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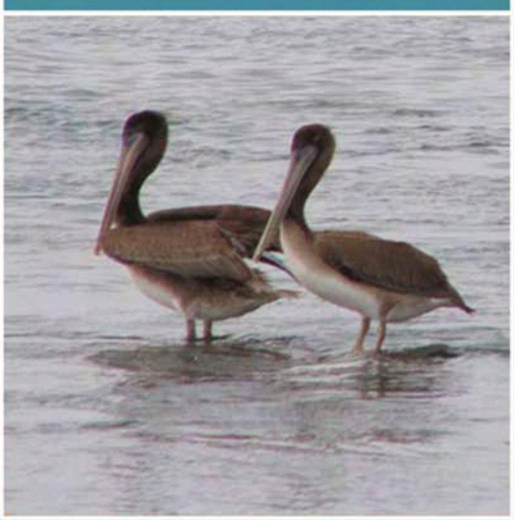

Utilization Patterns of Estuarine Intertidal Habitats by Birds in Yaquina Estury, Oregon

SCIENCE

Office of Research and Development
National Health and Environmental Effects Research Laboratory, Western Ecology Division

UTILIZATION PATTERNS OF INTERTIDAL HABITATS BY BIRDS IN YAQUINA ESTUARY, OREGON

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SUMMARY

An assessment of bird utilization patterns of the intertidal soft sediment and low marsh habitats of the Yaquina estuary, Oregon was conducted from December 2007-November 2008. Daylight censuses of all birds utilizing selected estuarine intertidal habitats in the Yaquina estuary were conducted by a single observer from shoreline observation sites in each of five intertidal habitats [*Zostera marina* (eelgrass), *Upogebia* (mud shrimp)/mudflat, *Neotrypaea* (ghost shrimp)/sandflat, *Zostera japonica* (Japanese eelgrass), low marsh], and during five tide levels (<0.3, 0.6-0.9, 1.2-1.5, 1.8-2.4 and >2.4 m above MLLW). Censuses were designed to determine the spatial and seasonal utilization patterns of estuarine habitat by birds, and how these patterns changed during the tidal cycle. The estuary was divided into four sectors for surveying, Idaho Flat, Sally's Bend, Raccoon Flat and Upriver.

Field census data were collected for a one year period, during six, two-month count cycles. A total of 49,015 birds consisting of 79 distinct species and 10 composite taxa were recorded from the surveys. Gulls and terns comprised 42% of the total birds and, together with ducks, shorebirds, corvids and geese, accounted for about 92% of the total abundance. The addition of herons/egrets, rails (i.e. coots), and pelicans/cormorants comprised just over 98% of all birds observed. The remaining birds consisted of songbirds, loons/grebes, raptors and alcids.

Z. marina beds, the habitat lowest in the intertidal, were an important foraging area for gulls, crows, dabbling ducks, geese and coot when exposed, and for diving ducks, other diving birds, as well as herons and egrets when flooded. The eelgrass was consumed by some species of dabbling ducks, coot, Brant and Canada geese. The *Upogebia*/mudflat, typically located above the *Z. marina* beds in the intertidal, supported large numbers of foraging gulls, crows and shorebirds when exposed, and diving ducks when flooded. *Neotrypaea*/sandflat was utilized by ducks and gulls for roosting when lower habitats were flooded at high tide, and by large flocks of shorebirds for foraging during spring migration. The nonindigenous dwarf eelgrass, *Z. japonica* was little used in winter when above-ground biomass was reduced, but was more important during other seasons and was used by foraging shorebirds, gulls, crows, ducks and Canada geese. Emergent marsh was used as shelter and for foraging by ducks and coots in winter, as a roost area for herons, geese and shorebirds at high tide, and for foraging by land birds including swallows, European starlings and Song Sparrows. Emergent marsh tidal channels supported foraging shorebirds when exposed and fishing herons and egrets when flooded. Habitats/sectors with the highest bird densities were *Z. marina*, low marsh, Neo/sand, and Upo/mud habitats in Idaho Flat, and low marsh in the Sally's Bend sector.

To examine the relationship between habitat and bird use, we analyzed three indices of bird use: bird density, Shannon diversity index, and species richness standardized for habitat area. We also analyzed the relationship between bird density and habitat for three taxonomic subgroups: all birds excluding gulls, waterfowl (ducks and geese), and shorebirds. Analyses statistically controlled for variation in habitat area, location within the estuary (sector), and time of year (cycle). All metrics of bird use were

influenced by habitat type. However, regardless of habitat, birds appear to prefer certain sectors of Yaquina estuary. The embayments in the lower Yaquina estuary supported greater numbers and densities of birds than upriver areas, but species diversity was greater upriver. The sector referred to as Raccoon Flat had the lowest abundances and diversity.

Based on these analyses, *Z. marina* is an important bird habitat based on nearly all metrics of bird use. Overall bird density was relatively high in *Z. marina* habitats; and *Z. marina* supported statistically greater densities of waterfowl than other habitats, with the possible exception of low marsh. *Z. marina* also had statistically greater species richness than all other habitats, and higher Shannon diversity than all other habitats except low marsh. According to model estimates that statistically controlled for a habitat's area and location within the estuary, an average of about two times more species are predicted to be observed during a tidal cycle in *Z. marina* than the other habitats. An exception to this pattern was the low density of shorebirds in *Z. marina*.

One issue of recent potential concern is whether the introduction of *Z. japonica* will negatively affect bird use of intertidal habitat in estuaries, particularly for shorebirds. Although this study was not designed to address this question, a preliminary evaluation indicates there is no evidence that birds will be negatively impacted by the presence of this invasive species in Yaquina estuary. In Yaquina estuary, *Z. japonica* is most likely to supplant the *Neotrypea*/sand habitat. There were no significant differences between *Z. japonica* and *Neotrypea* /sand habitat for any metric of bird use, and many birds were observed using *Z. japonica*.

There were seasonal patterns in all bird use metrics. The highest total bird densities were observed in December/January. After this peak, both total density and diversity declines, reaching an annual low around June/July. During these months, abundance was only 22% of peak abundance. Shorebirds had a different seasonal pattern, with density appearing to peak around April/May during spring migration; however, the overall model affect of sample month was marginally non-significant. Shannon diversity and species richness metrics appeared to peak around October to January and again in April/ May.

Tide level was an important factor affecting bird distribution across intertidal habitats. Birds tended to move upslope across the intertidal flat with the incoming tide, and then move down slope to forage in newly exposed areas as the tide receded.

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INTRODUCTION

Increasingly there is an appreciation that many environmental decisions can be better informed through the use of a framework which takes a comprehensive view of the ecosystem services provided to humans by natural systems (MEA 2005a). Ecosystem services are the goods and processes through which natural systems sustain and fulfill human life (Daily 1997). It has been suggested that the reason many ecosystems are in decline is that they are not valued as much as the other activities and products that degrade them due to lack of public awareness of their ecologic, economic, societal, and cultural value (Daily et al. 1997; Cork et al. 2002). Ecosystem services vary among habitats (MEA 2005a, b). Some habitats are important for maintaining the structure, function, and sustainability of ecosystems. Other habitats are critically important for their high biodiversity, productivity, nursery value, importance to threatened or endangered species, or for other ecologic, economic, societal or cultural reasons. If the distributions of habitats change, so will the sum of the ecosystem services provided by the aggregate of habitats that make up the landscape or seascape.

The primary goal of this research was to describe bird use among five tidal wetland habitats commonly found in Yaquina estuary, OR, in order to begin assessing the value of these habitats. This research may help researchers predict how changes in the distribution of common estuarine habitats, due to current and future stressors, may affect bird populations. This project is a component of a larger research effort, the Estuarine Ecosystem Services Research Project (EESRP), of the U.S. EPA's Pacific Coastal Ecology Branch, Western Ecology Division. The goals of EESRP are to begin assessing the relative value of common tidal wetland habitats within a representative Pacific Northwest estuary, as well as to develop tools and approaches for estimating the effects of habitat alteration on important ecosystem services associated with estuarine tidal wetlands of the Pacific Northwest. EESRP research is focused on ecosystem services that are embodied in water quality designated uses (healthy fish, shellfish, and wildlife populations), or ecosystem services such as nutrient cycling that are critical to protection of water quality. The project will ultimately develop alternative futures scenarios that estimate changes in ecosystem services associated with estuarine habitat alterations resulting from such factors as global climate change.

The inclusion of birds in the EESRP is important due both to ecological and valuation reasons. A wide variety of bird species are highly dependent on the tidal wetland habitats found in estuaries in the Pacific Northwest of the U.S. (Buchanan 1988, Buchanan and Evenson, 1997, Colwell 1992, 1994, Baldwin and Lovvorn 1994a,b, Wilson and Atkinson 1995, Wetzel 1996, Page et al. 1999). In this region, daily tides of 2-3 meter amplitude cause large areas of estuaries to be intertidal. These intertidal habitats are utilized by many bird species for foraging and roosting. The Yaquina estuary has been designated as a Continentally Important Bird Area by the American Bird Conservancy (ref. http://yaquina.info/ybn/bird/iba.htm) because it provides critical habitat for a variety of birds including several gull species, Caspian terns, Brant, and a variety of shorebird species. Intertidal wetlands in the Yaquina and other Pacific Northwest estuaries are also important components of the Pacific Coast fly-way for migrating and overwintering shorebirds and waterfowl (ducks, geese, and swans). Both groups of birds forage in various habitats within the intertidal wetlands complex of the estuary.

Bird watching and waterfowl hunting are significant human recreational activities both in the U.S. and worldwide, and thus are amenable to economic valuation (US F&W 2007, Southwick Associates 2008). In Oregon, estimated expenditures on wildlife viewing exceed that from fishing, hunting and shellfishing combined (Dean Runyon Associates 2009). The economic impact of bird watching is now recognized by local businesses, which are willing to provide financial support to activities promoting bird watching. For example, with financial support from local businesses, chambers of commerce, and conservation organizations, the Oregon Coast Birding Trail has been established to encourage visits to the Oregon Coast from birders in the region (http://www.oregoncoastbirding.com/). The US Fish and Wildlife (US F&W 2009) estimates that in 2006 about 27% of Oregon state residents participated in the recreational activity of bird watching. In that year, 1,046,000 residents and non-residents in Oregon were either backyard bird watchers or more serious "birders", with 74% of these individuals being residents of the state (US F&W 2009). Expenditures by birders contribute to local, regional and national economies. In 2006, the US F&W estimated that nationally, trip and equipment expenditures of $36 billion associated with bird watching generated $82 billion in total direct and indirect economic outputs (US F&W 2009). This broad pattern of economic benefits associated with birding is also observed in economic analyses that focus more narrowly on wetlands. In a meta-analysis of the economic values associated with wetlands, Woodward and Wui (2001) found that bird watching was one of the highest valued services of wetlands.

In this study, patterns of bird use among estuarine intertidal habitats were assessed over tidal and annual cycles in the Yaquina estuary, Oregon. The principal products are summaries of relative bird habitat utilization expressed by various ecological metrics. There was no attempt to derive economic or non economic valuation information as part of the study, but the ecological data forms the basis for such translations as part of potential future studies.

METHODS

The Yaquina is a tidally-dominated, drowned river mouth estuary (Lee et al. 2006) located on the central Oregon coast (44.62° N, 124.06° W; Fig. 1). There are large intertidal embayments in the lower estuary which include a variety of habitat types, and narrow fringing marshes are found along much of the undeveloped shoreline. The mean tidal range at Newport near the mouth of the estuary is 2 m, while maximum tidal range exceeds 4 m. Principal freshwater input is from the Yaquina River, while several small streams enter the estuary through side channels locally termed sloughs. The estuary has a watershed of approximately 650 km^2, an estuarine area of 18.8 km^2 and an estuarine intertidal area of 9.05 km^2. While the estuary has a commercial shipping terminal and the navigation channel is dredged, it is primarily used for recreational boating, recreational and commercial fishing, crabbing, clamming, wildlife watching and tourism.

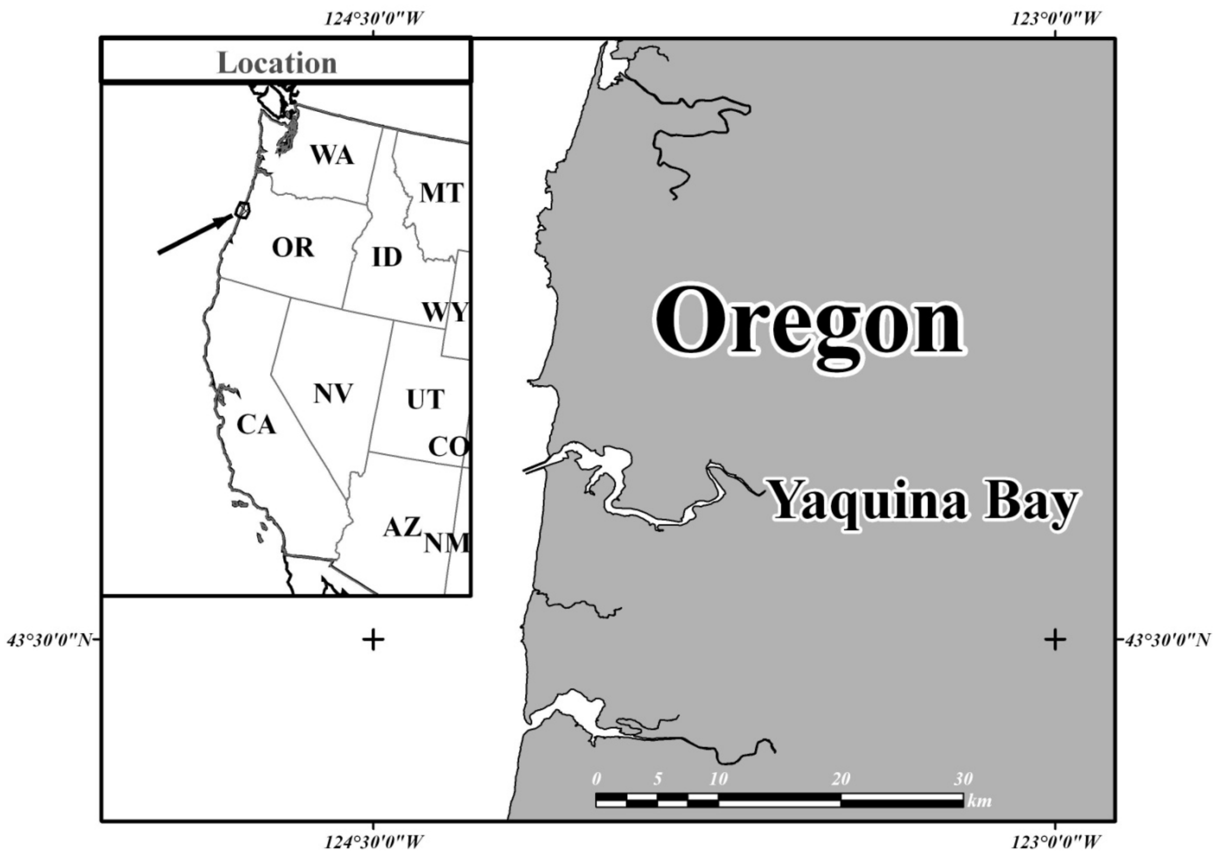

Figure 1. Location of the Yaquina estuary on the central Oregon coast.

Daylight censuses of all birds utilizing selected estuarine intertidal habitats in the Yaquina estuary were conducted during six, two-month cycles (December 2007-November 2008). Counts were made by a single observer (J. Lamberson) from shoreline observation sites (Fig. 2, Appendix A) in each of five intertidal habitats [*Zostera marina* (eelgrass), *Upogebia* (mud shrimp)/mudflat, *Neotrypaea* (ghost shrimp)/sandflat, *Zostera japonica* (Japanese eelgrass), low marsh], and during five tide levels (<0.3, 0.6-0.9, 1.2-1.5, 1.8-2.4 and >2.4 m above MLLW). Censuses were designed to determine the spatial and seasonal utilization patterns of estuarine habitat by birds, and how these patterns changed during the tidal cycle as the habitats became flooded or exposed with the rising or falling tide (Table 1). The estuary was divided into four sectors (Idaho Flat, Sally's Bend, Raccoon Flat and Upriver; Fig. 2), which covered the large intertidal embayments in the lower estuary, with an upriver termination of the census area at 18 km from the estuary mouth (milepost 11.1, Yaquina Bay Road). Total intertidal areas within each sector and habitat are presented in Table 2.

Table 1. Typical flooding or exposure of habitats at various tidal heights in the Yaquina estuary.

Intertidal Zone (m)	*Z. marina*	*Upogebia*/ Mudflat	*Neotrypaea*/ Sandflat	*Z. japonica*	Low Marsh
< 0.3	Exposed	Exposed	Exposed	Exposed	Exposed
0.6-0.9	Flooded	Exposed	Exposed	Exposed	Exposed
1.2-1.5	Flooded	Flooded	Exposed	Exposed	Exposed
1.8-2.4	Flooded	Flooded	Flooded	Flooded	Exposed
> 2.4	Flooded	Flooded	Flooded	Flooded	Flooded

Table 2. Areas (ha) of intertidal habitats within each sector of the Yaquina estuary.

Sector	*Z. marina*	*Upogebia*/ Mudflat	*Neotrypaea*/ Sandflat	*Z. japonica*	Low Marsh	Total
Idaho Flat	14.32	59.84	43.37	0.87	8.92	127.32
Sally's Bend	104.29	50.29	29.50	23.11	1.66	208.85
Raccoon Flat	30.62	35.61	12.07	1.88	1.58	241.04
Upriver	11.10	31.36	95.06	8.62	95.06	81.76
Total	160.33	177.10	180.00	34.48	107.06	658.97

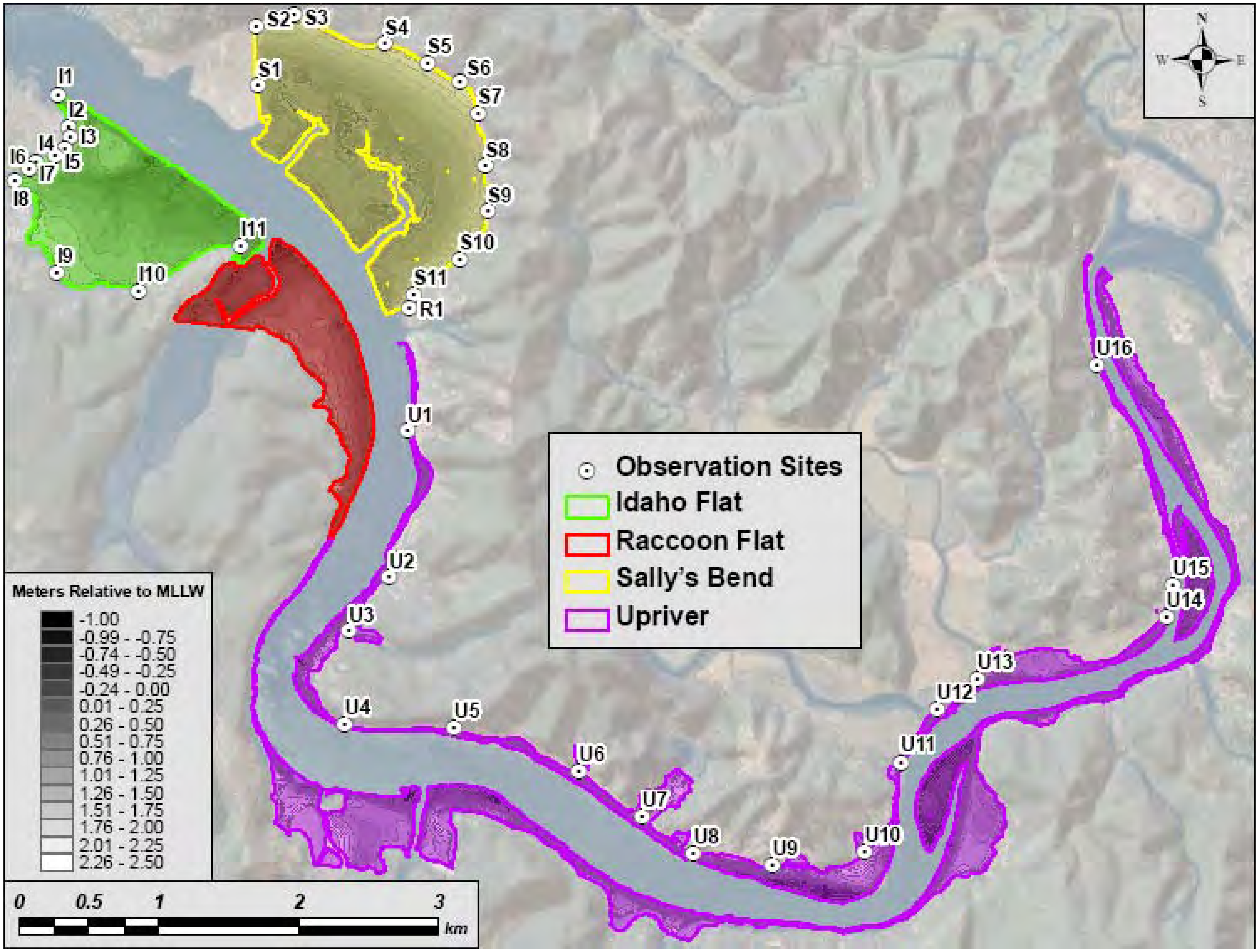

Figure 2. Sectors of Yaquina estuary, locations of observation sites (Appendix A), and bathymetry of the estuary. Highlighted regions are the sector areas exposed between -0.6 and +2.4 meter tidal elevations relative to MLLW.

Habitat Descriptions

The five intertidal habitats within Yaquina estuary selected for the study of bird utilization are defined and described in the following paragraphs, and their distribution within the estuary is shown in Fig. 3.

The *Zostera marina* (eelgrass) habitat (Fig. 3) occurs typically at the lowest intertidal elevation as patches or meadows of the seagrass on mudflats, and may also contain two species of burrowing shrimp, *Upogebia pugettensis* (mud shrimp) and/or *Neotrypaea californiensis* (ghost shrimp) (Ferraro and Cole 2007). If *Z. marina* was present in mixed habitat the area was classified as *Z. marina* habitat. Benthic macrofaunal biodiversity and abundance within this habitat are high (Ferraro and Cole 2007), potentially providing a rich food source for birds when the habitat is flooded. The blades and rhizomes of *Z. marina* are consumed by dabbling ducks, coot, brant and geese (Bayer 1996a). Grazing of seagrasses and submerged aquatic vegetation (SAV) by waterfowl has been well documented (e.g. Phillips 1984, Thayer et al. 1984, Nienhuis and Groenendijk 1986). When the *Z. marina* habitat floods with the incoming tide, the eelgrass can provide cover for species such as fish and crabs, which move into the habitat and serve as prey for some bird species.

The unvegetated mudflat habitat (Fig. 3) typically occurs at a higher intertidal elevation than *Z. marina* and consists of a mixture of mud to muddy-sand sediments with relatively low to moderate organic content. *U. pugettensis* often colonizes this substrate, forming U-shaped relatively permanent burrows lined with mucus, and is a prey item for long-billed shorebirds such as whimbrel, curlew and godwit. This habitat supports abundant populations of macrofaunal benthic species of worms, crustaceans and molluscs (Ferraro and Cole 2007), a food source for some birds.

The unvegetated sandflat habitat (Fig. 3) is characterized by well sorted medium quartz sand with a low organic content. *N. californiensis* colonizes extensive areas of this habitat within the Yaquina estuary, constructing complex burrows up to about 1-m deep with numerous openings. *N. californiensis* is a major bioturbator (DeWitt et al. 2004), mixing oxygenated sediment to the depth of its burrows. Biodiversity of macrofaunal benthic species that serve as potential prey items for small shorebirds is low relative to other intertidal habitats in Yaquina estuary (Ferraro and Cole 2007). *N. californiensis* is itself a prey species for long-billed shorebirds such as whimbrels and marbled godwit.

