EXECUTIVE SUMMARY FOR THE M.S. PROJECT OF

Benyamin Knieff Wishnek for the degree of Master of Science in Environmental Sciences with an emphasis in Natural Resources presented on 25 November 2014.

Title: Avian Response to Tidal Salt Marsh Restoration at Bandon Marsh National Wildlife Refuge in Southern Oregon, USA: Ecological, Social and Management Implications

Executive Summary Approved: ____

Dr. Paul Adamus

An imperative set of skills for any natural resource management professional to possess is the ability to communicate information regarding natural resource management activities in a manner that is understood and appreciated by different audiences. Three of these audiences are: scientists/researchers, the general public, and other management professionals. This body of work seeks to communicate information about avian response to a tidal marsh restoration project that occurred at Bandon Marsh National Wildlife Refuge in Southern Oregon to the three aforementioned audiences.

- Chapter 1 serves as an introduction to ecological restoration, this specific restoration project and previous research that has looked at avian response to tidal salt marsh restoration.
- Chapter 2 uses a community analysis approach to look at compositional differences in the avian communities on the restoration site and a reference site before and after restoration. A second portion of this chapter seeks to determine which individual avian species could serve as indicators of change before and after restoration.
- Chapter 3 discusses the findings of chapter 2 in the context of the importance of tidal marshes and their avian communities in a manner that can be appreciated by the general public.
- Chapter 4 discusses the information presented in the first three chapters with recommendations to inform the management of avian monitoring in tidal marshes and on tidal marsh restoration projects in the future.

Avian Response to Tidal Salt Marsh Restoration at Bandon Marsh National Wildlife Refuge in Southern Oregon, USA: Ecological, Social and Management Implications

By

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Dr. Flaxen Conway (Committee Member), representing Marine Resource Management

I understand that my M.S. Project Report will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my M.S. Project Report to any reader upon request.

Benyamin Knieff Wishnek, Author

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DEDICATION

This research project is dedicated to my Grandma Bea. She passed away when I was still relatively young, but I feel that her love of the outdoors has had a great influence on my scholastic and career choices.

Chapter 1: Introduction

1.1 Introduction

Estuaries and tidal marshes are regarded for the many ecosystem services that they provide including: migratory bird habitat, fisheries, carbon sequestration, recreation, commerce and aesthetics (Agardy et al. 2005, Mitsch and Gosselink 2007, McLeod and Leslie 2009, Granek et al. 2010). During the last 150 - 300 years the extent and functionality of estuaries and tidal marshes worldwide has been negatively impacted by a rapid increase in the footprint of humankind's resource demands (Bertness et al. 2004, Lotze et al. 2006). This pattern is apparent on the Oregon Coast where many of the estuarine habitats have been significantly altered for human uses (Good 2000). Loss of estuarine habitat has been countered by recent effort towards restoring many of these habitats (Zedler and Kercher 2005, Teal and Peterson 2009).

The Society for Ecological Restoration (SER) defines restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. Frequently, the ecosystem that requires restoration has been degraded, damaged, transformed or entirely destroyed as the direct or indirect result of human activities" (SER Ecological Restoration Primer 2004, Pg. 1). This term has been the subject of much intense debate in academia in recent years. Some persons question the philosophical basis for restoration and paint it as being hubristic and thus needing to be done with caution (Katz 1992). Others view restoration as a method for strengthening the relationship between humans and the planet (Higgs 2003, Jordan III 2003). Still others, with an applied management perspective, see restoration as imperative for returning the ecosystem services that are provided by estuaries and other coastal ecosystems (Barbier et al. 2011). Finally, from an integrated perspective, restoration can be seen as a buffer against the uncertainty of future climate and land use changes, wherein restoration is both a reactive and proactive tool to address these changes (Harris et al. 2006, Thompson and Bendik-Keymer 2012).

Along with the increase in restoration practice has come a growing body of scientific literature documenting response of biotic, abiotic and human communities to restoration projects (Suding 2011). Defining "successful" restoration is difficult and often subjective, often being specific to the scope of inference of the project (Mitsch and Wilson 1996, Wortley et al. 2013). It is important for restoration practitioners to define their goals at the outset of restoration projects and to use as benchmarks after the conclusion of the project to determine if their projects were successful or not (Howell et al. 2012). Many have suggested that results of these projects and whether or not they achieved their stated goals should be effectively communicated through multiple media making the message accessible and applicable to researchers, managers, policy-makers and the general public. This potentially increases cross-institutional knowledge of restoration and helps gain support for further research needed to resolve unanswered questions from prior studies (Christensen et al. 1996, Norton 1998, Aronson et al. 2010).

Restoration projects can have many goals. The choice of one or more goals often depends upon the ecology of the site and its likely drivers of ecological change (Hood and Simenstad 2012). In the case of the restoration of estuaries and tidal marshes much of the literature has focused primarily on the hydrology, geomorphology and vegetation of the restoration sites. When animal components are included in the studies, invertebrates and fish are often the focus. In contrast, avian communities have historically received less attention (Ruiz-Jaen and Aide 2005). In the last decade avian communities of tidal marsh ecosystems have been gaining more attention as an indicator of restoration success, but there are still many areas where restoration has occurred that are lacking in study of avian response to reintroduction of tides (Ortega-Alvarez and Lindig-Cisneros 2012).

The avian communities of tidal marshes on the Oregon Coast are important for many ecological and social reasons (Adamus 2005). Birds regulate some invertebrate communities in estuaries, scavenge carcasses of other dead animals, and transport marine and estuarine-derived nutrients often across broad spatial scales (Kiviat 1989, Sekercioglu 2006, Whelan et al. 2008, Wenny et al. 2011). Additionally, large aggregations of shorebirds and waterfowl attract both consumptive and non-consumptive human users to estuaries and surrounding communities which generates revenue for local businesses and tax dollars for local governments (Carver 2013).

1.2 Literature Review

Studies of avian response to tidal marsh restoration in the US have been conducted on the East Coast (especially in New England) and on the West Coast in states other than Oregon. What follows is a review of some of these previous studies and their results grouped by region. Grouping results by region acknowledges differences in tidal regimes, total area of tidal marsh and climate on the east versus west coast of the US, as each of these factors can impact the avian community present during surveys (Kiviat 1989, Callaway and Zedler 2009).

East Coast

Shriver and Greenberg (2012) reviewed much of the tidal marsh bird literature from New England and Atlantic Canada. They found that avian responses to tidal marsh restoration projects remained poorly understood because of: “inherent variability in avian sampling, relatively small spatial scale of many tidal restoration projects, and the temporal component (10-15 years) necessary for vegetation to return to some state of equilibrium”. Additionally, the time it takes for vegetation to reach equilibrium after restoration is often longer than funds typically support avian monitoring. The variability in avian sampling is seen in Konisky et al. (2006) who noted that avian diversity was monitored in 53 percent of a sample (n=36) of tidal marsh restoration monitoring projects surrounding the Gulf of Maine. Due to methodological differences among the studies, the authors could not find clear patterns in the response of avian species richness to restoration. Additional variability in sampling is highlighted by (Ruiz-Jaen and Aide 2005) that showed variability in sampling procedures across species and habitat types when determining ecological response to restoration. The absence of clear patterns in response of species richness to restoration is expected, as survey methods and restoration objectives vary from project to project.

The following studies demonstrate some of the variability of avian response to tidal restoration on the east coast. Seigel et al. (2005) found an increase in species richness and abundance and decreased evenness on two separate restored tidal marshes in urban New Jersey two years after restoration. Brawley et al. (1998) examined bird community change 14 years after a tidal wetland had been restored and compared it with four other restored sites in a wildlife management area in Connecticut. The authors concluded that initially after the tides have been reintroduced, tidal flushing can negatively impact nesting success of some marsh-nesting birds that nest in tidal marsh vegetation. After the system has time to equilibrate and the vegetation becomes more typical of a tidal marsh, then tidal marsh obligate species will colonize the site. Finally, an increase in richness the year after restoration was attributed to reintroduction of tidal flow to a site in Rhode Island (Raposa 2008).

