out-going tides. High numbers of Dunlin were most consistently observed with the in-coming tides. This usage pattern may be site-specific. We suspect Dunlin are opportunistically feeding across all of Willapa Bay, following the tidal submergence patterns. The south bay would be the last site in the bay to be covered by the incoming tide, thus focusing shorebirds onto that site. Once tides covered the south bay, Dunlin rest at Leadbetter (Jacques, 2002), and then would likely work the first mudflats to show upon tidal withdraw (north bay). This pattern was observed on a micro-scale in south bay for most of the shorebird species. As the tides came in, they first worked the bare mudflat; once those were submerged they forged on the tilled and sprayed sites. A reverse pattern was observed as the tide withdrew from the mudflat.

Waterfowl and birds of prey: Ducks (mallards) were observed in higher numbers in the sprayed or spray-mowed site during winter/spring 2003 than in any other sites (Figure 10). There was only very minor usage of the tilled site and no usage of the *Spartina* meadow or bare mudflat.

These results were similar to those from winter 2003/2004, where no usage of *Spartina* meadow was observed (Figure 11). However, they contrast for the tilled site and bare mud site, where there were high duck counts during several days of observation. Species observed during this period were mainly Mallards, Gadwall, American Wigeons, and Green-winged Teal. Birds of prey have clear preference for usage of sites with controlled *Spartina*, both tilled and sprayed (Figure 12). There was consistent, but very low, usage of untreated *Spartina* and very low usage of bare mudflat. In comparison to an open mudflat, mudflats with *Spartina* canopy and stubble offered birds of prey an advantage for getting close to their prey undetected. Species observed during this period were mainly the Northern Harrier, with a few Peregrine Falcons and Bald Eagles.

Other biotic and abiotic factors affecting shorebird usage. Bird usage is a function of food availability (quantity), accessibility (exposed sediment, ease of foraging), and predator avoidance (ability to easily spot predators). Benthic infauna data indicated several magnitudes of order of greater prey density in the bare mudflats than the treated *Spartina* sites (Figure 12 and Tables 1 & 2). In the summer, the *Spartina* sites were quite variable, and showed only minor differences between them. Polychetes were the most common infauna at all sites. Bivalve populations, however, varied a lot by site (from very high in bare mud, to low in sprayed *Spartina* to none in tilled *Spartina*). During the winter, the polychete count was very high in the sprayed site (Table 2). Accessibility to the prey, based on ease of beak penetration, ranged from almost no resistance in the bare mudflat to fairly high resistance to penetration at the near shore tilled locations (Figure 13). In general, the sprayed sites were softer than the tilled site. These data reflect sediment firmness in the summer. We would expect softer sediment in the winter, owing to higher moisture content (higher tides and rain).

Access to prey can be prevented by thick coverage by dead *Spartina* stubble or by live *Spartina* stems. The degree that this interferes with foraging on a macro-site is hard to assess. However, on a micro-site some inferences can be made by comparing differences in footprint, fecal dropping and beak probe densities. While these parameters were not too useful in comparing across macro-sites, they can be very comparable within micro-sites. For three locations within Porter's Point, there was almost no evidence of any shorebird usage where there was live *Spartina* growing (Table 3). The bare mud and dead stubble locations usually displayed high counts of beak and foot prints and fecal droppings. Bare mud usually had twice as much shorebird usage as dead stubble. Although there were no observations which indicate a change in behavior of shorebirds in terms of predator avoidance at the *Spartina* sites, it was very evident that birds of prey showed a strong preference to work the controlled *Spartina* sites over bare mudflats.

Comparison of assessment methods: Each method of assessing shorebird provided somewhat different conclusions regarding shorebird usage of *Spartina*-affected mudflats. Video monitoring was the most accurate and provided the greatest wealth of data, but was more expensive and fraught with technical and logistical problems. Statistical analysis of the data is more complicated (data are not replicated within or by site, but across time)[3]. More expensive equipment would reduce maintenance costs and improve reliability; however each of these monitoring units costs more than $7,000 in comparison to under $700 for each of our units. The other problem with cameras is the time to view and convert video counts into data. Visual

[3] Statistical analysis of video monitoring data is pending. An additional consultation with a statistician is required.

monitoring was highly variable depending on the date and time of observation and the observer. Our initial foray into the use of five volunteers for simultaneous observations across several sites was less than satisfactory. Variation between observations was too high. With additional training, site rotations and observation dates, this would be minimized, but the logistics of doing so is time-consuming and difficult. A trained observer who frequented all sites during their peak daily use periods over a prolonged period provided excellent data at a fairly low expense. Variability across time got evened out with weekly data collection over time and subtle differences in behavior and species can be noted. Logistics of data collection and equipment maintenance were also not problematic. For detecting subtle differences in use within a micro-site indicator data like beak, footprint and fecal dropping density were very sensitive variables and easy to measure. However, these variables were not useful to compare between treatment sites, especially when comparisons are made against bare mudflats. Mudflats don't retain these variables very long and the data are almost impossible to collect by walking through the site.

Recommendations: Five conclusions and recommendations can be made from these data.

1) Restoring mudflats back to their original form and function will be extremely difficult. Even with tilling and several years of follow-up chemical control, and natural restoration processes occurring over several years, *Spartina*-affected mudflats are far from having shorebird usage even close to what normally occurred on a bare tidal mudflat. In addition, for low tidal energy sites like the south bay, where there is traditional high shorebird usage, the landscape-scale changes in bathymetry via *Spartina*-induced accretion make it unlikely that any restoration effort would be able to bring back the original bathymetry. This is especially true since native marsh is already succeeding in these areas (Patten 2004). It is therefore absolutely essential to eradicate all existing *Spartina* in these critical sites as quickly as possible, with no regard as to what method provides the best interim shorebird usage.

2) Softening up root masses and removing stubble and traces of *Spartina* canopy by tilling markedly improved shorebird utilization of *Spartina*-affected tidelands. It is not clear, however, how much of this effect can be strictly attributed to killing of the *Spartina*, vs. softening up the root masses or removal of *Spartina* stubble. Nor is it clear how much of this effect would be observed if the treatment was only carried out on a micro-scale and not over several hundred acres. It is also not clear how much improvement in shorebird utilization would occur by just killing *Spartina* and removing stubble. The lack of shorebird usage during the winter of 2004 in the spray sites, where there is little stubble remaining (treated in 2002), however, suggests that a time period of several years may be needed to gain significant shorebird usage. It would be especially true if large suitable adjacent sites are also available for competing use by shorebirds. Dr. Alan Gary (personal communication, 2003) indicated that shorebird usage of *Spartina*-affected tideflats in English estuaries has taken 10 to 15 years to occur once the *Spartina* has been eradicated. Nevertheless, large-scale tilling of selected areas as a control measure or for strictly restoration purposes should be considered. This should be focused in areas which have previously had high shorebird usage and where shorebirds continue to frequent the lower tidal zone in the immediate area. This strategic placement would help create discrete functional shorebird foraging units. An example of this would be to till a 50 to 100 acre swath of the Palix meadow after it had killed by herbicide.