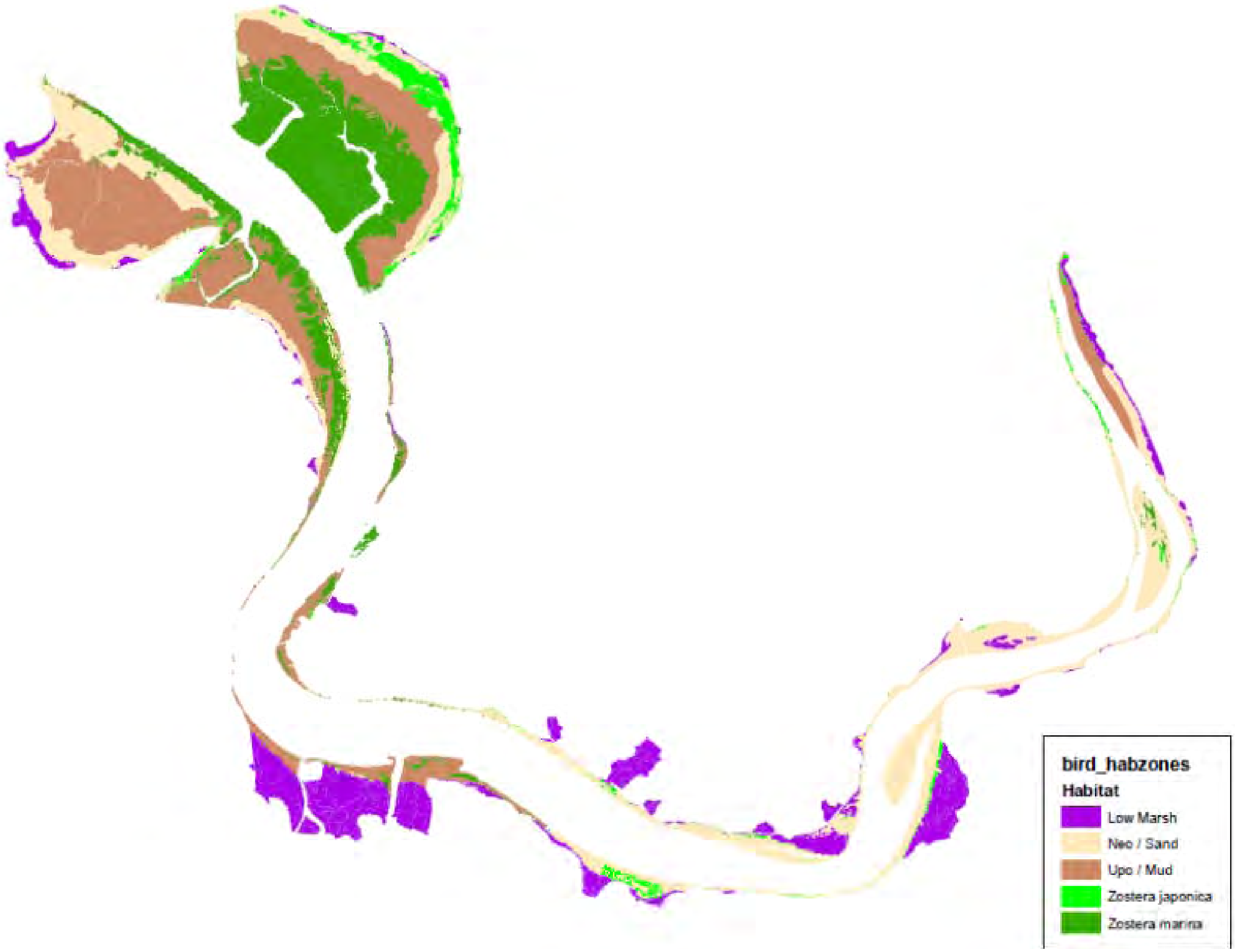

Figure 3. Selected intertidal habitats of the Yaquina estuary.

The nonindigenous Japanese dwarf eelgrass *Zostera japonica* is present year-round but its growth is seasonal, appearing lush and vigorous during late summer months, with significant winter die back (Kaldy 2006). *Z. japonica* was likely an unintentional introduction into Pacific Northwest estuaries with the establishment of Japanese oyster culture (*Crassostrea gigas*) in the early 20th century (Harrison and Bigley 1982). It has been gradually increasing in abundance in estuaries from California to British Columbia, although efforts to eradicate this eelgrass have been made in California (Kaldy 2006). The species was first reported in Yaquina estuary in 1976 (Bayer 1996a), and now forms patchy to extensive beds in upper intertidal portions throughout the estuary (Young et al. 2008). Because its presence will replace unvegetated sandflat habitat, a secondary focus of this study was to determine how various species of birds use this habitat relative to the sandflat. The blades and rhizomes of dwarf eelgrass are consumed by ducks, coot and geese (Baldwin and Lovvorn 1994, Bayer 1996a), and the above-ground eelgrass provides cover for an invertebrate community that may serve as prey for shorebirds, crows and gulls (Ferraro and Cole 2009).

Fringing, intertidal, low and high emergent marshes are found primarily in the upriver sector (Figs. 2, 3), in sloughs where creeks flow into the river, and in the major bends in the estuary. Dominant plants include *Deschampsia caespitosa, Distichlis spicata, Juncus balticus, Salicornia virginica, Argentina egedii* and *Carex lyngbyei*. The non-native cordgrass (*Spartina* spp.) is not present in the Yaquina estuary. Tidal channels were included as marsh habitat in this study.

Other habitats not included in this study but frequently used by birds include nearshore rocks and rocky beaches, floating docks, pilings and other man-made structures. Gulls, herons, cormorants, shorebirds and other species use these areas for roosting, sometimes in large numbers. At high tide, gulls roost on grassy areas on shores, ocean beaches, and roofs of buildings. Gulls and ducks may be found floating at the water’s surface over flooded intertidal and subtidal portions of the estuary when intertidal areas are flooded while crows and other passerines retreat to terrestrial habitats. Gulls, some ducks, and shorebirds also move to open ocean, ocean beaches, freshwater ponds and wet pastures.

Yaquina Estuary Sector Descriptions

Because it was not possible for one person to survey the entire estuary within the short tide windows, the estuary was censused by sector (Fig. 2). The *Idaho Flat* sector is characterized by extensive areas of unvegetated mudflat in the lower intertidal and sandflat in the upper intertidal. A fringe of *Z. marina* borders the adjacent river channel, and a few small patches of *Z. japonica* occur in the upper intertidal margin (Young et al. 2008). Fringing emergent low marsh occurs along the western to southern shoreline of this embayment.

The *Sally's Bend* sector is characterized by extensive beds of *Z. marina*, occurring in a large area of the central portion of this embayment and bordering the tidal channels that drain it. *Z. marina* also occurs along the river channel that forms the southwestern margin of the area (Figs. 2, 3). *Upogebia* is present within much of this *Z. marina* habitat. The upper intertidal margin consists primarily of sandflat with *Neotrypaea* burrows and is extensively colonized by *Z. japonica* (Young et al. 2008); although in winter the aboveground biomass of *Z. japonica* is greatly reduced (Kaldy 2006, Harrison 1982). Between the *Z. marina* bed and the sandflat are bands of unvegetated mudflat adjacent to and comingled with the *Z. marina* bed. Small patches of emergent low marsh are present at the upper edge of the embayment.

The *Raccoon Flat* sector includes an intertidal flat bordering the river channel up the estuary from Idaho Flat. It is adjacent to and contiguous with King's Slough, a sizeable embayment southeast of Idaho Flat. Because of property access issues, most of King's Slough was not monitored for birds, although the outer portion of this slough adjacent to Raccoon Flat was included in the survey as a part of Raccoon Flat. The main channel margin of Raccoon Flat is bordered by *Z. marina*, while mudflats with *Upogebia*, small areas of sandflat, *Z. japonica* and emergent marsh habitats are found at higher tidal elevations. The adjacent shoreline is wooded and undeveloped. "Raccoon Flat" is a nickname applied by EPA (Newport) researchers for the raccoons which are often observed foraging on the mudflat. This area is also referred to as South Bay in some publications (e.g. Bayer 1996b).

The *Upriver* sector has narrow bands of *Z. marina* bordering much of the main channel. *Z. japonica* occurs in bands in some areas (Young et al. 2008), as well as in patches in mudflat areas and in the tidal channels within marshes. In areas where the intertidal flat is wide, mudflats or sandflats with burrowing shrimp provide foraging opportunities for birds. Extensive areas of emergent marsh within sloughs and of fringing marsh along the main estuary channel comprise the largest habitat area within this sector of the estuary. In many areas, the channel is bordered by narrow strips of rocky beach, and although this area is occasionally used by birds for foraging, it was not surveyed. An oyster farm maintains extensive floats and pilings, which along with other privately maintained floating docks, serve as roosting areas for large numbers of gulls, cormorants, some shorebirds and harbor seals.

Count Methods

All counts were made from shore locations (Fig. 2, Appendix A) using 10X42 binoculars and a 65-mm spotting scope (Swarovski) equipped with a 20-60X zoom eyepiece. Birds were counted while using the habitats both during low tides when the habitat was exposed (roosting, preening, foraging) and at higher tides when flooded (fishing, dabbling, or diving to feed). Counts of birds observed in tidal channels that flowed through the five habitat classes were combined with counts of birds in the surrounding habitat. For example, tidal channels within emergent marsh were considered to be part of the marsh habitat. Data were recorded by habitat and activity, by exposed vs. flooded condition, and by habitat proper vs. tidal channel. Observations on food items consumed were made at the same times as the count observations. Activity and feeding data are qualitatively summarized in this report and are available in a complete database that is available online (http://www.epa.gov/wed/pages/models/Yaquina.htm).

Counts were made at various times throughout the two month count cycles at selected tide levels (see below) in a variety of weather conditions (Table 3). No counts were made on days when wind velocity exceeded 48 kph (30 mph), due to rough water conditions and difficulty in seeing birds. Weather conditions (wind speed and air temperature) were recorded from online data posted by the Hatfield Marine Science Center (HMSC) weather station (http://weather.hmsc.orst.edu/) in South Beach, Yaquina estuary. Conditions recorded at the HMSC weather stations are generally similar to those experienced at the sampling sites. Tide levels were predicted from online data provided by the South Beach tide station (http://tbone.biol.sc.edu/tide/index.html), and recalculated using real time online surge tide corrections provided by NOAA's Water Level Observation Network for South Beach (http://tidesonline.nos.noaa.gov/geographic.html).

Table 3. Summary of weather conditions encountered during count cycles.

Cycle	Months	Temp Range °C	Wind Range m s^{-1}	General Conditions During Surveys
1	Dec 2007 – Jan 2008	4 – 10	0 – 12	Clear skies to rain and hail squalls
2	Feb – Mar 2008	5 - 12	1 – 13	Clear skies to rain and hail squalls
3	Apr – May 2008	9 – 29	0 – 13	Clear skies to cloudy with light rain
4	Jun – Jul 2008	11 – 17	0 – 13	Clear skies to cloudy
5	Aug – Sep 2008	11 – 18	0 – 13	Clear skies to cloudy with rain and thunder
6	Oct – Nov 2008	10 - 21	0 – 10	Clear skies to cloudy

The tide levels during a census mostly determined whether the target habitats were exposed or flooded (Table 1). For bird counts occurring at tides <+0.3 m MLLW, all habitats were exposed. Much of the *Zostera marina* habitat occurred below the +0.3-m level, and thus was predominately flooded by tides above that level. For +0.6-0.9 m tide levels, birds were observed using the remaining exposed habitats, as well as wading or diving in the flooded *Z. marina* habitat. For +1.2-1.5 m tides, *Upogebia*/mudflat was generally flooded. For tides >+1.8 m, the sandflat and *Z. japonica* habitats were typically flooded. When tide levels exceeded +2.4 m, all habitats including lower parts of the emergent marsh were flooded (Table 1). During count cycles 3 and 4 (April-July), tide levels did not exceed +2.4 m during daylight hours, so counts could not be made for this tide level.

Identification of birds was made to the lowest taxonomic level possible. In a few cases, birds were assigned to composite taxa, such as genus, family or order because viewing conditions made detection of details difficult or birds were too far away to assign to species. In particular, all scaup were combined as "scaup spp.", and Calidrid shorebirds were recorded as "sandpipers" if species could not be determined. Large groups of gulls were not identified to species and were combined as "gulls, spp." because their behavior and use of estuarine habitats were similar. The gull species include Bonaparte's Gull (*Chroicocephalus philadelphia*), California Gull (*Larus californicus*), Glaucous-winged Gull (*Larus glaucescens*), Herring Gull (*Larus argentatus*), Mew Gull (*Larus canus*), Ring-billed Gull (*Larus delawarensis*), Thayer's Gull (*Larus thayeri*), and Western Gull (*Larus occidentalis*). Many of the large gulls in Yaquina estuary are apparent hybrids between Western and Glaucous-winged Gulls.

Birds were assigned to "species groups" representing broad taxonomic similarities (Table 4). The current report describes bird habitat relationships based on these groupings, although it is recognized that other users may wish to analyze habitat relationships at species level or by taxonomic grouping. Thus summary data on individual taxa are presented in the appendices, and the original data can be obtained from the online database.

Sampling Issues

To determine whether bird counts demonstrated repeatable patterns across space and time, replicate counts were made during low tide in one or two sectors during each count cycle, beginning with count cycle 2 (February-March, 2008). A replicate count was also made in December 2008 to give some idea of variability for count cycle 1. However, given the elapsed time from the original observations in count cycle 1 (December 2007 vs. 2008), these data were not included in the assessment of count variability. They are, however, provided for completeness in Appendices B, C, D.

Randomization tests were performed to determine whether the coefficient of variation (CV) within a sample group was significantly lower than the coefficient of variation among all the groups. CV was calculated by dividing the standard deviation of the counts by the average abundance of the counts within a sample group. For the randomization, habitat/sector/or cycle classes were randomly shuffled and a null coefficient of variation was calculated from the randomized data. This was repeated 1,000 times to determine the percentage of times that the random CV was smaller than the observed CV.

Birds may have been counted repeatedly within the same sector at different tide levels as they moved among habitats with the changing tides, or counted on successive days. Movement patterns are further complicated by individual species, since some species, such as gulls, scoters, and alcids, may move among estuarine and non-estuarine habitats on a daily basis. However, given the objective of this study, we felt these limitations did not bias the determination of relative usage of the habitats.

Regional Observations

Limited, qualitative observations of bird utilization of a subset of habitat types and tide levels were made in 8 additional Pacific Northwest estuaries (Alsea, Coos Bay, Nestucca, Netarts, Salmon, Siletz, Tillamook estuaries in Oregon, Willapa Bay in Washington). These observations provided an opportunity to compare patterns of intertidal habitat structure and utilization by birds across systems to determine whether patterns of habitat utilization in Yaquina estuary were similar regionally.

Statistical Analysis

To analyze patterns of bird use among intertidal habitats and for seasonal trends, we did not include tidal heights >2.4 m because this tide height could not be collected for all cycles. Of the remaining surveys (N=480), about 32% had zero observed birds due to the natural tendency of birds to aggregate. To ameliorate this problem, we combined the birds observed during all 4 tidal levels (0 to +2.4 m) for each sector/habitat/cycle (referred to as a “sampling period”), for a sample size of 120 observations (Appendix E). In contrast, for analyses of bird use based on tidal cycle we used the raw survey data (birds observed for each sector/habitat/cycle/tide, N=600).

We analyzed three indices of bird use: bird density, Shannon diversity index, and species richness standardized for habitat/sector area. Bird density data were double square root transformed ($\sqrt{\sqrt{}}$(number of birds ha^{-1} sampling period^{-1})). We also analyzed the relationship between bird density and habitat for three taxonomic subgroups: all birds except gulls, waterfowl (ducks and geese), and shorebirds. For analyses of bird diversity, we excluded some composite taxa (Mergus sp., Calidris spp., Anas spp., Podiceps sp., Charadriiformes unid., Emberizidae sp., Tachycineta spp.; Appendices B, C, D) because they did not necessarily represent unique species. The Shannon diversity (H') index was calculated for each sampling period as:

$$H' = \sum_{i=1}^{S} (p_i \ln p_i)$$

where S is the total # of species, and p_i is the proportional abundance of species i (i.e. the number of individuals of species i divided by the total number of individuals). For standardized species richness (number of bird species), we corrected for unequal habitat areas using rarefaction techniques. The number of individual birds predicted to occur in 5 ha was calculated, and then rarefaction (Hurlbert 1971, Oksanen et al. 2009) was used to predict the number of species. For example, if 500 birds were observed in a sampling period within an area of 100 hectares, the number of species was predicted for 25 birds (i.e. standard of 5 hectares / 100 hectare sample area * 500 individuals = 25 individuals). Samples from habitats/sectors with areas less than 5 hectares were excluded from further analyses of standardized species richness (analyzed sample size: N= 96). Excluded samples were the low marsh habitat in the Sally's Bend and Raccoon sectors of the estuary and the *Z. japonica* habitats from Idaho Flat and Raccoon sectors. The "vegan" package (Oksanen et al. 2009) was used to generate the rarefaction estimates of species numbers and to calculate Shannon diversity.

Statistical analyses were performed in the R environment (v. 2.8.1; R Development Core Team 2008). For analyses of bird use among habitats, predictor variables included: habitat, count cycle, and ln area. Area was included as a predictor because it often had an effect on bird use metrics even though the metrics were corrected for sample area (density and rarefaction) or are considered relatively insensitive to sample effort (Shannon Index). Habitat analyses were similar to randomized block designs, with each of the five habitats represented in the four sectors of the estuary. To help control for the influence of sector on bird use we analyzed the data with mixed effects regression models using the nlme package (Pinheiro et al. 2009). For all but two analyses (total bird density and bird density excluding gulls), we used a varying intercepts model which makes the simplifying assumption that habitat effects are the same among the sectors. A more complex model allowed both the intercepts and slopes to vary, which tests for interactions between habitat and sector. Based on log-likelihood ratio tests, the use of the more complex model was not supported ($P>0.05$) in most cases. One clear exception was the analysis of total bird density (Likelihood ratio test: χ^2=29.21, df=14, P = 0.01), and there was marginal support for the more complex model for analyzing bird density excluding gulls (χ^2=23.40, df=14, P=0.05).

Based on these analyses, we present model estimates and standard errors that can be used to predict bird use. Habitat and cycle are analyzed as factors, and as such, the estimates for these variables represent the average predicted bird use in each category; area is analyzed as a continuous variable, and thus, model estimates describe the change in the bird use variable given a one unit change in ln area. To make the results more intuitive, all model estimates are presented for a 30 ha plot (ln area – ln 30), rather than using the model default of a zero hectare plot. For cycle, the first sample period (Dec. 2007 - Jan. 2008) was used as the reference observation period against which the other cycles were compared.

Bird use among the habitats and yearly cycles was compared using the pairwise Tukey's correction for multiple comparisons. These values were calculated using simultaneous inference methods with the "multcomp" package (Hothorn et al. 2008).

To analyze bird use in regard to tidal cycle, a linear regression model was used to analyze the direct and interactive effects of tide level and habitat on both √√bird density and abundance.

RESULTS

Abundance and Raw Species Richness Data

A total of 49,015 birds consisting of 79 species and 10 composite taxa were recorded from the surveys conducted over a one year study period. Gulls and terns comprised 42% of the total observed birds, and together with ducks, shorebirds, corvids and geese comprised 92% of observed birds (Fig. 4, Table 4). The addition of herons/egrets, rails (i.e. coots), and pelicans/cormorants comprised about 98% of all birds observed. The remaining birds consisted of songbirds, loons/grebes, raptors and alcids. If we consider the data from the replicate counts, there were an additional 5,606 bird observations, but only 3 additional taxa. Complete lists of abundance for all bird taxa collected are given in Appendices B, C, D.

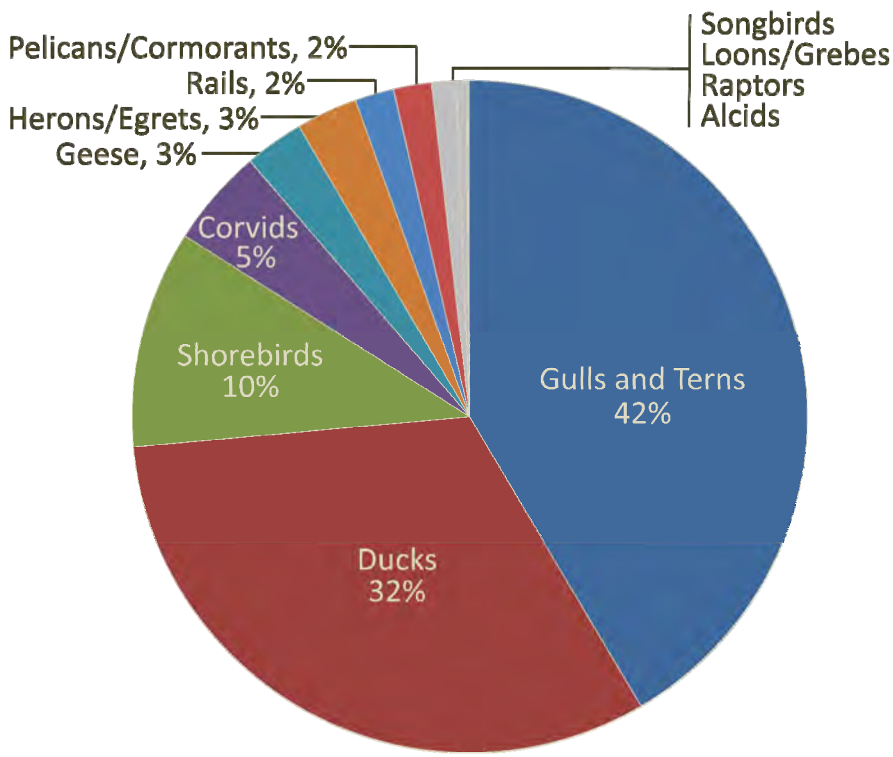

Figure 4. Percentages of observed bird groups.

Table 4. Abundance by species group and count cycle of birds utilizing five intertidal habitats.

Cycle	Group	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
1 Dec-Jan	Geese	60	0	243	2	0	305
	Ducks	2510	2689	1222	300	491	7212
	Loons/Grebes	72	12	2	0	1	87
	Pelicans/Cormorants	1	4	2	0	0	7
	Herons/Egrets	35	19	10	0	21	85
	Raptors	2	9	1	0	0	12
	Rails	490	49	10	114	160	823
	Shorebirds	0	251	103	205	45	604
	Terns/Gulls	527	1411	421	0	0	2359
	Alcids	0	0	0	0	0	0
	Corvids	277	50	90	10	0	427
	Songbirds	3	1	1	0	83	88
Cycle 1 Total		3977	4495	2105	631	801	12009
2 Feb-Mar	Geese	114	17	109	0	57	297
	Ducks	538	588	121	10	109	1366
	Loons/Grebes	25	4	5	2	0	36
	Pelicans/Cormorants	3	0	3	0	0	6
	Herons/Egrets	14	17	7	1	12	51
	Raptors	0	0	4	0	4	8
	Rails	52	0	0	0	0	52
	Shorebirds	0	0	372	2	293	667
	Terns/Gulls	316	1473	777	1	0	2567
	Alcids	0	0	0	0	0	0
	Corvids	143	160	288	1	7	599
	Songbirds	0	0	3	0	32	35
Cycle 2 Total		1205	2259	1689	17	514	5684
3 Apr-May	Geese	0	2	99	0	73	174
	Ducks	269	98	96	0	28	491
	Loons/Grebes	8	9	4	0	0	21
	Pelicans/Cormorants	16	5	2	0	0	23
	Herons/Egrets	52	37	23	0	20	132
	Raptors	5	2	8	0	0	15
	Rails	0	0	0	0	0	0
	Shorebirds	285	2175	304	3	67	2834
	Terns/Gulls	538	484	302	1	3	1328
	Alcids	4	0	0	0	0	4
	Corvids	50	78	70	9	18	225
	Songbirds	0	4	6	1	92	103
Cycle 3 Total		1227	2894	914	14	301	5350

Table 4. Continued.