West Coast

Much of the literature on the west coast has come from the southern part of San Francisco Bay where expansive commercial salt ponds are being restored to their historical tidal marsh condition. Takekawa et al. (2001) surveyed bird use of artificial salt ponds and compared that with use of other baylands (tidal marshes). They found that the total number of species and Shannon-Weiner diversity index was greater in baylands than unrestored salt ponds while the densities of birds (#/ha) were greater in salt ponds than baylands as a result of a large concentration of species such as lesser scaup (*Aythya marila*), greater scaup (*Aythya affinis*), ruddy duck (*Oxyura jamaicensis*) and eared grebe (*Podiceps nigricollis*). Athearn et al (2012) also looked at bird use of restored salt ponds in the southern part of San Francisco Bay. Raw counts of birds showed greater use of existing salt ponds than salt ponds restored to tidal marshes. In a more in-depth evaluation of avian community dynamics on the salt pond restoration areas of the San Francisco Bay, Stralberg et al. (2003) also found decreased numbers of birds but increased diversity of birds on restored salt ponds. This tradeoff between greater densities of birds and greater diversity of species is one that managers in that system will need to consider when moving forward with further restoration. Stralberg et al. (2003) concluded that in order to preserve and enhance the bird communities in the future, managers and restoration project designers should work towards a mosaic of habitats that includes salt ponds interspersed with salt marsh in various successional stages (e.g. mudflat, low marsh, high marsh) to complement the varied habitat needs of the salt marsh bird community of the San Francisco Bay.

Elsewhere in California, Armitage et al. (2007) saw that shorebird use of a group of restored marshes five years after restoration varied by site and species. They attributed these differences to differences in habitat heterogeneity, proximity of man-made structures, tidal flat cover, water cover, and creek length. Deza et al. (2013) saw increases in waterfowl and shorebird abundance one and two years after restoration of a tidal lagoon system in San Diego. They compared that site with three reference sites within ~300 km. Increases in shorebirds and waterfowl (mean number of individuals per hectare) were seen on reference sites, but were not as great as increases seen on the restoration site. Numbers of seabirds and wetland birds did not fluctuate to a great extent on the restoration site, but did on one of the reference sites in the two years after restoration. NMDS (non-metric multidimensional scaling) ordination showed guilds and individual species composition on the restoration site to be most similar to the geographically closest (~50 km apart) reference site.

Along the Salish Sea in the Pacific Northwest, Woo et al. (2011) measured bird abundance on restored tidal marsh and enhanced freshwater wetlands in the delta of the Nisqually River, Washington. Because surveys occurred almost entirely after restoration had been completed, inferences regarding influence of restoration on birds were minimal. Simenstad and Thom (1996) reported on avian use of a constructed 3.9 ha tidal wetland in the Puyallup River estuary using count data collected weekly to monthly by various observers from the Tahoma Audubon Society. These data were observational and thus were not statistically analyzed. Nonetheless, the data suggested that four years after restoration, open water, intertidal flats, and dike habitats consistently supported more birds than the border, cattail, aerial and upland habitats. Waterfowl (no specific species were mentioned) dominated the intertidal flats except during the summer. Shorebirds rarely accounted for more than 10% of the total individuals until August, when their numbers were comparable with those of waterfowl species (Simenstad and Thom 1996).

Need for Research on Avian Response to Tidal Marsh Restoration in Oregon

Estuaries in Oregon are smaller and less extensive than estuaries in Washington and California due to rockier shoreline, a narrow continental shelf, and greater frequency of tectonic activity than the East Coast and other areas of the West Coast (Nelson et al. 2004). Oregon estuaries provide critical stopover habitat for many migratory avian species in the Pacific Flyway (PCJV 1994, Page et al. 1999). Tidal marsh habitat has been restored in multiple Oregon estuaries, but no monitoring studies have looked at avian response to the projects. Previous avian surveys of Bandon Marsh National Wildlife Refuge did not specifically look at response to restoration (Hodder and Graybill 1984, Castelein and Lauten 2006). Older census projects of birds in Oregon tidal marshes took place in the late 1970's but these were looking at habitat associations of certain bird species rather than response to restoration (Magwire 1976, Roye 1979). A more recent census of bird use of different habitat types in the Yaquina Bay of Oregon did not focus specifically on restored versus non-restored sites before and after restoration (Lamberson et al. 2011). Previous studies of avian habitat associations in Oregon estuaries did not specifically examine the response to restoration, but provide references as to how different species use estuaries.

The protection and restoration of estuaries was named as one of the goals for land use planning in the state of Oregon (Oregon Department of Land Conservation and Development 2014). Therefore, it is important to initiate and continue studies that can contribute to that specific land use planning goal by understanding how protection and restoration efforts impact biotic and abiotic components of estuaries such as avian communities. Monitoring to ensure effectiveness of restoration actions should be done using Before-After Control-Impact (BACI) study designs (i.e., surveys before and after restoration on both restoration sites and multiple reference sites). Planning these studies with BACI designs in advance of restoration projects will directly measure change, control for spatial variation, and control for temporal variation (Anderson and Dugger 1996). Given that estuaries are a resource to be protected and restored, information about the biota that inhabit them, including avian species, will work towards contributing to the statewide planning process and the Comprehensive Conservation Planning goals for Bandon Marsh National Wildlife Refuge (U.S. Fish and Wildlife Service 2013).

1.3 Timeline of Tidal Marsh Restoration at Bandon Marsh National Wildlife Refuge

Near the mouth of the Coquille River on the southern Oregon Coast lies the 360 hectare Bandon Marsh National Wildlife Refuge (BMNWR, hereafter) managed by the U.S. Fish and Wildlife Service (USFWS, hereafter). Until 2000 BMNWR protected 124 ha of tidal marsh habitat in the 191 ha Bandon Marsh unit which was the only remaining tidal marsh in the Coquille river estuary where 94% of the tidal marsh had been lost or altered for agricultural purposes (Good 2000).

In 2000, the USFWS began the acquisition process, as a unit of BMNWR, of a 236 ha area that included 169 ha of former tidal marsh and tidal Sitka Spruce swamp forest that had been converted to agricultural pasture for cattle grazing via installation of tidegates, levees and an extensive drainage ditch system. This unit was given the name Ni-les'tun which means "people by the fish dam" in reference to the Native Americans that used the historical tidal marsh as a fishing site (USFWS 2013). Restoration of the tidal marsh habitat began in late 2009 with the removal of cattle, removal of fencing, and excavation of pilot tidal channels.

During 2010, the bulk of the ground work was completed when the majority of the 8.05 km of pilot tidal channels were excavated. Designs for the pilot tidal channels were based on aerial imagery of the configuration of tidal channels in other tidal marshes in the Siletz, Nestucca and Umpqua river estuaries in Oregon. Excess soil from digging the pilot channels was used to fill the network of 17.7 km of agricultural ditches on the site. Approximately 100 trees with root wads attached were installed into the tidal channels for fish habitat. North Bank Lane, which runs along the north side of the main project site, had its grade raised to protect from tidal inundation when the dikes were breached. Two fish-friendly culverts were installed where Fahy's Creek runs under the road in the western portion of the site and Redd Creek runs under the road at the eastern portion of the site as part of the road grade raise. A final activity during 2010 was putting underground an aerial electric transmission line that ran through the site and across the river, to eliminate bird strike hazard. This involved drilling nearly 2.7 km under the river and feeding the wires through to the other side. Complications during this part of the project delayed completion of the project to the summer of 2011.

Extending the timeline of project implementation allowed for more preparatory work before returning tidal flow to the site. Additional channels were created, and 50 additional trees were installed for fish habitat in the newly excavated tidal channels. In August 2011 at the end of the construction period, 1960 m of levees were removed along with tidegates at the mouths of three creeks that ran through the site. Removal of tidegates allowed the first tidal flows on to the site in approximately 100 years. Main roads used during the site's tenure as a farm and for equipment movements during restoration were decommissioned. Throughout the summer of 2011 visitor facilities were enhanced. That included installation of interpretive panels, creation of a gravel walking trail into the site, and repaving the access road (North Bank Lane) along the northern boundary of the project. On 1 October 2011 the construction work was completed and the site was dedicated (see figure 1.1 for map of restoration actions).

From 2012 to present, the USFWS has installed plantings of willow (*Salix* sp.) on the northwestern corner of the site to facilitate the successional processes necessary to recover the lost Sitka Spruce swamp habitat. The site continues to be utilized for education of other restoration practitioners, school groups and community members interested in tidal marsh ecology, restoration and management. In 2013, a great number of mosquitos that colonized pooled water on the restoration site became annoying to local landowners. More information about the mosquito issue, as it pertains to the avian component of BMNWR, is included in chapter 4 of this document.