3) In contrast to shorebirds, there does not appear to be any real benefit of tilling compared to spraying to achieve foraging by waterfowl. Spraying of *Spartina* would appear to be adequate to achieve some level of restoration for waterfowl.

4) Some type of dead *Spartina* canopy management (stubble) could be useful to enhance shorebird usage. Our data indicate that prey accessibility and forage behavior at least on a micro-site can be improved if the stubble is crushed, removed, or shorted. This short-term effect may not be very cost-effective, as all the dead stubble will eventually decay or break off with 12 to 24 months. Two alternative management practices could be employed to evaluate if this short-term micro-site effect has any real value to shorebird populations. The first would be to evaluate if crushing 50 to 100 acre tracts of sprayed *Spartina* meadow in early winter would help shorebirds utilize those sites for the next few season. The other more cost-effective method would be to consider early application of herbicide on a large-scale, aimed at an area where shorebird foraging is especially important. Early herbicide applications (early June) prior to major lignifications and thickening of the stems result in much shorter stubble (Patten, unpublished data) than applications of herbicides in July to September. The caveat is that too early an application can compromise control. This would appear to be less of a factor with imazapyr than glyphosate.

5) Based on these studies, we can infer that restoration of *Spartina*-affected tidelands for shorebirds will be a challenge. Much more information will be required to make good adaptive management decisions. A few sightings of large flocks of shorebirds landing on a mudflat where *Spartina* has been controlled by a given treatment mean little in terms of restoration value. Detailed, long-term monitoring over several replicated large sites will be required to make judgments on the ecological value of a given treatment. Restoration for shorebirds must be taken in context with the restoration for other uses, such as shellfish or eelgrass. Designing large-scale monitoring plots to evaluate how to best achieve restoration should be considered at the beginning of a control effort, not after the fact. Use of the Palix meadow, which has easy monitoring access and has had previous high bird usage, would be an ideal site to implement such as study.

6) *Spartina*-induced accretion of sediment has already resulted in permanent transition of mudflat to native marsh at some sites. There has been little consideration of how to treat this newly forming native marsh for maximum shorebird value. For example, should certain plant species be selectively seeded or should the site be naturally seeded by the most opportunistic and aggressive plants. These latter species could in fact be non-natives wetland plants.

Results

Shorebird foraging: Based on visual and remote observation data during the time course of this study, none of the *Spartina* control methods resulted in shorebird usage comparable to the bare mudflats (Figures 1 & 2). Flux density of shorebirds during winter and spring of 2003 was repeatedly higher in the bare mudflat than in the tilled areas, often by orders of magnitude (Figures 1 & 2). Flux densities of shorebirds on the tilled site were higher than the sprayed or spray-mowed site. Only minor differences were observed between these latter two sites. During 480 hours of video recordings, no shorebirds were ever observed at the *Spartina* meadow site. Western sandpipers did not appear to have any real preference over the two sites, while Dunlin showed a higher usage of the bare mudflat. From a behavioral perspective, it appeared that the tilled site had the lowest percentage of skittish feeding and the bare mudflat the lowest percentage of resting (data not shown).

Based on short-term comparisons in shorebird footprints, fecal droppings and beak probe densities, there were major differences in shorebird microsite habitat preferences (Table 1). All types of dead *Spartina* stubble or live *Spartina* stems drastically interfered with shorebird foraging. For three locations within Porter Point, there was almost no evidence of any shorebird usage where there was live *Spartina* growing. The bare mud and dead stubble locations usually displayed high counts of beak and foot prints and fecal droppings. Bare mud usually had twice as much shorebird usage as dead stubble.

Soil and plant data: Spartina meadows rapidly began a transition to native middle to upper salt marsh as soon as the *Spartina* was killed (Figure 3). Within two years of treatment, four salt marsh plant species extended 400 m out from their native marsh habitat. At this particular site, the transition from mudflat to *Spartina* meadow to salt marsh has all occurred with ten years and represents a permanent loss of hundreds of hectares of prime shorebird habitat. In an analysis of soil parameters at this meadow, (data not shown) we have found the dead *Spartina* root mat extends down to 35 cm, with the bulk of the soil volume being comprised of organic matter and pore space. Only 15% of the elevation rise could be accounted for by sediment accretion.

Discussion

Restoring mudflats back to their original form and function will be extremely difficult. Even with tilling and several years of follow-up chemical control, and natural restoration processes occurring over several years, *Spartina*-affected mudflats are far from having shorebird usage comparable to what normally occurred on a bare tidal mudflat. This may be especially true for low tidal energy sites in the southern half of Willapa Bay, where there is traditional high shorebird usage. At these sites, the landscape-scale changes in bathymetry via *Spartina*-induced accretion and root mass accumulation make it unlikely that any restoration effort would be able to bring back the original bathymetry. This is especially true since native marsh is already succeeding in these areas. Once these sites have transitioned to stable salt marshes, there will be little likelihood that they could ever become functional mudflats again. To prevent irreversible loss of prime shorebird habitat, it is therefore absolutely essential to eradicate all existing *Spartina* in these critical sites as quickly as possible.

Can we realistically achieve functional shorebird habitat of *Spartina*-affected tidelands post-control? If the site has undergone major elevation changes, it is likely that it will become a stable salt marsh and achieving shorebird habitat over the long term will be problematic. If the site has not undergone major *Spartina*-induced elevation changes, then habitat restoration is feasible. Restoration may be expedited with a process that breaks up root masses and removes stubble and traces of *Spartina* canopy, such as tilling. This process is not inexpensive. Tilling of large *Spartina* meadows is cost-prohibitive, requires very specialized equipment and is very slow (<1 ha/day). Tilling several small 2-3 ha restoration units throughout treated meadows might be a more cost-effective approach to restoring shorebird utilization of sites. It is not clear, however, how much of this tilling effect on shorebirds can be strictly attributed to the actual physical effects of tilling (breaking up the root mass) versus the creation of an open flat smooth surface that is more shorebird friendly. If the latter is the case, then waiting for natural processes to remove residual stubble to create an open surface would be sufficient.

From our data and that of others, it is still unclear what are the most critical factors driving shorebird usage of tideflats post-*Spartina* control – prey density, prey accessibility, predator avoidance behavior, or other variables. Research on changes in prey density post-*Spartina* control has been inconsistent (Lacambra et al. 2004). We found slightly higher benthic infauna on tilled vs. herbicide-treated *Spartina*-affected mudflats, but both were orders of magnitude less than on adjacent unaffected mudflats (data not shown). Based on our data, ease of access to prey is certainly a very significant factor. Removal of live canopy, dead stubble, or thick root mat immediately improves shorebird usage of a site. The presence of stubble and canopy is also likely to affect predator avoidance behavior. Our observational data (not shown) indicated birds of prey exclusively utilized tilled and herbicide-treated *Spartina* meadows rather than open mudflats to hunt shorebirds, even though the latter had orders of magnitude higher shorebird density.

Data from Great Britain on *S. anglica* indicate that shorebird usage of *Spartina*-affected tideflats in English estuaries has taken decades to occur once the *Spartina* has been eradicated or naturally died off (Lacambra et al. 2004). Unless there is a change in sea level or a major subduction event, the prospect of shorebird utilization of the thousands of hectares of *Spartina*-affected mudflats in Willapa Bay could take a similar or even longer time period.

