Effects of regional wetland restoration on the Alviso Shoals of South San Francisco Bay: pre-restoration assessment of shorebird and invertebrate populations

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EXECUTIVE SUMMARY

- The San Francisco Bay is a designated site of Hemispheric Significance for shorebirds in large part due to its tidal mudflats that serve as the principal foraging resource. Predicted losses of 32 to 50% of current mudflat area with 50 to 90% conversion of salt ponds to tidal marsh in the South Bay Salt Pond Restoration Project could impact migratory shorebirds. Our goal was to evaluate communities of benthic invertebrates and shorebirds on the Alviso mudflat prior to breaching Pond A6 to serve as the baseline for future assessments of potential impacts.

- We sampled benthic cores at 36 locations in 3 regions of the Alviso shoals monthly from June to November 2010 to classify pre-restoration characteristics of invertebrate densities by region, distance from shore, and month. We conducted area bird count surveys to characterize baseline peak abundances of birds by month and region and by guild and species. We also conducted behavioral observations of individual birds from two foraging guilds: shallow probers (Western Sandpiper and Dunlin) and deep probers (Long-billed Curlews or Marbled godwits) as an index of habitat quality.

- Overall invertebrate community structure varied by region within the Alviso Shoals. Mean density in Region 2 (the mudflat adjacent to Pond A6) was 40% higher than Region 1 (the mudflat adjacent to Pond AB2). The two regions exhibited similar community structure characterized by bivalves, polychaetes, oligochaetes, nematodes and cumaceans. The invertebrate community in Region 3 adjacent to Alviso Slough was distinct and closer in composition to vegetated marsh dominated by oligochaetes and nematodes.

- Bivalves were the most dominant taxa on the Alviso Shoals and comprised 70% and 88% of all invertebrates sampled in Region 1 and 2, respectively of which *Gemma gemma* (gem clam) constituted 87 and 98% of individuals sampled by region, respectively. Bivalves were most densely aggregated at distances greater than 500 meters from shore. In contrast, bivalves made up 14% of all individuals in Region 3. Polychaetes were the second most abundant taxa (mean abundance of 450 individuals/m^2 in Region 1 and 363

individuals/m² in Region 2). Polychaetes comprised 11% of observed individuals in Region 2, though only 4% relative abundance in Region 2 and 3.

- Different invertebrate taxa showed substantial seasonal variation. Oligochaetes and nematodes were detected in greatest densities during June, the gastropod population spiked in November, and bivalve abundances peaked in June and November. It is unclear why these strong seasonal patterns occurred, though they may be related with the reproductive cycle of invertebrates or predation pressures from shorebirds.

- We found similar overall benthic invertebrate densities on the Alviso compared with Dumbarton mudflat, but that the Alviso shoals community was dominated by a single taxa (Bivalves, 67%) whereas density at Dumbarton shoals was more evenly distributed among taxa. Spatial patterns also differed, with 37% of the total density at Dumbarton detected in the near-shore core while densities at Alviso shoals were more evenly spread at different distances from the shore.

- During 5 months of area surveys, we detected 10 medium shorebird species: American Avocet, Black-bellied Plover, Dowitcher, Killdeer, Marbled Godwit, Long-billed Curlew, Red Knot, Greater Yellowlegs, Whimbrel, and Willet. We also detected 4 small shorebird species: Dunlin, Least Sandpiper, Semipalmated Plover, and Western Sandpiper. We found differences in medium versus small shorebirds by region, with higher abundances of small shorebirds in Region 1 and medium shorebirds in Region 2. Possible reasons may include increased differences in prey densities or availability.

- Western Sandpiper was the most abundant small shorebird with peak abundances > 4,000 birds across the mudflat in November. Western Sandpipers decreased in abundances from September in Region 1 but increased in September in Region 2. Dunlin was the second most abundant small shorebird overall but occurred in low numbers prior to October. Black-bellied Plover was the most abundant medium shorebird (32% of medium shorebird detections) followed by Willet, Marbled Godwit, American Avocet, and Dowitcher.

- During fall migration, shorebirds increased in abundances as the tide receded in Region 2, but maintained stable abundances across the tidal cycle in Region 1. While near-shore bathymetry was not yet available for this site, we observed east to west tidal movement in Region 1, likely related with the irregular topography of the site and embedded channels that may increase habitat availability for shorebirds on the AB1 mudflat over the tidal cycle.

- In our count surveys, we found distinct differences in small and medium shorebird abundances in Alviso versus Dumbarton mudflats. Alviso had a higher abundance of shorebirds overall, particularly in July and August, when the Dumbarton mudflat was nearly empty but the Alviso mudflat hosted substantial numbers of Western Sandpipers in early migration.

- In behavioral surveys on the AB1 mudflat within 2-hours of low tide, we observed 29 Western Sandpipers, 58 Dunlin, and 68 Marbled Godwit. Dunlin and Western Sandpipers spent the majority of their time foraging in contrast with Marbled Godwit that spent almost half their time resting while on the tideline at flood tide. This suggests that the larger shorebirds such as Marbled Godwit may be less limited overall in their accessibility to food compared with small shorebirds such as Western Sandpiper and Dunlin that fed almost constantly at low tide.

- *Future Studies.* A key uncertainty in the South Bay Salt Pond Restoration Program remains – how does restoration affect the ecology of adjacent mudflats that support the majority of vertebrate diversity in the Bay? Our main goal of sampling the Alviso Shoals before December, 2010 was to characterize the invertebrate and bird communities before restoration of Ponds A6 and A8. A before- and after-restoration comparison is essential to learn from this Phase I restoration to yield insights for adaptive restoration. It is also essential that we continue to investigate what aspects of mudflats provide high quality foraging habitat with respect to both prey density and accessibility for shorebird or diving duck species of conservation concern as a means to prioritize mudflat areas for conservation.

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INTRODUCTION

Wetland habitats provide wintering grounds and migratory stopover habitats for millions of migratory birds along the Pacific Flyway, for which tidal mudflats serve as the principal foraging resource (Stenzel and Page 1988). Substantial area of wetland habitats have been lost or degraded since 1800 (Skagen and Knopf 1993) and in San Francisco Bay, tidal mudflat habitat has decreased from about 20,000 ha to about 12,000 hectares (Colwell 1994, Goals Project 1999). In recognition of the importance of stop-over and wintering habitat, the Western Hemisphere Shorebird Reserve Network was established and the San Francisco Bay designated a site of “Hemispheric Significance” for shorebirds (Myers et al. 1987).

The South Bay Salt Pond Restoration Project, the largest tidal marsh restoration on the Pacific coast, is expected to increase sediment demand to restoring ponds from adjacent mudflats. Of about 50 square kilometers of South Bay mudflats south of the San Leandro Marina channel, Brew and Williams (2010) predicted a 32% loss of mudflat area under a 50-50 conversion scenario and 50% loss of mudflat area under a 90% conversion scenario, in comparison with 14% mudflat loss without restoration. However, the effect of that change on the adjacent shoals, the benthic invertebrates, and migratory birds is unknown. If sediment supply is insufficient, erosion of existing mudflat habitats may result in changes to food webs, such as reduced invertebrate prey or altered composition, which could reduce mudflat value for migratory birds.

Sediment supply and the response of migratory birds are key uncertainties identified for the South Bay Salt Pond Restoration Project. Phase I restoration projects will include restoring Ponds A6 and A8 in FY2010-FY2011, and our studies are focused on the shoals adjacent to these ponds. While the original intent of this study duration included baseline and post-restoration data through November, 2010, we focused on the pre-restoration period due to the delay in the Pond A6 breach event that occurred on December 6, 2010. This study thus provides pre-restoration baseline estimates of bird population and benthic invertebrate densities on the Alviso Shoals, which when combined with future studies, will address one of the largest uncertainties facing the SBSP restoration project: migratory bird responses to changing sediment demand.

Objectives

Our primary objectives were to:

1. Assess the pre-restoration benthic macroinvertebrate community on the Alviso Shoals in relation to season and spatial location.
2. Assess the pre-restoration migratory bird community on the Alviso Shoals in relation to season and spatial location through monthly surveys and behavior observations.

METHODS

1.0 Invertebrates

1.1 Field data collection

Our study area was located on the Alviso Shoals that extends from the mouth of Coyote Creek to the western shore of the South Bay (Figure 1). Following field reconnaissance visits we set up 36 invertebrate sampling locations (Figure 2) to capture the area where the largest sediment changes were expected following restoration activities at Ponds A6 and A8. We collected monthly benthic sediment cores from June 2010 to November 2010 to classify pre-restoration characteristics of the benthic invertebrate community within the Alviso mudflat.

Invertebrate sampling consisted of 7 transects aligned perpendicular to shore with core locations at approximately 100 m intervals (Figure 2). The transects were established within three regions of the study area: Region 1 consisted of two transects (AA and AB) established west of Guadalupe Slough that contained 9 core locations each; Region 2 consisted of two transects (AC and AD) east of Guadalupe Slough with 6 core locations each; and Region 3 contained three short transects (AE-AG) that were established adjacent to pond A6 within the mouth of Coyote Creek, between Guadalupe and Alviso Sloughs, with 2 core locations each.

We used a boat acquired specifically for shallow-water sampling of mudflats, a "flats" boat known as a Flatscat® that is a tunnel-hulled motorboat that is able to travel in less than 15 cm of water. We accessed the mudflat at high tide and took a single mud core at each of the 36 unique locations using a stainless steel long corer. Each core was 10 cm diameter, taken to 10 cm depths. The number of samples was based on an examination of variation from the Dumbarton Shoals (J. Yee, USGS statistician). We also collected a smaller sample from the top 1-2cm of the core for sediment analysis for use in future studies (B. Jaffe, USGS, unpubl. Data).

We relocated sites for monthly sampling using GPS coordinate of each invertebrate location. Spring and early summer conditions in this part of the South Bay result in heavy wind-waves during the afternoon to early evening; thus, we adjusted sampling to the period just before sunset to obtain the samples at this mudflat.

1.2 Lab processing and analysis

Within one week of collection, all samples were sieved with 0.5 mm mesh by elutriation, whereby samples were carefully rinsed into a clean 5 gallon bucket and sprayed gently in order to help break apart the sediment core. With this method, the largest, heaviest sediments settle to the bottom of the bucket and the water (with suspended invertebrates) is then gently poured over the 0.5 mm sieve (Figure 3; Photo 1). This process was repeated until the core was completely broken up and rinsed into the sieve. The remaining sample matrix was placed into a properly labeled jar containing a 70% ethanol and rose bengal dye solution. The rose bengal dye stains animal tissue vivid pink, distinguishing it from vegetation and inorganic debris.

The invertebrate samples were then spread out among petri dishes and sorted under stereo dissection microscopes at a magnification range of 7x to 35x at the San Francisco Bay Estuary Field Station invertebrate lab. Animal matter was picked from the shell fragments and plant debris and stored in a vial containing 70% ethanol. All invertebrate technicians conformed to our internal QA/QC procedures for a sorting efficiency of 90%. Invertebrates were later identified by experienced invertebrate specialists to the lowest possible taxonomic unit and identification for all samples was confirmed with laboratory manuals, taxonomic guides, and reference collections. Taxa were enumerated and bivalves were sorted into size classes (0-2 mm, 2-4 mm, 4-6 mm, 6-12 mm, 12-18 mm).