Increase in the tidal marsh habitat of the estuary was intended to increase habitat for the migratory waterfowl and shorebirds that use the site as an important rest stop in the pacific flyway (National Audubon Society 2013). Other species that were targeted to benefit from the restoration were wading birds and raptors that utilize tidal marsh habitats for food and cover (US Fish and Wildlife Service 2013).

Restoration Effectiveness Monitoring Efforts

Throughout the restoration process there has been extensive monitoring of both the Ni-les'tun unit and the Bandon Marsh unit which has served as a control for comparison. In addition to the monitoring of bird responses described in this report, the responses of hydrology, soil, salinity, vegetation, macroinvertebrate, and fish have been monitored for changes pre and post restoration (Hudson et al. 2010, Brophy and Van de Wetering 2012, Brophy et al. 2014).

1.4 Site Conditions

Elevation

Elevations on the restoration site ranged from 1.8 to 2.3 m with the areas of least elevation in the southwest portion of the site and the areas of greatest elevation near the man-made levee on the river bank and the northwest portion of the site near the Sitka spruce swamp border (Brophy et al. 2014). Elevations on the reference site were 2.1 to 2.4 m, which is typical of high marshes (Brophy et al. 2014). The differences in elevation can be attributed to subsidence, which can occur when tidal marshes are diked and restricted from inputs of sediment

(Thom et al. 2002). Once tidal regimes have been restored, the accretion process on the site may be rapid based on observations of soil and vegetation on the reference site (Brophy et al. 2014).

Tidal Regime

Daily maximum tidal height before restoration on the restoration site was 1.29 m in 2009 during the pre-restoration period and 2.09 m during the post-restoration period in 2012 (Brophy et al. 2014). Daily maximum tidal height both before and after restoration on the reference site measured 2.15 m (Brophy et al. 2014). This shows successful restoration of tidal regime to the site (Brophy et al. 2014)

Salinity

Mean water salinity before restoration in tidal channels furthest from the influence of the river increased from 0.05 PSU before restoration to 6.0 PSU after restoration (Brophy et al. 2014). Mean water salinity on the reference site increased from 5.3 PSU before restoration to 8.8 PSU after restoration (Brophy et al. 2014). Pre-restoration water salinity measurements were taken from 1 May – 15 August 2011 and post-restoration water salinity measurements were taken from 1 May – 15 August 2013 (Brophy et al. 2014). Soil salinity increased on the restoration site from 3.7 PSU in 2010 to 19.7 PSU in 2013. Soil salinity on the reference site increased from 15.7 PSU to 32.3 PSU in the same time period (Brophy et al. 2014). These increases in salinity were likely due to lower rainfall in 2013 than 2010 and could not be attributed entirely to restoration (Brophy et al. 2014).

Vegetation

When converted for agricultural uses the vegetation on the 169 ha restoration site of the Ni-les'tun unit was a wet meadow colonized by non-native pasture vegetation such as bentgrass (*Agrostis stolonifera*) and tall fescue (*Schedonorous arundinaceus*). Non-native vegetation composed of an average of 55.9% of the cover on each of the 14 vegetation monitoring transects and native vegetation was an average of 52.6% of the cover when surveyed in 2010. Common native plant species on the restoration site included: baltic rush (*Juncus balticus*), pacific silverweed (*Potentilla anserina*) and slough sedge (*Carex obnupta*) (Brophy 2010, unpublished data).

The 124 ha Bandon Marsh unit is classified as a predominantly low sand marsh with an extensive area of high marsh in the north, and a fringe of mature high marsh adjacent to the forest upland in the east (Jefferson 1975). Native vegetation composed an average of 84.8% of the cover on the 4 vegetation monitoring transects on the reference site when surveyed in 2010, while non-native vegetation only composed an average of 17.6% of the vegetation on these transects. Common native plant species on the Bandon Marsh unit included pacific silverweed, baltic rush and seashore saltgrass (*Distichlis spicata*) (Brophy 2010, unpublished data).

NMDS ordination showed vegetation community composition on the restoration site converging with that on the reference site after restoration (Brophy et al. 2014). Some salt intolerant species, such as Tall fescue (*Schedonorus arundinaceus*) and birdsfoot trefoil (*Lotus corniculatus*) decreased in abundance. Total plant cover decreased with loss of salt-intolerant species. Bare ground created in the vacancy of salt intolerant species will likely be colonized by salt tolerant species in the future (Figure 1.2) (Brophy et al. 2014).

1.5 Conclusion

Analysis and reporting of restoration efficacy monitoring data informs other researchers about the species and habitat response to projects and provides managers with information that can be used in the future to guide management decisions based on past observations. Communicating the process of restoration and monitoring restoration projects is important in educating the public about restoration and gaining support for further projects. My intent with this project is to examine the avian community response to the restoration at BMNWR and communicate it in a way that can be understood and used by biologists (Chapter 2), members of the general public (Chapter 3) and natural resource managers (Chapter 4).

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1.7 Figures

Figure 1.1 Map showing locations of restoration actions taken from 2009 - 2011 on the Ni-les'tun Unit of Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA.

Bandon Marsh National Wildlife Refuge Tidal Marsh Restoration Actions (2009 to 2011)

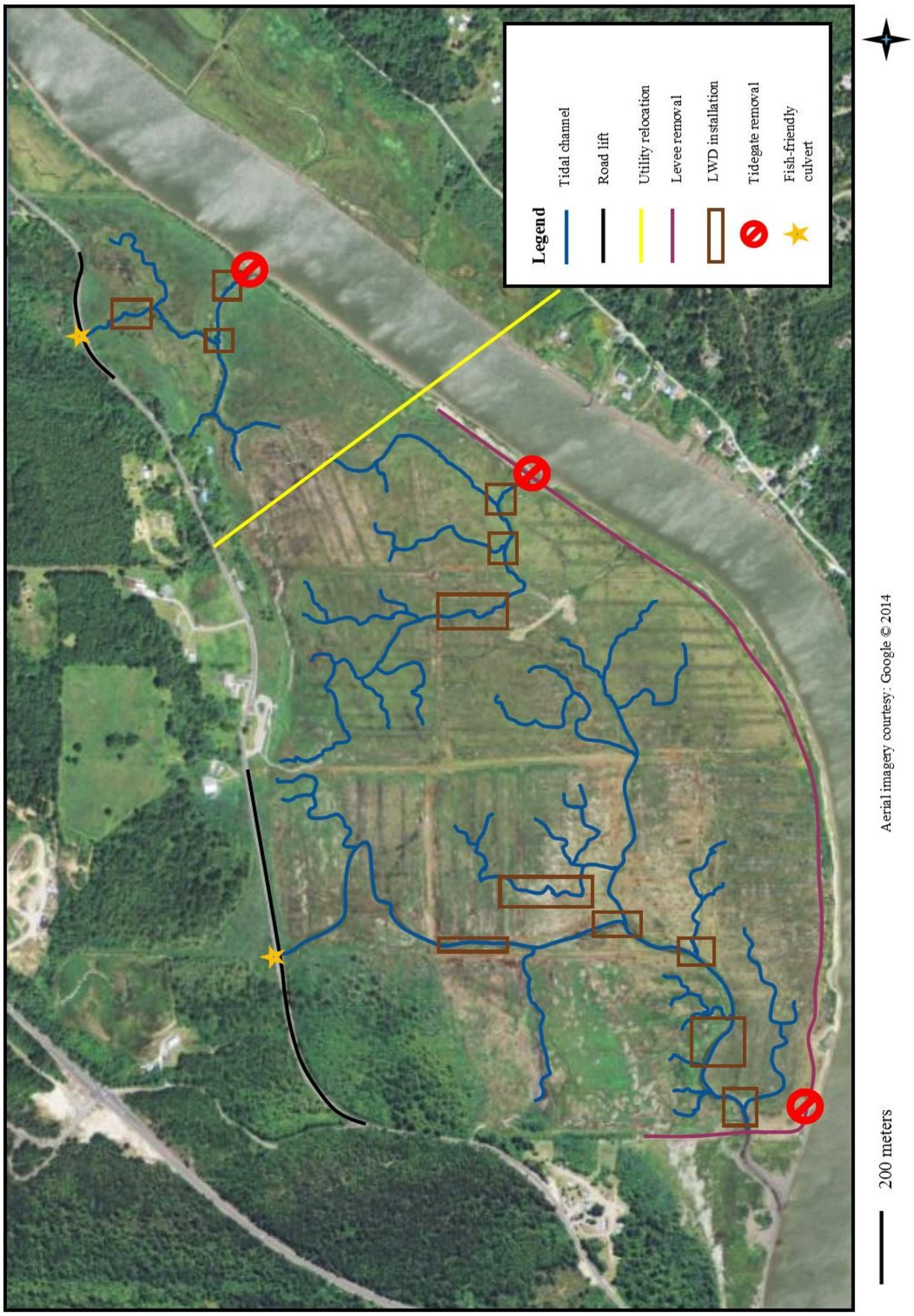

Figure 1.2 Photo showing bare ground on the restoration site where native salt-tolerant plant species will likely colonize in the near future at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. Photo taken 28 September 2014 by B. Wishnek