Cycle	Group	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
4 Jun-July	Geese	0	14	17	0	26	57
	Ducks	14	2	0	0	0	16
	Loons/Grebes	0	0	0	0	0	0
	Pelicans/Cormorants	13	0	0	0	0	13
	Herons/Egrets	195	73	31	2	4	305
	Raptors	3	1	2	0	2	8
	Rails	0	0	0	0	0	0
	Shorebirds	0	72	299	1	69	441
	Terns/Gulls	441	975	656	8	0	2080
	Alcids	5	0	0	0	0	5
	Corvids	69	99	79	38	3	288
	Songbirds	1	12	32	10	163	218
Cycle 4 Total		741	1248	1116	59	267	3431
5 Aug-Sept	Geese	45	63	113	132	16	369
	Ducks	141	16	3	3	166	329
	Loons/Grebes	9	0	2	0	0	11
	Pelicans/Cormorants	192	80	82	0	5	359
	Herons/Egrets	349	91	30	9	58	537
	Raptors	2	2	0	0	1	5
	Rails	0	0	0	0	0	0
	Shorebirds	17	217	98	23	39	394
	Terns/Gulls	1486	2522	951	5	1	4965
	Alcids	0	0	0	0	0	0
	Corvids	44	92	28	74	13	251
	Songbirds	1	2	0	2	72	77
Cycle 5 Total		2286	3085	1307	248	371	7297
6 Oct-Nov	Geese	10	129	0	26	25	190
	Ducks	1929	3220	155	0	999	6303
	Loons/Grebes	69	7	4	0	1	81
	Pelicans/Cormorants	176	112	93	0	106	487
	Herons/Egrets	119	61	39	24	92	335
	Raptors	0	3	0	1	0	4
	Rails	0	2	36	0	0	38
	Shorebirds	0	36	121	18	13	188
	Terns/Gulls	3104	3208	674	57	0	7043
	Alcids	0	0	0	0	0	0
	Corvids	121	308	18	66	2	515
	Songbirds	0	1	2	0	57	60
Cycle 6 Total		5528	7087	1142	192	1295	15244
Total		14964	21068	8273	1161	3549	49015

The distribution of total annual bird abundance across sectors and habitats (Fig. 5, Tables 5, 6) shows marked spatial variation. Qualitatively, most birds were observed within the broad intertidal flat areas nearer the mouth of the estuary and in habitats located across the mid and lower intertidal levels of these sectors. Total bird abundance was lower in the upriver sector. There was also more than a 10 times greater abundance in *Upogebia*/mudflat and *Z. marina* habitats as compared to *Z. japonica*, a comparison complicated by the fact that the area of these habitats was more than 4 times greater than that of *Z. japonica* (Table 2). There were intermediate total bird abundances in *Neotrypaea*/sandflat and low marsh habitats.

The seasonal distribution of total bird abundance showed marked variation (Tables 5, 6). During the peak months of bird abundance (Oct – Jan), there were nearly 4 times as many birds observed than during the months of lowest bird abundance (Jun – Jul).

The spatial distribution of total annual bird species richness across habitats and sectors (Fig. 6, Tables 7, 8) shows an appreciably different pattern from total abundance. Qualitatively, while high total bird abundances were observed on the broad intertidal flat areas relative to the upriver areas, these areas had similar species richness. In fact, total bird species richness was actually highest in the upriver sector (Table 8). All the habitats had about the same total number of bird species observed, with the exception of *Z. japonica* which was about 50% lower. Subsequent analyses controlling for differences in area (see below) suggest that this is at least partially due to the relatively small area of this habitat.

The seasonal distribution of total bird species richness also showed a different pattern than the total abundance data (Table 7). Peak species richness occurred in the April – May period, and was nearly 50% greater than for other sample periods.

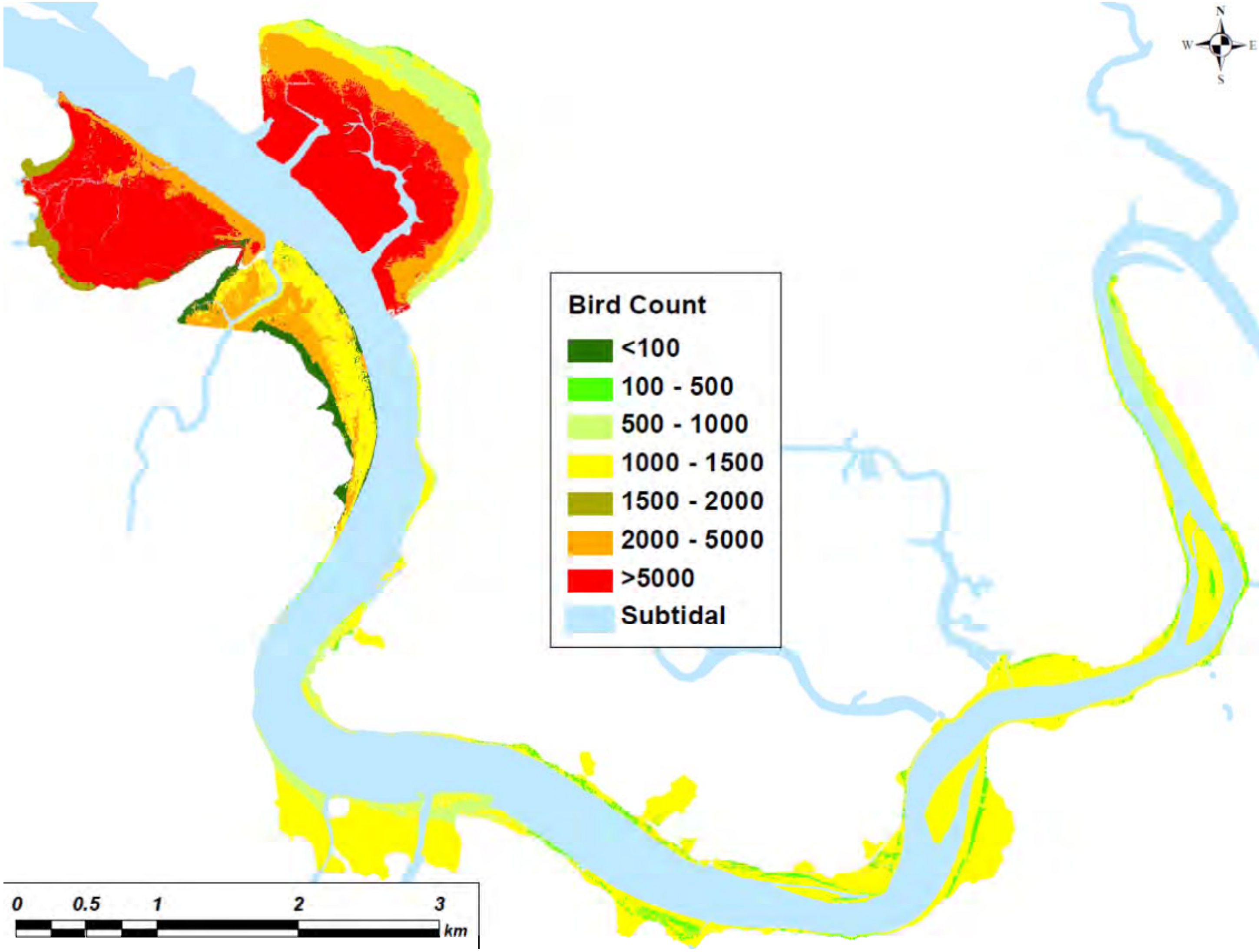

Figure 5. Abundance of birds by habitat and sector in the Yaquina estuary

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Table 5. Abundance by sector and count cycle of birds utilizing five intertidal habitats.

Sector	Cycle	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
Idaho Flat	1	2204	3016	1307	80	200	6807
	2	157	1336	999	0	353	2845
	3	89	868	511	0	67	1535
	4	92	270	896	0	96	1354
	5	169	1722	1118	0	210	3219
	6	1161	4851	747	0	900	7659
Idaho Flat Total		3872	12063	5578	80	1826	23419
Raccoon Flat	1	169	698	0	0	0	867
	2	191	441	0	0	0	632
	3	72	127	0	0	1	200
	4	114	683	2	0	0	799
	5	443	247	0	0	3	693
	6	325	1183	11	1	1	1521
Raccoon Flat Total		1314	3379	13	1	5	4712
Sally's Bend	1	1292	603	615	551	264	3325
	2	670	413	351	11	2	1447
	3	1008	1836	123	9	49	3025
	4	489	238	126	43	14	910
	5	1398	896	128	215	34	2671
	6	3894	947	85	118	3	5047
Sally's Bend Total		8751	4933	1428	947	366	16425
Upriver	1	312	178	183	0	337	1010
	2	187	69	339	6	159	760
	3	58	63	280	5	184	590
	4	46	57	92	16	157	368
	5	276	220	61	33	124	714
	6	148	106	299	73	391	1017
Upriver Total		1027	693	1254	133	1352	4459
Grand Total		14964	21068	8273	1161	3549	49015

Table 6. Abundance by count cycle for birds utilizing five intertidal habitats.

Cycle	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
1 (Dec-Jan)	3977	4495	2105	631	801	12009
2 (Feb-Mar)	1205	2259	1689	17	514	5684
3 (Apr-May)	1227	2894	914	14	301	5350
4 (Jun-July)	741	1248	1116	59	267	3431
5 (Aug-Sep)	2286	3085	1307	248	371	7297
6 (Oct-Nov)	5528	7087	1142	192	1295	15244
Total	14964	21068	8273	1161	3549	49015

Table 7. Species richness by count cycle for birds utilizing five intertidal habitats. Gull species (n=7) are combined.

Cycle	*Z. marina*	*Upogebia/* mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
1 (Dec-Jan)	27	24	25	8	18	38
2 (Feb-Mar)	21	13	23	8	17	36
3 (Apr-May)	21	26	33	5	22	52
4 (Jun-July)	11	11	18	7	20	35
5 (Aug-Sep)	20	19	17	10	25	40
6 (Oct-Nov)	23	33	19	8	20	42
Total	45	53	51	23	49	79

Table 8. Species richness by sector for birds utilizing five intertidal habitats. Gull species (n=7) are combined.

Sector	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
Idaho Flat	24	38	38	1	29	57
Raccoon Flat	22	17	2	1	2	24
Sally's Bend	38	26	27	17	16	52
Upriver	28	33	39	13	37	61
Total of All Sectors	45	53	51	23	49	79

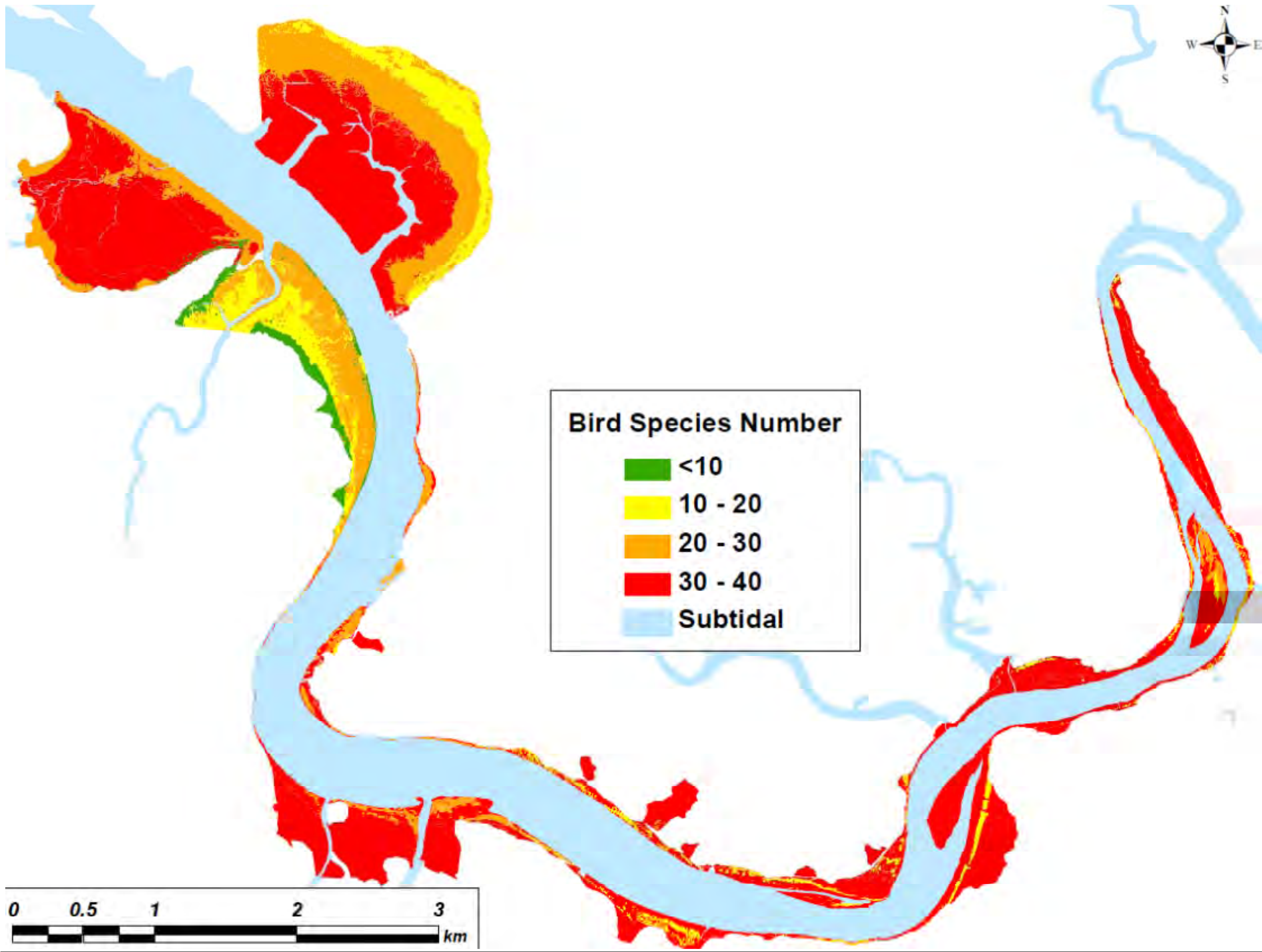


Figure 6. Species richness of birds by habitat and sector in the Yaquina estuary

Density Patterns

Based on the raw data, habitats/sectors with the highest bird density were *Z. marina*, low marsh and *Upogebia*/mud habitats in Idaho Flat, and low marsh in the Sally's Bend sector (Fig. 7, Table 9). Comparison based on bird density increased the importance of low marsh habitats within the lower estuary sectors relative to bird abundance.

After statistically controlling for potentially confounding factors of area and sector, there were significant differences among habitats in bird density for all of the bird subgroups examined (Figs. 8-11A, Table 10). When all birds were considered (Fig. 8A), *Z. marina* (P=0.003) and possibly *Upogebia*/mudflat (P=0.070) habitats had significantly greater bird densities than *Z. japonica*; whereas low marsh and *Neotrypaea*/sandflat were intermediate and statistically indistinguishable from all other habitats. This pattern was the same when gulls were excluded (Fig. 9A), indicating that the general pattern was not driven by gulls even though this group accounted for a large proportion of observed birds. For the waterfowl (Fig. 10A), *Z. marina* had significantly greater densities than *Upogebia*/mudflat (P=0.020), *Neotrypaea*/sandflat (P<0.001), and *Z. japonica* (P<0.001); low marsh had intermediate bird densities and was statistically indistinguishable from all other habitats. Shorebirds displayed a different distributional pattern (Fig. 11A). For this group, estimated mean density was lowest in *Z. marina* habitat, and densities in *Z. marina* were statistically significantly lower than all other habitats except *Z. japonica*, and possibly *Upogebia*/mudflat (P=0.059).

Models that included a random sector (region within estuary) effect were better supported (i.e. lower AIC values) than models without this variable, indicating that bird density varied among the sectors of Yaquina Estuary (Figs. 8B – 11B). Idaho Flat had the highest estimated total bird densities (Figs. 8B, 9B), perhaps due to the ducks that used this sector during the winter (Fig. 10B). Sally's Bend supported the highest density of shorebirds (Fig. 11B). The Raccoon Flat sector was the least used region within the estuary for all metrics of bird use (Figs. 8-11B).

For analyses of total bird density and total density excluding gulls, there were significant interactions between sector and habitat on overall bird use (Figs. 8B, 9B). Qualitatively, *Z. marina* and *Upogebia*/mudflat habitats were about equally used regardless of location within the estuary, whereas the other habitats varied in quality depending on sector. The most variable habitat in terms of estimated bird density was low marsh, for which bird densities were very high in the Sally's Bend and Idaho Flat sectors and very low in the Raccoon Flat sector.

Habitats with larger areas were associated with higher densities of waterfowl (P=0.003, Fig. 10A). The relationship between shorebird density and habitat area was marginally non-significant (P=0.090, Fig. 11A), suggesting that a response to habitat area may be present for these taxa as well.

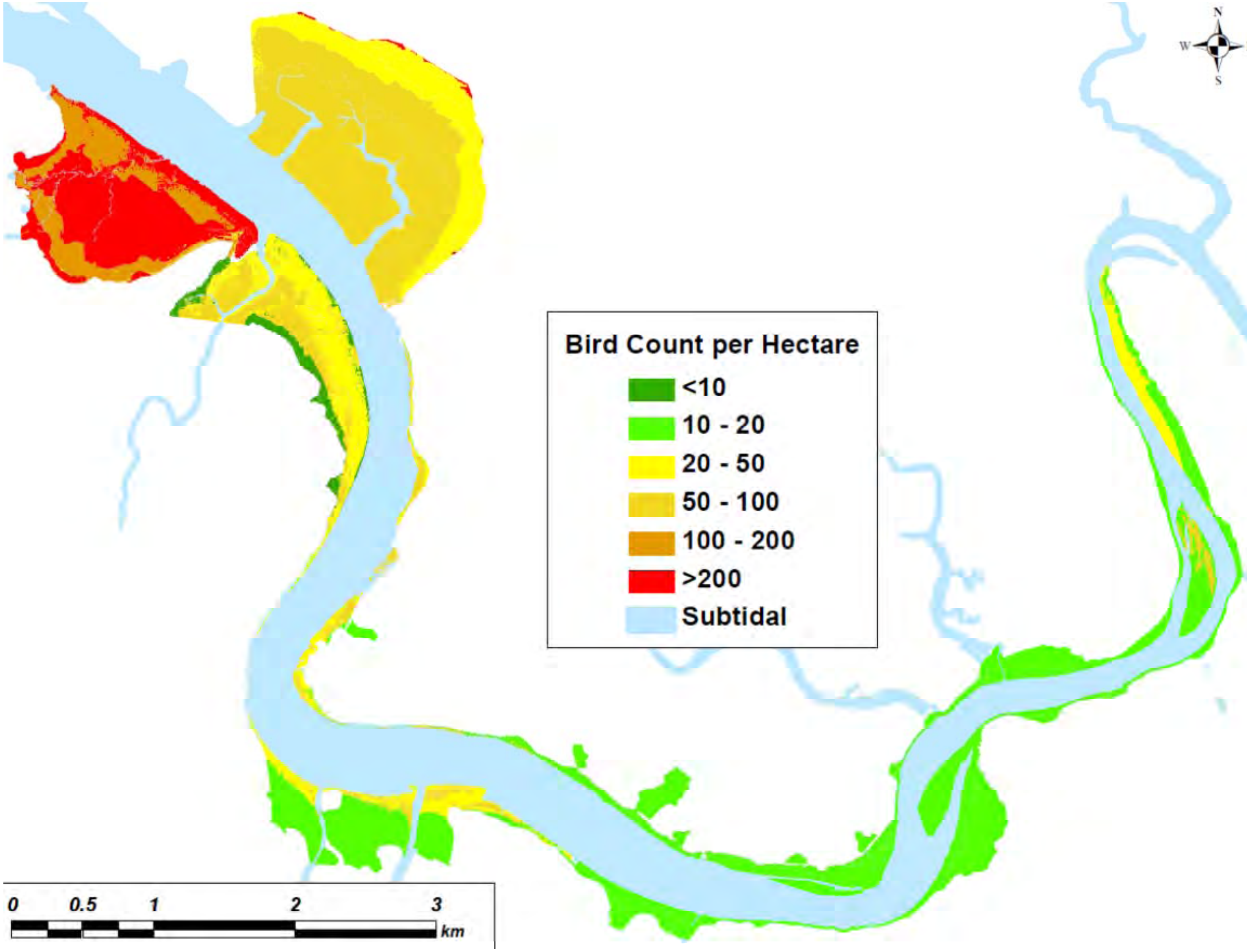


Figure 7. Bird densities (ha^{-1}) by habitat and sector in the Yaquina estuary.

Table 9. Bird density (ha^{-1}) by count cycle and sector in five intertidal habitats. Sector and Habitat grand totals were calculated by dividing the total bird abundance in a given habitat or sector by the total area of the habitat/sector within the estuary. Relative use values for the habitats were calculated by dividing each habitat grand total by the least used value.