We present number of individuals per meter square where non-detected taxa were represented as 0 for any given core. Our goal with the pre-restoration baseline data is to provide a description of the invertebrate community by region, month, and distance from shore. To gain insights into larger spatial variability we also compare invertebrate density for the Alviso and Dumbarton mudflats.

2.0 Birds

2.1 Avian area surveys

We conducted count surveys to characterize baseline bird abundances at the Alviso mudflat prior to breaching Ponds A6 and A8. We sampled two regions of the Alviso shoals: Region 1 to the west of Guadalupe Slough, and Region 2 to the east of Guadalupe Slough (Figure 4). Region 1 occurred on a previously surveyed subsection (2008-2010) adjacent to Pond AB1 and was delineated by two transects located 400 m apart from the edge of Ponds AB1 and AB2 extending perpendicular to the shoreline 800 meters into the bay. The second region consisted of the triangular mudflat area adjacent to Pond A6 within the intersection of Guadalupe and Alviso Sloughs ending at the power towers intersecting the mud flat just north of A6. This region was selected to capture the area of maximum impact expected for Phase I restoration at Ponds A6 and A8, and where near-shore bathymetry was expected to be measured (B. Jaffe, USGS). The 38, 1" PVC poles at 100-m intervals served as visual reference to record the tideline and to avoid double counting individual birds (Figure 4).

We surveyed the Alviso mudflat during ebb tide and counted shorebirds in 15-minute periods across the ebb tidal cycle. Two experienced observers per day used spotting scopes to count birds from vantage points on levees during an ebb tide when the mudflat was exposed. During surveys observers identified birds to species and recorded their behavior as either foraging or roosting. We conducted initial reconnaissance of the site in mid June, 2010 after funding was received and were able to begin surveys from July through November 2010.

Our primary goal was to provide baseline abundances of birds detected by month in the two study regions. Since shorebirds typically move with the tideline across the tidal cycle, we summed the number of birds detected across each region during subsequent 15-minute surveys, and report the maximum detected using the mudflat by month and region to represent peak abundance that utilized the Alviso Shoals mudflat by guild and species. We assessed peak abundance changes across the ebb tide. We also compared abundances at Alviso versus Dumbarton mudflats to provide a larger spatial context for observed abundances.

2.3 Avian behavioral observations

We conducted one minute observations of individual birds from two foraging guilds: shallow probers (Western Sandpiper and Dunlin) and deep probers (Long-billed Curlews or

Marbled godwits). These species were selected to enable future comparison with an associated study occurring at the Dumbarton mudflat. We conducted focal observations from July 2010 through November 2010 on the Alviso mudflat adjacent to Pond AB1 in South San Francisco Bay within 2-hours of low tide.

Focal observations lasted for a minimum of 60 seconds or until the bird flew away. Within each observation we recorded the amount of time spent in each of the following behaviors: peck, probe, turn (> 45º), walk, run, vigilance, prey capture, flight, rest, preen, aggression, and interference. We defined pecking as a jabbing of the sediment with at least the bill tip below the surface, and probing as insertion of the entire bill into the sediment. In addition to behavior, we recorded the focal bird's distance from tideline, the nearest neighboring bird's species and distance, flock size and composition, the bird's location with respect to the flock, the distance between the tideline and the shore, and the water depth at the location of the focal bird. To delineate the survey area and measure tide distance, observations were recorded in relation to PVC poles installed in two rows perpendicular to the shore and spaced apart every 100 meters out to a distance of 800 meters. We recorded all behavior and location data into a voice recorder and subsequently transcribed it.

For the purpose of this report, we summarize the behavioral observations as the percent time an individual spent engaged in each behavior by location (tideline versus mudflat) and tide (ebb versus flood). We used all observations with greater than 45 seconds of data. No birds were observed during the behavioral surveys on the mudflat in July and August so our analysis was restricted to the fall period. We compared the percent time of each behavior between ebb and flood tides and between mudflat and tideline locations for each species as well as among species. These behaviors represent the pre-restoration conditions prior to the breaching of Pond A6.

RESULTS AND DISCUSSION

1.0 Invertebrates

We detected 13 benthic macroinvertebrate taxa during our six month sampling period within the Alviso shoals complex (Table 1, Table 2). The six most abundant taxa across the entire site comprised 99% of total abundance; these consisted of clams (Bivalvia, 59%), oligochaetes (Annelida, 21%), nematodes (Nematoda, 9%), polychaetes (Annelida, 6%), cumaceans (Crustacea, 2%), and amphipods (Crustacea, 2%). To gain some insight into the spatial and temporal variation within the Alviso Shoals, we summarize inverterbrate densities by distance from shore and month by region, and we compare Alviso to the Dumbarton mudflat.

1.1 Invertebrate density by distance from shore and region

Region 1. Five taxonomic groups were dominant in the region: bivalves, polychaetes, cumaceans, oligochaetes and nematodes. Of these, bivalves were the most dominant taxa (mean abundance of 2,774 individuals/m^2) and comprised 70% of all invertebrates sampled. Four bivalve species were detected in this region with *Gemma gemma* (gem clam) being the dominant species (87% of relative bivalve abundance in Region 1; Figure 3, Photo 2). *G. gemma* is a small (0-5 mm) surface dwelling clam, commonly found in soft sediment mudflats throughout San Francisco Bay in high abundances due to its opportunistic life history strategy. Gem clams produce multiple broods each year, and juvenile success is increased by internal brooding and local dispersal (Nichols and Thompson 1985). The majority of bivalve densities were detected approximately 500 meters off shore (36%; Figure 5a). *G. gemma* densities were greatest between cores 5 and 9 with the densest aggregations occurring approximately 500 meters offshore. The other three bivalve species, *Macoma petalum*, *Corbula amurensis* and *Venerupis philippinarum* (7%, 6%, <0.1%, respectively) exhibited the greatest abundances near shore in the first four core locations (400 meters; Figure 3, Photo 2). The invertebrate taxonomic assemblage in Region 1 was consistent with other soft sediment estuarine communities (Thompson et al. 2007).

Polychaetes were the second most abundant taxa (mean abundance of 450 individuals/m^2; 11% relative abundance) in Region 1. We detected four species of polychaete across all core locations with highest densities greater than 400 meters offshore (Figure 5a). The errant and highly mobile *Neanthes succinea* was the most common polychaete (45% relative abundance) followed by the tubiculous and sedentary *Streblospio benedicti* (29% relative abundance). A predatory and mobile polychaete, *Eteone lighti* (18% relative abundance) was the only polychaete species to be found at greater abundances in the near shore samples than in the off shore samples. Capitellidae was the fourth polychaete taxa detected in Region 1 (8% relative abundance) and exhibited peak densities at cores 4 and 8 (Table 1; Figure 3, Photo 3).

Cumaceans were the most abundant crustaceans and the third densest taxonomic group detected in Region 1, with 202 individuals/m^2 recorded (5% relative abundance; Figure 3, Photo 4). Amphipods and ostracods were also observed in Region 1 but at lower densities (2% relative abundance, each; Table 1).

<u>Region 2.</u> Region 2 exhibited a similar community structure to Region 1 and was characterized by the same five most abundant taxa: bivalves, polychaetes, oligochaetes, nematodes and cumaceans. The overall mean density in Region 2 (9,767 individuals/m^2) was approximately 48% higher than Region 1 (3,935 individuals/m^2; Figure 5b). Bivalves comprised 88% of all individuals sampled (8,589 individuals/m^2) of three species. *G. gemma* represented 98% of total bivalve abundance in Region 2, while *C. amurensis* and *M. petalum* each

represented 1%. *G. gemma* abundances increased with increasing distance from shore, with peak abundances occurring at core 6 (16,435 individuals/m²).

Polychaetes were the second most abundant taxa, comprising 4% of individuals detected, and contained the same four species as Region 1. Region 2 polychaete abundances were less than those found in Region 1 (363 individuals/m²), however they exhibited higher species evenness (*N. succinea*, 31%; *S. benedicti*, 26%; *E. lighti*, 23%; Capitellidae, 20% relative polychaete abundance). Lower abundance taxa detected in Region 2 included oligochaetes, nematodes and cumaceans (2% each, overall relative abundances; Table 2).

<u>Region 3.</u> Region 3 cores were closer to vegetated marsh characterized by compact mud that was challenging to rinse away during sieving and contained large quantities of vegetative debris. The invertebrate community was very distinct from the other two regions and was dominated by oligochaetes and nematodes (Figure 3, Photos 5a, 5b). Oligochaetes represented 59% of all measured individuals in the region, 98% of which were located in the near-shore core along the edge of Coyote Creek (Figure 5c). Nematodes were the second most abundant taxa that represented 17% of individuals, 95% of which were detected adjacent to shore. The benthic community differed substantially 100 meters off shore. Bivalves made up 14% of all individuals in Region 3, 80% of which resided in core 2 samples. Similar to Regions 1 and 2, *G. gemma* was the dominant bivalve species representing 65% of bivalves detected, where *C. amurensis* and *M. petalum* comprised 18% and 17% of bivalves detected. Polychaetes made up approximately 4% of overall benthic community, of which 80% of individuals were detected in core 1. Region 3 polychaetes exhibited the greatest number of species, with four sedentary polychaetes (*Streblospio benedicti*, Capitellidae, Cirratulidae, and Sabellidae) and two errant polychaetes (*Eteone lighti* and *Neanthes succinea*; Table 3).

The overall abundance of Region 3 was the highest of the three regions, although this is largely due to the dominance of oligochaetes in June (9,001 individuals/m² overall mean abundance; Jun: 25,168 individuals/m²; Jul-Nov mean: 5,768 individuals/m²).

1.2 Invertebrate density by month

In addition to spatial variation, we observed seasonal patterns across taxonomic groups (Figure 6). In all 3 regions, oligochaetes and nematodes were detected in greatest densities during June, declined by July and remained low throughout the course of the monitoring period. Though in low densities overall, gastropods demonstrated the opposite trend with relatively low abundances in June that increased gradually until population spiked in November. Bivalve abundances peaked twice across regions, in June and November, with lower observed densities from July through October. Other taxa that exhibited significant seasonal patterns included ostracods (peaked in November), and nematodes and oligochaetes (highest detected abundances in June).

Within Region 1, invertebrate density was highest in November 2010 due to a bivalve population spike during this month (Figure 6a, Table 1). Region 2 exhibited a similar seasonal pattern with peak densities in June and November 2010 (Figure 6b, Tables 1 and 2). Bivalves were again responsible for the high invertebrate presence in June within Region 2 (18,972 individuals/m²). In Region 3 oligochaetes and nematodes had highest densities in June (25,168 and 12,648 individuals/m², respectively) which dropped abruptly in July (934 and 403 individuals/m², respectively; Figure 6c, Table 3), after which total macrofaunal abundance increased in August and remained relatively consistent through November, 2010. While we do not know the cause of these monthly shifts in invertebrate densities, they are likely related with the seasonality of invertebrate reproduction as well as predation pressure from migrating shorebirds.