Chapter 2: Avian Community Response to Tidal Marsh Restoration at Bandon Marsh National Wildlife Refuge in Southern Oregon, USA

2.1 Summary of Key Findings

Following are the key findings of the community analysis:

- Transect legs closest to tidal creeks with greatest tidal influence on the restoration site are most similar in avian species composition and abundance to the reference site after restoration. Other legs on the restoration site were more similar in avian species composition to conditions before restoration and may take more time to develop avian species composition more similar to the reference site.
- Reference versus restoration sites were significantly different in avian community composition before restoration and not significantly different in avian community composition after restoration. No significant difference in avian community composition was seen on the restoration site as a whole before versus after restoration. No significant difference was seen on the reference site before versus after restoration in avian community composition. Effect sizes of these relationships were not great.
- Three species [great blue heron (*Ardea herodias*), great egret (*Ardea alba*) and Northern pintail (*Anas acuta*)] with life histories that can be related to tidal marshes were significant indicators on the restoration site after restoration.
- Diversity measures were variable across transect legs pre and post restoration.

2.2 Introduction

The restoration project at Bandon National Wildlife Refuge was designed in part to improve habitat quality for wetland birds. The avian community of estuaries can be used as an indicator of change, as different species rely on different abiotic and biotic aspects of estuaries for different parts of their life histories (Stolen et al. 2005, Weilhoefer 2011). As such, quantifying the avian response to the restoration project assesses the efficacy of the restoration project in improving habitat for wetland birds.

One approach to determining if birds responded to this restoration project is to look at species independently. Taking a single species approach is useful if a species of concern was a target for habitat restoration or if a single species can serve as a meaningful surrogate for understanding bird community response to changes in habitat. This aligns with a recent management directive within the USFWS, the surrogate species approach, which seeks to identify individual species for conservation that could serve as indicators of landscape and habitat conditions (USFWS 2012). A second approach to measuring restoration success is to assess the dynamics of the entire avian community. Monitoring avian communities may expose underlying patterns of community development that may not be seen when looking at single species and works to contribute to knowledge in the field of avian community ecology (Wiens 1989, Noss 1990). Monitoring on the restoration site indicated that many abiotic and biotic factors, such as invertebrates and vegetation, used for food by multiple avian species, tidal fluctuations and vegetation composition that can impact bird occurrence and abundance did become more similar to that of a functioning tidal marsh as a result of restoration activities (Brophy et al. 2014).

This study quantified the response of the avian community and then quantified the response of individual species to the restoration of tidal flow to the Ni-les'tun unit of BMNWR. Species and community-level dynamics on the Ni-les'tun unit restoration site were compared with observed patterns of species and community-level dynamics on the Bandon Marsh unit reference site. Results from these analyses are intended to inform the USFWS of the response of the avian community to the restoration project two years after restoration had been completed.

2.3 Research Questions

●RQ 1, Community Composition Difference: Is there a difference in the avian community composition of the restoration site versus the reference site at the scale of transect leg before and after restoration?

Composition of biological communities can be influenced by many abiotic and biotic parameters. When large-scale perturbations are made to habitats the composition of the biological communities in many habitats can change based on perturbations that have occurred. Habitat change from non-tidally influenced to tidally influenced wetlands has been shown in the past to contribute to changes in the hydrologic, edaphic, vegetative, nekton components of sites to more closely resemble tidally influenced wetlands (section 1.1 of this document, Roman and Burdick 2012). Given that each of the aforementioned factors that can influence the avian community changed to become similar to the reference site after restoration it was expected that the avian community on the restoration site would change as well. Differences in community composition were analyzed in a BACI (Before-After Control-Impact) format to assess change within and between the communities before and after restoration (Anderson and Dugger 1996). The expected outcome using the BACI format was to see a significant difference in composition between the communities on the restoration and reference sites before restoration and no significant difference in composition of the communities between the sites after restoration. Additionally, a significant difference in composition was expected on the restoration site before and after restoration and no significant difference in composition was expected on the reference site before versus after restoration (see figure 2.1 for conceptual diagram of expected outcome).

●RQ 2, Indicator Species: Which species are most strongly associated with the restoration and reference sites? Are these species different before and after restoration?

Species ability to respond to changes in habitat can vary intra and interspecifically. Identifying species that significantly increased and other species that significantly decreased in abundance across the restoration site and reference site over the period of the study was done to determine which members of the avian community were driving changes in community composition. No species were expected to be seen as indicators on the reference site and a change in the types of species identified as indicators on the restoration site from terrestrial to tidal marsh species was expected, as the restoration project was designed to benefit waterfowl, shorebirds, raptors and waders (USFWS and FHWA – Western Lands 2009).

2.4 Avian Survey Methods

Data Collection Schedule

Avian surveys were conducted on one transect on the restoration site (Ni-les'tun unit, NLT hereafter) and two transects (Bandon Marsh North and Bandon Marsh South, BMN and BMS respectively, hereafter) on the reference site (Bandon Marsh unit) every other week during the non-migration and non-breeding season (October-March) and weekly during the migration and breeding season (April-September) from November 2009 – August 2013. The only exception to this was the 2012 migration and breeding season (April-September) when surveys were conducted on a bi-weekly basis due to lack of funding for survey personnel. These dates were broken up into two periods referred to as pre-restoration (December 2009 – August 2011) and post-restoration (December 2011 – August 2013). Surveys from September – November 2011 were removed from these analyses to make the pre and post restoration periods of equal length to account for the seasonality of some species, particularly waterfowl and shorebirds.

Avian Monitoring Personnel

From November 2009 – July 2010 Bill Bridgeland (refuge restoration biologist) conducted the surveys on NLT and BMN. Curt Beyer (USFWS intern) took over surveys on NLT and BMN from July - September 2010. Bill Bridgeland took over avian surveys on the NLT and BMN from September 2010-January 2011. From January 2011-December 2011 Ben Wishnek (USFWS intern) took over surveys on NLT and BMN. In January 2012 Bridgeland resumed the surveys on NLT and BMN until March 2013 when Joe Metzler (USFWS intern) took over the surveys on NLT and BMN and finished collecting the data at the end of August 2013 (see Appendix A for survey observer and weather data). The number of observers that participated in the data collection added a source of potential bias to the data due to interobserver variation in hearing ability and degree of expertise in identification (Fannes and Bystrak 1981). Bill Bridgeland, refuge restoration biologist, accompanied all observers during their first few surveys in order to help ensure that observers' species identification skills and ability to count large flocks of birds were similar.

Site Selection and Transect Locations

The Bandon Marsh unit was selected as a reference site due to its relatively unaltered state. The Bandon Marsh unit was broken into two transects, which served as a reference site for the comparison with the transect on the restoration site. The BMN transect encompassed mostly high tidal marsh habitat types (more similar to the desired future condition of the Ni-les'tun unit) on the Bandon Marsh unit of the refuge while the BMS transect encompassed more low marsh and mudflat habitat types. The greater amount of mudflat on BMS had a different suite of species and different species abundances that would not serve as a biologically similar reference site as would the BMN transect and was not included in the analyses. Additionally, surveying the entire Bandon Marsh unit with one transect would not have been feasible due limited accessibility from fluctuations in tidal stage. The transect on the restoration site was established in a similar loop configuration as the transects on the reference site to maintain uniformity in survey methodology. Each transect on the restoration and reference site was broken into "legs" that corresponded with major changes in habitat type on the transect (see figure 2.2 for map of transects and transect legs; see table 2.1 for habitat types that corresponded with each transect leg).