- Restoration
  - Bird usage
    - Spartina has a profound effect on bird usage.
    - Zero bird usage in untreated Spartina meadows
    - Moderate shorebird usage of tilled Spartina meadows
    - Modest shorebird and considerable Mallard usage of herbicide treated Spartina meadows
  - Benthic infauna

        - Treated Spartina meadows have several magnitudes of order less than native mudflats
    - Sediment texture
        - Treated Spartina meadows are much firmer than native mudflats
    - Ecology
        - Due to Spartina induced changes in elevation, the ecology of a Spartina meadow after control is unlikely to ever return to its pre-invasion status. Once controlled, the bulk of upper intertidal zone of that Spartina meadows will convert to a saltmarsh.

    - Practical consideration
        - Only an immediate large-scale eradication effort will prevent additional large-scale permanent habitat loss
        - Physical manipulation of the *Spartina* root mass with tillage appears to expedite restoration. Large scale tilling, however, is too costly and slow to be considered a viable option.

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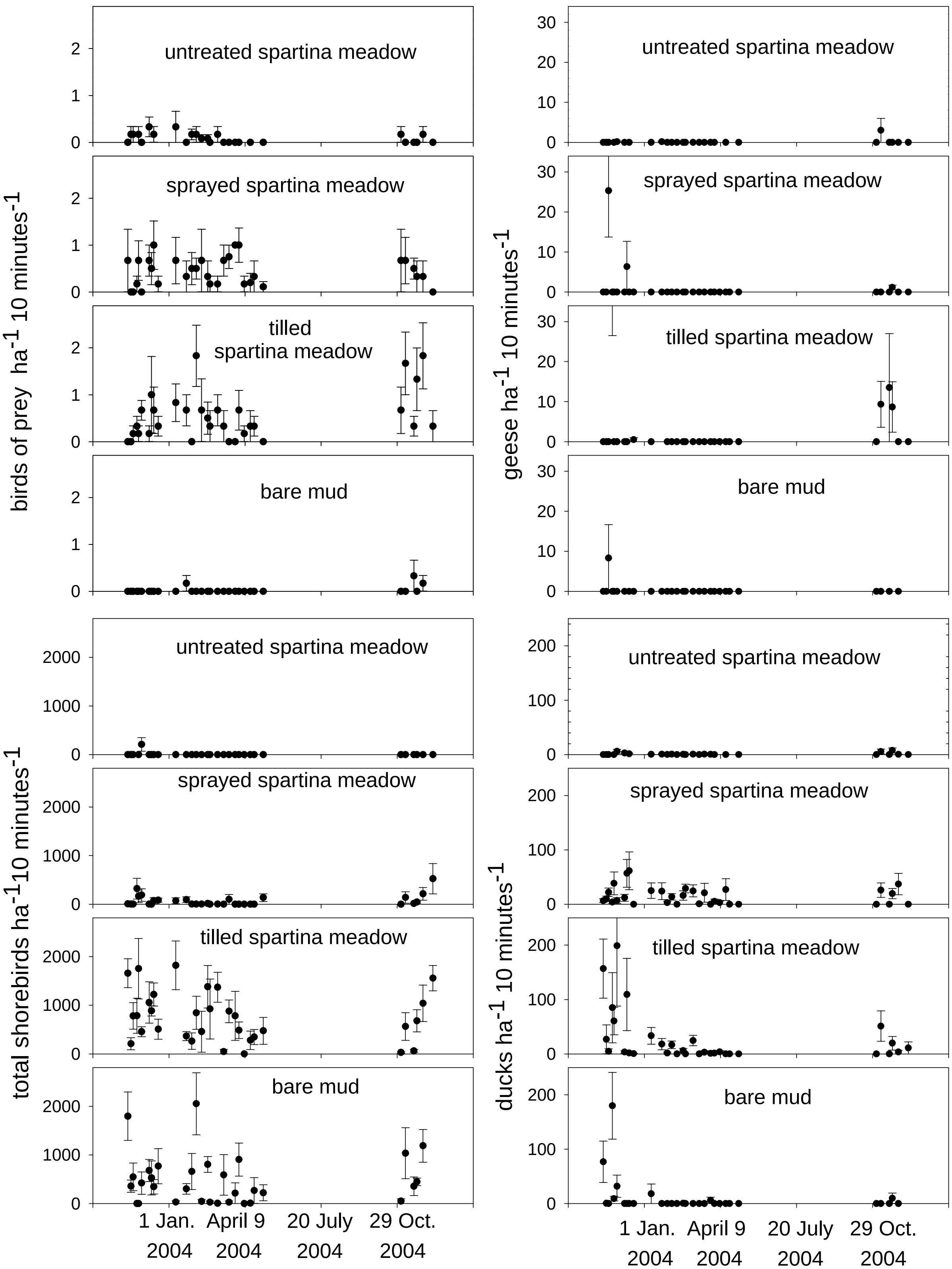
TABLE 1. Mean bird flux density across all observation times as a function of type of bird, method of observation and Spartina treatment.

		Mean bird flux density (bird ha^{-1} hr^{-1}) ∀std. err			
Bird	Method of observation*	Bare mud	Tilled	Sprayed	Spartina meadow
shorebirds	visual	2838∀552	3446∀552	411∀121	39∀39
shorebirds	video	4016∀1410	503∀119	250∀214	0
Western Sandpiper	visual	110∀30	2159∀459	343∀114	39∀39
Dunlin	visual	869∀308	1584∀386	26∀20	0

Black-bellied Plover	visual	168∀54	158∀29	39∀14	3∀3
Dowitchers	visual	8∀5	38∀17	2∀2	0
Duck	visual	64∀36	158∀50	92∀18	6∀3
water fowl	visual	64∀36	173∀53	98∀18	7∀3
water fowl	video	0	4∀2	59∀59	0
Geese	visual	2∀2	17∀11	6∀4	0
Birds of prey	visual	0	3∀1	3∀0.3	0

*Visual data converted from bird ha^{-1} 10 min^{-1} ; video data covert from birds m^{-2} hr^{-1}



FIGUIRE 1 . Shorebird, birds of prey, geese and duck flux density based on visual census of Spartina affected tideflats in response to treatment method.