1.3 Comparison of Dumbarton and Alviso shoals invertebrate communities

Overall benthic invertebrate densities on the Alviso mudflat (7,019 individuals/m²) were similar to those at the Dumbarton mudflat (8,450 individuals/m²) during the same time period (June – November 2010). Both sites shared the same six most abundant taxa (bivalves, amphipods, nematodes, polychaetes, oligochaetes and cumaceans). However, taxonomic composition differed between the sites: the Alviso shoals community was dominated by a single taxa (Bivalves, 67%) whereas density at Dumbarton shoals was more evenly distributed among taxa (Table 4; Figure 7). The invertebrate community composition also varied by distance from shore between the two sites. At Dumbarton shoals, 37% of the total density was detected in the near-shore sampling location, whereas densities at Alviso shoals were more evenly spread out at different distances from shore (Figure 7). Bivalves in particular exhibited distinct spatial patterns between sites. At Dumbarton, 99% of all bivalves were detected in cores 1-5, whereas at Alviso density was highest in cores 4-6 (64%) and was generally more spread out at all distances. Amphipods were rarely detected at Alviso Shoals (2%) but were the second most abundant taxa at Dumbarton shoals (21%), where they were most abundant in the deeper water areas further from shore (cores 6-9, 98%).

Monthly density patterns were similar between sites with highest mean densities observed in June and November 2010 (Figure 8). Dumbarton shoals exhibited higher total densities in June (53%) than Alviso shoals (37%; Figure 8). This difference was due in part to the presence of amphipods on the Dumbarton shoals which were not detected at Alviso.

Bivalves were the dominant taxa on both mudflats and we evaluated the spatial distributions by size classes. The large bivalves (6-24 mm) were rare at both Dumbarton (2%) and Alviso (4%) and were concentrated in the near-shore cores (Figure 9). Juvenile bivalves (0-2 mm) were the second most abundant size class on both mudflats (45% at Dumbarton, 27% at Alviso). The most abundant size class of clams at both sites were 2-4 mm, primarily *Gemma gemma*, comprising over 50% of bivalve abundance at both sites (52% at Dumbarton, 68% at Alviso). Densities of 0-4 mm size classes at Dumbarton were highest near shore and decreased with increasing distance from shore, whereas this size class had highest densities in 400-600 meters from shore at Alviso shoals (Figure 9).

2.0 Birds

2.1 Avian area surveys

During 5 months of area surveys, we detected 10 medium shorebird species, 4 small shorebird species, and 2 egret species on the Alviso mudflat (Tables 5 and 6). Medium shorebirds were Black-bellied Plover (*Pluvialis squatarola*), American Avocet (*Recurvirostra americana*), Dowitcher (*Limnodromus griseus* & *L. scolopaceus*), Killdeer (*Charadrius vociferus*), Marbled Godwit (*Limosa fedoa*), Long-billed Curlew (*Numenius americanus*), Red Knot (*Calidris canutus*), Greater Yellowlegs (*Tringa melanoleuca*), Whimbrel (*Numenius phaeopus*), and Willet (*Tringa semipalmata*). The small shorebird species were Dunlin (*Calidris alpina*), Least Sandpiper (*Calidris minutilla*), Semipalmated Plover (*Charadrius semipalmatus*), and Western Sandpiper (*Calidris mauri*).

We conducted an average of 7 counts across one low tide per month on the mudflat east of Guadalupe Slough (Region 1) and 6 counts on the mudflat west of Guadalupe Slough (Region 2). We summarize these data as peak counts per month to characterize the maximum shorebird use of the Alviso mudflat by region and month. Western Sandpipers were most abundant (49% of total detections), followed by Black-bellied Plover (14%), Dunlin (13%), Marbled Godwit (8%), American Avocet (7%), Least Sandpiper (5%), and Dowitcher (3%) which constituted 99% of all detections.

The shorebird community differed on the Alviso mudflat east and west of Guadalupe Slough. We found overall higher abundances of small shorebirds in Region 1 (62%) and medium shorebirds in Region 2 (58%) across months (Figure 10). While numerous studies have documented a relationship between shorebird density and prey abundance or biomass (e.g., Colwell and Landrum 1993), prey availability is also critical for shorebirds (Goss-Custard 1984). We found higher densities of polychaetes in Region 1 but higher densities overall in Region 2 largely comprised of the bivalve *G. gemma*. However, differences in accessibility to prey among regions may include substrate texture which affects overall water-holding capacity and the overall topography of a site (Colwell 2010). Near-shore bathymetry has yet to be processed for this site, but we did observe a more rapid filling and draining of Region 2 versus Region 1 that could have greater effect upon small shorebirds with shorter legs and bills compared with medium shorebirds. While we do not have diet samples of shorebirds from this specific mudflat, the invertebrate taxa and size classes found in this study, including amphipods, bivalves, cumaceans, polychaetes and oligochaetes, have been documented to provide important prey for our focal shorebird species from this and other estuaries (Recher 1966, Herbert 1994, Warnock and Gill 1996, Stenzel et al. 1983, Gratto-Trevor 2000, Lowther et al. 2001).

Western Sandpipers were the most abundant small shorebird overall (73% of small shorebird detections), with peak abundances > 4,000 birds across the mudflat in November. Western Sandpipers maintained high abundances over the study period, but their abundance decreased in Region 1 as it increased in Region 2 over the study period (Figure 11). Southward migration of Western Sandpipers is protracted and generally occurs from late June through October, where adults generally leave the breeding grounds before juveniles (Butler et al. 1987, Wilson 1994). Observed differences in our study may relate with these different age-class pulses. Dunlin was the second most abundant small shorebird overall (13% of small shorebird detections), but only occurred on the mudflat during Fall migration in October and November (Figure 11).

Black-bellied Plover was the most abundant medium shorebird (32% of medium shorebird detections) followed by Willet (26%), Marbled Godwit (19%), American Avocet (15%) and Dowitcher (7%). As a group, medium shorebird abundances were highest across the study area in September and October likely corresponding with peak migratory periods. Across the study area, medium shorebirds generally increased in Region 1 and decreased in Region 2 over months (Figure 12), the opposite pattern as that observed for small shorebirds. Long-billed Curlews were not abundant in the Alviso mudflat, with only 60 birds detected across surveys.

During fall migration, shorebirds increased in abundances as the tide receded in Region 2, but maintained stable abundances across the tidal cycle in Region 1 (Figure 13). While near-shore bathymetry data has yet to be processed for this site, we observed east to west tidal movement in Region 1, likely related with the more shallow, irregular topography of the site and embedded channels. Increased topographic heterogeneity may increase the duration of available habitat for shorebirds on this section of the Alviso mudflat over the tidal cycle (Evans and Dugan 1984).

We found distinct differences in small and medium shorebird abundances in Alviso versus Dumbarton mudflats (Figure 14). Alviso had a higher abundance of shorebirds overall, particularly in July and August for Western Sandpipers during the early-migratory period, when the Alviso mudflat hosted > 1000 medium shorebirds and nearly 3000 small shorebirds but the Dumbarton mudflat was nearly empty. During the fall migration period in October and November, the Alviso mudflat hosted > twice the number of birds as the Dumbarton mudflat, though this was also related with greater overall mudflat area.

2.2 Avian behavioral surveys

Shorebird prey intake generally increases with prey density that defines their functional response and in turn affects the overall numerical (population) response to varying habitat conditions. The overall proportion of time spent foraging is related with intake rate, and thus serves as an index to habitat quality. We conducted behavioral observations of 155 individual birds during September, October, and November of 2010 on Region 1 of the Alviso mudflat. We used a minimum of 45 seconds per observation with 96% of observations greater than 60 seconds. We observed 29 Western Sandpipers, 58 Dunlin, and 68 Marbled Godwit (Table 7). Long-billed Curlew was an intended focal species but no curlews were detected during behavioral surveys on the Alviso mudflat in any month.

Overall, Dunlin and Western Sandpipers spent the majority of their time pecking in contrast with Marbled Godwit that spend a greater proportion of time probing and less time foraging overall (Figure 15). These differences likely reflect the basic difference in the evolutionary traits of longer bill and legs (Barbosa and Moreno 1999) that allows a greater accessibility of the larger shorebirds to foraging resources that vary with prey density, substrate texture, and water depth. Willet has been found to feed over ebb, flood, and slack tides and to use different foraging techniques over habitats and tidal stages (Lowther et al. 2001). In our study Marbled Godwit spent almost half of their time (51.9%) resting while on the tideline at flood tide, and a quarter of their time (26.1%) resting while on the mudflat at ebb tide. In contrast, Western Sandpipers spend almost no time resting. These observations suggest that medium shorebirds such as Marbled Godwit and Willet may be less limited overall in their accessibility to food on the San Francisco Bay mudflats compared with small shorebirds such as Western Sandpiper and Dunlin that need to feed almost constantly at low tide.

Dunlin spend more time pecking during flood tides (86.1%) than ebb tides (65.8%), while Western Sandpipers spend more time pecking during ebb tides (85.9%) than flood tides (77%; Figure 15). These differences may represent a spatial segregation of resources for these similar species to reduce interference or exploitative competition. It may also reflect differences in the basic foraging strategies of these birds based on bill morphology. Western sandpipers spent the greatest time foraging on the tideline during the ebb tide, but did spend a substantial portion of time foraging on the mudflat at both ebb and flood tides, suggesting that the full breadth of the mudflat continued to provide relatively high quality habitat for them across the tidal cycle on this mudflat though it is unknown whether they maintained similar intake rates. In contrast, Dunlin spent a lower proportion of time foraging on the mudflat compared with tideline during the ebbing tide (Figure 15).

SUMMARY AND RECOMMENDATIONS

In this report, we have provided a descriptive assessment of the benthic invertebrate and shorebird communities that occurred in the Alviso Shoals prior to the restoration of Ponds A6 and A8 within the South Bay Salt Pond Restoration Project. Prior to pond breaching, we found very high densities of benthic invertebrates at the Alviso mudflat, similar to those of Dumbarton, but with differing community composition and spatial distribution between sites. We also observed high peak abundances of small and medium shorebirds on the Alviso mudflat compared with Dumbarton that included use by Western Sandpipers in early migration. Our study thus documents that the Alviso Shoals provide a critical foraging resource for migratory shorebirds, and perhaps more so than other sites around the South Bay.

Given the loss of 40% of tidal mudflat area within the San Francisco Bay, and the predicted additional reduction of 32 to 50% of existing mudflats in 50 to 90% salt pond to tidal marsh conversion scenarios within the South Bay (Brew and Williams 2010), we recommend that the selection of ponds for restoration proceed with the goal of minimizing mudflat loss. We also suggest emphasis on maintenance of mudflat areas that provide particularly high quality foraging resources in terms of both prey quality and accessibility, particularly for small shorebirds.

Foraging resources at migratory stop-over sites can have overall population consequences for shorebirds that fly thousands of kilometers each year with the fundamental goals of producing young during the breeding season and surviving the harsh winter months. Kraan et al. (2009) documented the relationship between suitable foraging area, the spatial predictability of food, and red knot survival. Several shorebird species have undergone population declines including Dunlin that have been attributed to continued loss and degradation of wetland habitats (Warnock and Gill 1996). The San Francisco Bay provides one of the most important wintering and stop-over sites along the Pacific Flyway for numerous shorebird species, and maintenance of high quality foraging resources of tidal mudflats remains essential.