Sector	Cycle	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Sector Grand Total
Idaho Flat	1	153.9	50.4	30.1	92.0	22.4	53.5
	2	11.0	22.3	23.0	0.0	39.6	22.3
	3	6.2	14.5	11.8	0.0	7.5	12.1
	4	6.4	4.5	20.7	0.0	10.8	10.6
	5	11.8	28.8	25.8	0.0	23.5	25.3
	6	81.1	81.1	17.2	0.0	100.9	60.2
Idaho Subtotals		270.4	201.6	128.6	92.0	204.7	183.9
Raccoon Flat	1	5.5	19.6	0.0	0.0	0.0	10.6
	2	6.2	12.4	0.0	0.0	0.0	7.7
	3	2.4	3.6	0.0	0.0	0.6	2.4
	4	3.7	19.2	0.2	0.0	0.0	9.8
	5	14.5	6.9	0.0	0.0	1.9	8.5
	6	10.6	33.2	0.9	0.5	0.6	18.6
Raccoon Subtotals		42.9	94.9	1.1	0.5	3.2	57.6
Sally's Bend	1	12.4	12.0	20.8	23.8	159.0	15.9
	2	6.4	8.2	11.9	0.5	1.2	6.9
	3	9.7	36.5	4.2	0.4	29.5	14.5
	4	4.7	4.7	4.3	1.9	8.4	4.4
	5	13.4	17.8	4.3	9.3	20.5	12.8
	6	37.3	18.8	2.9	5.1	1.8	24.2
Sally's Subtotals		83.9	98.1	48.4	41.0	220.5	78.6
Upriver	1	28.1	5.7	1.9	0.0	3.6	4.2
	2	16.8	2.2	3.6	0.7	1.7	3.2
	3	5.2	2.0	2.9	0.6	1.9	2.4
	4	4.1	1.8	1.0	1.9	1.7	1.5
	5	24.9	7.0	0.6	3.8	1.3	3.0
	6	13.3	3.4	3.1	8.5	4.1	4.2
Upriver Subtotals		92.5	22.1	13.2	15.4	14.2	18.5
Habitat Density		93.3	119.0	46.0	33.7	33.1	74.4
Habitat Relative Use		2.8	3.6	1.4	1.0	1	

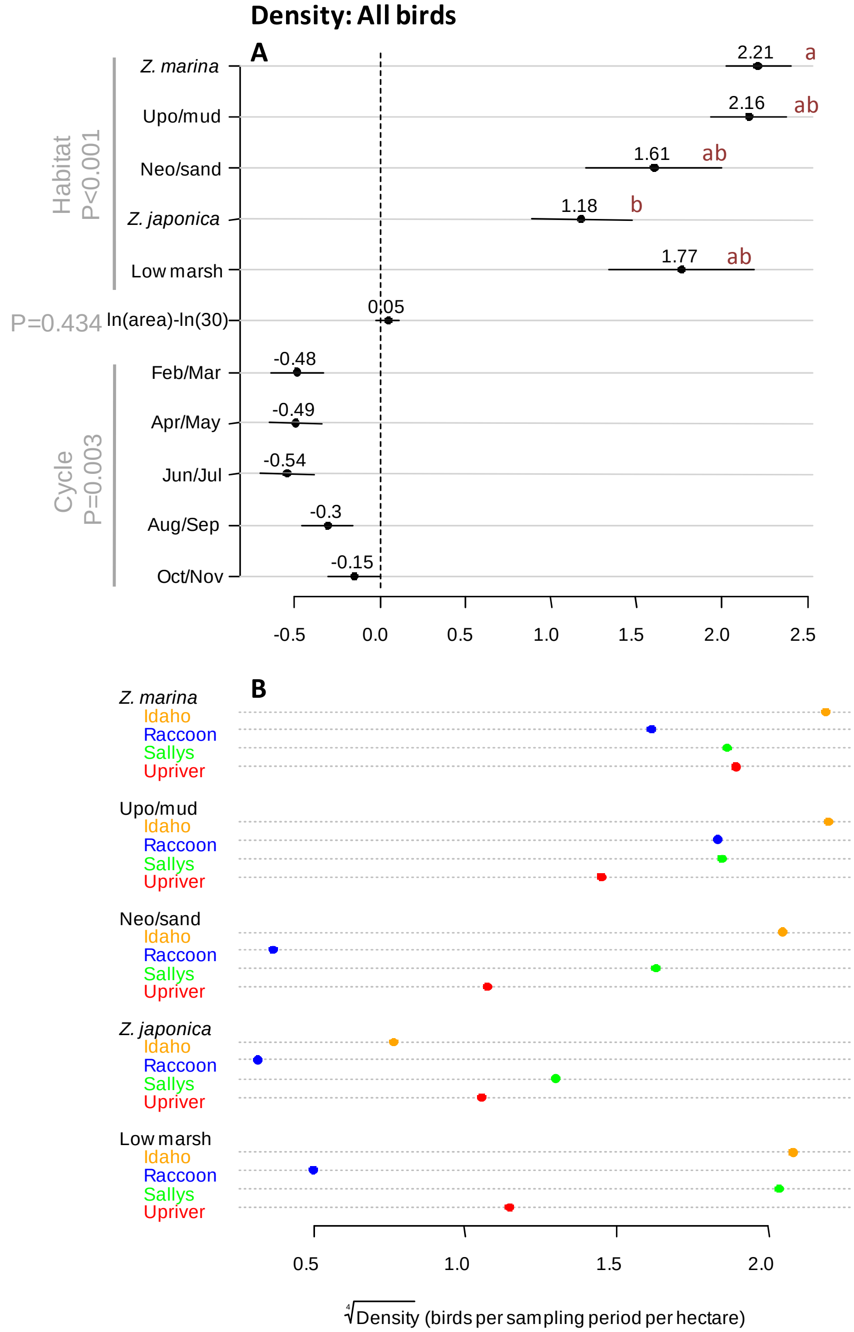


Figure 8. Statistical model estimates for all birds: A) Model estimates (± standard error) for transformed bird density (√√birds· sample period^{-1}·ha^{-1}) as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for √√bird density based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

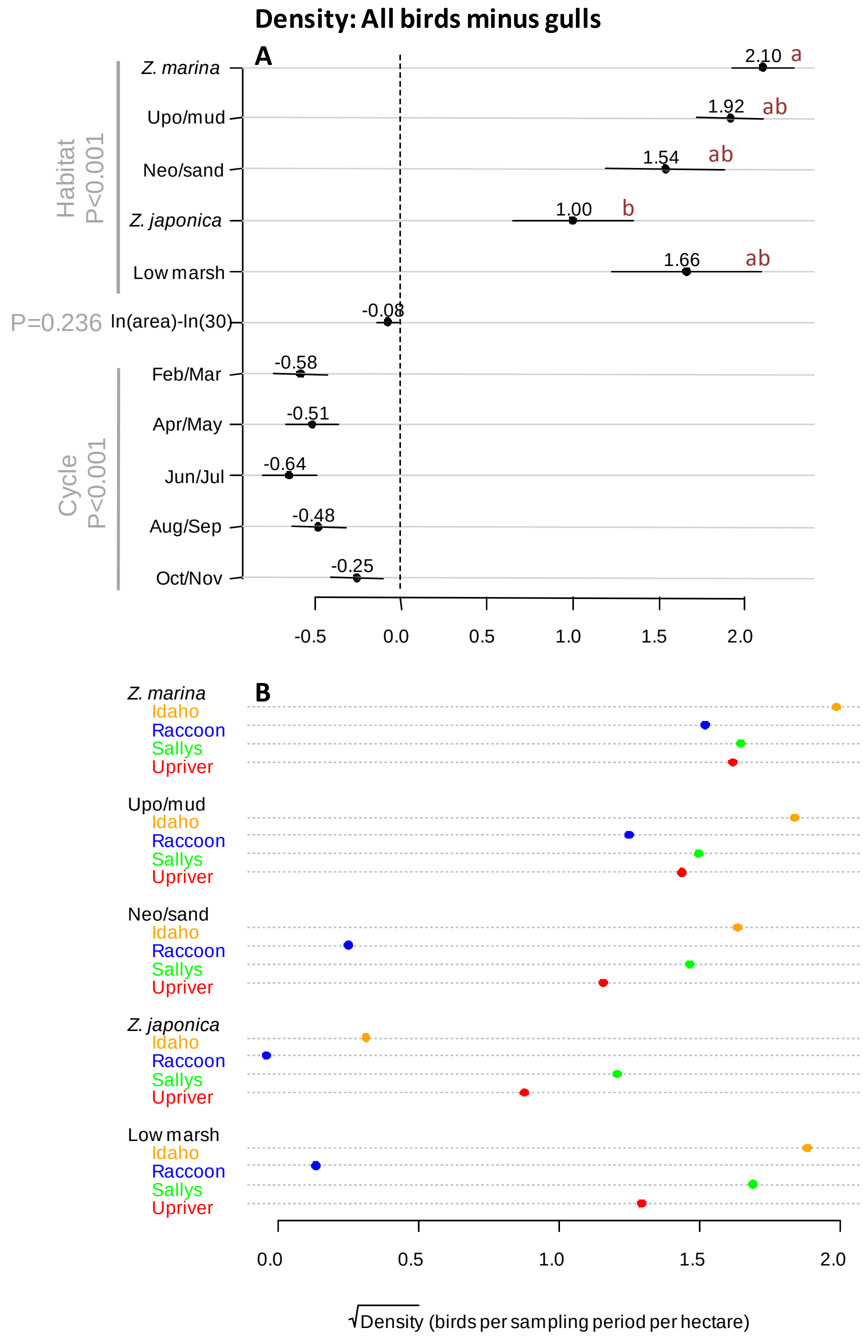


Figure 9. Statistical model estimates for all birds minus gulls: A) Model estimates (± standard error) for transformed bird density (√√birds·sample period^{-1}·ha^{-1}) as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for √√bird density based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

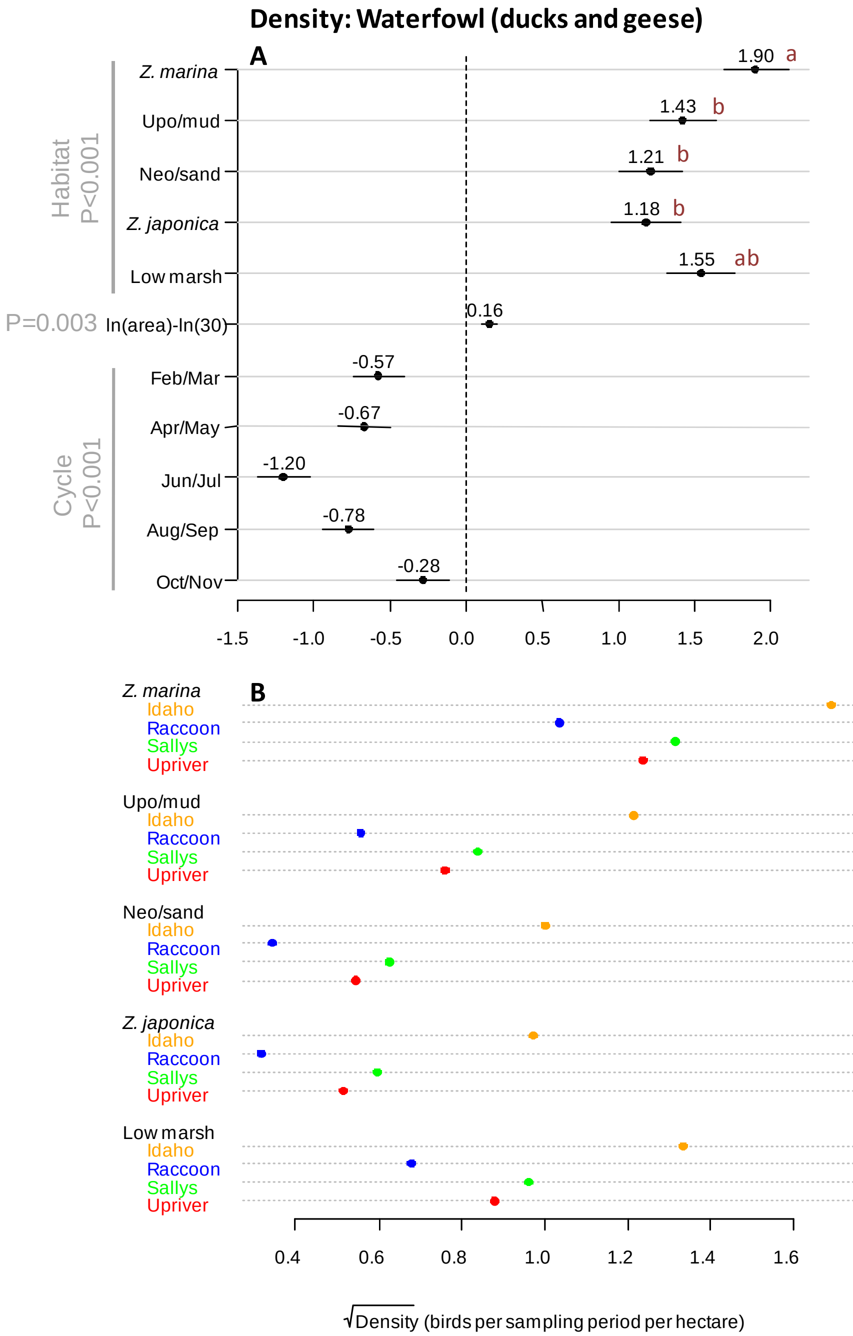


Figure 10. Statistical model estimates for waterfowl (ducks and geese): A) Model estimates (±standard error) for transformed bird density (√√birds·sample period^{-1}·ha^{-1}) as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for √√bird density based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

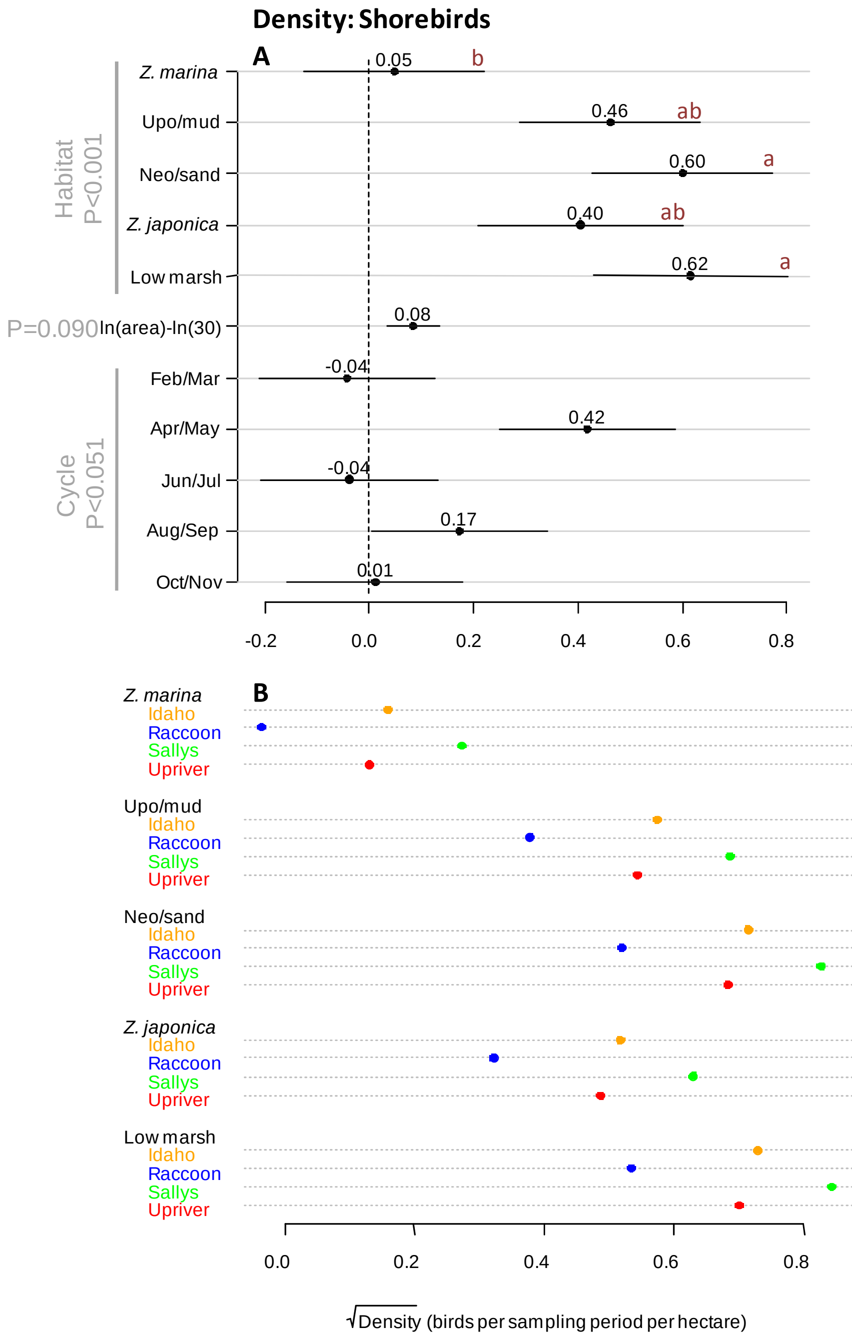


Figure 11. Statistical model estimates for shorebirds: A) Model estimates (± standard error) for shorebirds for transformed bird density (√√birds·sample period^{-1}·ha^{-1}) as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for √√bird density based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

Table 10. Pairwise comparison of modeled density and diversity values among habitats with p-values after Tukey's correction. Gray highlighted values: $p < 0.05$.

	√√Density				Diversity	
Habitats	All	No gulls	Waterfowl	Shorebirds	Shannon	# Species
Low marsh vs. *Neo*/sand	0.920	0.963	0.313	0.999	0.314	0.999
Low marsh vs. *Upo*/mud	0.823	0.942	0.963	0.905	0.147	0.716
Low marsh vs. *Z. japonica*	0.352	0.310	0.139	0.647	0.033	0.839
Low marsh vs. *Z. marina*	0.669	0.718	0.218	0.006	0.781	0.001
Neo/sand vs. *Upo*/mud	0.473	0.550	0.642	0.893	0.985	0.405
Neo/sand vs. *Z. japonica*	0.751	0.471	0.999	0.826	0.972	0.820
Neo/sand vs. *Z. marina*	0.226	0.238	<0.001	0.003	0.006	<0.001
Upo/mud vs. *Z. japonica*	0.070	0.092	0.722	0.998	0.999	0.175
Upo/mud vs. *Z. marina*	0.999	0.675	0.020	0.059	0.001	0.011
Z. marina vs. *Z. japonica*	0.003	0.023	<0.001	0.261	0.003	<0.001

<u>Standardized Diversity Patterns</u>

According to statistical analyses, Bird diversity varied among habitats in the Yaquina estuary (Table 10). Based on the Shannon diversity index (Fig. 12A), *Z. marina* had significantly greater diversity than all other habitats, except low marsh which although higher than the other habitats, was only significantly greater than *Z. japonica*. With respect to the area standardized estimates of species richness, significantly more bird species were observed within the *Z. marina* habitat than for any other habitat (Fig. 13A, Table 10). According to model estimates that statistically control for habitat area and sector, about two times more species are predicted to be observed in *Z. marina* during a sampling period than the other habitats.

Habitats with larger areas had significantly greater bird diversity based on the Shannon index ($P < 0.001$, Fig. 12A). There was no significant relationship between habitat area and standardized species richness ($P = 0.24$, Fig. 13A).

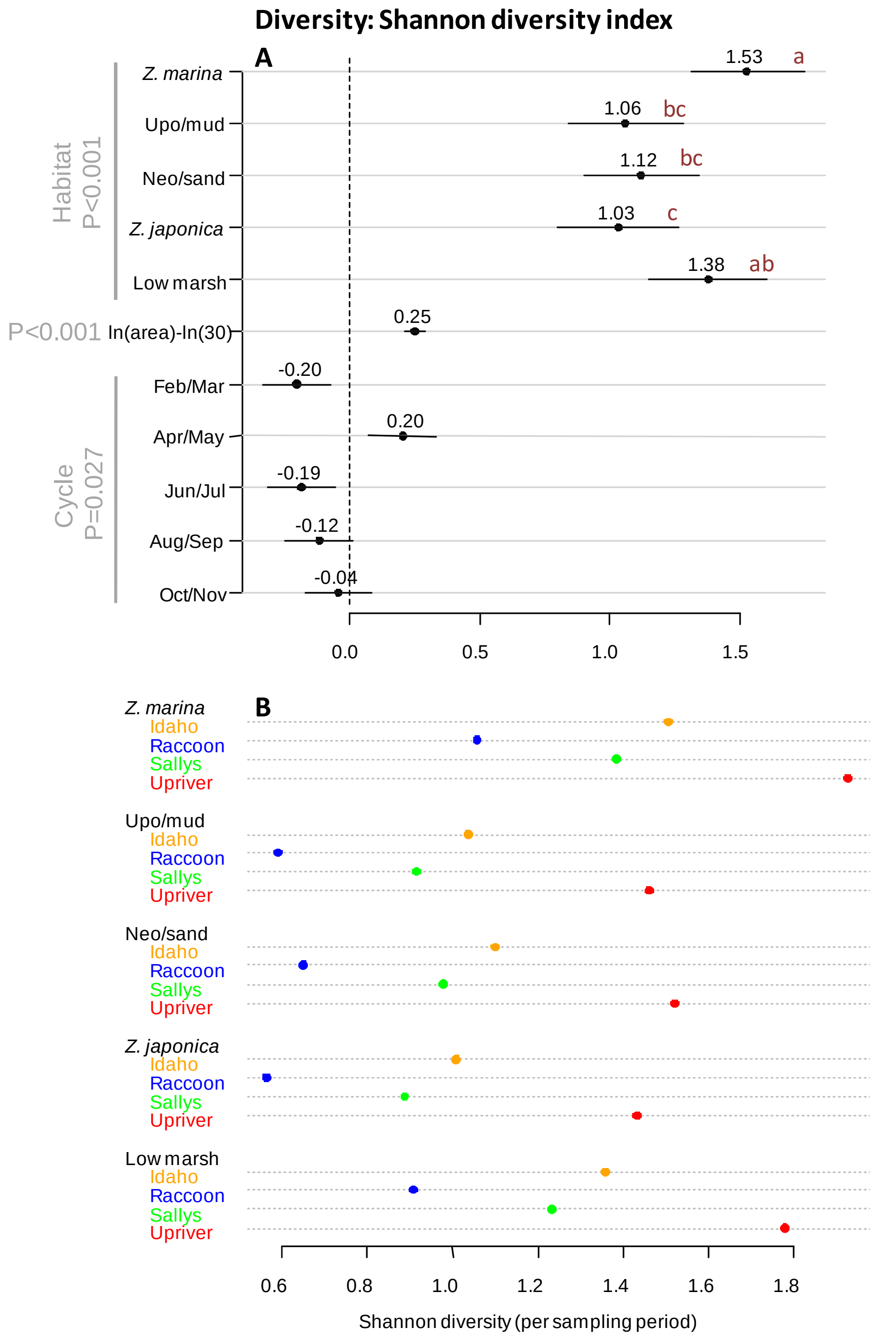


Figure 12. Statistical model estimates for Shannon diversity: A) Model estimates (± standard error) of the Shannon diversity index as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for the Shannon index of diversity based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

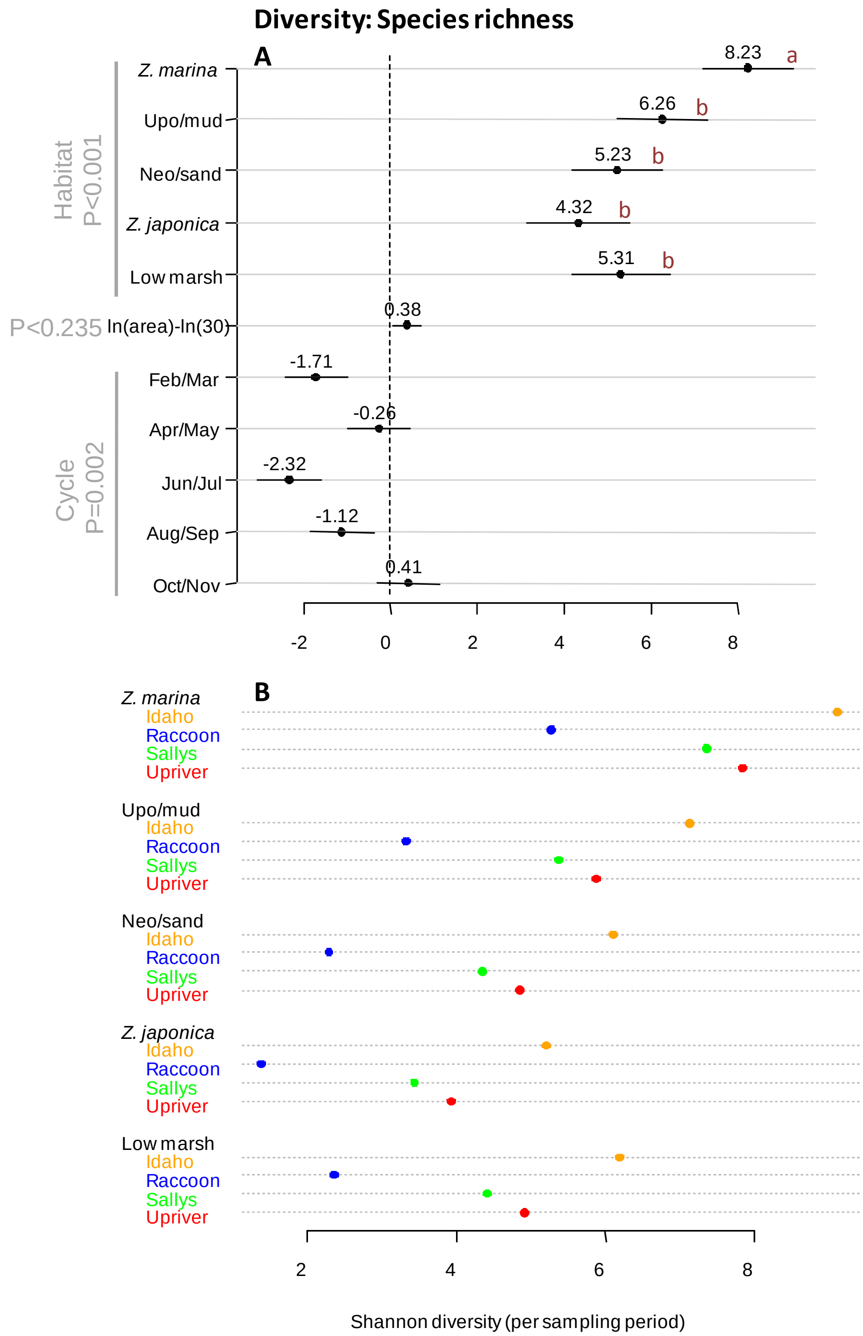


Figure 13. Statistical model estimates for species richness: A) Model estimates (± standard error) the estimated number of species after rarefaction as a function of habitat, area, and cycle. Zero is the baseline prediction for a 30 ha area sampled in Jan/Dec. Habitats with the same letters were not significantly different. B) Model predictions for the estimated number of species after rarefaction based on habitat and sector (standardized for a 30 hectare plot and averaged across all sample months).