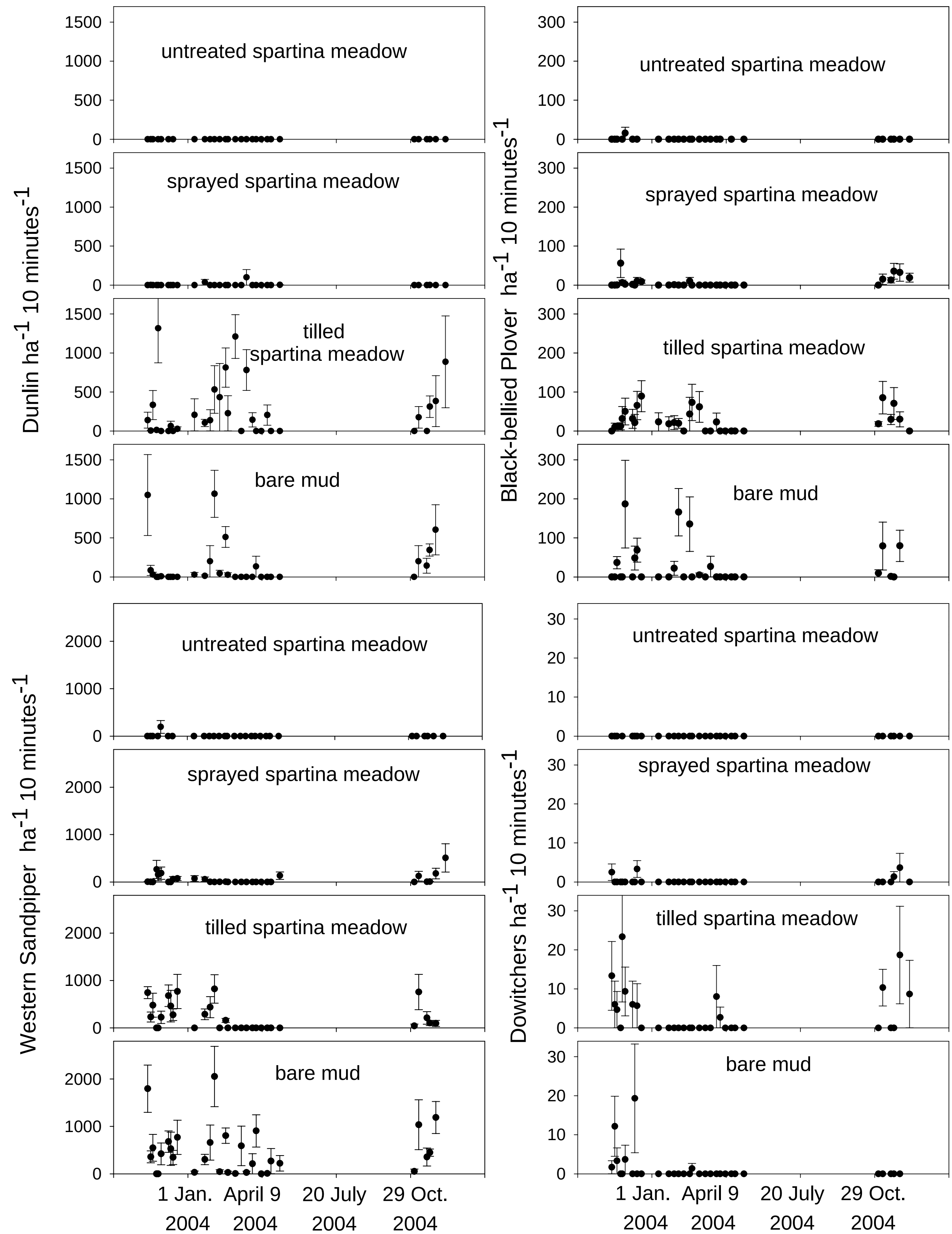


FIGURE 2. Western Sandpiper, Dunlin, Dowitchers, and Black-bellied Plover density based on visual census of Spartina affected tideflats in response to treatment method.

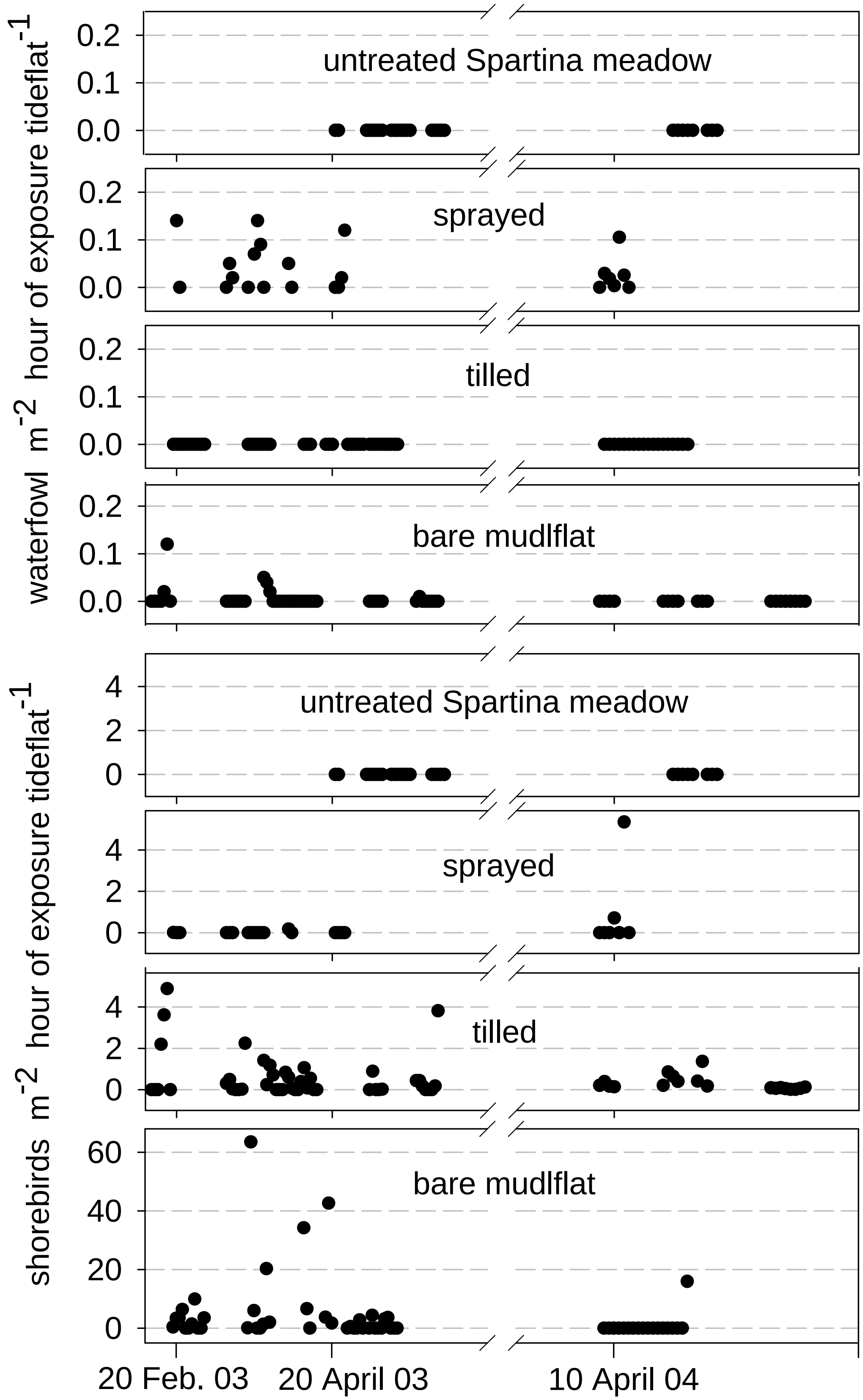


FIGURE 3 Shorebird and waterfowl flux density based on remote video camera recording of Spartina affected tideflats in response to treatment method.