FUTURE STUDIES

A key uncertainty in the South Bay Salt Pond Restoration Program remains – how does restoration affect the ecology of adjacent mudflats that supports the majority of vertebrate diversity in the Bay? The main goal of sampling the Alviso Shoals before November 2010 was to capture the nature of the invertebrate community, bird community, and bird foraging activity before restoration of Ponds A6 and A8. A before- and after-restoration comparison is essential to learn from this Phase I restoration and to inform adaptive restoration within the SBSP program for the following decades. A post-restoration study would allow assessment of changes in the invertebrate community and birds in response to changes in the mudflat adjacent to the tidal marsh restoration. This would be the first opportunity for the SBSP restoration project to obtain scientific information on this key uncertainty as the basis for future phases of the restoration program.

For future decision making regarding which ponds to convert, it is also essential that we use existing and new datasets to investigate the fundamental ecology of shoals for both invertebrates and birds. What aspects of mudflats provide high quality foraging habitat with respect to both prey density and accessibility for shorebird or diving duck species of conservation concern? What physical parameters (sediment texture, elevations, slope, innundation time) affect the distribution of invertebrates? In addition to prey distributions, what physical parameters affect prey accessibility for shorebirds? Answers to these fundamental questions will yield insights into priorities for which mudflats to protect. In addition, the findings from the mudflat studies will be the key to better understanding the likelihood that climate change effects and sea level rise will impact migratory birds.

Answers to these questions require an interdisciplinary perspective. When available, data on the physical parameters associated with mudflats, such as near-shore bathymetric measurements, will yield critical insights for invertebrate and bird distributions. In current and future studies, we will continue to collaborate with the interdisciplinary USGS Shoals Project led by 3 USGS centers in the Western Region including the California Water Science Center

(CAWSC), Marine and Coastal Geology Pacific Science Center (CMG PSC), and Biological Resources Western Ecological Research Center (WERC).

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TABLES AND FIGURES

Table 1. Mean abundance of benthic invertebrate taxa from June to November 2010 (individuals/m²) in Region 1 of Alviso Shoals, prior to breaching Pond A6.

Invertebrate Taxa	Jun	Jul	Aug	Sep	Oct	Nov
Phylum NEMATODA	509	21	14	57	28	127
Phylum ANNELIDA						
Class Polychaeta						
Capitellidae	7	14	21	64	50	78
Eteone lighti	127	28	99	92	35	92
Neanthes succinea	212	113	219	325	149	198
Streblospio benedicti	340	28	134	92	14	170
Class Oligochaeta						
Oligochaeta	707	35	42	28	28	92
Phylum MOLLUSCA						
Class Gastropoda						
Littorina spp.	42	42	71	64	64	141
Nassarius obsoletus	-	-	-	-	7	-
Class Bivalvia						
Corbula amurensis	113	35	233	248	134	163
Gemma gemma	1,075	813	2,150	1,966	2,320	6,225
Macoma petalum	78	85	191	354	170	276
Venerupis philippinarum	-	14	-	-	-	-
Phylum ARTHROPODA						
Class Ostracoda						
Myodocopa	7	14	7	21	64	241
Podocopa	-	-	7	-	-	-
Class Malacostraca						
Order Amphipoda						
Amphipoda spp. juv.	7	-	-	-	-	14
Ampelisca abdita	50	-	78	149	134	42
Grandidierella japonica	7	-	7	-	7	-
Order Tanaidacea						
Pancolus californiensis	-	-	14	-	-	-
Order Cumacea	255	106	226	212	92	318
Class Entognatha						
Collembola	-	-	-	-	-	64

Table 2. Mean abundance of benthic invertebrate taxa from June – November 2010 (individuals/m²) in Region 2 of Alviso Shoals, prior to breaching Pond A6.

Invertebrate Taxa	Jun	Jul	Aug	Sep	Oct	Nov
Phylum NEMATODA	435	127	74	149	424	106
Phylum ANNELIDA						
Class Polychaeta						
Capitellidae	46	53	53	95	95	95
Eteone lighti	313	64	42	21	42	32
Neanthes succinea	104	117	117	180	95	64
Streblospio benedicti	243	21	42	138	85	64
Class Oligochaeta	845	149	106	53	127	127
Phylum MOLLUSCA						
Class Gastropoda						
Littorina spp.	35	11	42	11	42	106
Class Bivalvia						
Corbula amurensis	197	308	74	21	11	32
Gemma gemma	18,682	5,581	6,494	2,844	4,318	13,953
Macoma petalum	93	64	74	138	117	117
Phylum ARTHROPODA						
Class Maxillopoda						
Cirripedia	-	-	-	11	-	-
Class Ostracoda						
Myodocopa	35	42	11	21	85	191
Podocopa	-	-	-	-	64	64
Class Malacostraca						
Order Amphipoda						
Amphipoda spp. juv.	35	-	-	-	-	-
Ampelisca abdita	12	-	21	11	-	-
Grandidierella japonica	-	11	-	-	-	-
Corophium spp.	12	-	-	-	-	-
Monocorophium spp.	23	-	-	-	-	-
Order Isopoda	-	-	-	-	-	11
Order Cumacea	845	138	95	106	53	138
Class Entognatha						
Collembola	-	-	-	-	-	53

Table 3. Mean abundance of invertebrate taxa from June – November 2010 (individuals/m²) in Region 3 of Alviso Shoals, prior to breaching Pond A6.

Invertebrate Taxa	Jun	Jul	Aug	Sep	Oct	Nov
Phylum NEMATODA	12,648	403	891	637	573	340
Phylum ANNELIDA						
Class Polychaeta						
Capitellidae	21	-	21	-	21	21
Eteone lighti	424	106	255	276	467	212
Neanthes succinea	42	64	21	-	21	21
Streblospio benedicti	573	85	488	403	127	340
Sabellidae	21	-	-	-	-	-
Cirratulidae	-	-	-	-	-	21
Class Oligochaeta	25,168	934	11,459	9,783	2,801	3,862
Phylum MOLLUSCA						
Class Gastropoda						
Assiminea californica	-	-	-	-	-	340
Littorina spp.	-	127	21	-	106	64
Class Bivalvia						
Corbula amurensis	785	340	509	255	106	361
Gemma gemma	1,061	785	997	573	1,825	3,183
Macoma petalum	510	340	170	488	361	382
Phylum ARTHROPODA						
Class Maxillopoda						
Copepoda	127	-	-	-	-	-
Class Ostracoda						
Myodocopa	-	-	-	-	42	85
Podocopa	21	21	21	-	106	276
Class Malacostraca						
Order Amphipoda						
Amphipoda spp. juv.	-	64	-	-	-	1,061
Corophium spp.	-	297	-	-	-	1,613
Order Cumacea	255	21	42	21	64	64
Class Insecta						
Order Diptera (larvae)	-	-	-	-	-	21
Class Entognatha						
Collembola	-	-	-	-	-	85

Table 4. Relative abundances of six dominant taxa at Dumbarton and Alviso from June to November 2010.

	Dumbarton	Alviso
Bivalves	36%	67%
Amphipods	21%	2%
Nematodes	17%	5%
Polychaetes	11%	7%
Oligochaetes	7%	14%
Cumaceans	5%	3%
	97%	**98%**

Table 5. Peak abundance (and percent foraging) of shorebird species detected from June to November 2010 in Region 1 (west of Guadalupe Slough) of Alviso Shoals, prior to breaching Pond A6.

Bird species	Jul	Aug	Sep	Oct	Nov
Medium Shorebirds					
American Avocet	-	(33%) 3	(38%) 610	(27%) 373	(99%) 307
Black-bellied Plover	(45%) 100	(100%) 320	(21%) 470	(100%) 950	(93%) 55
Dowitcher	(100%) 8	-	-	(100%) 85	(100%) 10
Killdeer	(100%) 2	-	-	-	-
Marbled Godwit	(100%) 55	(100%) 160	(100%) 280	(6%) 729	(100%) 496
Long-billed Curlew	-	(100%) 3	(67%) 3	(30%) 43	(100%) 4
Red Knot	-	-	-	(98%) 107	-
Greater Yellowlegs	-	-	-	(100%) 2	(100%) 1
Whimbrel	(100%) 1	-	(100%) 3	(100%) 2	-
Willet	(100%) 6	-	(0%) 300	(100%) 201	(100%) 82
Small Shorebirds	-	-	-	-	-
Dunlin	-	-	-	(100%) 950	(100%) 1,575
Least Sandpiper	(100%) 10	(100%) 12	(100%) 290	(83%) 890	(100%) 45
Semipalmated Plover	-	(100%) 14	(100%) 18	(0%) 2	-
Western Sandpiper	(100%) 2,800	(100%) 2,600	(100%) 770	(100%) 1,050	(100%) 1,850
Egrets					
Great Egret	-	(0%) 1	(0%) 1	-	-
Snowy Egret	(100%) 2	-	(0%) 1	(100%) 2	(100%) 1

Table 6. Peak abundance (and percent foraging) of shorebirds detected from June to November 2010 in Region 2 (east of Guadalupe Slough) of Alviso Shoals, prior to breaching Pond A6.

Bird species	Jul	Aug	Sep	Oct	Nov
Medium Shorebirds					
American Avocet	-	(100%) 10	(20%) 91	(100%) 600	(100%) 45
Black-bellied Plover	(12%) 510	(100%) 576	(76%) 1,250	(44%) 45	-
Dowitcher	(100%) 350	(100%) 265	(100%) 170	(100%) 20	-
Killdeer					
Marbled Godwit	(100%) 43	(100%) 80	(100%) 82	(74%) 461	(100%) 200
Long-billed Curlew	-	-	-	(67%) 6	(100%) 1
Whimbrel	-	-	(100%) 1	-	-
Willet	(100%) 951	(100%) 875	(19%) 743	(100%) 198	(100%) 210
Small Shorebirds					
Dunlin	-	-	-	(100%) 75	(100%) 1,381
Least Sandpiper	(100%) 15	(100%) 40	(100%) 130	(100%) 180	(100%) 20
Western Sandpiper	(100%) 320	(100%) 617	(100%) 567	(100%) 2,475	(100%) 2,165
Egrets					
Snowy Egret	(100%) 4	(100%) 2	(100%) 1	(100%) 2	(100%) 3

Table 7. Temporal and spatial distribution of bird behavioral observations. Surveys were conducted during July and August but no birds were detected during behavioral surveys on the mudflat during those months. Dunlin were not detected in September and Long-billed Curlew were not detected during any of the surveys.

Month	Species	Mud flat		Tideline		Total
		Ebb	Flood	Ebb	Flood	
9	All	10		9		19
	Marbled Godwit			9		9
	Western Sandpiper	10				10
10	All	23	10	26	20	79
	Dunlin	12	5	9	5	31
	Marbled Godwit	6		15	15	36
	Western Sandpiper	5	5	2		12
11	All	2	5	38	12	57
	Dunlin		2	17	8	27
	Marbled Godwit	2	3	14	4	23
	Western Sandpiper			7		7

Figure 1. Map of the study area showing the Alviso shoals adjacent to Pond A6.

Figure 2. Benthic invertebrate core sampling locations in three regions of the Alviso Shoals study area. The colored surface along Coyote Creek, Guadalupe Slough, and the deep water portion of the Region 2 mudflat represents bathymetry data collected by David Finlayson during mid-January, 2010.