Survey Protocol

Observers walked quietly and at a moderate pace along the transect to listen for birds and record observations. Numbers of individuals, species, perpendicular distance from the transect (m), transect leg on which individual(s) were located and method of detection of each individual bird or flock observed (call, song, or visual) within 200 m of the transect was recorded. Species and numbers of birds that flew above the transect and did not land within 200 m were recorded as fly-overs but not included in the analyses. If a bird was detected in the air, but obviously took off from a location within 200 m of the transect, the distance from the transect was recorded. To avoid double counting, individuals detected behind the observer were only recorded if they were believed to be present when the observer passed by, but were not detected. Birds greater than 200 m from the transect that were of management interest were recorded but not included in the analyses. Surveys were conducted at tidal heights that allowed observers to cross tidal channels on days with wind speeds less than 4 on the Beaufort scale and skies were clear to overcast with no persistent precipitation.

2.5 Data Analysis Methods

Data Management and Adjustments

Field data sheets with bird observations were entered into a Microsoft Excel spreadsheet and then transferred to a Microsoft Access Database (Microsoft Corporation 2013). Data in Microsoft Access was filtered to exclude birds greater than 200 meters from the transect and fly-overs. Research questions pertained more to the effect of restoration than inter-seasonal variation. As such, abundances of each species were separated by transect leg and summed over the pre- and post-restoration periods, regardless of year or month, to obtain total numbers of each species seen during the two time periods on each transect leg. Sums of abundances were then divided by the total area of the transect leg (leg length times 400 meters width) to obtain the total abundance per hectare of each species on each transect leg before and after restoration. These numbers were put in a species matrix in Microsoft Excel that showed total number of individuals per hectare of each species observed on each transect leg. A second matrix in Microsoft Excel classified the total numbers of each avian species per hectare by time period by a binary variable representing pre-restoration or post-restoration. These matrices were imported into the community analysis software package PC-ORD 6.08 (McCune and Mefford 2011).

Once in PC-ORD, the values in the species matrix were log(x+1) transformed to re-scale greater abundance of the most common species and improve linearity of relationships between species abundances. This is a common transformation when preparing data for community analyses that allows patterns of relatedness between species abundance and habitat to be exposed that otherwise might have been masked by greater abundances of fewer species in the untransformed data (McCune and Grace 2002; Peck 2010).

Diversity Measures

Diversity measures were calculated to provide a basic understanding of the compositional heterogeneity of species on BMN and NLT transects both pre and post-restoration. The first two diversity measures that were calculated were Whitaker's beta diversity (a measure of heterogeneity) and gamma diversity (total number of species on each transect) (Whitaker 1972). Additional diversity measures including the mean species richness (or number of species) on each transect leg, species evenness (a measure of equitability in number of species) and Simpson's diversity index (likelihood that two randomly chosen individuals are the same species) were calculated to look for differences pre and post restoration in diversity on the restoration and reference sites. Data used for species diversity measures was log (x+1) transformed to remain consistent with the transformation applied to the data for all analyses described below. The community analysis software package PC-ORD 6.08 was used to generate diversity statistics with the exception of Whitaker's beta diversity (McCune and Mefford 2011).

Two-way Cluster Analysis

A two-way cluster analysis was performed to expose underlying structure in the data. This analysis method simultaneously classifies relatedness of sample units based on their species abundances and relatedness of species abundances based on the sample units in which they occur. Data were relativized by species maximum to improve linearity of relationships between species abundance and habitat. The final matrix used for this analysis was coded by percentiles by columns. This allowed for species to be represented by abundances across transect legs with darker colors showing greatest abundance and lighter colors showing least abundance. For example, brown creeper (*Certhia americana*) was less common, so it was of greatest abundance on one leg and represented by a dark square on this leg. A more common species, the song sparrow (*Melospiza melodia*), was represented by dark squares on legs with greatest abundances and light squares on legs with least abundances (see figure 2.3 for visual explanation of the cluster analysis). The two-way cluster analysis was run using both Sørensen and Euclidean distance measure with Ward's method of clustering. Euclidean distance and Ward's clustering method are from the same mathematical formula, while Sørensen distance and Ward's clustering method combination are not. Using distance measures and clustering methods from different mathematical bases increases the likelihood that chaining will distort the groups in the analysis. Chaining, which should be minimized, can occur due to a variety of factors such as incompatible distance measures or lesser underlying structure in the data and causes groups to be classified in the analysis with relatedness patterns that look like a staircase and distort the relationships of species and sample units (McCune and Grace 2002, Peck 2010). The community analysis software package PC-ORD 6.08 was used to run this analysis (McCune and Mefford 2011)

Multi-Response Permutation Procedures

Ecological community data often do not meet the distributional assumptions required to validly use traditional parametric statistical tests (McCune and Grace 2002). In recent years, many non-parametric techniques have emerged that allow ecologists to interpret their datasets in meaningful ways without meeting the rigorous assumptions of many parametric statistical procedures. One of these methods is the Multi-Response Permutation Procedures (MRPP) which tests for species compositional differences between sample units of a study area (Mielke et al. 1976).

One of the increasingly common methods of assessing effect of land management practices on biotic community composition is the MRPP. While the literature did not show this form of analysis used to assess the effect of tidal marsh restoration on avian communities, MRPP has been used to assess the effect of other land management practices on many other avian communities (e.g. Gaines et al. 2007, Olechnowski et al. 2009, Steen et al. 2013).

Output of MRPP consisted of an *A* value (chance-corrected within-group agreement) and a *p*-value. The *A* value measured effect size. If the *A* value was less than 0.2, the effect size was minimal. *A* values greater than 0.2 indicated a substantial effect size. *P* – value measured significance at the $\alpha = 0.05$ level. The community analysis package PC-ORD 6.08 was used to run this analysis (McCune and Mefford 2011). After the initial analyses were run, data were tested to address the performance of the MRPP analysis with the following permutations:

- MRPP was re-run with legs 1,2 and 8 of NLT and leg 1 of BMN removed because composition of species on these legs appeared different from other legs based on the two-way cluster analysis. Species with greatest abundances on these legs of the transects were a mix of primarily forest-dependent songbirds and raptors whose life histories are not directly linked to tidal salt marshes, which is the primary community of focus for these analyses.
- Species detected only once were removed and the MRPP analysis was re-run. This consisted of 18 species on BMN pre restoration and 28 post-restoration. 16 species were detected only once on NLT pre-restoration and 14 detected only once post-restoration. Rare species can create noise in the data that may interfere with the interpretation of a statistically meaningful signal.

- Legs 3,4 and 7 on NLT were seen in the two-way cluster analysis to be the legs that were most different pre versus post-restoration and were used in an MRPP to see if the change observed in the two-way cluster analysis on these three legs was significant.

Indicator Species Analysis

By itself, an MRPP test exposes differences in bird community structure between the restoration and reference sites but it does not provide information on which individual species are characteristic of each transect, based on their spatial presence and abundance, pre versus post restoration (McCune and Grace 2002). As such, the next logical step is determining which individual species could be used as indicators on each transect and if the species identified as indicators changed temporally (before and after restoration). This was done with the indicator species analysis (ISA), which is often used complementarily with MRPP (Dufrêne and Legendre 1997; McCune and Grace 2002).

An ISA was used to calculate indicator values for each species in each group (pre and post-restoration on each transect leg) based on the standards of a perfect indicator, i.e., one which is always present in a group and never occurs in another group. In this analysis, a species that was abundant on many of the transect legs before and after restoration received a lesser indicator value, while a species that was abundant on less of the transect legs before restoration and more of the transect legs after restoration, or vice versa, received a greater indicator value. Indicator values were tested for statistical significance using 4999 runs of a Monte Carlo randomization model (McCune and Grace 2002). *P*-value measured significance at the $\alpha = 0.05$ level. If life histories of the indicator species can be tied to other ecological parameters affected by restoration, their response can be used as partial justification by managers for the restoration.