Regardless of habitat, the sector of the estuary had an effect on bird diversity (Figs. 12B - 13B). Qualitatively, the Upriver sector had the highest mean values of the Shannon diversity index (Fig. 12B), with the Idaho Flat sector second. In contrast, the Idaho Flat had the highest rarefaction estimate of number of species (Fig. 13B), with the Upriver sector second. The Raccoon sector had the lowest diversity for both metrics.

<u>Seasonal Patterns of Density and Diversity</u>

There was a statistically significant relationship between count cycle and total bird density ($P=0.003$), total density excluding gulls ($P<0.001$), and waterfowl ($P<0.001$). In general, the densities of these groups appear to peak around Dec/Jan (count cycle 1, Figs. 8-10, Table 11). Densities then decline during Feb/Mar, with abundance at only about 22% of peak abundance (Table 6, Appendix F). Densities remain low through Jun/Jul and then increase from Aug/Nov. Peak densities correspond to a period when waterfowl were present (Table 3), gulls were abundant, and foraging crows and overwintering flocks of shorebirds were common. The low densities during February/March (count cycle 2) correspond to decreases in abundance of American Wigeon, Northern Pintail and American Coot (Tables 4, 11). The increase in density that occurs during Aug/Nov corresponds to a period when herons, egrets, gulls, ducks, and geese returned to the estuary (Table 4). Brown Pelicans were present in the lower Yaquina estuary in September.

Shorebirds had a different seasonal density pattern than the other taxonomic groups, with their numbers peaking around April/May (Fig. 11) during spring migration. However, none of the pairwise comparisons among sample cycles were significantly different (Table 11), and the overall model effect of cycle was marginally non-significant ($P=0.051$).

Seasonal patterns of Shannon diversity and species richness are somewhat more complicated (Figs. 12-13, Table 11). The analyses suggest there may be two yearly peaks in diversity, one around Oct-Jan and then around Apr/May. For Shannon diversity, Apr/May had significantly greater diversity than either Feb/Mar or Jun/Jul. For species richness, Oct/Nov had significantly greater diversity than either Feb/Mar or Jun/Jul. Interestingly the period of high diversity in Apr/May corresponds to a period of relatively low bird abundance. Similar to the density data, species diversity metrics were relatively low in June/July (Figs. 12-13, Table 11).

Table 11. Pairwise comparison of modeled density and diversity values between count cycles with p-values after Tukey's correction. Gray highlighted values: p ≤0.05.

	√√Density				Diversity	
Sample Months	All	No gulls	Waterfowl	Shorebirds	Shannon	# Species
Dec vs. Feb	0.023	0.003	0.010	0.999	0.631	0.171
Dec vs. Apr	0.020	0.014	0.001	0.133	0.630	0.999
Dec vs. Jun	0.006	<0.001	<0.001	0.999	0.708	0.017
Dec vs. Aug	0.361	0.028	<0.001	0.910	0.947	0.638
Dec vs. Oct	0.934	0.580	0.565	1.000	0.999	0.994
Feb vs. Apr	1.000	0.997	0.993	0.070	0.024	0.339
Feb vs. Jun	0.999	0.999	0.003	1.000	1.000	0.959
Feb vs. Aug	0.863	0.984	0.846	0.795	0.987	0.964
Feb vs. Oct	0.255	0.286	0.516	0.999	0.825	0.041
Apr vs. Jun	0.999	0.957	0.024	0.074	0.034	0.050
Apr vs. Aug	0.842	1.000	0.990	0.699	0.139	0.843
Apr vs. Oct	0.233	0.575	0.199	0.154	0.416	0.943
Jun vs. Aug	0.638	0.893	0.132	0.807	0.995	0.557
Jun vs. Oct	0.107	0.128	<0.001	0.999	0.880	0.002
Aug vs. Oct	0.912	0.716	0.043	0.930	0.993	0.287

Tide Level Patterns

Tide level was also an important factor in bird distribution across the intertidal habitats. Bird use of habitat changed with the tide as indicated by the significant interaction between tide and habitat (P< 0.001) regardless of whether bird abundance or √√density was analyzed. Bird use is highest, as the tide approaches or recedes from the habitat. Bird densities decline dramatically when the habitat is flooded (Fig. 14).

Within the broad general pattern, responses to tidal level varied among both bird groups and habitats (Fig. 15A-E). Both abundance and density was generally higher for birds foraging on intertidal *Z. marina* and *Upogebia*/mudflat habitats at low to mid tide levels (<0.3 – 0.9 m) than at tidal levels above +1.5 m (Tables 12, 13). At mid tide levels (+1.2-1.5 m) most gulls moved to intertidal *Neotrypaea*/sandflats higher in the intertidal zone to rest and preen as the lower elevation habitats became flooded (Fig. 15C). Over the winter, dabbling ducks drifted on the water's surface at mid tide levels without utilizing the intertidal habitats, and thus were not counted. In contrast, diving ducks and herons moved in to forage on invertebrates and fish as the lower habitats were flooded and prey became available. At higher tide levels (+1.8 to >2.4) gulls dispersed to higher ground or floated in the main estuary channel, ducks and geese fed on marsh plants and in some cases on *Z. japonica* in the upper intertidal region, while herons and geese roosted in exposed, emergent marsh. Shorebirds followed the tide at the water's edge, foraging in *Z. marina* and *Upogebia*/mudflats when those habitats were exposed, then moving across *Neotrypaea*/sandflats and *Z. japonica* habitats as the tide rose, and roosting on exposed rocks, floats and in emergent marsh at high tide. Corvids had similar foraging patterns in the intertidal habitats to the gulls, but retreated to trees or other terrestrial habitats at high tide. Other passerines occasionally visited emergent marsh and other habitats to forage when those habitats were exposed.

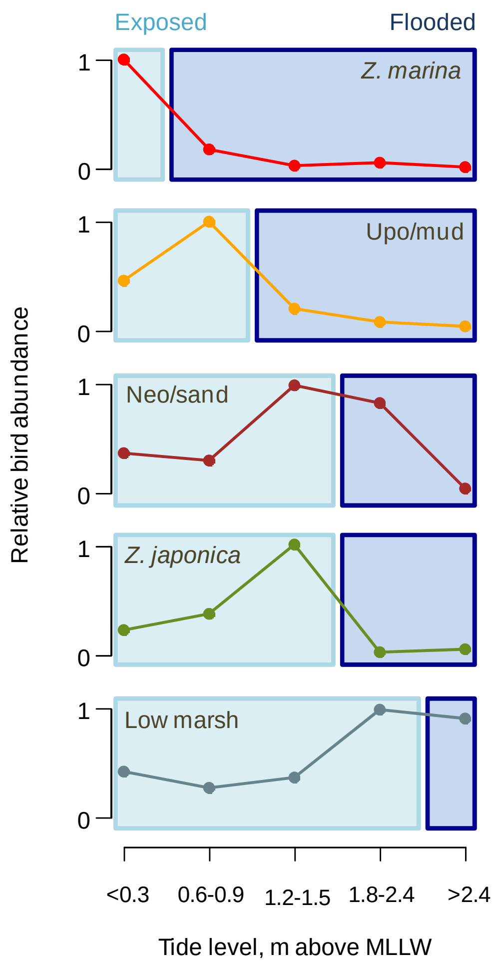


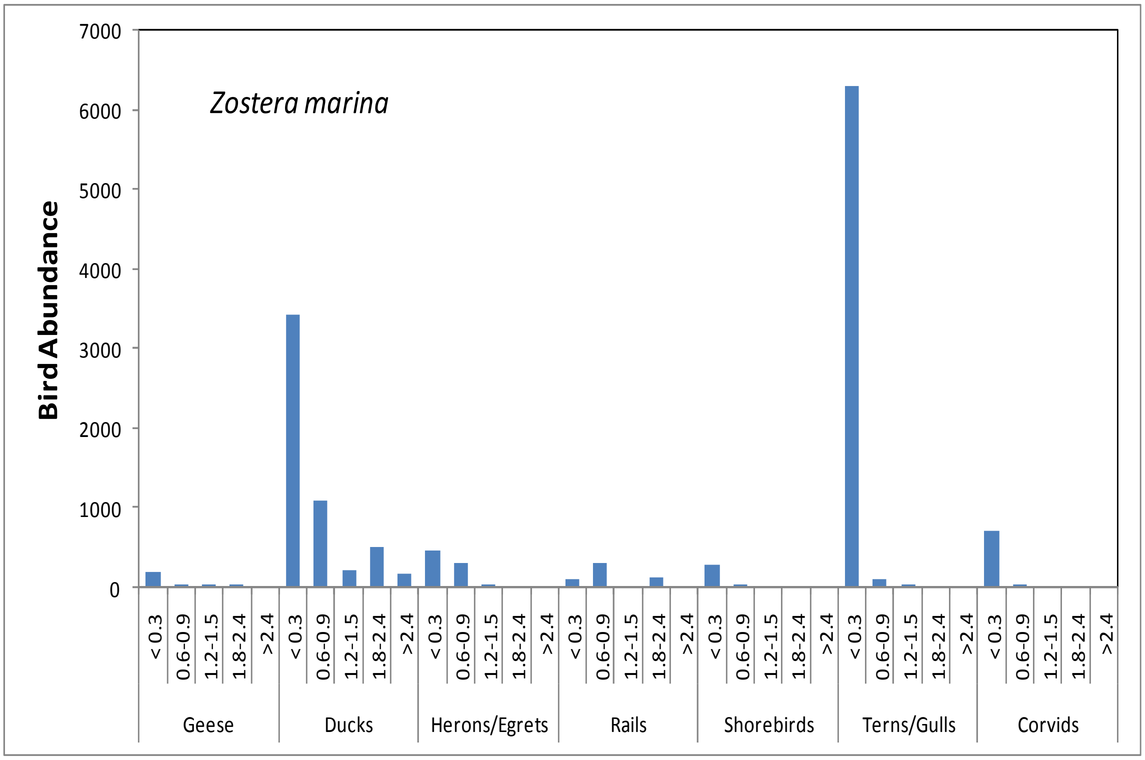
Figure 14. Comparison of relative bird abundance versus tide level for five intertidal habitats. Relative abundance was calculated using the average bird counts of observation periods for each habitat and tide cycle. Within each habitat, the average bird abundance for each tide cycle was divided by the tide cycle with the highest abundance. Within a habitat, bird use is highest just before or after habitat flooding.

Table 12. Abundance by tide level and count cycle of birds utilizing five intertidal habitats. Tide levels did not exceed +2.4 m during daylight hours in count cycles 3 and 4 (April-July).

Cycle	Tide (m)	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Total
1	< 0.3	2892	326	146	3	7	3374
Dec-	0.6-0.9	604	2300	201	80	84	3269
Jan	1.2-1.5	148	1365	472	513	171	2669
	1.8-2.4	270	360	1170	2	499	2301
	>2.4	63	144	116	33	40	396
Cycle 1 Total		3977	4495	2105	631	801	12009
2	< 0.3	874	802	304	1	330	2311
Feb-	0.6-0.9	95	744	207	7	61	1114
Mar	1.2-1.5	88	547	1093	0	28	1756
	1.8-2.4	123	133	70	7	79	412
	>2.4	25	33	15	2	16	91
Cycle 2 Total		1205	2259	1689	17	514	5684
3	< 0.3	1100	429	272	2	38	1841
Apr-	0.6-0.9	78	2378	120	10	41	2627
May	1.2-1.5	7	14	165	2	96	284
	1.8-2.4	42	73	357	0	126	598
Cycle 3 Total		1227	2894	914	14	301	5350
4	< 0.3	602	153	312	9	90	1166
Jun-	0.6-0.9	124	1078	79	15	36	1332
July	1.2-1.5	6	13	371	35	39	464
	1.8-2.4	9	4	354	0	102	469
Cycle 4 Total		741	1248	1116	59	267	3431
5	< 0.3	1646	973	110	71	32	2832
Aug-	0.6-0.9	549	1990	127	95	21	2782
Sept	1.2-1.5	25	100	641	82	57	905
	1.8-2.4	24	10	419	0	66	519
	>2.4	42	12	10	0	195	259
Cycle 5 Total		2286	3085	1307	248	371	7297
6	< 0.3	4533	2706	74	67	5	7385
Oct-	0.6-0.9	571	3520	250	54	84	4479
Nov	1.2-1.5	57	362	462	71	56	1008
	1.8-2.4	279	307	329	0	317	1232
	>2.4	88	192	27	0	833	1140
Cycle 6 Total		5528	7087	1142	192	1295	15244
Total		14964	21068	8273	1161	3549	49015

Table 13. Bird density (ha^{-1}) by tidal level and count cycle in five intertidal habitats.

Cycle	Tide (m)	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z. japonica*	Low Marsh	Tidal Level or Cycle
1	< 0.3	18.0	1.8	0.8	0.1	0.1	5.1
Dec-	0.6-0.9	3.8	13.0	1.1	2.3	0.8	5.0
Jan	1.2-1.5	0.9	7.7	2.6	14.9	1.6	4.1
	1.8-2.4	1.7	2.0	6.5	0.1	4.7	3.5
	>2.4	0.4	0.8	0.6	1.0	0.4	0.6
Cycle 1 Total		24.8	25.4	11.7	18.3	7.5	18.2
2	< 0.3	5.5	4.5	1.7	0.0	3.1	3.5
Feb-	0.6-0.9	0.6	4.2	1.2	0.2	0.6	1.7
Mar	1.2-1.5	0.5	3.1	6.1	0.0	0.3	2.7
	1.8-2.4	0.8	0.8	0.4	0.2	0.7	0.6
	>2.4	0.2	0.2	0.1	0.1	0.1	0.1
Cycle 2 Total		7.5	12.8	9.4	0.5	4.8	8.6
3	< 0.3	6.9	2.4	1.5	0.1	0.4	2.8
Apr-	0.6-0.9	0.5	13.4	0.7	0.3	0.4	4.0
May	1.2-1.5	0.0	0.1	0.9	0.1	0.9	0.4
	1.8-2.4	0.3	0.4	2.0	0.0	1.2	0.9
Cycle 3 Total		7.7	16.3	5.1	0.4	2.8	8.1
4	< 0.3	3.8	0.9	1.7	0.3	0.8	1.8
Jun-	0.6-0.9	0.8	6.1	0.4	0.4	0.3	2.0
July	1.2-1.5	0.0	0.1	2.1	1.0	0.4	0.7
	1.8-2.4	0.1	0.0	2.0	0.0	1.0	0.7
Cycle 4 Total		4.6	7.0	6.2	1.7	2.5	5.2
5	< 0.3	10.3	5.5	0.6	2.1	0.3	4.3
Aug-	0.6-0.9	3.4	11.2	0.7	2.8	0.2	4.2
Sept	1.2-1.5	0.2	0.6	3.6	2.4	0.5	1.4
	1.8-2.4	0.1	0.1	2.3	0.0	0.6	0.8
	>2.4	0.3	0.1	0.1	0.0	1.8	0.4
Cycle 5 Total		14.3	17.4	7.3	7.2	3.5	11.1
6	< 0.3	28.3	15.3	0.4	1.9	0.0	11.2
Oct-	0.6-0.9	3.6	19.9	1.4	1.6	0.8	6.8
Nov	1.2-1.5	0.4	2.0	2.6	2.1	0.5	1.5
	1.8-2.4	1.7	1.7	1.8	0.0	3.0	1.9
	>2.4	0.5	1.1	0.2	0.0	7.8	1.7
Cycle 6 Total		34.5	40.0	6.3	5.6	12.1	23.1



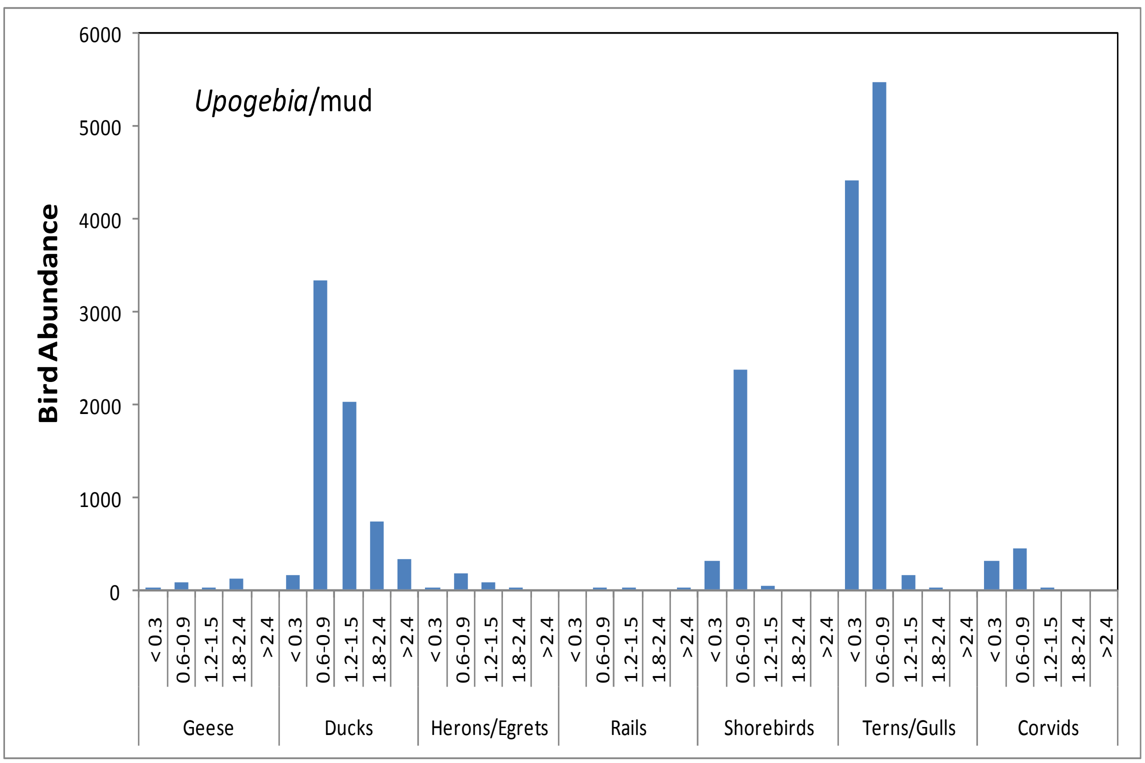
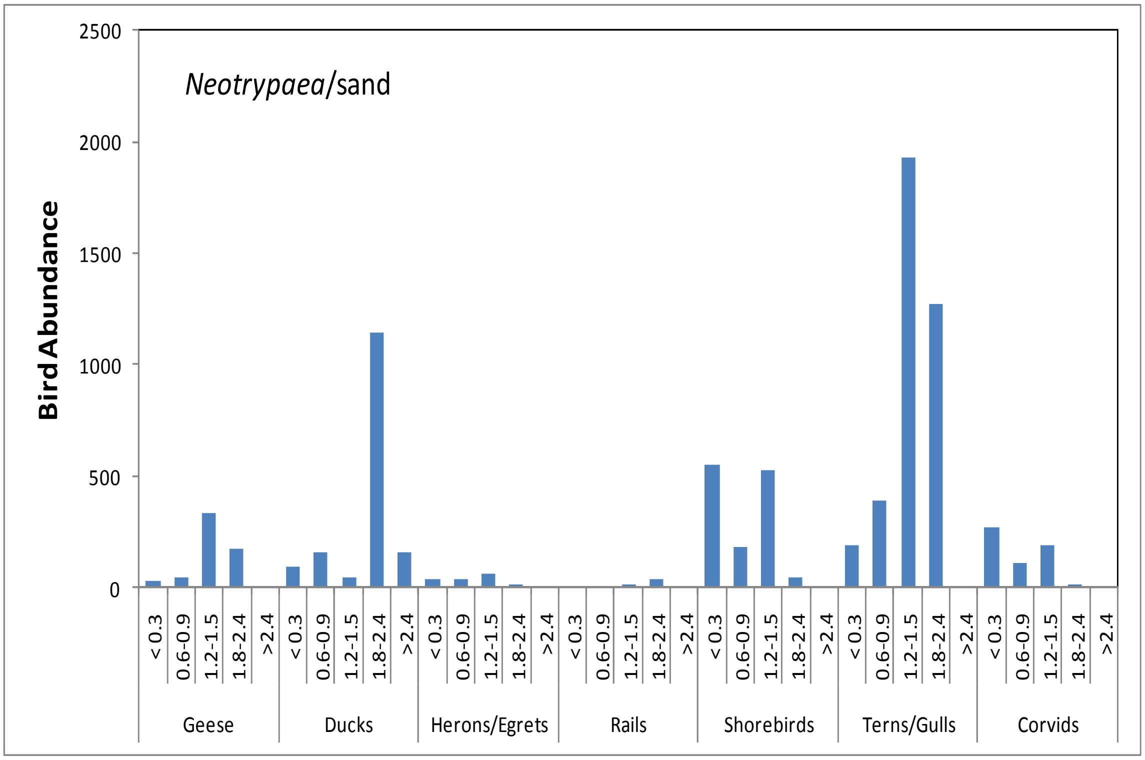


Figure 15. Abudances of selected groups of birds on intertidal habitats in Yaquina estuary at different tide levels. A. (*Z. marina*), B (*Upogebia*/mud), C. *(Neotrypaea/*sandflat*),* D *(Z. japonica*), E. (Low Marsh).Vertical scales vary.



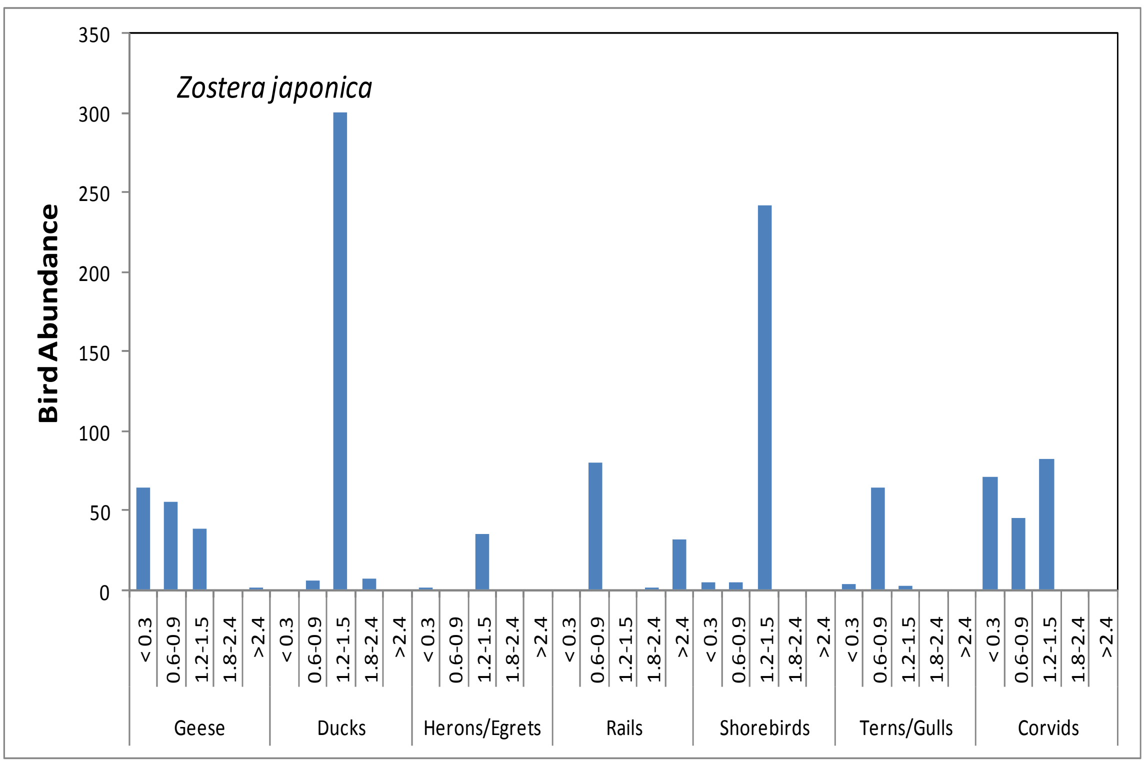


Figure 15 (cont.)