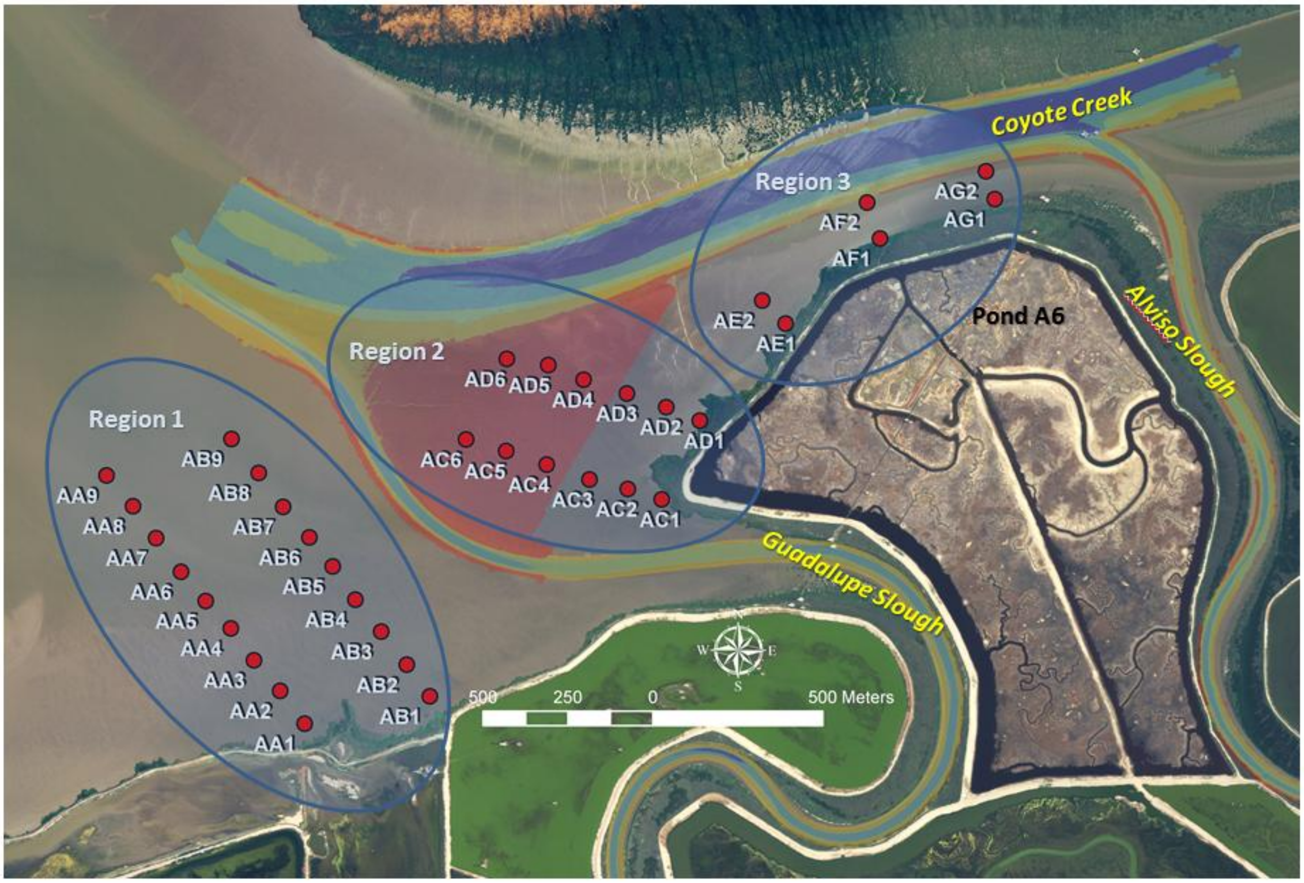


Figure 3. Photos of benthic invertebrate sampling and organisms.

Photo 1. Invertebrate technician sieving benthic core by elutriation method.

Photo 2. Common bivalve species represented in the Alviso mudflat. Top to bottom: *Macoma petalum* (15 mm), *Corbula amurensis* (7 mm), *Gemma gemma* (3 mm).

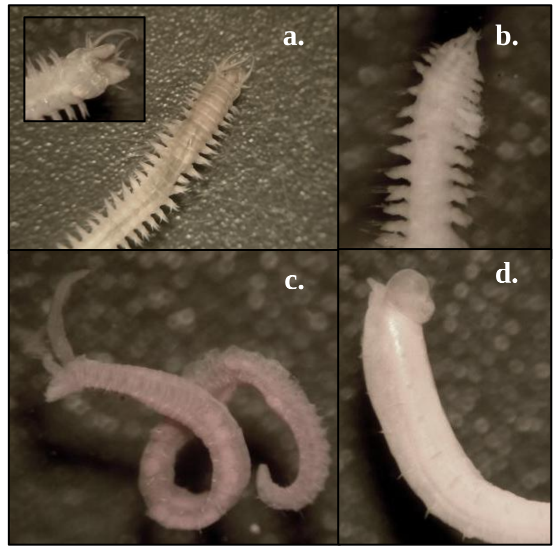


Photo 3 a-d. Common polychaete taxa. a. *Neanthes succinea* (16 mm); b. *Eteone lighti* (11 mm); c. *Streblospio benedictii* (13 mm); d. Capitellidae (9 mm).

Photo 4. Cumacea (3 mm).

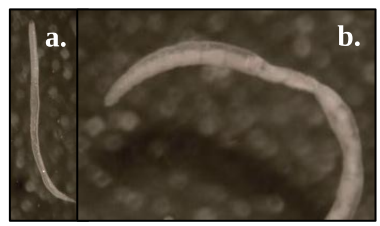
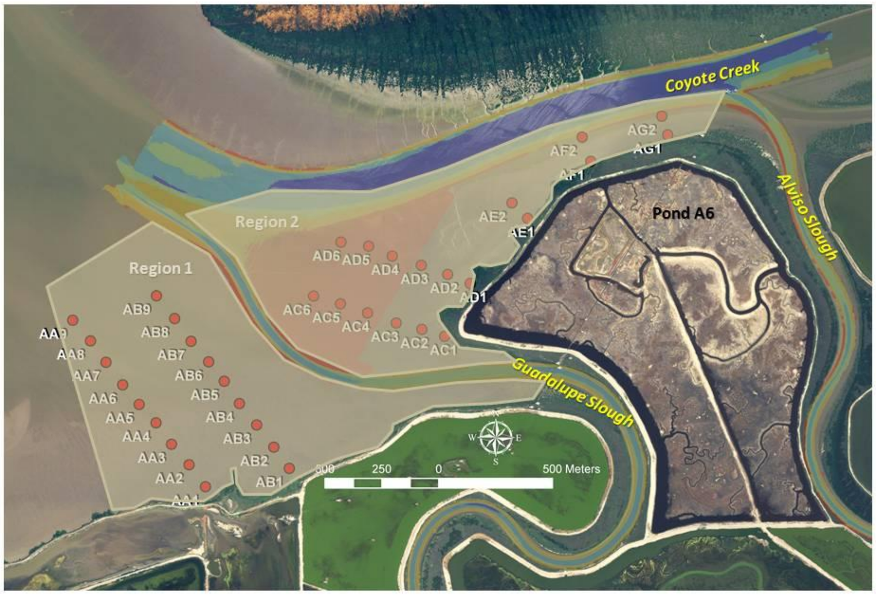


Photo 5. Common taxa in Region 3. a. Nematoda (2 mm); b. Oligochaeta (6 mm).

Figure 4. Avian survey locations in Alviso Shoals showing a) Region 1 (west of Guadalupe Slough) and Region 2 (east of Guadalupe Slough) with overlapping invert coring locations, and b) location of poles used for visual reference for tide.

a.



b.

Figure 5. Mean benthic invertebrate abundance (individuals/m²) by core location (perpendicular to shore and spaced at approximately 100 m intervals) (a- n = 12; b- n = 11; c- n = 18).

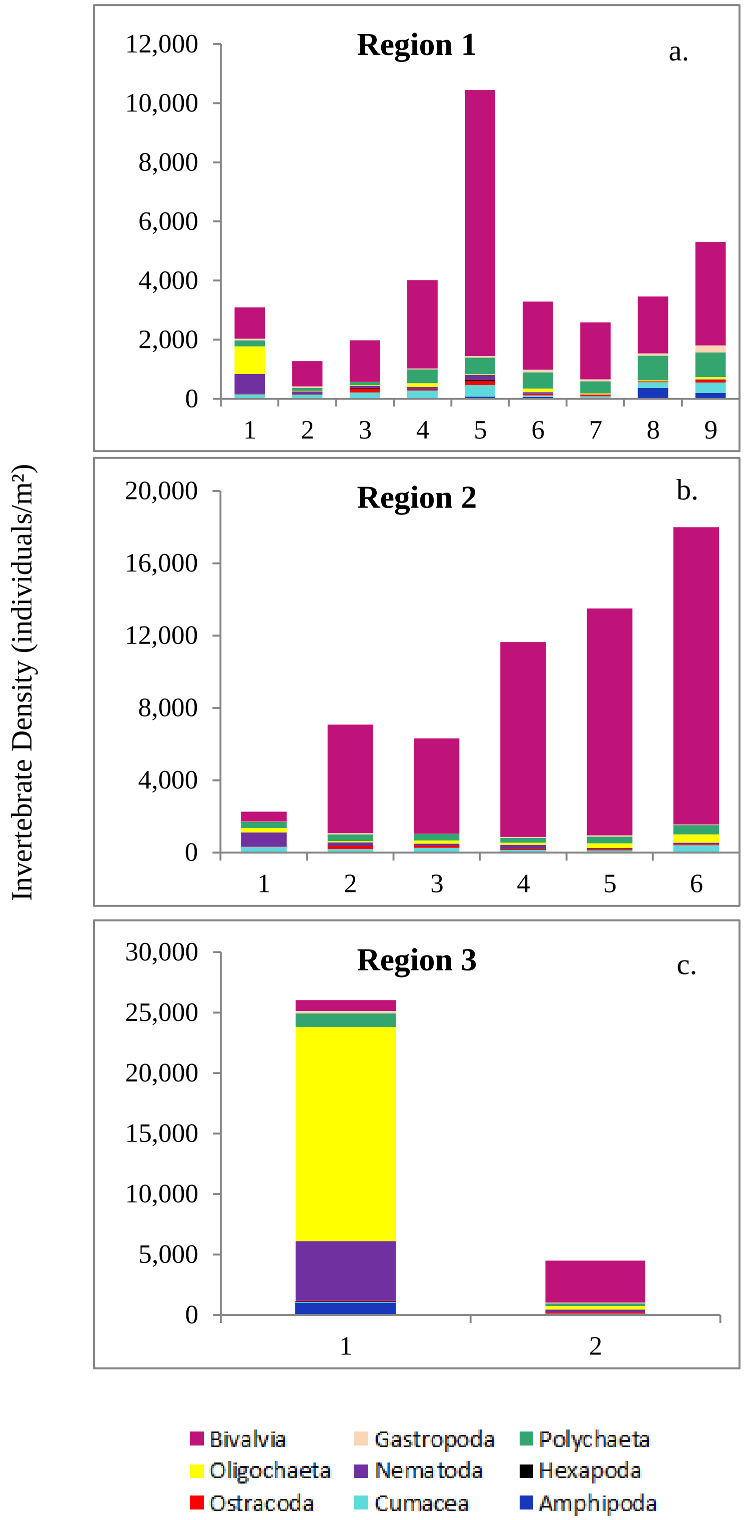


Figure 6. Monthly mean benthic invertebrate abundance (individuals/m²) by region. (a- n = 18; b- n = 11; c- n = 6).