2.6 Results

Diversity Measures

Mean richness (or number of species per transect leg) increased on BMN and decreased on NLT after restoration (see Figure 2.4). Whitaker's beta diversity (compositional heterogeneity) and Gamma diversity (or landscape-level diversity measured as total number of species across transect legs) increased on both BMN and NLT after restoration (see Table 2.2). Mean evenness per transect leg increased on BMN and decreased on NLT after restoration (see Figure 2.5). Mean Simpson's diversity (D) increased on BMN and decreased on NLT after restoration (see Figure 2.6). Increases and decreases in diversity measures were not analyzed for statistical significance. See Appendix B for raw abundances of each species pre and post-restoration. See Appendix C for richness, evenness and Simpson's diversity measures by leg of transect.

Two-Way Cluster Analysis

Less chaining was observed when clustering with Sørensen distance and Ward's clustering method (3.35% for transect legs and 1.08% for species) compared with the Euclidean distance and Ward's clustering method (8.55% for transect legs and 2.07% for species). However, chaining observed with both distance measures was less than the 15-25% threshold at which the data does not have enough group structure to be reliably interpreted by a two-way cluster analysis (Peck 2010). Euclidean distance and Ward's clustering method was selected because (1) the same general biological interpretations were able to be made from clusters with both Euclidean and Sørensen distance measures (2) Euclidean distance and Ward's method are derived from the same mathematical equation and (3) the amount of chaining in both Euclidean and Sørensen clusters was below the threshold for concern regarding the amount of structure in the data (McCune and Grace 2002).

There were three main species groups that were comprised of predominantly forest birds (e.g. songbirds and some raptors), predominantly tidal marsh birds (e.g. waterfowl, shorebirds and wading birds) and a group of five common species [American crow (*Corvus brachyrhynchos*), marsh wren (*Cistothorus palustris*), song sparrow, Canada goose (*Branta canadensis*) and savannah sparrow] (see figure 2.7 for Two-way Cluster Analysis output). Raw abundance data showed few very common and abundant species and many less common and less abundant species, so the groupings produced with log (x + 1) transformations best fit the data by allowing greater expression of the relatedness of less common and abundant species while acknowledging the more common and abundant species as a separate group.

A group of transect legs observed in this analysis was comprised of leg 1 of BMN and legs 1, 2 and 8 of NLT pre and post restoration. Within this group NLT leg 1 post-restoration became more similar to BMN leg 1. NLT leg 2 and 8 did not become more similar to any legs on the reference site after restoration. All of these legs (NLT 1,2,8 and BMN 1) bordered forested habitats and thus captured many of the more forest-dependent species of birds that were not observed in great abundances on other legs that had marsh habitat on either side. Transect legs other than the ones mentioned above generally grouped according to restoration and reference site. There were two exceptions which were the group of legs BMN 2 pre, NLT 3 post and NLT 4 post and the group of BMN 2 post and NLT 7 post.

MRPP

Community composition was similar for the reference site pre vs. post restoration (A = -0.024, p = 0.859), suggesting conditions at the reference site were similar during the two time periods. The restoration site differed from the reference site pre restoration (*A* = 0.052, *p* = 0.034) but not post restoration (*A* = 0.028, *p* = 0.093). This same pattern was observed when the group of transect legs with forested borders were removed and when species with one observation were removed (see table 2.3 for summary of MRPP analyses). There was no difference in the avian community on the restoration site before and after restoration (*A* = 0.006, *p* = 0.300), when all transect legs were included in the analysis, but considering only transect legs 3,4 and 7, the avian community was different pre vs post restoration (*A* = 0.125, *p* = 0.045).

ISA

Indicator Species Analysis showed that three species including: great blue heron (observed indicator value = 79.1, mean indicator value from randomized groups = 54.5, standard deviation = 8.91, *p* = 0.004), great egret (observed indicator value = 84.5, mean indicator value from randomized groups = 31.6, standard deviation = 11.29, *p* – value = 0.002) and Northern pintail (observed indicator value = 62.5, mean indicator value from randomized groups = 29.0, standard deviation = 11.04, *p* – value = 0.024) could be considered significant indicators of the restoration site after restoration. Two species, Brewer's blackbird (*Euphagus cyanocephalus*) (observed indicator value = 60.4, mean indicator value from randomized groups = 32.5, standard deviation = 10.95, *p* = 0.027) and White-tailed kite (*Elanus leucurus*) (observed indicator value = 61.6, mean indicator value from randomized groups = 37.9, standard deviation = 10.42, *p* = 0.034), were significant indicators of NLT pre-restoration. Finally, savannah sparrow was seen to be a significant indicator of BMN pre restoration (observed indicator value = 56, mean indicator value from randomized groups = 52.5, standard deviation = 1.91, *p* = 0.049). See Table 2.4 for summary of indicator species analyses. See Figures 2.8 and 2.9, respectively, for detections and numbers of individuals per hectare of NLT post-restoration indicator species.

2.7 Discussion

The first research question sought to determine if the avian community composition on NLT and BMN changed pre and post restoration. The initial MRPP showed that the bird communities on NLT and BMN were significantly different before restoration, but were not significantly different after restoration. The caveat to this relationship is the small effect size of the relationship. The small effect size is not surprising because of the two year pre and two year post restoration timeline of the study. In some studies of avian response to tidal marsh restoration, there was a significant change in single bird species or groups of birds one to two years after restoration (Seigel et al. 2005, Armitage et al. 2007, Raposa 2008, Deza et al. 2013). Other studies suggested that it may take 5 to 20 or more years after restoration to see full development of the avian community (Brawley et al. 1998, Shriver and Greenberg 2012). The significant but not strong difference in abundance and composition of avian communities pre restoration and not strongly similar communities post restoration indicate that there may be certain species, such as the great blue heron, great egret and Northern pintail, identified in the ISA (see Appendix B for summary of observations of each species before and after restoration), that are driving the change in the community through abundance and presence on multiple transect legs, and that it may take longer than the timeframe of this study to see the communities become strongly similar.

Data for the MRPP were tested within a BACI framework to ensure the robustness of the inferences regarding the patterns of differences in avian community composition. No significant difference was seen in the composition of the transect legs on the restoration site before vs after restoration and no significant difference was seen on the reference site before versus after restoration. This was unexpected, as it was thought that the community would change on the legs of the restoration site pre vs post restoration but not change on the legs of the reference site.

The cluster analysis showed that legs 3,4 and 7 on the restoration site were the legs that became most similar to the reference site before versus after restoration. MRPP with only these three legs included showed significant differences in composition of the transect legs before versus after restoration on the restoration site. Having these three legs, but not all of the legs on the restoration site, be significantly different before versus after restoration shows that the strongest signal of an effect of restoration on the avian community was localized to certain portions of the restoration site.

The two-way cluster analysis showed that legs 1, 2 and 8 of NLT and leg 1 of BMN as different based on the composition and abundances of bird species observed. The same statistical conclusion (of a difference in composition before restoration but no difference in composition after restoration) with removal of these legs from the analysis showed that the change in avian species composition and abundance on legs of the transects abutting forested habitat were less of a driver of change than were changes in composition and abundance of species observed on the marsh legs of the transects.

Finally, many species in the dataset were only detected once or twice and rare species can have an influence on the outcome of community analyses and can be removed to increase the strength of the statistical signal. A conservative approach to species deletion was taken at the recommendation of Peck (2010) and species with only one detection were deleted to see if the detection of rare species influenced the outcome of the analysis. The same result of significantly different community composition before restoration but not significantly different community composition after restoration between NLT and BMN was observed. This shows that the rarest species did not have a measurable effect on the outcome of the analysis. Results from the MRPP with the different permutations of the data described above gives greater confidence in inferring that the communities of the NLT and BMN became more similar after restoration due to changes in species composition on certain transect legs of the restoration site although the change was not great.