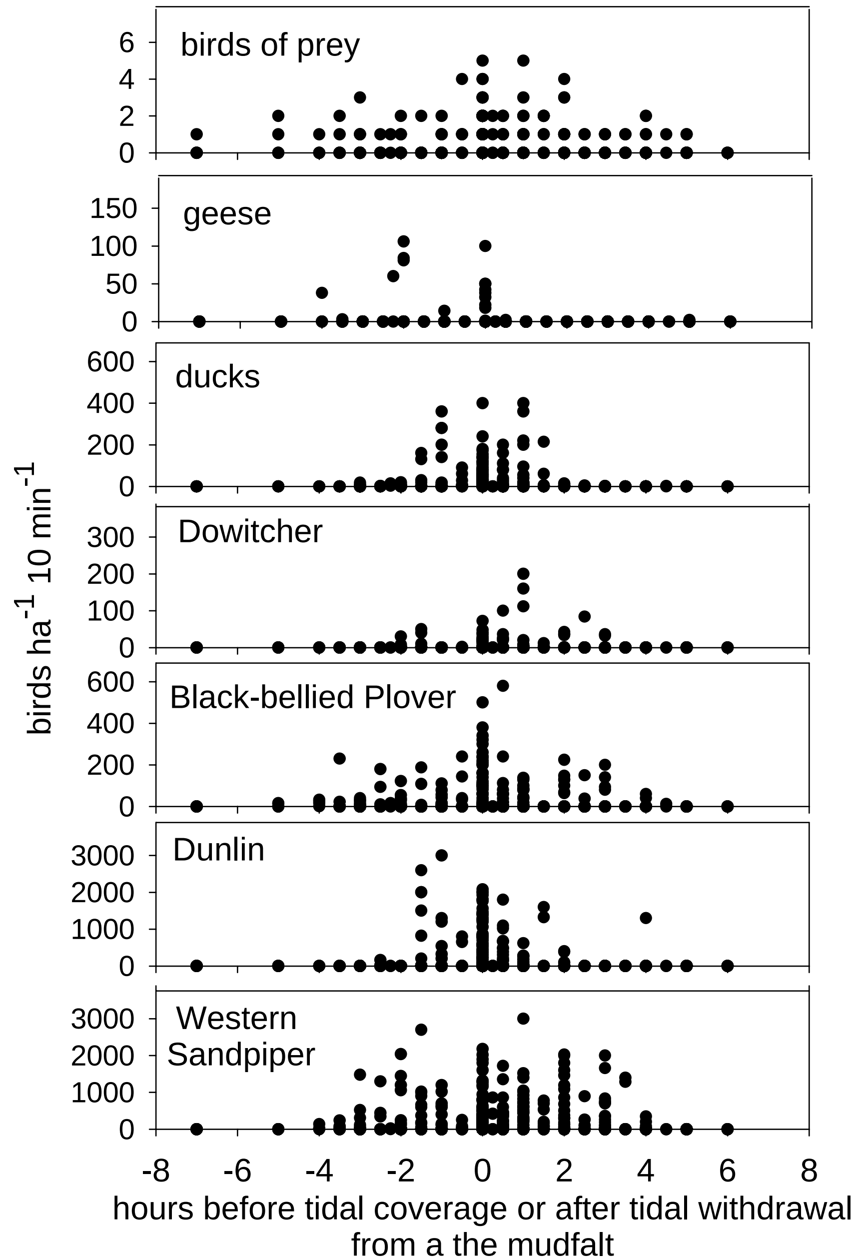


FIGURE 4. Western Sandpiper, Dunlin, Dowitchers, Black-bellied Plover, duck and birds of prey flux density as a function hours before tidal coverage or after tidal withdrawal from a mudflat.