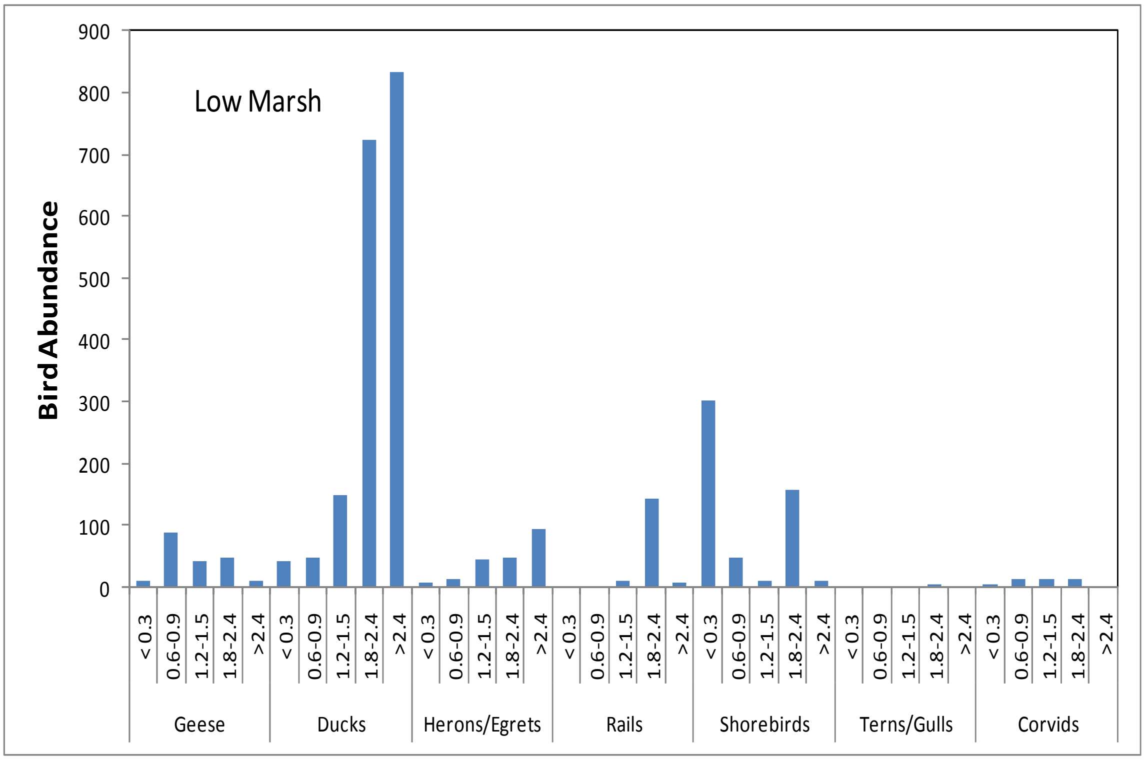


Figure 15 (cont.).

Replicate Counts

There was a strong stochastic element of bird use due to the transient nature of flocks of shorebirds, gulls, and geese which is evident in the raw abundance data of the two counts shown in Table 14. This characteristic of bird use will inevitably contribute to variation in any bird study based on census counts. However, the variation in bird use within cycles, habitat, and sector was significantly lower than predicted by chance alone, indicating that birds are also responding to their environment in predictable ways (Table 15). For example, within a cycle/sector/habitat, the variation in bird use was only about 20% of the total variation, indicating that bird use was highly repeatable.

Table 14. Comparison of bird abundance by habitat and sector for replicate counts of one or more sectors conducted in count cycles 2-6 at low tide (<0.3 m). CV – Coefficient of Variation.

Cycle	Sector	Habitat	Original Count	Repeat Count	Average	SD	CV*
2	Idaho	*Z. marina*	130	271	200.5	99.70	0.50
		Upo/mud	545	336	440.5	147.79	0.34
		Neo/sand	59	27	43.0	22.63	0.53
		Z. japonica	0	0	0.0	0.00	0.00
		Low Marsh	297	2	149.5	208.60	1.40
3	Sally's Bend	*Z. marina*	928	556	742.0	263.04	0.35
		Upo/mud	19	43	31.0	16.97	0.55
		Neo/sand	1	3	2.0	1.41	0.71
		Z. japonica	1	0	0.5	0.71	1.41
		Low Marsh	3	1	2.0	1.41	0.71
4	Upriver	*Z. marina*	20	16	18.0	2.83	0.16
		Upo/mud	53	154	103.5	71.42	0.69
		Neo/sand	0	0	0.0	0.00	0.00
		Z. japonica	0	0	0.0	0.00	0.00
		Low Marsh	0	0	0.0	0.00	0.00
	Raccoon	*Z. marina*	36	32	34.0	2.83	0.08
		Upo/mud	24	93	58.5	48.79	0.83
		Neo/sand	65	18	41.5	33.23	0.80
		Z. japonica	0	7	3.5	4.95	1.41
		Low Marsh	28	29	28.5	0.71	0.02
5	Idaho	*Z. marina*	83	310	196.5	160.51	0.82
		Upo/mud	854	1268	1061.0	292.74	0.28
		Neo/sand	20	56	38.0	25.46	0.67
		Z. japonica	0	0	0.0	0.00	0.00
		Low Marsh	9	0	4.5	6.36	1.41
6	Sally's Bend	*Z. marina*	3506	1036	2271.0	1746.55	0.77
		Upo/mud	126	190	158.0	45.25	0.29
		Neo/sand	10	12	11.0	1.41	0.13
		Z. japonica	10	243	126.5	164.76	1.30
		Low Marsh	0	0	0.0	0.00	0.00
	Total Average CV = (SD all counts/avg. all counts)			2.669	Average CV within Cycle/Sector/Habitat =		0.538

* When both counts were 0, CV was classified as 0.

Table 15. Average coefficients of variation within treatment groups. Relative CV values are calculated by dividing the within group CVs by the total CV of all the counts. P-values indicate whether the CV within a group is significantly smaller than expected by chance. * Calculations in Table 14.

		Variation within group	
	All Counts*	Cycle/Sector/ Habitat*	Sector/ Habitat
Avg CV	2.67	0.54	0.67
Relative CV	1.00	0.20	0.25
P-value	--	<0.001	<0.001

Regional Observations

Observations on birds occupying estuarine intertidal habitats in estuaries other than Yaquina were made opportunistically in conjunction with other studies (Appendix G). These observations, though not as rigorous as those in this study, showed that bird use of intertidal habitats in Pacific Northwest estuaries from Coos Bay, Oregon to Willapa Bay, Washington were generally consistent with bird use in Yaquina. However, some birds observed in the Low Marsh habitats of these estuaries were not commonly encountered in Yaquina salt marshes, such as Savannah Sparrow, Marsh Wren and Virginia Rail, which primarily use more freshwater marsh habitats.

Other Observations

People and other mammals

Observations of habitat use by people and other mammals were recorded as bird counts were conducted. Harbor seals used *Upogebia*/mudflat and *Z. marina* habitats adjacent to channels in Sally's Bend for haul-outs. Raccoons were frequently seen foraging on *Upogebia*/mudflat on Raccoon Flat and Idaho Flat, and deer or their tracks were occasionally observed on *Neotrypaea*/sandflat or rocky beaches. People were observed walking, collecting burrowing shrimp, digging clams or conducting research, primarily on *Upogebia*/mudflats and *Neotrypaea*/sandflats, as well as boating, kayaking and kite boarding over flooded sandflats, mudflats and eelgrass beds. Flocks of gulls, ducks and shorebirds were occasionally disturbed during counts by helicopters, boats, kite boarders and people with children or dogs chasing birds, though the primary source of disturbance was raptors such as Peregrine Falcons or Bald Eagles.

Use of Other Habitats

Bird use of other habitats was noted but not counted or included in the analyses for this report because these habitats were outside of the survey design. This included birds that sometimes foraged on rocky beaches, as well as the flocks of gulls and cormorants, as well as smaller numbers of herons and shorebirds that roosted on rocks, floats and pilings during high tide. Green Herons were seen fishing from floats, bald eagles often perched on pilings above mudflats and sandflats, and Black-crowned Night Herons were seen roosting in trees above emergent marsh.

DISCUSSION

The primary goal of this study was to assess the relative usage of five different tidal wetland habitats within the Yaquina estuary in regard to bird use. Previous studies of tidal wetland habitat use in west coast estuaries have tended to focus on either single species (Warnock and Takedawa 1995, Wilson and Atkinson 1995), or on a limited group of species (Baldwin and Lovvorn 1994a), particularly shorebirds (Colwell 1993, Conners 2008, Warnock et al. 2002). Our assessment of the relative use of tidal habitats by the complete bird assemblage was complicated by the fact that bird use within the estuary is affected by location within the estuary (sector), type of bird, season, and by the tidal level. However, given the large amount of data collected in this study, patterns of differences in habitat utilization among sectors, tide levels, time of year, and habitats were apparent. One limitation of the study is that results for the *Z. japonica* habitat should be interpreted cautiously due to the small area of this habitat relative to others.

Habitat and Spatial Patterns

Z. marina is a valuable bird habitat in Yaquina estuary based on almost all metrics of bird use. *Z. marina*, along with low marsh, supported statistically greater densities of waterfowl than the other habitats. *Z. marina* also had higher species diversity (Shannon index, standardized richness) than all other habitats, except low marsh for the Shannon index. An exception was that *Z. marina* had significantly lower densities of shorebirds than any other habitat except *Z. japonica* and *Upogebia*/mudflat. *Z. marina* habitat provides a foraging area for Brant, large numbers of ducks, gulls, crows, herons, and shorebirds when exposed at low tides. The habitat also serves as a roosting area for herons and cormorants. The *Z. marina* bed was the preferred habitat, when exposed at low tide, by dabbling ducks (wigeon spp., Northern Pintail, Mallard, Green-winged Teal), American Coot, and Brant. Based on feeding observations (online database, Appendix H), when inundated at tide levels >0.3 m, flooded eelgrass flats were used by birds dabbling for *Z. marina* (wigeon, Brant, and American Coot), diving for fish and intertidal mollusks and crustaceans (Bufflehead, Common Goldeneye, scaup spp., Ruddy Duck and scoters), foraging or diving for fish (herons, egrets, loons, grebes, mergansers, cormorants, Osprey and Belted Kingfisher). Flooded channels were used by ducks (wigeon spp., Bufflehead, scaup spp., Ruddy Duck, scoters) foraging for invertebrates, and by herons, egrets, mergansers and cormorants for fishing. Eelgrass plants in these channels were consumed by coots and wigeon, and the channels were used for roosting by cormorants.

These results are consistent with other studies that have shown close spatial association of some birds to estuarine food resources. Brant usage of estuarine habitats in Willapa Bay, Washington was positively associated with presence of *Z. marina* habitat and negatively associated with oyster bed habitat (Wilson and Atkinson 1995) as a result of the direct use of eelgrass as food by the birds. Balwin and Lovvorn (1994a) examined three intertidal elevations zones in Boundary Bay, British Columbia, Canada, and found that the biomass and numbers of most food items for dabbling ducks and Brant were greatest in the zones with *Z. japonica* and *Z. marina*, which is where the birds were observed to primarily feed.

The *Upogebia*/mudflat habitat appears to support relatively high total bird densities regardless of the sector in the estuary (Fig. 8B). Furthermore, this habitat was extensively used at low to mid-tide (<0.3 to 0.6-0.9 m) by foraging gulls (many of which were also foraging in *Z. marina*). At mid-tide levels (0.6-0.9 m), when *Z. marina* was flooded and inaccessible, exposed *Upogebia*/mudflat was used by foraging ducks and gulls, feeding and roosting Canada Geese, foraging and roosting herons, shorebirds (foraging Dunlin and "peep" sandpipers, Whimbrel foraging and feeding on burrowing shrimp), foraging crows, and occasionally by roosting Caspian Terns and raptors such as Bald Eagle. The flooded mudflat (tide levels >1.2 m) was utilized by diving ducks (Bufflehead, Common Goldeneye, scaup, scoter and merganser), herons, loons, grebes, cormorants, kingfisher, and terns for preying on fish and invertebrates such as cockles; and by dabbling ducks (wigeon spp., Northern Pintail) and American Coot feeding on drift plant material. Flooded channels were used by foraging ducks (wigeon, feeding on drift *Z. marina*) and by herons, egrets and cormorants.

The *Neotrypaea*/sandflat habitat was utilized primarily when flooded at mid to high tide levels by foraging ducks and shorebirds, and, when it was exposed, by roosting gulls when the preferred feeding grounds (*Z. marina* and *Upogebia*/mudflat) were flooded. The exposed sandflat was used by geese (Brant and Canada Geese) for roosting or foraging on green macroalgae (Appendix H), and by roosting herons and a few raptors (osprey and eagle). The exposed sandflat was also used at mid to high tide levels (>1.5 m), by some foraging gulls, crows, and a few dabbling ducks (Mallard, wigeon and Northern Pintail) feeding on drift plant material. A variety of shorebirds foraged in the habitat, especially Whimbrel, which were observed to capture and consume *Neotrypaea* shrimp. The flooded sandflat (>1.8 m tide levels) was used by dabbling ducks foraging on drift plant material at the water's edge, and by diving ducks preying on intertidal invertebrates. Herons fished at water's edge as the tide came in, and grebes, cormorants, osprey and kingfisher foraged when the sandflat flooded. Channels within the flooded habitat were also used by herons and diving ducks for foraging and fishing, and when the habitat was exposed, the channels provided foraging habitat for a variety of shorebirds.

The *Z. japonica* beds were used primarily by ducks (mostly mallards) and rails (coot) foraging on *Z. japonica* blades either at mid-tide levels (0.6-1.5 m) when *Z. marina* beds were flooded, or at high tide (>1.8 m) when the *Z. japonica* was flooded but shallow. In late winter, the aboveground biomass of this eelgrass species died and was largely reduced to stubble, and shorebirds foraged both within this habitat and in the adjacent *Neotrypaea*/sandflat without apparent regard to the presence of the stubble. The *Z. japonica* habitat was used as a foraging area by a few crows, and occasionally as a roosting area by gulls, herons, terns and geese. Based on feeding observations (online database, Appendix H), *Z. japonica* was consumed by American Coot, wigeon, Northern Pintail and Canada Geese. Mallard consumed *Z. japonica*, but no Brant were observed feeding or roosting in *Z. japonica* beds in Yaquina estuary during this study.

One issue of recent potential concern is whether the introduction of *Z. japonica* will negatively affect bird use of intertidal habitat in estuaries, particularly for shorebirds. Although this study was not primarily designed to address this question, it provided a preliminary evaluation of the issue. In Yaquina estuary, *Z. japonica* is most likely to supplant the *Neotrypea*/sand habitat. There were no significant differences between *Z. japonica* and *Neotrypea* /sand habitat for any metric of bird use. Currently, there is no evidence that birds will be negatively impacted by the presence of this invasive species in Yaquina estuary. Baldwin and Lovvorn (1994a) have shown that *Z. japonica* is readily fed on and is an important food source for brant and a variety of dabbling ducks including American Wigeon, Northern Pintail, and Mallard. In the Yaquina, Canada Geese and American Coots were also observed to feed on *Z. japonica* (Appendix H).

Low marsh habitat is a potentially valuable habitat, particularly for waterfowl (Fig. 10) and shorebirds (Fig. 11), and may have high Shannon diversity (Fig. 12). The low marsh habitat was exposed at low to mid-tide levels (<1.8-2.4 m), and served as roosting and foraging grounds for herons, Mallard and Canada geese, and as hunting and foraging area for a variety of shorebirds as well as swallows, blackbirds, starlings and other passerines (Appendix C). When tidal channels were flooded (>1.8 m) and the lower portions of the marsh were inundated (>2.4 m), the habitat served as foraging and fishing ground for American Wigeon, Northern Pintail, American Coot, a variety of diving ducks, herons and kingfishers.

The division of the estuary into four sectors was driven by the logistical demands of sampling. However, spatial location within the estuary as represented by the sectors influenced all metrics of bird use. The Idaho Flat sector generally supported the largest total bird densities, waterfowl densities, and species richness. The Sally's Bend sector supported the largest density of shorebirds. The Upriver sector had high Shannon diversity. The Raccoon Flat sector had the lowest bird use based on all metrics. The specific factors driving the observed bird use patterns among sectors are unknown. However, it is clear that bird use varies depending on location within the estuary, even when the dominant habitat is the same. It is likely that unmeasured variables associated with different regions of the estuary – such as human development (McKinney et al. 2006), distance from estuary mouth, etc. - influence bird use. Wetzel (1996) noted that human activities on the water and on the shore adjacent to eelgrass beds in Yaquina estuary were a major influence on the use of these habitats by Brant. Studies comparing the relative value of habitats in regard to bird use should consider these potentially confounding variables.

Seasonal Patterns

Bird use of the estuary varied dramatically over the course of a year. In general, total bird densities appeared to peak around Dec/Jan (Figs. 8-10); then declined around Feb/Mar and remained relatively low until after Jun/Jul; after which, they began to increase. In Dec/Jan ducks were the most abundant group of birds observed, while gulls predominated in Feb/Mar. Gull abundance on intertidal habitats decreased in Apr/May during breeding season and increased during Jun/Jul with the dispersal of young Western and Glaucous-winged Gulls and hybrid gulls from local nesting grounds.

There was also an influx of California Gulls from their inland breeding grounds, joined by Caspian Terns and their young dispersing from Columbia River nesting grounds. Shorebirds have a different seasonal pattern, and their densities appeared greatest during spring migration in Apr/May (Fig. 11).

Seasonal patterns of Shannon diversity and species richness are somewhat more complicated. Similar to total density, species diversity metrics appeared relatively low in Jun/Jul (Figs. 12-13). The analyses suggest there may be two yearly peaks in diversity, one around Oct-Jan and then around Apr/May.

The seasonal trends observed are consistent with those observed by Merrifield (1998, 2001) during extensive bird surveys conducted in the Yaquina estuary during 1993-94 and 1997-99. Counts of individual species differed between the two studies because the present study focused on birds directly utilizing intertidal estuarine habitats, whereas Merrifield recorded all birds present on the estuary. Additionally, Merrifield's counts were primarily at low tide, while in the present study counts were made at five tide levels.

Tidal Patterns

In the Yaquina estuary, and presumably in other Pacific Northwest estuaries with similar tidal patterns, the tides drive bird feeding patterns and habitat utilization across the intertidal zone (Fig. 14, Tables 12 and 13). Overall, bird abundance is highest as the tide approaches or recedes from the habitat. Bird densities are lower when the habitat is flooded (Fig. 14).

Based on observations during this study, different bird groups respond differently to tidal stage (Fig. 15). The observational data yields the following general patterns of tidal response. At low tide when all intertidal habitats were exposed, gulls, dabbling ducks, geese, crows and shorebirds forage for invertebrates and feed on plant material in the lower intertidal habitats: *Zostera marina* and unvegetated mudflat. These habitats are rich in invertebrate prey (Ferraro and Cole, 2007). As the tide rises and the seagrass habitat is covered, gulls and shorebirds move upslope and continue to forage on exposed plant material and invertebrates on the exposed mudflat. Herons, egrets and diving species such as cormorants, loons, grebes and pelicans were observed eating fish and crabs that moved in with the tide (Appendix H; online data). Shorebirds follow the water's edge, and diving ducks move over the flooded intertidal habitats to dive for mollusks and other invertebrates. As the rising tide covers the lower intertidal seagrass and mudflat habitats, birds move upslope, and gulls roost and preen in the upper intertidal sandflat, while shorebirds and crows continue to forage in this habitat. Herons and diving birds forage in the flooded seagrass and mudflat, while crows, shorebirds, dabbling ducks and geese forage in upper intertidal *Z. japonica* patches. As the unvegetated habitats and *Zostera* patches are flooded, herons, geese and dabbling ducks rest or forage in non-flooded portions of exposed marsh, shorebirds roost on rocks, floating docks or in the marsh or head for ocean beaches, gulls drift offshore or roost on land, crows take refuge in trees, and diving ducks continue to feed in flooded habitats.

In addition to the broader group responses described above, a range of studies have demonstrated that the responses of birds to the tidal cycle in estuaries may vary depending on species. Similar to the pattern observed in the Yaquina, abundance of Sanderlings in Bodega Bay decrease sharply on intertidal flats at higher tide levels (Conners et al. 1981). In this case, the birds are moving off of the estuarine flats to the outer coast sand beaches at mid-level and high tides on a regular basis. This movement is consistent with observations on the location of maximum density of prey items for Sanderlings, which is higher at lower elevations on the tide flats. In Elkhorn Slough, California, small sandpipers are more abundant at high tide within wetlands with muted tidal action, moving from the open tide flats to these areas where the substrate stays exposed longer (Conners 2008). In contrast, the larger stilts and avocets which can forage in shallow water generally show no difference between the two habitat types over the tidal cycle.

For waterfowl such as Brant, tidal depth is also important in terms of habitat utilization. Wetzel (1996) found that Brant dispersed across the Yaquina at high tide, and concentrated at the shore to feed on eelgrass at lower tidal stages. Moore and Black (2006) found strong tidal stage effects on Brant foraging in Humboldt Bay. Birds tended to feed in the deepest possible areas permitted by tidal stage, which tended to be where eelgrass plants had highest levels of protein, calcium and biomass.

Sampling Issues

The aggregated nature of birds requires very large sample sizes in order to resolve patterns of bird use among habitats. Within a given habitat/sector/tide/season the variation in observed birds on a single observation can be very large due to stochastic sources of variation, such as weather, local human disturbance, or presence of a predator. A complex issue is the relation of bird abundance to area of the habitat being sampled. Even after converting abundance to density for comparison in the present study, the effect of area was often still statistically present. Benoit and Askins (2002) examined the relationship of habitat area and abundance and distribution of specialized tidal marsh birds in Connecticut. Rather than a complete areal census, constant areas were sampled. Responses were species specific. Salt Marsh Sparrow and Willet were found in higher abundance in larger marshes, especially those exhibiting lower levels of fragmentation, while other species such as Virginia Rail, Marsh Wren and Swamp Sparrow showed no response to marsh area. We have not attempted to determine habitat responses at the species level in the present study.

All results of the present study are based on day time visual surveys. Shepherd et al. (2003) used radio telemetry to examine diurnal differences in Dunlin habitat usage in the Fraser River estuary, British Columbia, and found that the birds spent equal times foraging in both day and night. The Dunlin used terrestrial habitats adjacent to the intertidal areas more frequently at night. Sole use of day time surveys thus may underestimate the importance of near estuary terrestrial habitats to some shorebird species, with important consequences to conservation planning. In the Yaquina estuary, the lowest tides during the winter period occur at night, presenting considerable foraging opportunity. The extent of nocturnal usage and its relative distribution among estuarine habitats is presently unknown for this system.

Use for Assessing Ecosystem Services

The present bird habitat assessment study is part of an EPA research program to develop approaches to quantify the benefits, or ecosystem services (Millennium Ecosystem Assessment 2005), that estuaries provide for people. One aim of the research program is to determine whether it is feasible to use major estuarine habitats as a framework to assess ecosystem services. This approach may be ideal because habitats can be mapped using a variety of remote sensing and ground based approaches. If services can be associated to habitats then it may be possible to predict how changes in habitat from various causes will alter the services we derive from ecosystems.

The results from this study suggest that alterations of the most common habitats in the Yaquina estuary will affect bird use. Various habitats have different ecological roles, and the loss of a given habitat will affect various species differently. For example, if *Z. marina* populations decline, overall bird usage may be negatively affected given the overall diversity and abundance of birds associated with this habitat, but shorebird populations will likely be less affected than waterfowl.

Predictions using the present study data should be made cautiously. There are many complicating factors that may confound the results. We could not control for several variables that will covary with habitat. For example, some habitats are more likely to be located near the margins of the estuary, which may be perceived by birds as less safe. The best way to control for these confounding variables is to conduct similar studies in other estuaries to determine which habitat patterns persist

The present study has determined that assessing bird use among habitat type within estuaries can establish relative usage patterns. The results do indicate that usage within a habitat type is not constant across the spatial extent of the estuary, and thus location must be considered in ecosystem services assessments. There was no attempt during the present study to collect data that would allow quantification of final ecosystem services, either monetized or non-monetized, which would require collection of socioeconomic data in addition to biological data. However, we conclude that a habitat based assessment approach is generally feasible for use in developing estimates of ecosystem services related to the presence of birds within estuarine systems.