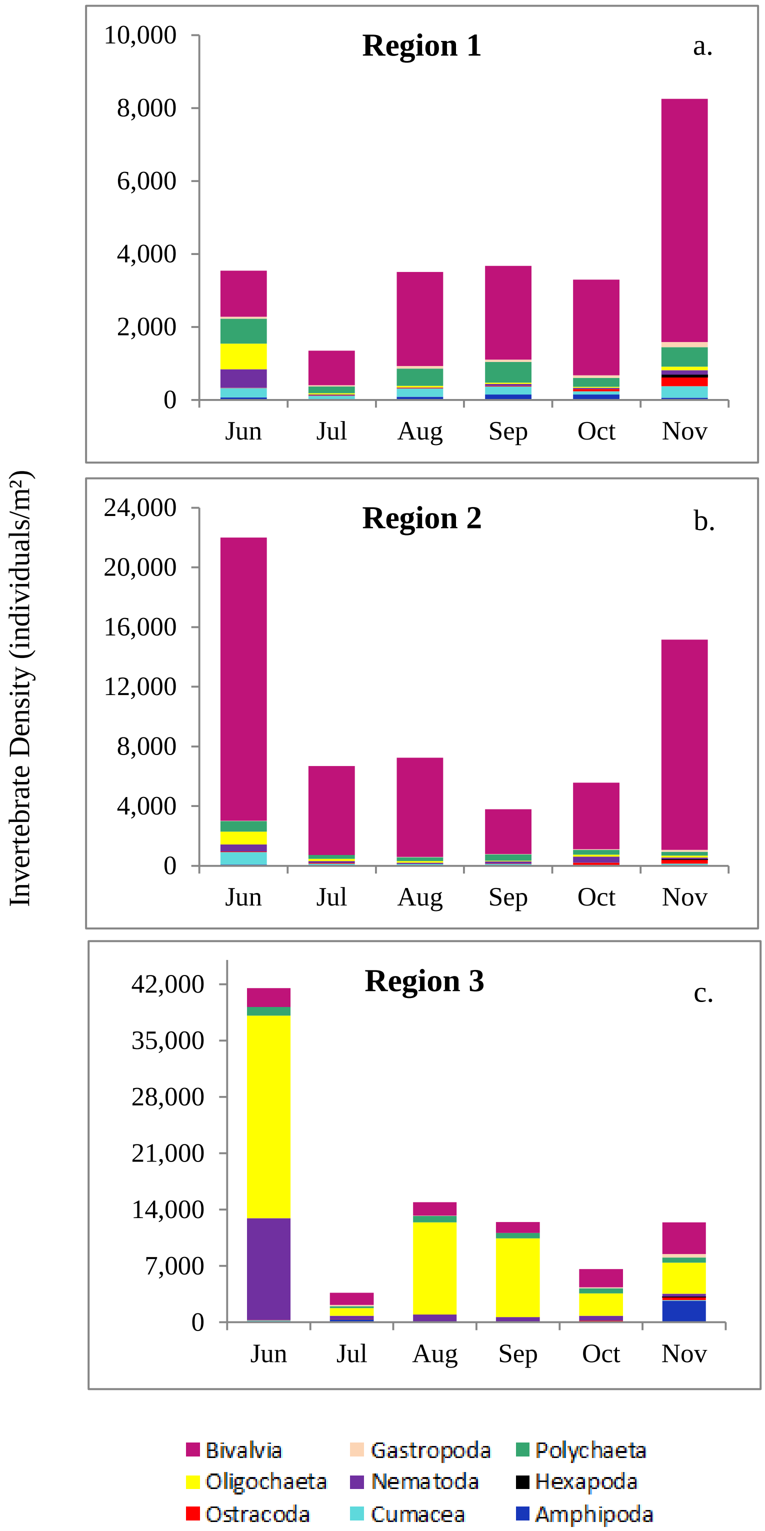


Figure 7. Mean benthic invertebrate abundance (individuals/m²) by core location between sites (perpendicular to shore and spaced at approximately 100 m intervals).

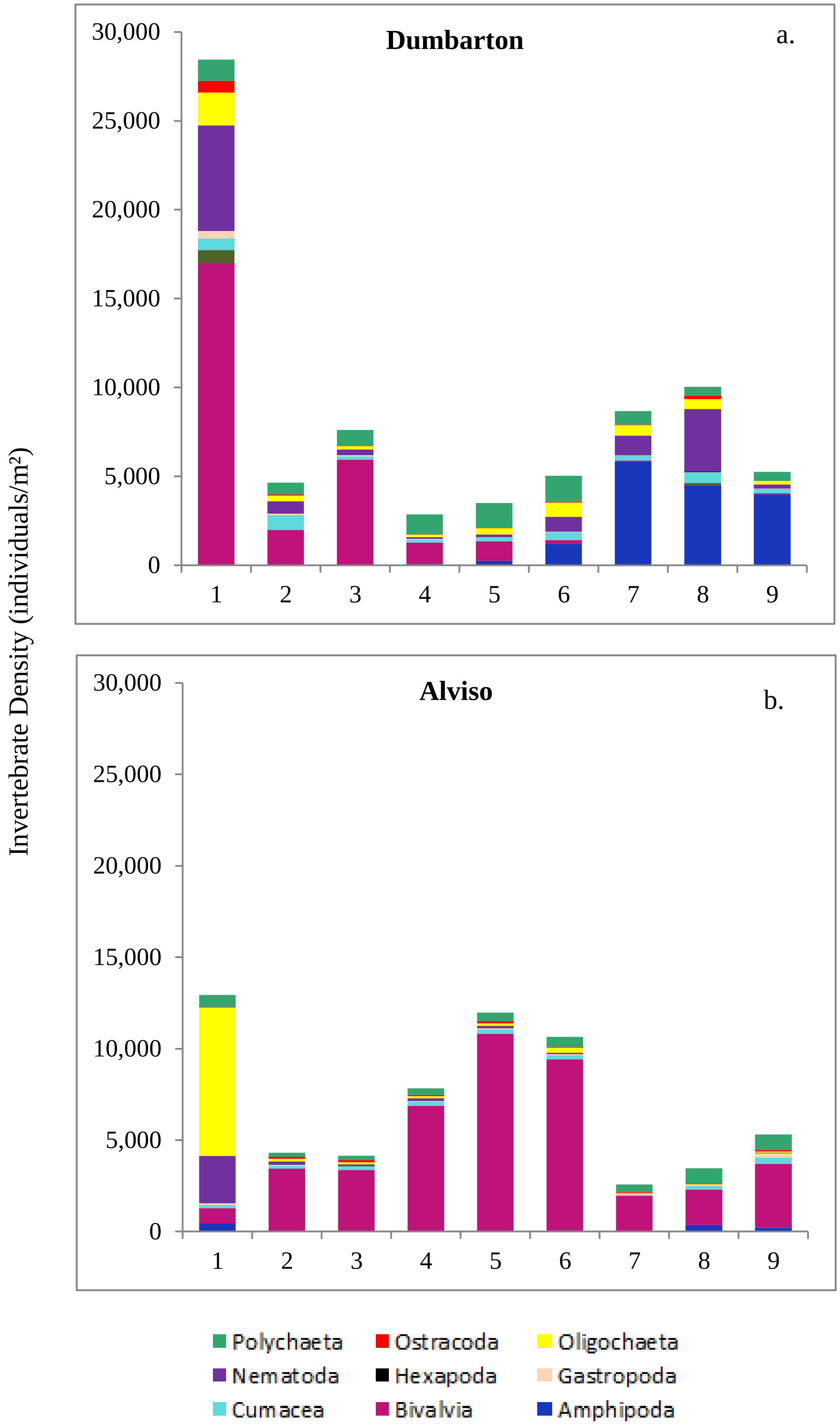


Figure 8. Monthly mean benthic invertebrate abundance (individuals/m²) at Dumbarton and Alviso Shoals.

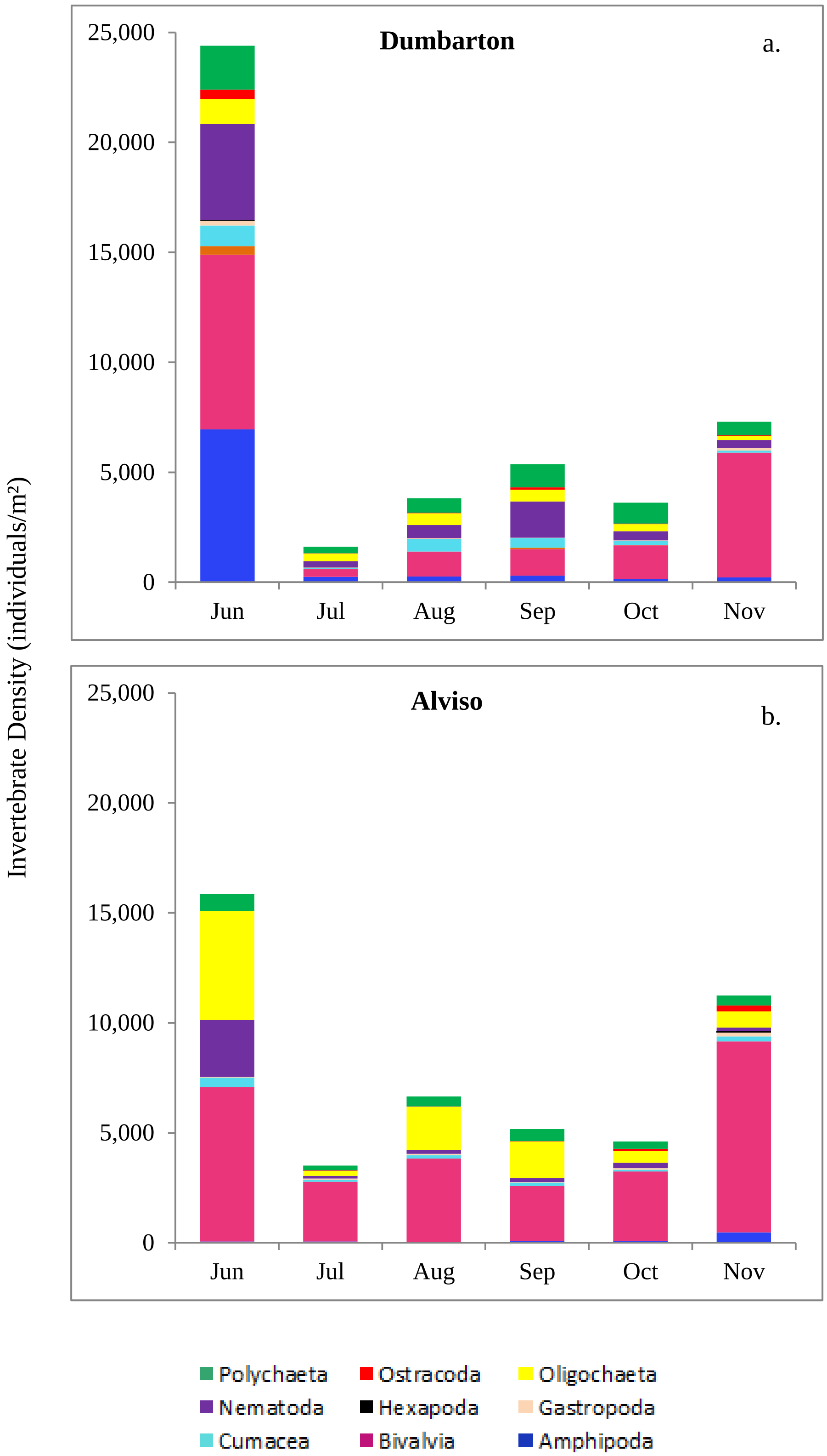


Figure 9. Bivalve size class distribution by core location (perpendicular to shore and spaced at approximately 100 m intervals) at Dumbarton and Alviso Shoals.