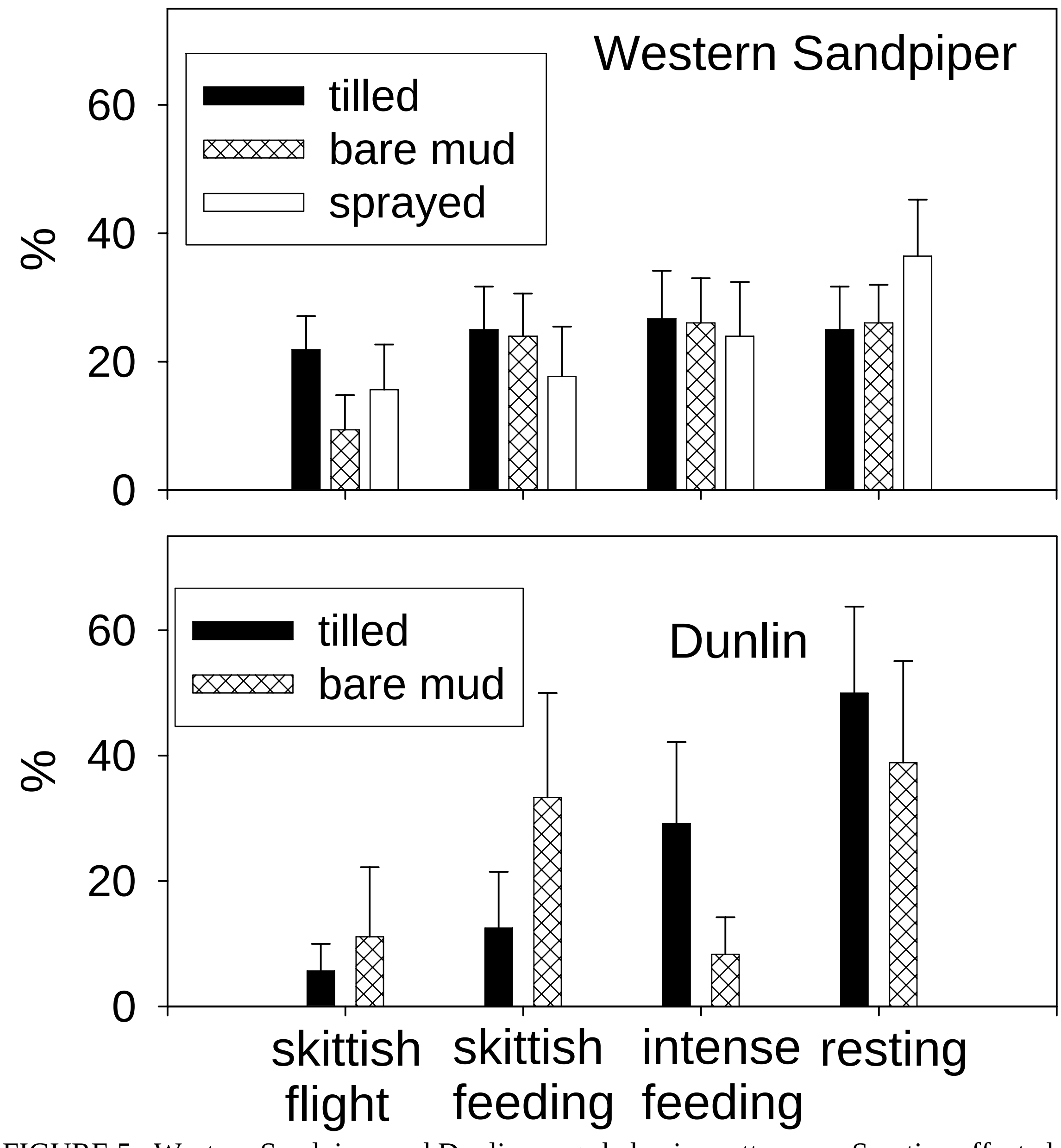
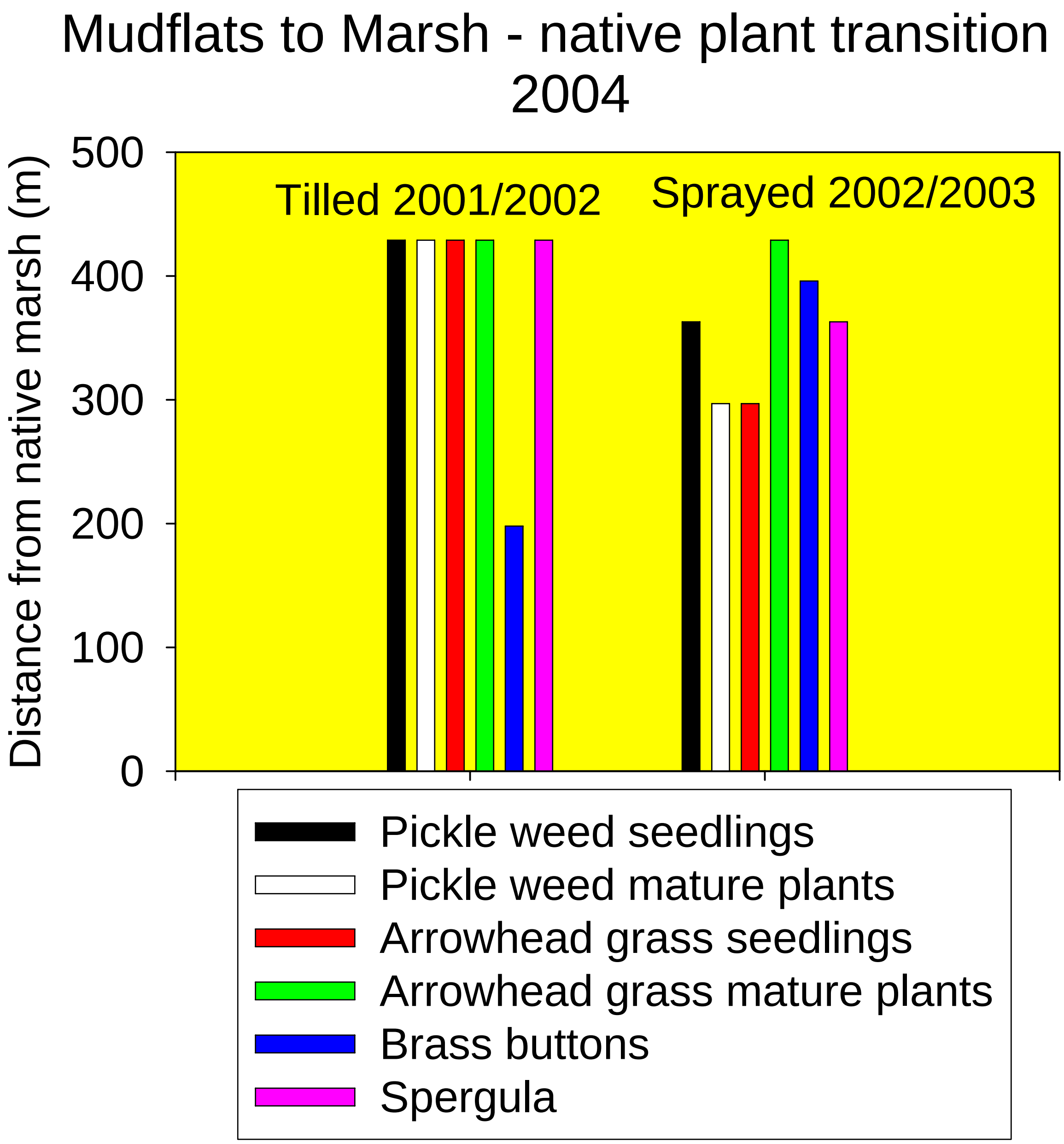
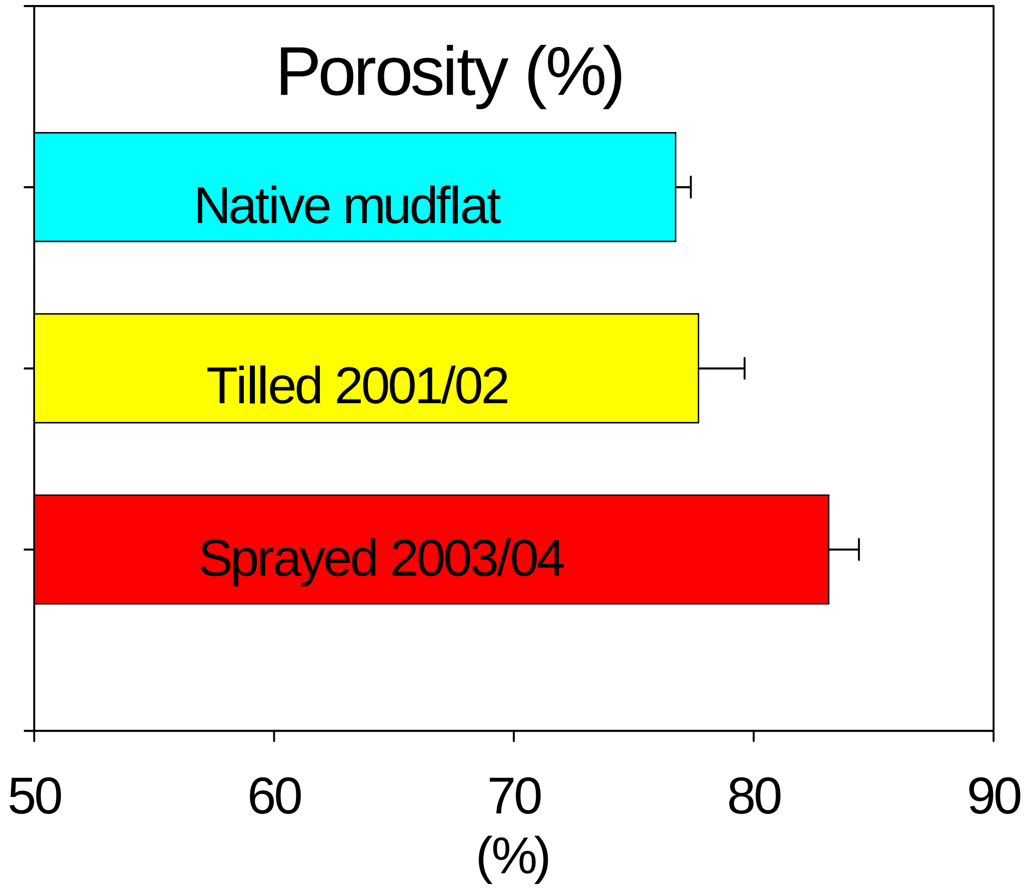
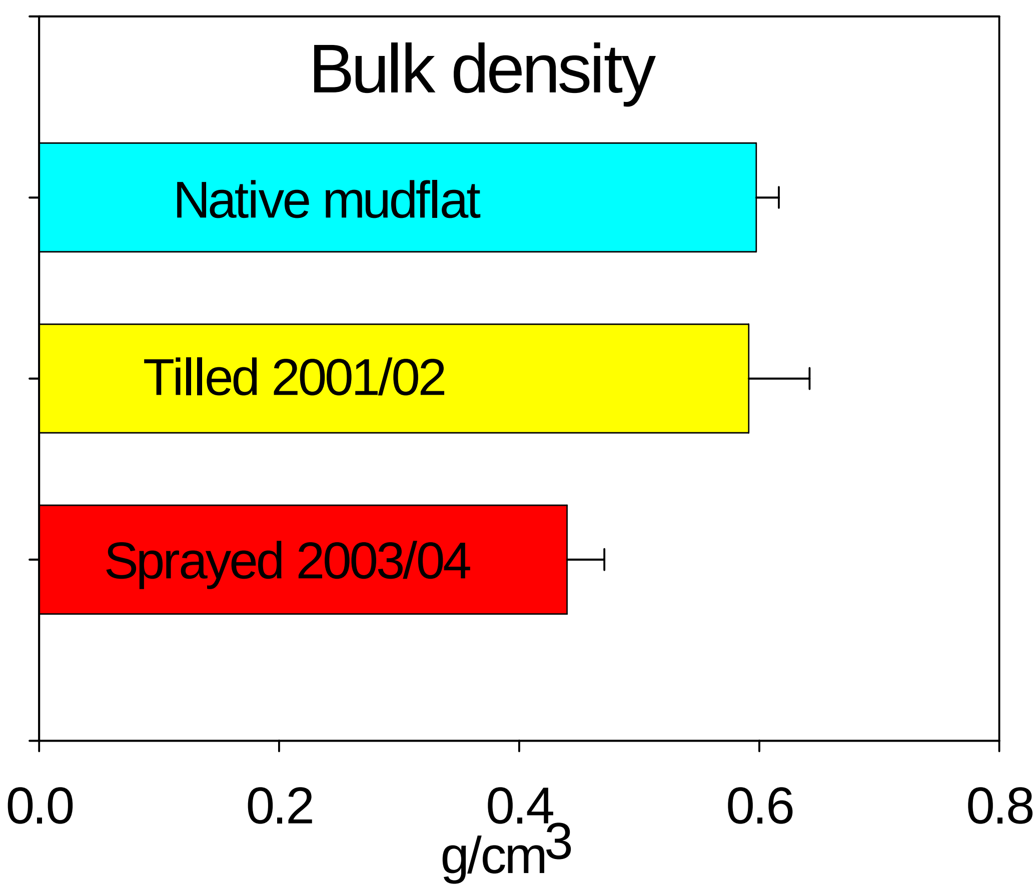
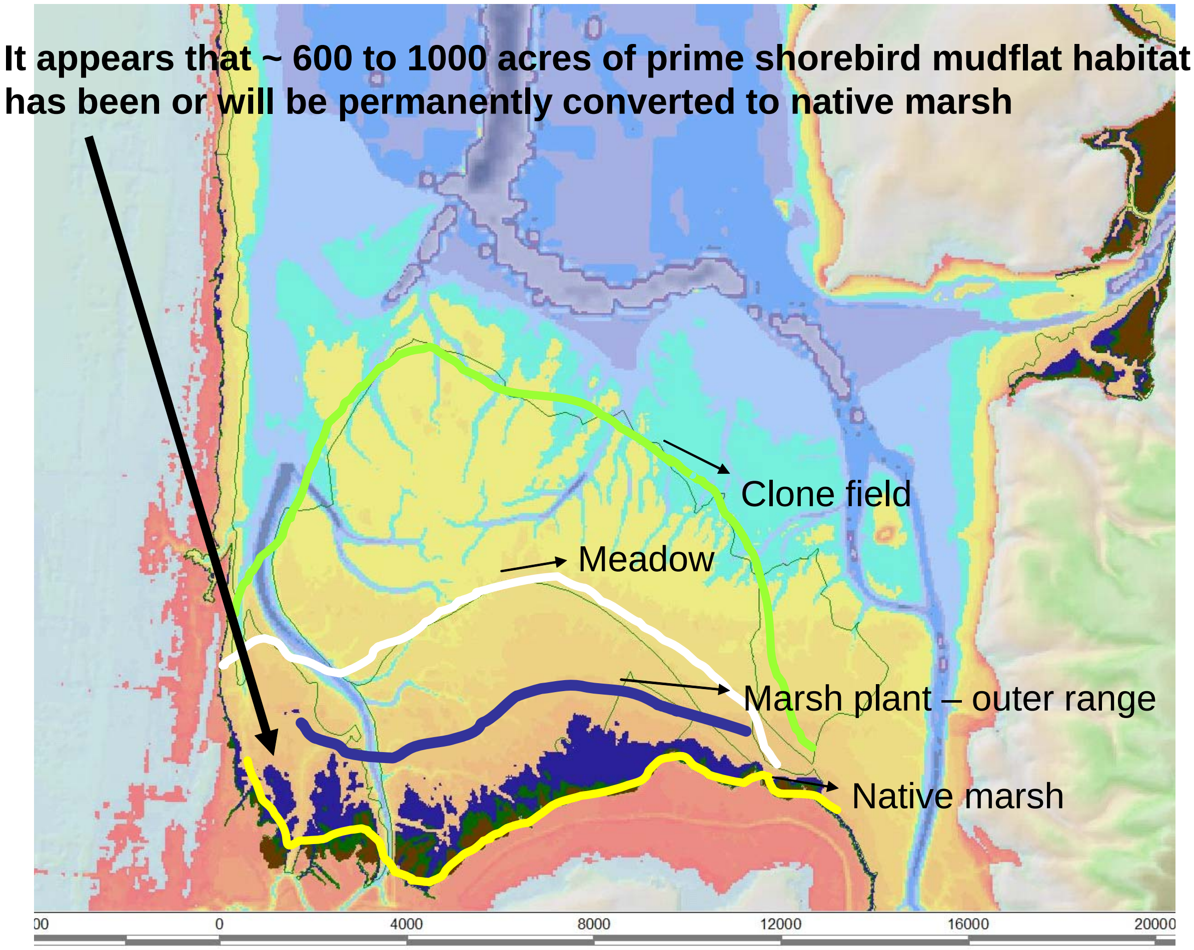