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Appendix A. Locations of observation sites in the Yaquina estuary, Oregon.

Sector	No.	Stop ID	Latitude	Longitude	Mileage	Description
Idaho Flat	I1	Pumphouse	44.6240	-124.0427	0	HMSC pump house dock
	I2	EPA Beach	44.6219	-124.0417	0.2	HMSC nature trail east of EPA building
	I3	Low Bench	44.6212	-124.0415	0.26	Bench near nature trail opposite EPA building
	I4	Shelter	44.6205	-124.0420	0.3	HMSC nature trail wooden shelter
	I5	Trail	44.6201	-124.0429	0.35	HMSC nature trail
	I6	High Bench	44.6196	-124.0446	0.4	HMSC nature trail elevated observation point with bench
	I7	Bridge	44.6192	-124.0452	0.5	HMSC natural trail bridge
	I8	Log Pond	44.6184	-124.0465	0.9	South end of HMSC trail at HMSC drive
	I9	35th St Marsh	44.6125	-124.0426	1.1	Salt marsh along road at south section of Idaho Flat
	I10	Leeks High Road	44.6114	-124.0352	1.6	SE 35th and SE Leeks High Road
	I11	Idaho Point	44.6144	-124.0260	2.0	End of peninsula between Idaho Flat and Kings Slough
Sally's Bend	S1	LNG	44.6247	-124.0247	0	End of road adjacent to gate into LNG property
	S2	Base	44.6285	-124.0249	1.3	North end of road leading to LNG facility
	S3	Benson	44.6293	-124.0215	1.5	Roadside pullout along Yaquina Bay Road near Benson Road
	S4	George	44.6275	-124.0133	1.9	Roadside pullout near SE George St.
	S5	Little Cut	44.6263	-124.0094	2.1	Roadside pullout halfway between SE George St. and SE John Nye Road
	S6	Nye	44.6251	-124.0065	2.3	Roadside pullout near SE John Nye Road
	S7	Cut Bank	44.6231	-124.0048	2.4	Roadside pullout near vertical road cut along Yaquina Bay Road
	S8	Grassy	44.6197	-124.0041	2.7	Roadside grassy area along Yaquina Bay Road
	S9	Brown Sign	44.6168	-124.0038	2.9	Roadside pullout nearly opposite two driveways
	S10	Tele Pole	44.6137	-124.0063	3.2	Yaquina Bay Road overview
	S11	Coquille	44.6114	-124.0104	3.4	Coquille Point, overview of Sally's Bend
Raccoon Flat	R1	Raccoon Flat	44.6105	-124.0108	3.5	Coquille Point, looking across the river
Upriver	U1	Sawyers	44.6026	-124.0108	4.0	Sawyer's Landing Marina
	U2	Storage	44.5932	-124.0123	4.4	Storage building parking area
	U3	Parker Slough	44.5897	-124.0159	4.7	Parker's Slough bridge
	U4	Oneatta Pt	44.5837	-124.0161	5.4	Oneonta Point pullout
	U5	Winant	44.5836	-124.0063	6.1	Winant Slough pullout, just upstream of milepost 6
	U6	OR Oyster	44.5809	-123.9950	6.6	Bridge overlooking slough and Oregon Oyster facility floats
	U7	Johnson Slough	44.5780	-123.9893	7.0	Johnson Slough bridge
	U8	Old Barge	44.5757	-123.9846	7.3	Pullout next to an old beached barge
	U9	Martin Houses	44.5750	-123.9775	7.6	Pullout near pilings with purple Martin houses
	U10	Boone Family	44.5759	-123.9692	8.2	Pullout with historical sign, walk back downstream to marsh channel under road
	U11	Boone Trestle	44.5817	-123.9660	8.6	Pullout near old railroad trestle adjacent to Boone Slough marshland
	U12	Boone High Trestle	44.5851	-123.9628	8.9	Pullout near old railroad trestle overlooking tidegate into Boone Slough
	U13	Nute Slough	44.5871	-123.9592	9.1	Pullout near old railroad trestle adjacent to entrance into Nute Slough (yellow sign)
	U14	Port of Toledo Park	44.5913	-123.9422	10.1	Fishing pier at Port of Toledo park and boat launch
	U15	Critesers Landing	44.5933	-123.9417	10.2	Criteser's Landing Marina
	U16	Mp 11 Pullout	44.6074	-123.9488	11.1	Roadside pullout just upstream from milepost 11

Appendix B. Abundance of all birds observed for each count cycle in the Yaquina estuary during December 2007-December 2008. Counts are provided for both the Base assessment and for the comparative counts (QA). Values are sums of all birds seen on all four sectors, all five habitats, and at all tide levels (QA* - data listed in the QA column for Count Cycle 1 were collected in December 2008).

	Count Cycle	1		2		3		4		5		6		Total
Group	Common Name, Species	Base	QA*	Base	QA	Base	QA	Base	QA	Base	QA	Base	QA	
Geese	Brant, *Branta bernicla*	303	94	230	94	52						129		902
	Cackling Goose, *Branta hutchinsii*			2		1								3
	Canada Goose, *Branta canadensis*	2	10	65		121		57	41	369		61		726
Ducks	American Wigeon, *Anas americana*	3768		154		2				134		3727		7785
	Bufflehead, *Bucephala albeola*	1010	69	442	49	135						981	30	2716
	Canvasback, *Aythya valisineria*	5												5
	Common Goldeneye, *Bucephala clangula*	27	4	20								5		56
	Common Merganser, *Mergus merganser*	3								10		2		15
	Eurasian Wigeon, *Anas penelope*	5		1								11		17
	Gadwall, *Anas strepera*			2										2
	Green-winged Teal, *Anas crecca*			3		33						4		40
	Hooded Merganser, *Lophodytes cucullatus*	2	3									4		9
	Mallard, *Anas platyrhynchos*	186	118	85		69	6	2		151		370		987
	merganser sp., *Mergus* sp.	1												1
	Northern Pintail, *Anas acuta*	707	2	6						31		904		1650
	Northern Shoveler, *Anas clypeata*					6								6
	Red-breasted Merganser, *Mergus serrator*	20	12	21		24	3					23		103
	Ruddy Duck, *Oxyura jamaicensis*	22		8	2							0		32
	scaup sp., *Aythya* spp.	224		463	55	191		14				173	30	1150
	Surf Scoter, *Melanitta perspicillata*	243		161	15	29				3		98		549
	White-winged Scoter, *Melanitta fusca*	19				2								21
	wigeon and pintail, *Anas* spp.	970												970
	Wood Duck, *Aix sponsa*											1		1
Loons/Grebes	Common Loon, *Gavia immer*	14	6	6		9	1			2		11		49
	grebe sp., *Podiceps* sp.									3				3
	Horned Grebe, *Podiceps auritus*	34		18	3	1				2		51		109

	Pacific Loon, *Gavia pacifica*			5		1				1		2		9
	Pied-billed Grebe, *Podilymbus podiceps*											2		2
	Red-necked Grebe, *Podiceps grisegena*	2								2		5		9
	Red-throated Loon, *Gavia stellata*	7		5								2		14
	Western Grebe, *Aechmophorus occidentalis*	30		2		10				1		8	5	56
Pelicans /Cormorants	Brandt's Cormorant, *Phalacrocorax penicillatus*					1	74	5		2				82
	Brown Pelican, *Pelecanus occidentalis*						1			80	3	215		299
	Double-crested Cormorant, *Phalacrocorax auritus*	7		5		20		8		277	1	272		590
	Pelagic Cormorant, *Phalacrocorax pelagicus*			1		2								3
Herons/Egrets	Great Blue Heron, *Ardea herodias*	85	28	51	5	103	66	299	23	345	41	202	7	1255
	Great Egret, *Ardea alba*		2	0		29	3	6		192	3	133	4	372
	Green Heron, *Butorides virescens*		1											1
Vultures/Raptors	Bald Eagle, *Haliaeetus leucocephalus*	12	1	4		1		3		2		3		26
	Northern Harrier, *Circus cyaneus*			2				1	1					4
	Osprey, *Pandion haliaetus*					4		3		3				10
	Peregrine Falcon, *Falco peregrinus*											1		1
	Red-tailed Hawk, *Buteo jamaicensis*			1										1
	Turkey Vulture, *Cathartes aura*					10		1						11
	White-tailed Kite, *Elanus leucurus*			1										1
Rails	American Coot, *Fulica americana*	823	75	52	9							38		997
Shorebirds	Black Turnstone, *Arenaria melanocephala*										2			2
	Black-bellied Plover, *Pluvialis squatarola*					1		1				11		13
	dowitcher sp., *Limnodromus* spp.					35	1			7		1		44
	Dunlin, *Calidris alpina*	49				169				5		11		234
	Greater Yellowlegs, *Tringa melanoleuca*	13	2	10		1	2	9		11		10		58
	Killdeer, *Charadrius vociferus*	33	2	3		1	1	7	1	11		20	9	88
	Least Sandpiper, *Calidris minutilla*	26				9		60	5	38		74	3	215
	Long-billed Curlew, *Numenius americanus*					1								1
	Marbled Godwit, *Limosa fedoa*					1						22		23
	peeps, *Calidris* spp.	250		40						60		15		365
	Red Knot, *Calidris canutus*					3								3
	Red-necked Phalarope, *Phalaropus lobatus*					25								25

	Sanderling, *Calidris alba*	149	90	610										849
	Semipalmated Plover, *Charadrius semipalmatus*					53		4			2			59
	shorebirds unid., Charadriiformes unid.					4				1				5
	Spotted Sandpiper, *Actitis macularius*	4		4		4				3				15
	Western Sandpiper, *Calidris mauri*	80	65			2367		207	1	198		24		2942
	Whimbrel, *Numenius phaeopus*					160	1	153		60	3			377
Terns/Gulls	Caspian Tern, *Hydroprogne caspia*					11		47		12				70
	gulls spp., *Larus* spp.	2359	280	2567	380	1317	422	2033	215	4953	1575	7043	1183	24327
Alcids	Common Murre, *Uria aalge*							5						5
	Pigeon Guillemot, *Cepphus columba*					4					1			5
Corvids	American Crow, *Corvus brachyrhynchos*	427	37	599	24	225	21	286	34	251	3	515	210	2632
	Common Raven, *Corvus corax*							2						2
Songbirds (including hummingbirds and kingfishers)	American Goldfinch, *Carduelis tristis*							2	2	1				5
	American Robin, *Turdus migratorius*					7		5	1	1				14
	Barn Swallow, *Hirundo rustica*					29		61	5	16				111
	Belted Kingfisher, *Megaceryle alcyon*	6	1	2		1		12	1	8		7		38
	Brewer's Blackbird, *Euphagus cyanocephalus*								1	2				3
	Bushtit , *Psaltriparus minimus*									2				2
	Cliff Swallow, *Petrochelidon pyrrhonota*							1						1
	European Starling, *Sturnus vulgaris*	70		33		10		63	6	30		30		242
	Fox Sparrow, *Passerella iliaca*	3												3
	Purple Martin, *Progne subis*					5		9		8				22
	Red-winged Blackbird, *Agelaius phoeniceus*							25						25
	Rufous Hummingbird, *Selasphorus rufus*								1					1
	Savannah Sparrow, *Passerculus sandwichensis*							1		1				2
	Song Sparrow, *Melospiza melodia*	9	1			2		18	1	8		22		61
	sparrow sp., Emberizidae sp.											1		1
	swallows spp., *Tachycineta* spp.						1	11	10					22
	Tree Swallow, *Tachycineta bicolor*					9		6						15
	Violet-green Swallow, *Tachycineta thalassina*					38		4						42
	White-crowned Sparrow, *Zonotrichia leucophrys*					2								2
Grand Total		12009	903	5684	636	5350	603	3431	349	7297	1634	15244	1481	54621

Appendix C. Abundance of birds observed in five intertidal habitats in the Yaquina estuary during December 2007-December 2008. Counts are provided for both the Base assessment and for the comparative counts (QA).

	Habitat	*Z. marina*		*Upogebia*/mud		*Neotrypaea*/sand		*Z. japonica*		Low Marsh		Total
Group	Common Name, Species	Base	QA	Base	QA	Base	QA	Base	QA	Base	QA	
Geese	Brant, *Branta bernicla*	174	188	142		398						902
	Cackling Goose, *Branta hutchinsii*					1				2		3
	Canada Goose, *Branta canadensis*	55	10	83	41	182		160		195		726
Ducks	American Wigeon, *Anas americana*	2357		3347		854		303		924		7785
	Bufflehead, *Bucephala albeola*	1614	141	682	2	181	5	7		84		2716
	Canvasback, *Aythya valisineria*	2		3								5
	Common Goldeneye, *Bucephala clangula*	29	4	13		10						56
	Common Merganser, *Mergus merganser*	3		9		3						15
	Eurasian Wigeon, *Anas penelope*	4		6		2				5		17
	Gadwall, *Anas strepera*	2										2
	Green-winged Teal, *Anas crecca*	20		15		2				3		40
	Hooded Merganser, *Lophodytes cucullatus*	1		4		1	3					9
	Mallard, *Anas platyrhynchos*	224	24	202		112	45	3		322	55	987
	merganser sp., *Mergus* sp.	1										1
	Northern Pintail, *Anas acuta*	233		748		232				435	2	1650
	Northern Shoveler, *Anas clypeata*			6								6
	Red-breasted Merganser, *Mergus serrator*	48	10	22		18	5					103
	Ruddy Duck, *Oxyura jamaicensis*	29	2			1						32
	scaup sp., *Aythya* spp.	500	85	425		120				20		1150
	Surf Scoter, *Melanitta perspicillata*	326	15	148		60						549
	White-winged Scoter, *Melanitta fusca*	8		12		1						21
	wigeon and pintail, *Anas* spp.			970								970
	Wood Duck, *Aix sponsa*			1								1
Loons/Grebes	Common Loon, *Gavia immer*	28	7	7		6		1				49
	grebe sp., *Podiceps* sp.	3										3
	Horned Grebe, *Podiceps auritus*	90	3	8		7		1				109
	Pacific Loon, *Gavia pacifica*	7		1						1		9
	Pied-billed Grebe, *Podilymbus podiceps*	2										2

	Red-necked Grebe, *Podiceps grisegena*	4		3		2					9
	Red-throated Loon, *Gavia stellata*	10		3					1		14
	Western Grebe, *Aechmophorus occidentalis*	39	5	10		2					56
Pelicans /Cormorants	Brandt's Cormorant, *Phalacrocorax penicillatus*	7	74			1					82
	Brown Pelican, *Pelecanus occidentalis*	73	4	164		48			10		299
	Double-crested Cormorant, *Phalacrocorax auritus*	321	1	35		132			101		590
	Pelagic Cormorant, *Phalacrocorax pelagicus*			2		1					3
Herons/Egrets	Great Blue Heron, *Ardea herodias*	618	151	221	7	116	9	21	109	3	1255
	Great Egret, *Ardea alba*	146	12	77		24		15	98		372
	Green Heron, *Butorides virescens*						1				1
Vultures /Raptors	Bald Eagle, *Haliaeetus leucocephalus*	4		13	1	6		1	1		26
	Northern Harrier, *Circus cyaneus*								3	1	4
	Osprey, *Pandion haliaetus*	4		2		4					10
	Peregrine Falcon, *Falco peregrinus*			1							1
	Red-tailed Hawk, *Buteo jamaicensis*								1		1
	Turkey Vulture, *Cathartes aura*	4		1		5			1		11
	White-tailed Kite, *Elanus leucurus*								1		1
Rails	American Coot, *Fulica americana*	542	9	51	75	46		114	160		997
Shorebirds	Black Turnstone, *Arenaria melanocephala*		2								2
	Black-bellied Plover, *Pluvialis squatarola*			8		2			3		13
	dowitcher sp., *Limnodromus* spp.		1	12		23			8		44
	Dunlin, *Calidris alpina*	3		150		28		47	6		234
	Greater Yellowlegs, *Tringa melanoleuca*		2	2		33	2	3	16		58
	Killdeer, *Charadrius vociferus*					34	11	15	26	2	88
	Least Sandpiper, *Calidris minutilla*	16		16		89	3	14	72	5	215
	Long-billed Curlew, *Numenius americanus*			1							1
	Marbled Godwit, *Limosa fedoa*			7		11			5		23
	peeps, *Calidris* spp.			285		75			5		365
	Red Knot, *Calidris canutus*					3					3
	Red-necked Phalarope, *Phalaropus lobatus*	2		23							25
	Sanderling, *Calidris alba*				90	320		149	290		849
	Semipalmated Plover, *Charadrius semipalmatus*			3	2	54					59

	shorebirds unid., Charadriiformes unid.					1				4		5
	Spotted Sandpiper, *Actitis macularius*			3		5				7		15
	Western Sandpiper, *Calidris mauri*	274		2067	66	465		12		58		2942
	Whimbrel, *Numenius phaeopus*	7		174	3	154	1	12		26		377
Terns/Gulls	Caspian Tern, *Hydroprogne caspia*	2		26		42						70
	gulls spp., *Larus* spp.	6410	1468	10047	2221	3739	123	72	243	4		24327
Alcids	Common Murre, *Uria aalge*	5										5
	Pigeon Guillemot, *Cepphus columba*	4	1									5
Corvids	American Crow, *Corvus brachyrhynchos*	704	281	785	34	573	12	198		43	2	2632
	Common Raven, *Corvus corax*			2								2
Songbirds (including hummingbirds and kingfishers)	American Goldfinch, *Carduelis tristis*									3	2	5
	American Robin, *Turdus migratorius*							2		11	1	14
	Barn Swallow, *Hirundo rustica*			4		11	1	7		84	4	111
	Belted Kingfisher, *Megaceryle alcyon*	5		7	1	7	1			17		38
	Brewer's Blackbird, *Euphagus cyanocephalus*							2	1			3
	Bushtit , *Psaltriparus minimus*									2		2
	Cliff Swallow, *Petrochelidon pyrrhonota*									1		1
	European Starling, *Sturnus vulgaris*			9		16		2	6	209		242
	Fox Sparrow, *Passerella iliaca*									3		3
	Purple Martin, *Progne subis*					10				12		22
	Red-winged Blackbird, *Agelaius phoeniceus*									25		25
	Rufous Hummingbird, *Selasphorus rufus*										1	1
	Savannah Sparrow, *Passerculus sandwichensis*									2		2
	Song Sparrow, *Melospiza melodia*									59	2	61
	sparrow sp., Emberizidae sp.									1		1
	swallows spp., *Tachycineta* spp.									11	11	22
	Tree Swallow, *Tachycineta bicolor*									15		15
	Violet-green Swallow, *Tachycineta thalassina*									42		42
	White-crowned Sparrow, *Zonotrichia leucophrys*									2		2
Grand Total		14964	2500	21068	2543	8273	222	1161	250	3549	91	54621

Appendix D. Abundance of birds observed in four sectors of the Yaquina estuary during December 2007- December 2008. Counts are provided for both the Base assessment and for the comparative counts (QA).

	Sector	Idaho Flat		Raccoon Flat		Sally's Bend		Upriver		Total
Group	Common Name, Species	Base	QA	Base	QA	Base	QA	Base	QA	
Geese	Brant, *Branta bernicla*	540	94	108	94	66				902
	Cackling Goose, *Branta hutchinsii*							3		3
	Canada Goose, *Branta canadensis*	240				212		223	51	726
Ducks	American Wigeon, *Anas americana*	5613		278		1628		266		7785
	Bufflehead, *Bucephala albeola*	974	49	286	40	1097	30	211	29	2716
	Canvasback, *Aythya valisineria*					5				5
	Common Goldeneye, *Bucephala clangula*	3		8		34		7	4	56
	Common Merganser, *Mergus merganser*	11						4		15
	Eurasian Wigeon, *Anas penelope*	12				5				17
	Gadwall, *Anas strepera*							2		2
	Green-winged Teal, *Anas crecca*	17				20		3		40
	Hooded Merganser, *Lophodytes cucullatus*	1				5			3	9
	Mallard, *Anas platyrhynchos*	29		256	9	91	6	487	109	987
	merganser sp., *Mergus* sp.	1								1
	Northern Pintail, *Anas acuta*	1267		1		350		30	2	1650
	Northern Shoveler, *Anas clypeata*	6								6
	Red-breasted Merganser, *Mergus serrator*	7		16	2	36	3	29	10	103
	Ruddy Duck, *Oxyura jamaicensis*	15	2			14		1		32
	scaup sp., *Aythya* spp.	644	55	25		357	30	39		1150
	Surf Scoter, *Melanitta perspicillata*	199	15	45		285		5		549
	White-winged Scoter, *Melanitta fusca*	6				2		13		21
	wigeon and pintail, *Anas* spp.	970								970
	Wood Duck, *Aix sponsa*							1		1
Loons/Grebes	Common Loon, *Gavia immer*	3		1		15	1	23	6	49
	grebe sp., *Podiceps* sp.					3				3

	Horned Grebe, *Podiceps auritus*	16	3	8		58		24		109
	Pacific Loon, *Gavia pacifica*	2				5		2		9
	Pied-billed Grebe, *Podilymbus podiceps*					2				2
	Red-necked Grebe, *Podiceps grisegena*					8		1		9
	Red-throated Loon, *Gavia stellata*					5		9		14
	Western Grebe, *Aechmophorus occidentalis*	26		4		5	5	16		56
Pelicans	Brandt's Cormorant, *Phalacrocorax penicillatus*			1		6	74	1		82
/Cormorants	Brown Pelican, *Pelecanus occidentalis*	87	3	126		29	1	53		299
	Double-crested Cormorant, *Phalacrocorax auritus*	160	1	32		158		239		590
	Pelagic Cormorant, *Phalacrocorax pelagicus*							3		3
Herons/Egrets	Great Blue Heron, *Ardea herodias*	265	46	250	18	344	73	226	33	1255
	Great Egret, *Ardea alba*	88	3	20	2	90	7	162		372
	Green Heron, *Butorides virescens*								1	1
Vultures/Raptors	Bald Eagle, *Haliaeetus leucocephalus*	15			1	6		4		26
	Northern Harrier, *Circus cyaneus*							3	1	4
	Osprey, *Pandion haliaetus*	6				2		2		10
	Peregrine Falcon, *Falco peregrinus*	1								1
	Red-tailed Hawk, *Buteo jamaicensis*							1		1
	Turkey Vulture, *Cathartes aura*							11		11
	White-tailed Kite, *Elanus leucurus*	1								1
Rails	American Coot, *Fulica americana*	290	9	82		314		227	75	997
Shorebirds	Black Turnstone, *Arenaria melanocephala*		2							2
	Black-bellied Plover, *Pluvialis squatarola*	12						1		13
	dowitcher sp., *Limnodromus* spp.	30				8	1	5		44
	Dunlin, *Calidris alpina*	66				146		22		234
	Greater Yellowlegs, *Tringa melanoleuca*	6					2	48	2	58
	Killdeer, *Charadrius vociferus*	2				41	10	32	3	88
	Least Sandpiper, *Calidris minutilla*					36	3	171	5	215
	Long-billed Curlew, *Numenius americanus*			1						1
	Marbled Godwit, *Limosa fedoa*	22				1				23
	peeps, *Calidris* spp.	55		250				60		365

	Red Knot, *Calidris canutus*	3								3
	Red-necked Phalarope, *Phalaropus lobatus*	23		2						25
	Sanderling, *Calidris alba*	560				199			90	849
	Semipalmated Plover, *Charadrius semipalmatus*	23	2			29		5		59
	shorebirds unid., Charadriiformes unid.							5		5
	Spotted Sandpiper, *Actitis macularius*					3		12		15
	Western Sandpiper, *Calidris mauri*	566				1928		382	66	2942
	Whimbrel, *Numenius phaeopus*	120	3	105		146	1	2		377
Terns/Gulls	Caspian Tern, *Hydroprogne caspia*	61				8		1		70
	gulls spp., *Larus* spp.	9344	1955	2708	395	7894	1605	326	100	24327
Alcids	Common Murre, *Uria aalge*					5				5
	Pigeon Guillemot, *Cepphus columba*		1					4		5
Corvids	American Crow, *Corvus brachyrhynchos*	814	27	97	6	658	231	734	65	2632
	Common Raven, *Corvus corax*							2		2
Songbirds (including hummingbirds and kingfishers)	American Goldfinch, *Carduelis tristis*	2						1	2	5
	American Robin, *Turdus migratorius*	1				3		9	1	14
	Barn Swallow, *Hirundo rustica*	38				7		61	5	111
	Belted Kingfisher, *Megaceryle alcyon*	1		2		4		29	2	38
	Brewer's Blackbird, *Euphagus cyanocephalus*							2	1	3
	Bushtit , *Psaltriparus minimus*	2								2
	Cliff Swallow, *Petrochelidon pyrrhonota*	1								1
	European Starling, *Sturnus vulgaris*	102				42		92	6	242
	Fox Sparrow, *Passerella iliaca*					3				3
	Purple Martin, *Progne subis*	3				2		17		22
	Red-winged Blackbird, *Agelaius phoeniceus*	25								25
	Rufous Hummingbird, *Selasphorus rufus*								1	1
	Savannah Sparrow, *Passerculus sandwichensis*							2		2
	Song Sparrow, *Melospiza melodia*	4				5		50	2	61
	sparrow sp., Emberizidae sp.							1		1
	swallows spp., *Tachycineta* spp.	2					1	9	10	22
	Tree Swallow, *Tachycineta bicolor*	13						2		15

	Violet-green Swallow, *Tachycineta thalassina*	3						39		42
	White-crowned Sparrow, *Zonotrichia leucophrys*							2		2
Grand Total		23419	2270	4712	567	16425	2084	4459	685	54621

Appendix E. Data used in habitat/sector/cycle analyses. Bird observations from tides 0 to 2.4 m are combined. Observations from tides >2.4 and composite species are not included. For analyses, "Total birds ha^{-1}" was double square root transformed.