A second piece of evidence for community change was the two-way cluster analysis. Close groupings of NLT legs 3 and 4 post restoration with BMN leg 2 pre-restoration and NLT leg 7 post-restoration with BMN leg 2 post-restoration may be correlated with tidal regime influencing bird species and abundance. Hydrological monitoring of these areas pre and post restoration indicated that the flooding regime of the aforementioned NLT legs became more similar to the aforementioned BMN leg (Brophy et al. 2014). The shift of tidal regime on NLT, i.e. becoming more similar to that of BMN, may help explain the patterns in the bird community on the aforementioned transect legs becoming more similar to BMN. More of the species whose abundances were represented the greatest on NLT legs 3, 4 and 7 post restoration were shorebirds and waterfowl compared with species on these legs before restoration. These are species whose abundances can be tied to changes in the tidal regime on tidal marshes (Kiviat 1989). Abundance of some of these waterfowl and shorebird species has increased following restoration of natural tidal regimes on other sites, as it did at BMNWR (Simenstad and Thom 1996, Armitage et al. 2007).

Community diversity measures were run to look for differences pre and post restoration in community composition that could be attributed to restoration. Mean species richness (or alpha diversity) across transect legs decreased after restoration on NLT and increased after restoration on BMN. Examination of patterns of species richness at a transect leg resolution allowed a better idea of where the changes in species richness were taking place on the sites. Species richness decreased by as much as 21 on NLT leg 6 that was located in the high marsh zone. However, over half of the species that were detected pre-restoration but not post on this leg were only detected one to three times. Another example is BMN Leg 3 where there were ten more species detected after restoration than were detected before restoration, but many of these species were detected once or twice. Increases in species richness on legs 3, 4 and 7 of NLT were influenced more by species in the tidal marsh group of birds identified in the cluster analysis. Many of the novel species in the tidal marsh group of birds after restoration were only detected once or twice, but others like green-winged teal (*Anas crecca carolinensis*) and Wilson's snipe (*Gallinago delicata*) on NLT 7 were detected 9 and 24 times, respectively. Having these legs be closest to the most tidally influenced areas on NLT post-restoration and changes in species diversity being driven by marsh birds may indicate that the restored influence of the tide had an effect on the species richness on those legs. Raposa (2008) saw bird species richness increase after restoration of tidal flow, and could attribute that increase to an effect of restoration. Siegel et al. (2005) saw increases in species richness after restoration on one of the restored areas in the tidal marsh complex that was restored, but did not see an increase in species richness after restoration in another and attributed this to variation in configuration of the habitat.

The heterogeneity in species richness response to restoration seen by Seigel et al. (2005) is comparable to BMNWR where the species richness changed to a different extent on each transect leg. Extent of change in abiotic and biotic habitat variables that can influence avian abundance varied across the restoration site and may help explain the heterogeneity in change of species richness before and after restoration on some transect legs (Brophy et al. 2014). Such variation in richness (and changes in diversity and evenness reported in Appendix C) at

BMNWR on a transect leg scale has been observed in shorebird communities between restoration sites in California (Armitage et al. 2007). Armitage et al. (2007) used behavioral observations and microhabitat use data for each shorebird species to better explain the observed patterns in community diversity. Incorporation of behavioral and microhabitat use data into future bird surveys may provide evidence to better explain dynamics of community diversity observed at BMNWR.

The second research question looked to see which individual species changed the most in frequency and abundance before and after restoration on NLT and BMN. The indicator species analysis identified three species (great blue heron, great egret and Northern pintail) as indicators on the NLT after restoration that were not identified as indicators before restoration nor were they identified as indicators on BMN before or after restoration. The implication of this finding is that the habitat on NLT became more favorable for these species based on their individual ecologies, each of which can be related to tidal marshes. These three species are seen in the cluster analysis of having some of the greater abundances on NLT legs 3, 4 and 7 post-restoration, which are subject to the greatest tidal action on NLT and were seen as having the greatest degree of similarity to BMN. The ISA identifying a switch from terrestrial to aquatic avian species on the restoration site and having no ecologically significant species identified as indicators on the reference site provides further evidence of avian community change on the restoration site after restoration.

Environmental variables including prey availability and hydrology may be used to explain increases in abundance of indicator species on restoration sites after restoration. Butler (1997) summarized data that found the diets of great blue heron in estuaries of British Columbia to be composed of primarily gunnelfish (family Pholidae), sculpin (family Cottidae) and shiner perch (*Cymatogaster aggregata*) during the breeding season. Many great blue heron observations at BMNWR were made outside of the breeding season, when Butler (1997) found great blue heron to eat these species of fish, but some of these species were present year-round when great blue heron and great egret were present (Brophy et al. 2014). Similar diet preferences were seen in great blue heron and great egret in Yaquina Bay, OR by Bayer (1985) and in Coos Bay, OR by Warrick (1992). All three of these fish species were observed on NLT after restoration (Brophy et al. 2014, Bill Bridgeland - Personal communication). Catch per unit effort was summarized for staghorn sculpin (*Leptocottus armatus*, family Cottidae) and chinook salmon (*Oncorhynchus tshawytscha*) pre and post restoration. Increases in catch per unit effort during each sampling period after restoration on the two tidal creeks closest to NLT indicate increased use of the site by both of these fish species (Brophy et al. 2014). Data for gunnelfish and shiner perch were not available at the time of this writing. Although fish and bird abundance were not examined for correlation, the increases in catch per unit effort in fish surveys previously mentioned represent an increased food source for the great blue heron and great egret on NLT, and that may explain their increased abundances and identification as indicator species.

A secondary factor in the prey availability explanation for increased abundance of great blue herons and great egrets is tidal hydrology on NLT, which became more similar to tidal hydrology on BMN after restoration (Brophy et al. 2014). Lower water levels in the tidal channels at low tides leave fish more vulnerable to predation and the wading birds may have been capitalizing upon this vulnerability (Gawlik 2002). Concomitant increase in prey abundance and tidal amplitude after restoration on NLT may be one of the factors driving the increase in great blue heron and great egret abundance.

Northern pintail as an indicator on NLT may be explained by changes in food availability as well. In tidal marshes some of the more common foods utilized by Northern pintail include eelgrass (*Zostera* sp.) and wigeongrass (*Ruppia maritima*) (Baldwin and Lovvorn 1994, Ballard et al. 2004). Wigeongrass was observed to colonize and increase in coverage throughout the network of tidal channels on NLT after the first year of tidal inundation (see figure 2.10, Bill Bridgeland - Personal Communication). Increased food abundance may explain the increased abundance of Northern pintail and the ISA identifying them as an indicator species. Transect legs seen in the cluster analysis with great abundance of Northern pintail are NLT 3,4 and 7 post-restoration, which were legs with concomitant increases in other avifauna with similar ecologies. Increased tidal amplitude may have been a factor in the increase of Northern pintail on the site as well. Northern pintail, being dabbling ducks, have less propensity to dive for food in deeper water habitats. The more shallow water at lower tides in the tidal channels may have facilitated access to the submerged aquatic vegetation food source. Conducting surveys at low tides may have biased the results of the analyses, as the avian species composition on tidal marshes changes with tide height (Kiviat 1989).

Two species that were observed as indicators on NLT before restoration but not after were brewer’s blackbird and white-tailed kite. Detections of white-tailed kite, were of a single pair that nested nearby. Decreased use of NLT by white-tailed kite could have been a result of a number of factors such as local variation in prey population and/or interspecific competition (Dunk and Cooper 1994, Dunk 1995). An explanation for brewer’s blackbird being identified as an indicator on NLT before but not after restoration may be able to be tied to change in habitat as this species is less common in aquatic habitats, like tidal marshes, than terrestrial habitats (Martin 2002).

Savannah sparrow was found by the ISA to be an indicator on BMN pre-restoration. That makes sense because this species has affinity for high tidal marsh, and that was the habitat type present on most of the transect. The habitat on the reference site was not directly affected by restoration activities, so the Savannah Sparrow being identified as an indicator pre restoration but not post-restoration on BMN may have been a function of other related factors that can drive savannah sparrow populations such as demographic stochasticity, predation and migrant versus resident individuals (Curnutt et al. 1996). However, the p – value for this species is 0.049, which is non-significant if rounded up to two significant digits, so I do not have great confidence in ecological significance of this result.

2.8 Conclusion

Many factors need to be considered when interpreting the change of the avian community pre and post restoration. While a significant change was seen in the community as a whole in the MRPP analysis comparing the NLT vs. BMN, it was not a strongly significant difference. The significant change on the restoration site being localized to three transect legs seen in the cluster analysis and MRPP support the lesser effect size of the relationships in the MRPP with all transect legs included. Few species were identified by the ISA as clear indicators of change. This may be due to the ability of each species to adapt to change in the environment. Different species may be seen as indicators in the future as the habitat on NLT becomes more suitable for different species and greater abundances of species already present (Keer and Zedler 2002). This change in density and distribution was seen after restoration of a salt marsh in the Salish Sea by Simenstad and Thom (1996) where avian densities decreased in habitats bordering a restored marsh and increased in the restored area in the second, third and fourth years after restoration.