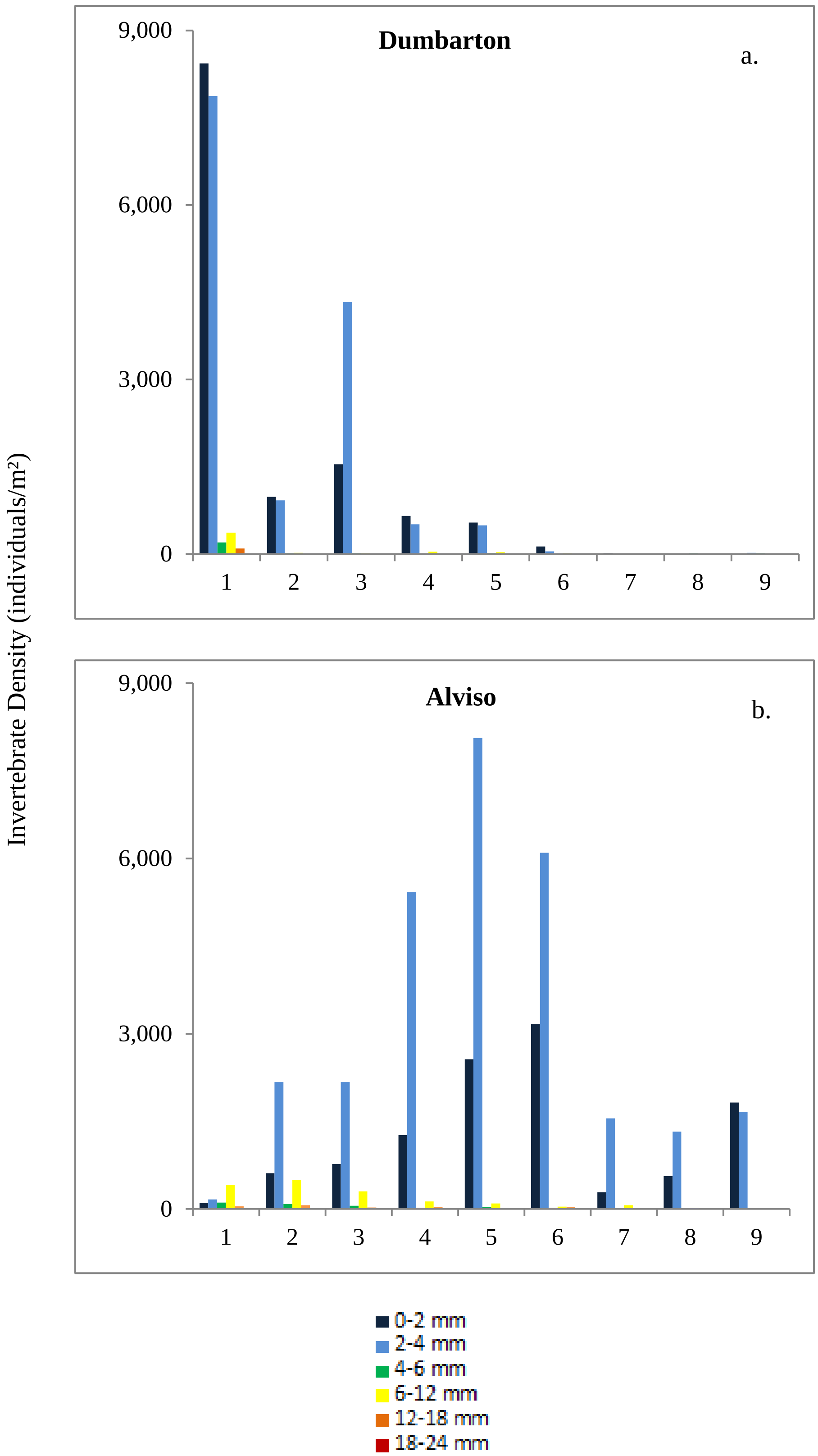


Figure 10. Peak small and medium shorebird abundance by guild across surveys by month in Region 1 (west of the Guadalupe Slough) and Region 2 (east of the Guadalupe Slough).

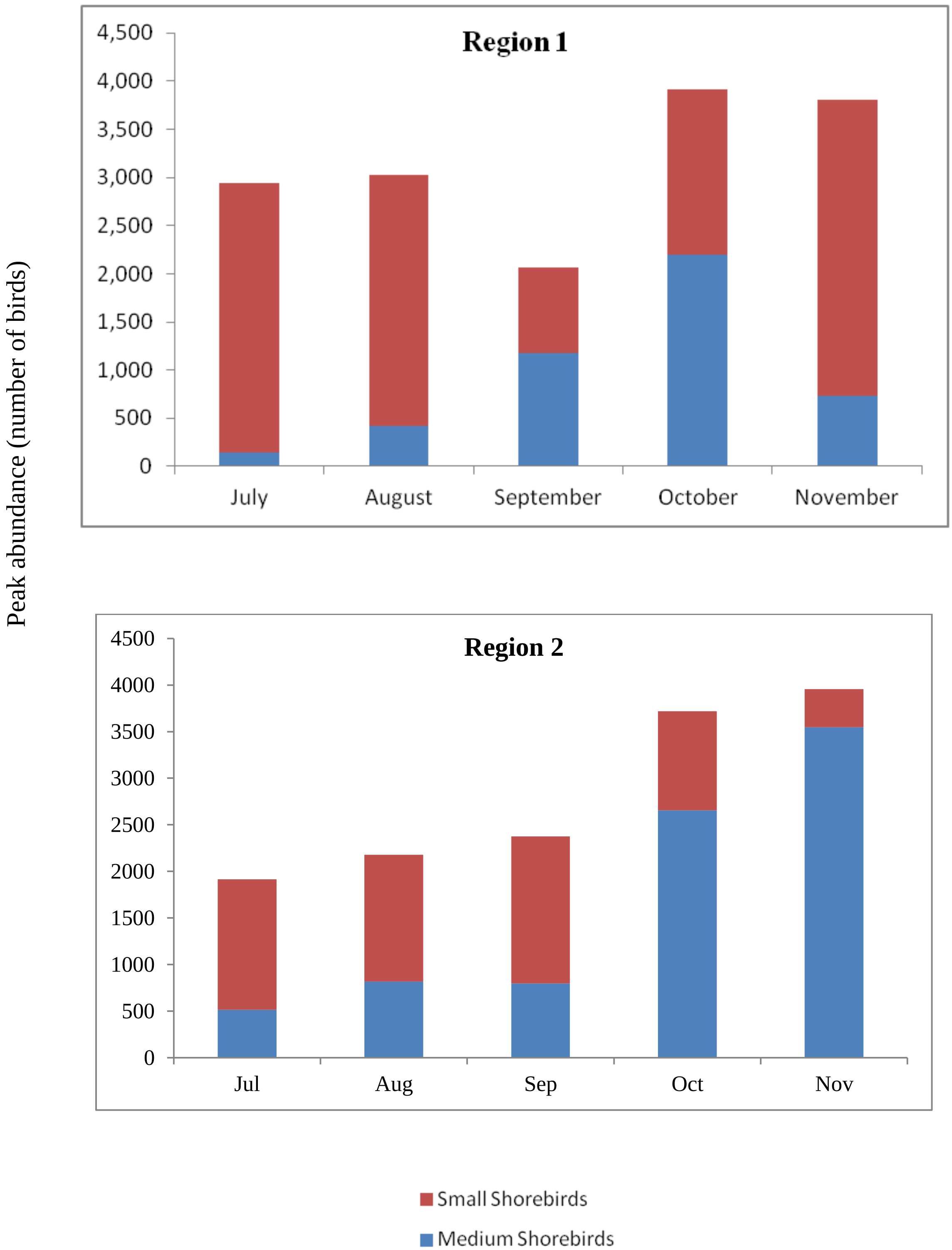


Figure 11. Peak small shorebird abundance by species across surveys by month in Region 1 (west of the Guadalupe Slough) and Region 2 (east of the Guadalupe Slough).

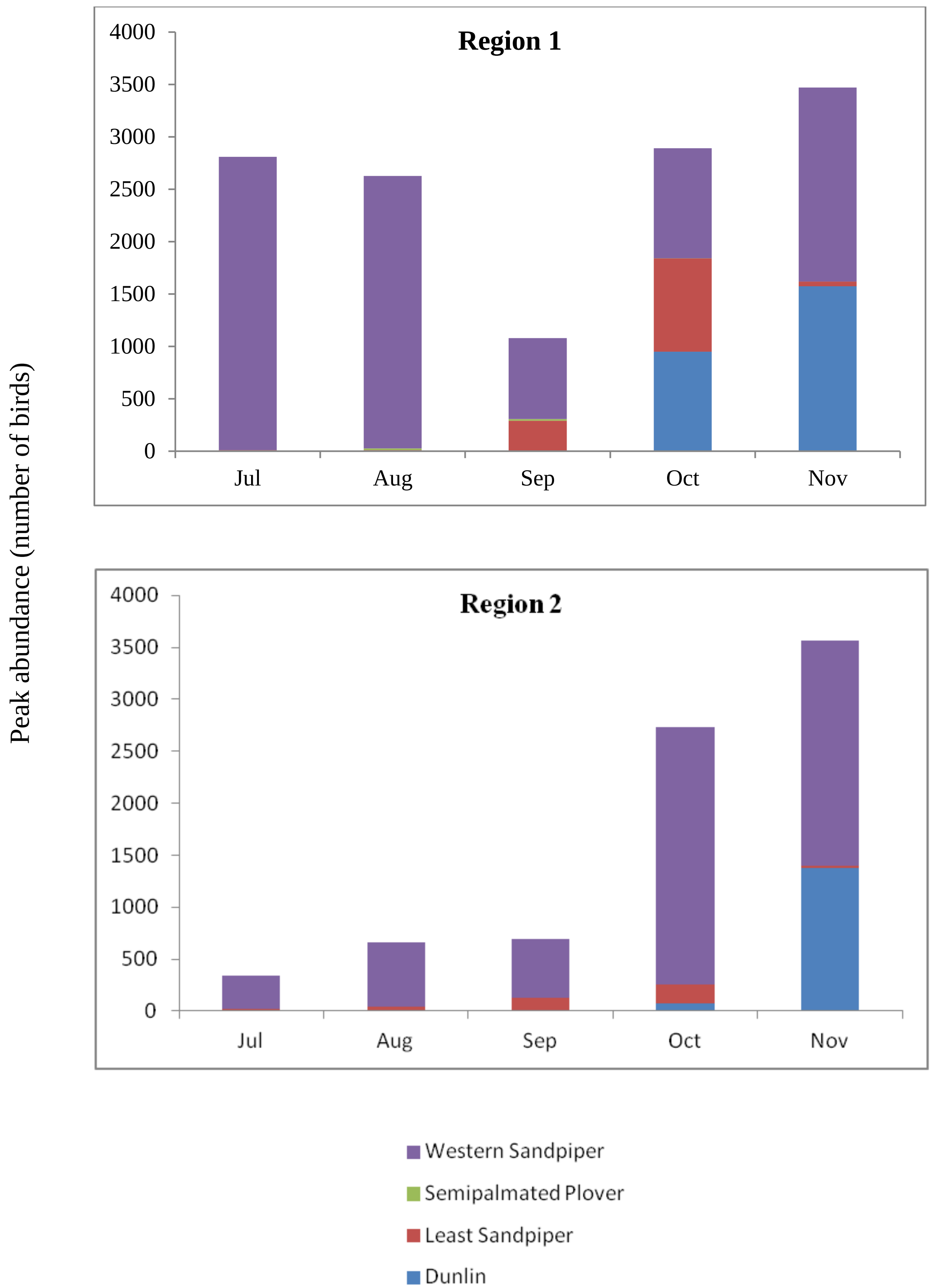


Figure 12. Peak medium shorebird abundance by species across surveys by month in Region 1 (west of the Guadalupe Slough) and Region 2 (east of the Guadalupe Slough).