Cycle	Sector	Habitat	Area (ha)	Total birds	Number species	Shannon diversity	Total birds ha^{-1}	Predicted number species in 5 ha area
1	Idaho	Low Marsh	8.92	200	6	1.127	22.4	5.1
1	Idaho	Neo/sand	43.37	1257	12	1.617	29	7.5
1	Idaho	Upo/mud	59.84	2960	6	1.058	49.5	5.2
1	Idaho	Z japonica	0.87	80	1	0.000	92	--
1	Idaho	Z marina	14.32	2201	15	1.428	153.7	13.7
1	Raccoon	Low Marsh	1.58	0	0	0.000	0	--
1	Raccoon	Neo/sand	12.07	0	0	0.000	0	0
1	Raccoon	Upo/mud	35.61	689	9	1.056	19.3	7
1	Raccoon	Z japonica	1.88	0	0	0.000	0	--
1	Raccoon	Z marina	30.62	165	9	1.507	5.4	5.9
1	Sallys	Low Marsh	1.66	263	8	1.237	158.4	--
1	Sallys	Neo/sand	29.5	563	8	0.668	19.1	5.6
1	Sallys	Upo/mud	50.29	584	10	1.004	11.6	4.6
1	Sallys	Z japonica	23.11	518	8	1.084	22.4	5.8
1	Sallys	Z marina	104.29	1237	19	1.764	11.9	9.1
1	Upriver	Low Marsh	94.9	298	13	1.995	3.1	6.6
1	Upriver	Neo/sand	95.06	169	15	2.094	1.8	5.3
1	Upriver	Upo/mud	31.36	118	14	1.858	3.8	6.8
1	Upriver	Z japonica	8.62	0	0	0.000	0	0
1	Upriver	Z marina	11.1	311	15	1.906	28	12.5
2	Idaho	Low Marsh	8.92	338	6	0.566	37.9	5.5
2	Idaho	Neo/sand	43.37	998	10	1.392	23	6.8
2	Idaho	Upo/mud	59.84	1325	11	1.262	22.1	6.3
2	Idaho	Z japonica	0.87	0	0	0.000	0	--
2	Idaho	Z marina	14.32	145	8	1.332	10.1	6.3
2	Raccoon	Low Marsh	1.58	0	0	0.000	0	--
2	Raccoon	Neo/sand	12.07	0	0	0.000	0	0
2	Raccoon	Upo/mud	35.61	441	3	0.168	12.4	2.3
2	Raccoon	Z japonica	1.88	0	0	0.000	0	--
2	Raccoon	Z marina	30.62	191	8	1.355	6.2	5.6
2	Sallys	Low Marsh	1.66	1	1	0.000	0.6	--
2	Sallys	Neo/sand	29.5	337	4	0.684	11.4	3.2
2	Sallys	Upo/mud	50.29	391	7	0.803	7.8	4
2	Sallys	Z japonica	23.11	9	3	0.684	0.4	1.4
2	Sallys	Z marina	104.29	657	18	1.784	6.3	7.6
2	Upriver	Low Marsh	94.9	159	13	1.728	1.7	4.1
2	Upriver	Neo/sand	95.06	339	19	1.664	3.6	6.1

2	Upriver	Upo/mud	31.36	69	6	1.550	2.2	4.4
2	Upriver	Z japonica	8.62	6	3	1.011	0.7	2.3
2	Upriver	Z marina	11.1	187	9	1.375	16.8	7.4
3	Idaho	Low Marsh	8.92	67	8	1.577	7.5	7
3	Idaho	Neo/sand	43.37	511	23	1.784	11.8	11.7
3	Idaho	Upo/mud	59.84	868	16	1.684	14.5	10.2
3	Idaho	Z japonica	0.87	0	0	0.000	0	--
3	Idaho	Z marina	14.32	89	11	1.806	6.2	7.2
3	Raccoon	Low Marsh	1.58	1	1	0.000	0.6	--
3	Raccoon	Neo/sand	12.07	0	0	0.000	0	0
3	Raccoon	Upo/mud	35.61	127	5	1.094	3.6	3.8
3	Raccoon	Z japonica	1.88	0	0	0.000	0	--
3	Raccoon	Z marina	30.62	72	11	1.726	2.4	5.2
3	Sallys	Low Marsh	1.66	49	9	1.697	29.5	--
3	Sallys	Neo/sand	29.5	123	11	2.097	4.2	8
3	Sallys	Upo/mud	50.29	1836	13	0.645	36.5	7.3
3	Sallys	Z japonica	23.11	9	3	0.849	0.4	1.6
3	Sallys	Z marina	104.29	1008	14	1.566	9.7	7.6
3	Upriver	Low Marsh	94.9	184	17	2.316	1.9	6.2
3	Upriver	Neo/sand	95.06	280	18	1.819	2.9	6
3	Upriver	Upo/mud	31.36	63	13	2.166	2	6.1
3	Upriver	Z japonica	8.62	5	3	0.950	0.6	2.2
3	Upriver	Z marina	11.1	58	7	1.669	5.2	6.5
4	Idaho	Low Marsh	8.92	96	11	1.777	10.8	9.4
4	Idaho	Neo/sand	43.37	896	11	1.075	20.7	6.1
4	Idaho	Upo/mud	59.84	270	7	0.956	4.5	4.2
4	Idaho	Z japonica	0.87	0	0	0.000	0	--
4	Idaho	Z marina	14.32	92	5	1.042	6.4	4.1
4	Raccoon	Low Marsh	1.58	0	0	0.000	0	--
4	Raccoon	Neo/sand	12.07	2	1	0.000	0.2	1
4	Raccoon	Upo/mud	35.61	683	3	0.479	19.2	3
4	Raccoon	Z japonica	1.88	0	0	0.000	0	--
4	Raccoon	Z marina	30.62	114	4	0.433	3.7	2.3
4	Sallys	Low Marsh	1.66	14	2	0.410	8.4	--
4	Sallys	Neo/sand	29.5	126	7	1.517	4.3	5.1
4	Sallys	Upo/mud	50.29	238	4	0.812	4.7	3
4	Sallys	Z japonica	23.11	43	5	1.085	1.9	3.2
4	Sallys	Z marina	104.29	489	9	0.875	4.7	3.7
4	Upriver	Low Marsh	94.9	157	14	1.773	1.7	4.2
4	Upriver	Neo/sand	95.06	92	11	1.997	1	3.6
4	Upriver	Upo/mud	31.36	57	7	1.377	1.8	3.7
4	Upriver	Z japonica	8.62	16	5	1.037	1.9	3.5
4	Upriver	Z marina	11.1	46	4	1.025	4.1	3.4

5	Idaho	Low Marsh	8.92	48	7	1.641	5.4	6.3
5	Idaho	Neo/sand	43.37	1115	9	0.703	25.7	5.6
5	Idaho	Upo/mud	59.84	1722	12	0.649	28.8	7.5
5	Idaho	Z japonica	0.87	0	0	0.000	0	--
5	Idaho	Z marina	14.32	155	8	1.406	10.8	7.5
5	Raccoon	Low Marsh	1.58	3	1	0.000	1.9	--
5	Raccoon	Neo/sand	12.07	0	0	0.000	0	0
5	Raccoon	Upo/mud	35.61	247	4	0.424	6.9	3
5	Raccoon	Z japonica	1.88	0	0	0.000	0	--
5	Raccoon	Z marina	30.62	440	8	1.242	14.4	5.5
5	Sallys	Low Marsh	1.66	34	3	0.444	20.5	--
5	Sallys	Neo/sand	29.5	127	6	1.334	4.3	4.5
5	Sallys	Upo/mud	50.29	893	7	0.500	17.8	5.1
5	Sallys	Z japonica	23.11	215	7	1.073	9.3	5
5	Sallys	Z marina	104.29	1375	12	0.639	13.2	5.4
5	Upriver	Low Marsh	94.9	91	17	2.511	1	4.2
5	Upriver	Neo/sand	95.06	55	8	1.651	0.6	2.4
5	Upriver	Upo/mud	31.36	211	11	1.411	6.7	6.4
5	Upriver	Z japonica	8.62	33	6	1.543	3.8	5.6
5	Upriver	Z marina	11.1	274	11	1.892	24.7	8.8
6	Idaho	Low Marsh	8.92	294	4	0.102	33	3
6	Idaho	Neo/sand	43.37	747	8	0.551	17.2	5.3
6	Idaho	Upo/mud	59.84	4844	21	1.324	80.9	11.3
6	Idaho	Z japonica	0.87	0	0	0.000	0	--
6	Idaho	Z marina	14.32	1136	11	1.553	79.3	9.1
6	Raccoon	Low Marsh	1.58	0	0	0.000	0	--
6	Raccoon	Neo/sand	12.07	11	2	0.305	0.9	1.5
6	Raccoon	Upo/mud	35.61	1077	10	1.026	30.2	7.1
6	Raccoon	Z japonica	1.88	1	1	0.000	0.5	--
6	Raccoon	Z marina	30.62	321	9	1.633	10.5	7.2
6	Sallys	Low Marsh	1.66	3	1	0.000	1.8	--
6	Sallys	Neo/sand	29.5	58	5	1.176	2	3.6
6	Sallys	Upo/mud	50.29	868	9	1.129	17.3	5.2
6	Sallys	Z japonica	23.11	118	7	1.478	5.1	5.7
6	Sallys	Z marina	104.29	3835	19	1.149	36.8	11.1
6	Upriver	Low Marsh	94.9	165	11	1.868	1.7	4.9
6	Upriver	Neo/sand	95.06	299	16	2.286	3.1	7.9
6	Upriver	Upo/mud	31.36	106	12	1.749	3.4	6
6	Upriver	Z japonica	8.62	73	5	0.795	8.5	4.5
6	Upriver	Z marina	11.1	148	15	2.426	13.3	13.8

Appendix F. Total density of birds (ha^{-1}) observed utilizing five intertidal habitats by species group and count cycle. Counts are sums of all birds seen in each habitat within species groups, calculated by estimated area of each habitat within each sector of the estuary.

Count Cycle	Group	*Z. marina*	*Upogebia* /mud	*Neotrypaea* /sand	*Z japonica*	Low Marsh	Total
	Geese	0.4	0.0	1.4	0.1	0.0	0.5
1	Group	15.7	15.2	6.8	8.7	4.6	10.9
Dec-	Loons/Grebes	0.4	0.1	0.0	0.0	0.0	0.1
Jan	Pelicans/Cormorants	0.0	0.0	0.0	0.0	0.0	0.0
	Herons/Egrets	0.2	0.1	0.1	0.0	0.2	0.1
	Raptors	0.0	0.1	0.0	0.0	0.0	0.0
	Rails	3.1	0.3	0.1	3.3	1.5	1.2
	Shorebirds	0.0	1.4	0.6	5.9	0.4	0.9
	Terns/Gulls	3.3	8.0	2.3	0.0	0.0	3.6
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	1.7	0.3	0.5	0.3	0.0	0.6
	Songbirds	0.0	0.0	0.0	0.0	0.8	0.1
Cycle 1 Total All Species		24.8	25.4	11.7	18.3	7.5	18.2
	Geese	0.7	0.1	0.6	0.0	0.5	0.5
2	Ducks	3.4	3.3	0.7	0.3	1.0	2.1
Feb-	Loons/Grebes	0.2	0.0	0.0	0.1	0.0	0.1
Mar	Pelicans/Cormorants	0.0	0.0	0.0	0.0	0.0	0.0
	Herons/Egrets	0.1	0.1	0.0	0.0	0.1	0.1
	Raptors	0.0	0.0	0.0	0.0	0.0	0.0
	Rails	0.3	0.0	0.0	0.0	0.0	0.1
	Shorebirds	0.0	0.0	2.1	0.1	2.7	1.0
	Terns/Gulls	2.0	8.3	4.3	0.0	0.0	3.9
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	0.9	0.9	1.6	0.0	0.1	0.9
	Songbirds	0.0	0.0	0.0	0.0	0.3	0.1
Cycle 2 Total All Species		7.5	12.8	9.4	0.5	4.8	8.6
	Geese	0.0	0.0	0.6	0.0	0.7	0.3
3	Ducks	1.7	0.6	0.5	0.0	0.3	0.7
Apr-	Loons/Grebes	0.0	0.1	0.0	0.0	0.0	0.0
May	Pelicans/Cormorants	0.1	0.0	0.0	0.0	0.0	0.0
	Herons/Egrets	0.3	0.2	0.1	0.0	0.2	0.2
	Raptors	0.0	0.0	0.0	0.0	0.0	0.0
	Rails	0.0	0.0	0.0	0.0	0.0	0.0
	Shorebirds	1.8	12.3	1.7	0.1	0.6	4.3
	Terns/Gulls	3.4	2.7	1.7	0.0	0.0	2.0
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	0.3	0.4	0.4	0.3	0.2	0.3
	Songbirds	0.0	0.0	0.0	0.0	0.9	0.2
Cycle 3 Total All Species		7.7	16.3	5.1	0.4	2.8	8.1

4 Jun-July	Geese	0.0	0.1	0.1	0.0	0.2	0.1
	Ducks	0.1	0.0	0.0	0.0	0.0	0.0
	Loons/Grebes	0.0	0.0	0.0	0.0	0.0	0.0
	Pelicans/Cormorants	0.1	0.0	0.0	0.0	0.0	0.0
	Herons/Egrets	1.2	0.4	0.2	0.1	0.0	0.5
	Raptors	0.0	0.0	0.0	0.0	0.0	0.0
	Rails	0.0	0.0	0.0	0.0	0.0	0.0
	Shorebirds	0.0	0.4	1.7	0.0	0.6	0.7
	Terns/Gulls	2.8	5.5	3.6	0.2	0.0	3.2
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	0.4	0.6	0.4	1.1	0.0	0.4
	Songbirds	0.0	0.1	0.2	0.3	1.5	0.3
Cycle 4 Total All Species		4.6	7.0	6.2	1.7	2.5	5.2
5 Aug-Sept	Geese	0.3	0.4	0.6	3.8	0.1	0.6
	Ducks	0.9	0.1	0.0	0.1	1.6	0.5
	Loons/Grebes	0.1	0.0	0.0	0.0	0.0	0.0
	Pelicans/Cormorants	1.2	0.5	0.5	0.0	0.0	0.5
	Herons/Egrets	2.2	0.5	0.2	0.3	0.5	0.8
	Raptors	0.0	0.0	0.0	0.0	0.0	0.0
	Rails	0.0	0.0	0.0	0.0	0.0	0.0
	Shorebirds	0.1	1.2	0.5	0.7	0.4	0.6
	Terns/Gulls	9.3	14.2	5.3	0.1	0.0	7.5
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	0.3	0.5	0.2	2.1	0.1	0.4
	Songbirds	0.0	0.0	0.0	0.1	0.7	0.1
Cycle 5 Total All Species		14.3	17.4	7.3	7.2	3.5	11.1
6 Oct-Nov	Geese	0.1	0.7	0.0	0.8	0.2	0.3
	Ducks	12.0	18.2	0.9	0.0	9.3	9.6
	Loons/Grebes	0.4	0.0	0.0	0.0	0.0	0.1
	Pelicans/Cormorants	1.1	0.6	0.5	0.0	1.0	0.7
	Herons/Egrets	0.7	0.3	0.2	0.7	0.9	0.5
	Raptors	0.0	0.0	0.0	0.0	0.0	0.0
	Rails	0.0	0.0	0.2	0.0	0.0	0.1
	Shorebirds	0.0	0.2	0.7	0.5	0.1	0.3
	Terns/Gulls	19.4	18.1	3.7	1.7	0.0	10.7
	Alcids	0.0	0.0	0.0	0.0	0.0	0.0
	Corvids	0.8	1.7	0.1	1.9	0.0	0.8
	Songbirds	0.0	0.0	0.0	0.0	0.5	0.1
Cycle 6 Total All Species		34.5	40.0	6.3	5.6	12.1	23.1
Total All Cycles		93.3	119.0	46.0	33.7	33.1	74.4

Appendix G. Regional observations of bird occurrence and activities in estuarine intertidal habitats in Oregon.

Habitat	Exposure	Estuary	Species	Calling	Foraging	Hunting	Resting
Low Marsh	Exposed	Alsea	American Crow, *Corvus brachyrhynchos*		4		
			Barn Swallow, *Hirundo rustica*			30	
			Great Blue Heron, *Ardea herodias*				1
			Greater Yellowlegs, *Tringa melanoleuca*		2		
			Red-tailed Hawk, *Buteo jamaicensis*			1	
			Red-winged Blackbird, *Agelaius phoeniceus*	4	6		
			Savannah Sparrow, *Passerculus sandwichensis*	3			
			Song Sparrow, *Melospiza melodia*	3			
			Tree Swallow, *Tachycineta bicolor*			4	
			Turkey Vulture, *Cathartes aura*			13	
		Nestucca	American Robin, *Turdus migratorius*		1		
			Barn Swallow, *Hirundo rustica*			3	
			Savannah Sparrow, *Passerculus sandwichensis*	8			
			Song Sparrow, *Melospiza melodia*	4			
		Netarts	Barn Swallow, *Hirundo rustica*			3	
			Canada Goose, *Branta canadensis*				4
			Great Blue Heron, *Ardea herodias*				40
			Savannah Sparrow, *Passerculus sandwichensis*	5			
			Turkey Vulture, *Cathartes aura*			1	
		Salmon	American Crow, *Corvus brachyrhynchos*		12		
			Barn Swallow, *Hirundo rustica*			8	
			Great Blue Heron, *Ardea herodias*		3		
			Greater Yellowlegs, *Tringa melanoleuca*		12		
			Marsh Wren, *Cistothorus palustris*	2			
			Savannah Sparrow, *Passerculus sandwichensis*	10			
			Song Sparrow, *Melospiza melodia*	4			
			Virginia Rail, *Rallus limicola*?	1			
		Siletz	Barn Swallow, *Hirundo rustica*			9	
			Canada Goose, *Branta canadensis*				25
			Savannah Sparrow, *Passerculus sandwichensis*	2			
			Song Sparrow, *Melospiza melodia*	2			
		Tillamook	American Crow, *Corvus brachyrhynchos*		1		
			American Robin, *Turdus migratorius*		2		

			Barn Swallow, *Hirundo rustica*			1	
			Canada Goose, *Branta canadensis*				2
			Common Yellowthroat, *Geothlypis trichas*	1			
			Red-winged Blackbird, *Agelaius phoeniceus*	1			
			Savannah Sparrow, *Passerculus sandwichensis*	4			
			Song Sparrow, *Melospiza melodia*	4			
	Flooded	Siletz	Belted Kingfisher, *Megaceryle alcyon*			1	
		Tillamook	Great Blue Heron, *Ardea herodias*				3
Neotrypaea/sand	Exposed	Alsea	Great Blue Heron, *Ardea herodias*				1
		Nestucca	American Crow, *Corvus brachyrhynchos*		2		
			Canada Goose, *Branta canadensis*				22
			Great Blue Heron, *Ardea herodias*				1
			Mallard, *Anas platyrhynchos*				15
		Netarts	American Crow, *Corvus brachyrhynchos*		16		
			Bald Eagle, *Haliaeetus leucocephalus*				2
			Bonaparte's Gull, *Chroicocephalus philadelphia*		2		
			gulls, spp.		1		38
		Salmon	American Crow, *Corvus brachyrhynchos*		2		
			Canada Goose, *Branta canadensis*				6
			gulls, spp.				16
			Mallard, *Anas platyrhynchos*		2		
		Siletz	Common Goldeneye, *Bucephala clangula*				3
		Tillamook	American Crow, *Corvus brachyrhynchos*		2		
			Brant, *Branta bernicla*		22		
			Canada Goose, *Branta canadensis*		15		
			Caspian Tern, *Hydroprogne caspia*				15
			Great Blue Heron, *Ardea herodias*				7
			gulls, spp.				86
			Semipalmated Plover, *Charadrius semipalmatus*		9		
			Whimbrel, *Numenius phaeopus*		39		
	Flooded	Netarts	Great Blue Heron, *Ardea herodias*		2		6
Upogebia/mud	Exposed	Siletz	American Crow, *Corvus brachyrhynchos*		21		
			Barn Swallow, *Hirundo rustica*			10	
			Canada Goose, *Branta canadensis*		6		
			gulls, spp.		19		
			Mallard, *Anas platyrhynchos*				2

			Whimbrel, *Numenius phaeopus*	6
	Flooded	Salmon	Great Blue Heron, *Ardea herodias*	2
			Great Egret, *Ardea alba*	1
		Siletz	Great Blue Heron, *Ardea herodias*	3
Z japonica	Exposed	Netarts	American Crow, *Corvus brachyrhynchos*	1
			Canada Goose, *Branta canadensis*	4
Z marina	Flooded	Netarts	gulls, spp.	1

Appendix H. Observations on feeding in birds. Food items were observed through binoculars or spotting scope.

	Feeding habit	*Z marina*	*Z japonica*	Macroalgae	Marsh Vegetation	Fish	Fish Species	Inverts	Invert Species	Other	Notes
Brant	dabble	X		X						grass	1 seen eating grass on Yaquina south jetty
Canada Goose	dabble	X	X	X	X						
Gadwall	dabble	X									
American Wigeon	dabble	X	X	X	X						
Mallard	dabble		X		X						
Pintail	dabble		X	X	X						
Scaup	dive	X	X								
Surf Scoter	dive							X	Bivalve		
White-winged Scoter	dive							X	Cockle		
Common Goldeneye	dive				X						
Common Merganser	dive				X	X					
Red-breasted Merganser	dive					X					
Hooded Merganser	dive							X	Crabs		
Common Loon	dive					X		X	Clam		
Western Grebe	dive					X	gunnel				
Horned Grebe	dive					X					
Brown Pelican	dive					X					
Brandt's Cormorant	dive					X					
Double-crested Cormorant	dive	X				X	sculpin				
Great Blue Heron	wade					X	sculpin				
Great Egret	wade					X	smolts				salmon smolts in "Log Pond"
Osprey						X					
Coot	dabble	X	X	X	X						diving for *Z japonica*
Whimbrel	probe							X	*Upogebia, Neotrypaea*		
Marbled Godwit	probe							X	*Neotrypaea*		
Western Gull	forage							X	Dungeness crab		

Glaucous-winged and Western Gull	forage					X	Discarded fish head	X	Cockles		cockles from *Upogebia*/mudflat dropped on parking lots and roofs
Belted Kingfisher	dive					X					
American Crow	forage	X									

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