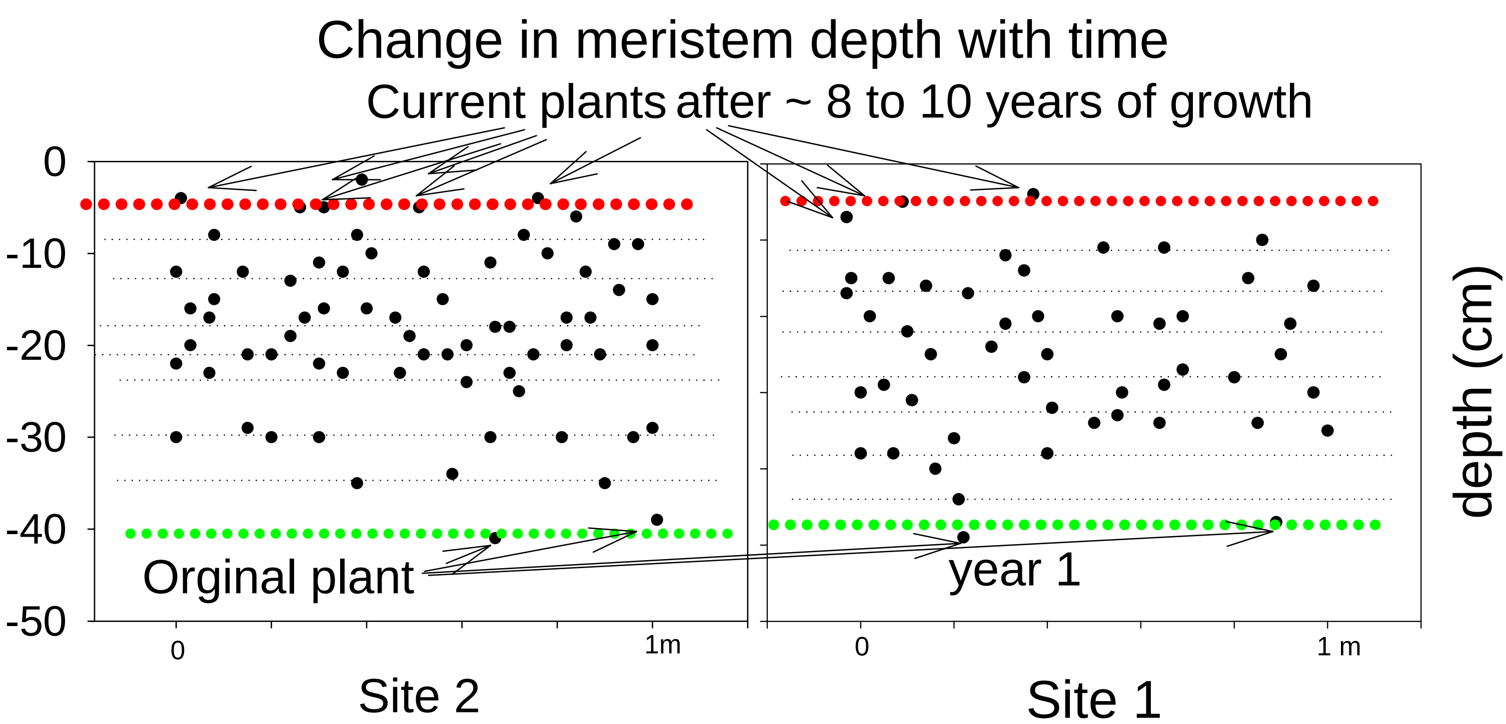
FIGURE 5. Western Sandpiper and Dunlin usage behavior patterns on Spartina affected tideflats as a function of treatment method.