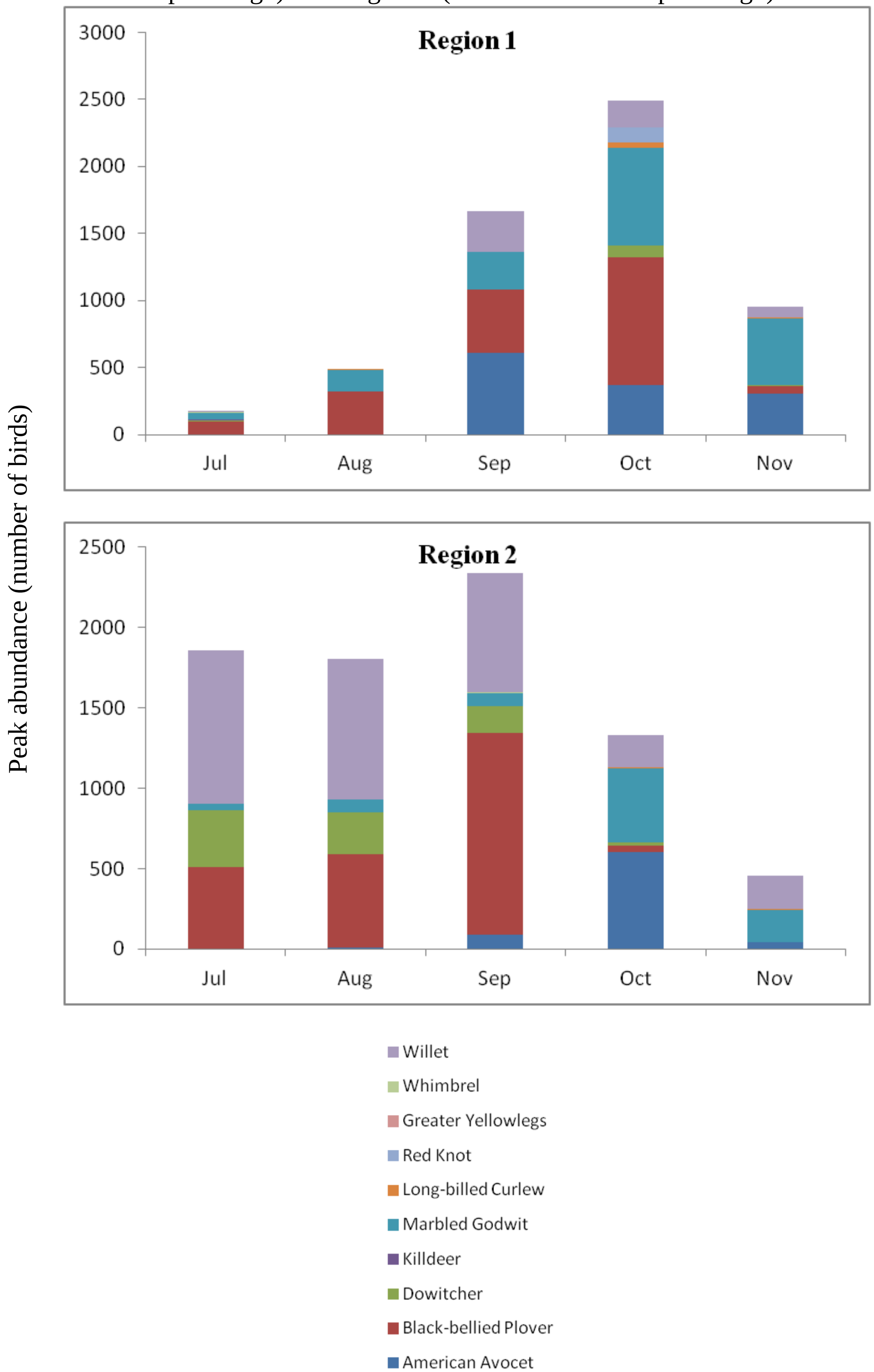


Figure 13 . Average of peak shorebird abundance during October and November fall migration period across the tidal cycle. Tides are predicted values from NOAA Tides and Currents at Coyote Creek.

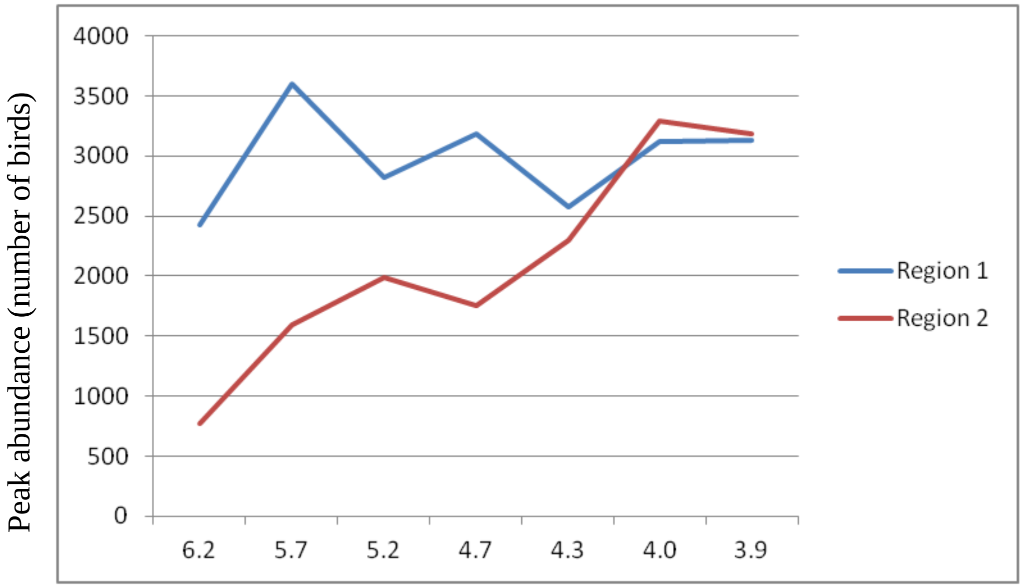


Figure 14. Peak abundances of small and medium shorebirds, herons and egrets at Dumbarton versus Alviso mudflats in July through November, 2010.

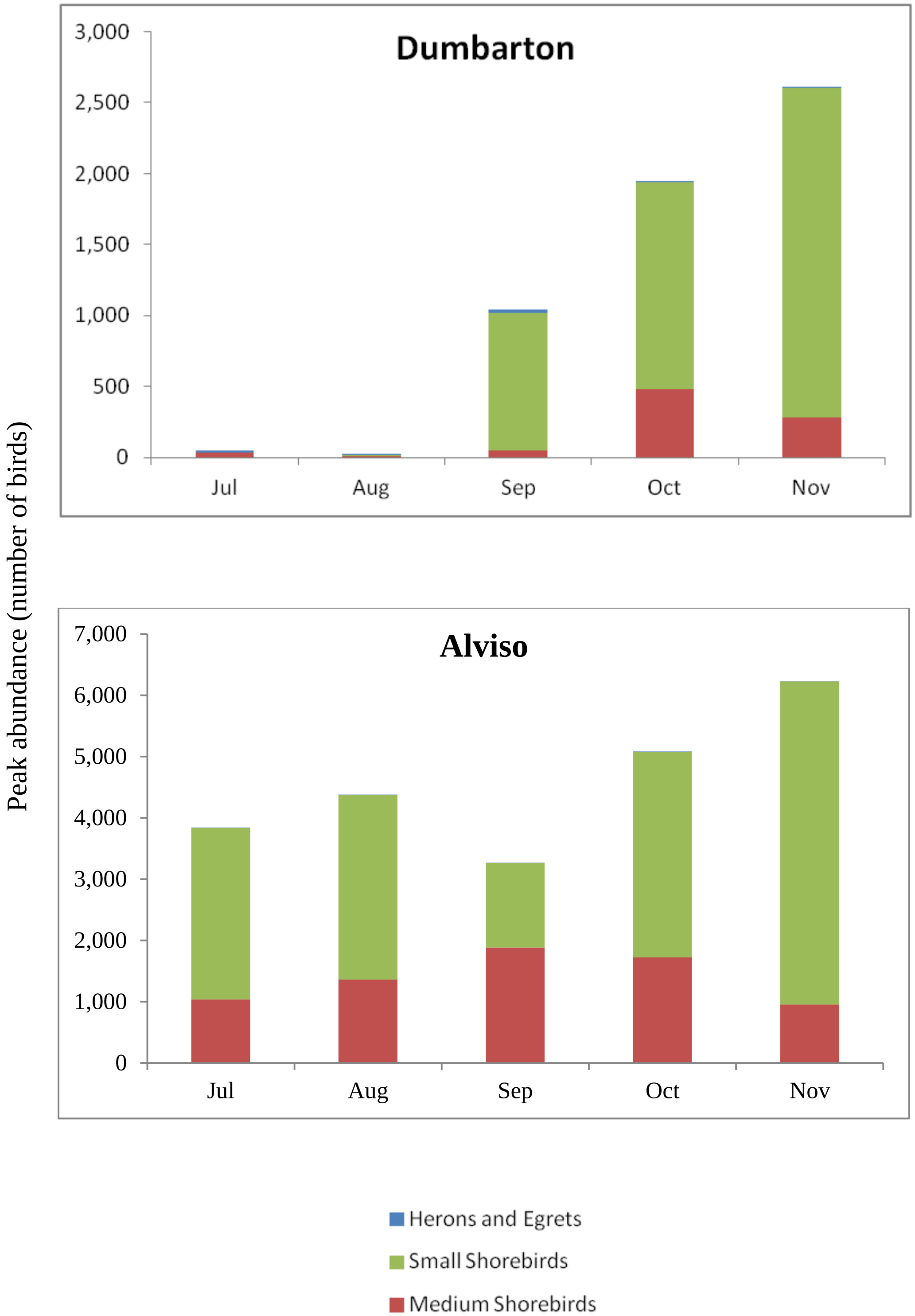


Figure 15. Percent time engaged in behaviors for Dunlin, Western Sandpipers, and Marbled Godwit during the Fall, 2010. No long-billed Curlews were detected during behavioral surveys.