Mudflats to Marsh - native plant transition
2004
Distance from native marsh (m)
500
400
300
200
100
0
Tilled 2001/2002
Sprayed 2002/2003
Pickle weed seedlings
Pickle weed mature plants
Arrowhead grass seedlings
Arrowhead grass mature plants
Brass buttons
Spergula


Porosity (%)
Native mudflat
Tilled 2001/02
Sprayed 2003/04
50
60
70
80
90
(%)


Bulk density
Native mudflat
Tilled 2001/02
Sprayed 2003/04
0.0
0.2
0.4
0.6
0.8
g/cm3


It appears that ~ 600 to 1000 acres of prime shorebird mudflat habitat has been or will be permanently converted to native marsh
Clone field
Meadow
Marsh plant – outer range
Native marsh
00
0
4000
8000
12000
16000
20000



~ increase in elevation 35 cm in ~ 8 to 10 year
~ 15% of soil volume is sediment

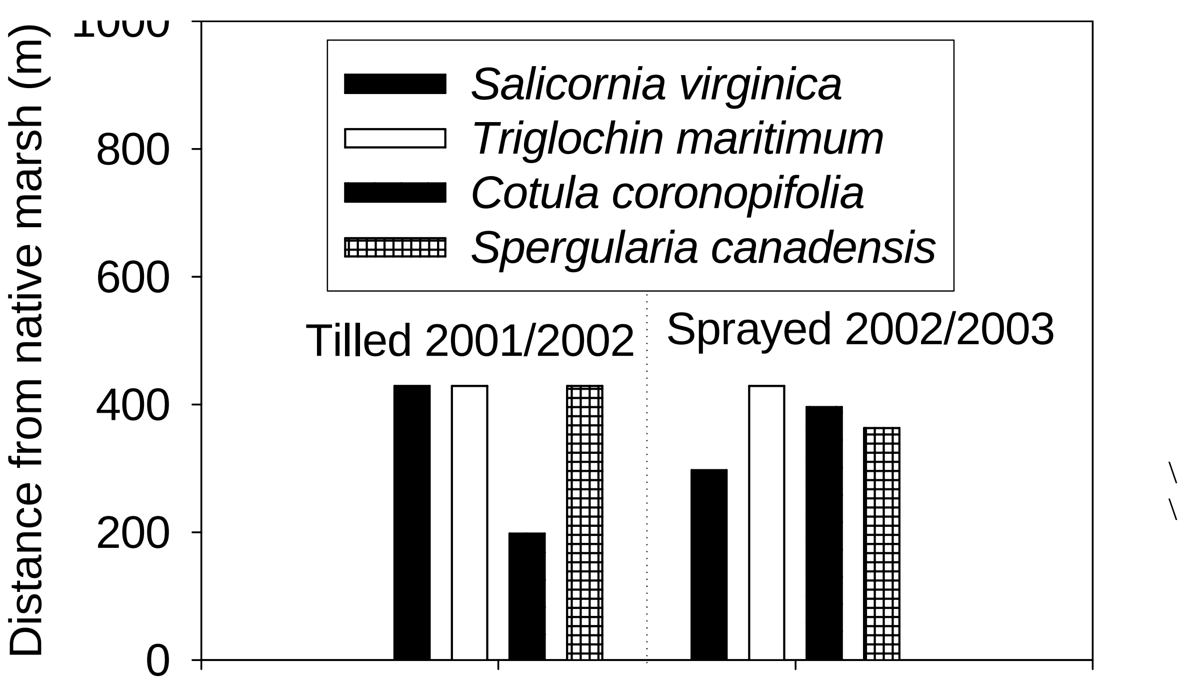


Figure 3. The mean maximum distance from the shoreline that salt marsh species were located after *Spartina* was controlled.
Data were collected June 2004.