Additional avian surveys at BMNWR are planned to commence in 2015 and will help determine longer-term trends in density and distribution in response to the restoration at BMNWR.

One drawback of the ISA is that it looked for species that changed in abundance on the most transect legs over time. Different analyses that look for statistical changes in abundances of individual species of management concern, but are habitat specialists, would add another dimension to the determination of which species responded most strongly to changes in habitat conditions before and after restoration (Ortega-Alvarez and Lindig-Cisneros 2012). For example, shorebirds and raptors that use the marsh were target species for which the project was designed and they did not show up in the ISA. An example is least sandpiper, that might serve as an indicator of habitat conditions, which increased in number of observations on a few transect legs of NLT at a much greater amount than BMN over the same time period. Other shorebirds saw similar increases in abundance on NLT while others did not increase to that great of an extent. For shorebirds and other migratory species, attributing response in abundance to restoration alone becomes a greater challenge as there are other factors such as habitat quality and interspecific interactions at the broad spatial scales at which migratory birds live, that can influence abundances at any time throughout the annual cycle. Raptors are another group species that was thought to increase in abundance after restoration. Some species of raptors, such as peregrine falcon (*Falco peregrinus*), that are associated with tidal marshes increased in abundance, just not to the extent that other groups of species increased in abundance. It may be that since raptors are at a higher trophic level they may need a greater amount of prey at lower trophic levels to increase in order to find NLT as worthwhile foraging grounds.

Different measures of animal population dynamics such as reproduction and survival can influence observed avian densities (Johnson 2005). Additional monitoring of these factors in species whose life histories are closely tied to tidal marshes may prove useful in determining the species' response to future restoration. Studies of avian reproduction and survival in response to restoration are the least common methods of assessing efficacy of restoration practices but provide some of the most valuable information (Konisky et al. 2006).

A caveat to the waterfowl observations was that waterfowl hunting occurred on the Bandon Marsh unit throughout the period of the study and no hunting was permitted on the Ni-les'tun unit. Hunting pressure along with other recreational activities have been shown to influence avian distribution to different degrees (Madsen 1998a, Madsen 1998b). Differential hunting pressure on the two units may have caused movement of birds from the Bandon Marsh unit to the Ni-les'tun unit. Quantification of abundance of waterfowl and other species that are affected by recreational activities combined with behavioral observations on days with and without these recreational activities occurring would have helped in determining whether or not the pressure of hunting or other recreational activities in the area, such as boating/fishing and clamming, affected avian abundance.

While the duration of this study is short in comparison with others that are 5 to 10 years long, these data inform managers of early trends in avian community composition after restoration. Monitoring of demography, species-specific abundance assessments and inclusion of monitoring at all tide stages would all contribute to assessment of the efficacy of the restoration project in increasing habitat for the suite of avian species on the site.

2.9 References

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2.10 Tables

Table 2.1. Habitat types of transect legs (based on Cowardin et al. 1979) on the restoration (NLT) and reference site (BMN) surveyed to assess avian response to tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA from December 2009 – August 2013.

Transect Leg	Length (m)	System	Subsystem	Class	Modifier
Restoration Site (Pre-restoration)					
NLT 1	500	Palustrine	N/A	Scrub-Shrub wetland	Semipermanently flooded
		Palustrine	N/A	Emergent wetland	Seasonally flooded
NLT 2	320	Palustrine	N/A	Scrub-Shrub wetland	Seasonally flooded
		Palustrine	N/A	Emergent wetland	Seasonally flooded
		Riverine	Lower Perennial	Emergent wetland	Semipermanently flooded
NLT 3	400	Palustrine	N/A	Emergent wetland	Seasonally flooded
		Riverine	Lower Perennial	Emergent wetland	Semipermanently flooded
NLT 4	400	Palustrine	N/A	Emergent wetland	Seasonally flooded
NLT 5	410	Palustrine	N/A	Emergent wetland	Seasonally flooded
NLT 6	790	Palustrine	N/A	Emergent wetland	Seasonally flooded
		Estuarine	intertidal	Emergent wetland	Regularly flooded
NLT 7	560	Palustrine	N/A	Emergent wetland	Temporarily flooded
NLT 8	360	Palustrine	N/A	Emergent wetland	Temporarily flooded
		Palustrine	N/A	Emergent wetland	Seasonally flooded
		Upland			
Restoration Site (Post-restoration)					
NLT 1	500	Palustrine	N/A	Scrub-Shrub wetland	Semipermanently flooded
		Estuarine	Intertidal	Emergent wetland	Irregularly flooded
NLT 2	320	Estuarine	Intertidal	Forested wetland	Irregularly flooded
		Estuarine	Intertidal	Emergent wetland	Regularly flooded

NLT 3	400	Estuarine	Intertidal	Emergent wetland	Regularly flooded
NLT 4	400	Estuarine	Intertidal	Emergent wetland	Regularly flooded
NLT 5	410	Estuarine	Intertidal	Emergent wetland	Regularly flooded
NLT 6	790	Estuarine	Intertidal	Emergent wetland	Irregularly flooded
NLT 7	560	Estuarine	Intertidal	Emergent wetland	Irregularly flooded
		Estuarine	intertidal	Emergent wetland	Regularly flooded
NLT 8	360	Estuarine	Intertidal	Emergent wetland	Permanently flooded
		Upland			
Reference Site					
BMN 1	700	Palustrine	N/A	Scrub-Shrub wetland	Temporary tidal
		Estuarine	Intertidal	Emergent wetland	Regularly flooded
		Palustrine	N/A	Forested wetland	Seasonally flooded
BMN 2	400	Estuarine	Intertidal	Emergent wetland	Regularly flooded
BMN 3	250	Estuarine	Intertidal	Emergent wetland	Regularly flooded
BMN 4	330	Estuarine	Intertidal	Emergent wetland	Regularly flooded
		Estuarine	Intertidal	Unconsolidated shore	Regularly flooded
BMN 5	300	Estuarine	Intertidal	Emergent wetland	Regularly flooded
		Estuarine	Intertidal	Unconsolidated shore	Regularly flooded
BMN 6	480	Estuarine	Intertidal	Emergent wetland	Regularly flooded
		Estuarine	Intertidal	Unconsolidated shore	Regularly flooded
		Estuarine	Intertidal	Scrub-Shrub wetland	Seasonally flooded

Table 2.2. Whitaker's Beta and gamma diversity measures for transects on the restoration (NLT) and reference (BMN) sites at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA before and after tidal marsh restoration.

	Whitaker's Beta	**Gamma**
BMN Pre	1.486	92
BMN Post	1.696	103
NLT Pre	1.382	106
NLT Post	1.644	110

Table 2.3. Results of MRPP analyses comparing differences in avian community composition between the transects on the restoration site (NLT) and the reference site (BMN) before and after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA show similarities and differences (*p* – values at the α = 0.05 level) in community composition between the restoration and reference sites before and after restoration. *A* values (Chance-corrected Within Group Agreement) less than 0.2 show that these relationships are not strong. All analyses were run using Sørensen distance measure.

Group Comparison	***A* - value**	***p* – value**
BMN Pre-restoration vs. NLT Pre-restoration	0.052	0.034
BMN Post-restoration vs. NLT Post-restoration	0.028	0.093
BMN Pre-restoration vs. NLT Pre-restoration (BMN Leg 1 and NLT Leg 1,2 and 8 removed)	0.100	0.004
BMN Post-restoration vs. NLT Post-restoration (BMN Leg 1 and NLT Leg 1,2 and 8 removed)	0.048	0.060
BMN Pre-restoration vs. BMN Post-restoration	-0.024	0.859
NLT Pre-restoration vs. NLT Post-restoration	0.006	0.300
NLT Pre-restoration vs. NLT Post-restoration (Only NLT Leg 3,4,7 included)	0.125	0.045
BMN Pre-restoration vs. NLT Pre-restoration (species with only one detection removed)	0.054	0.032
BMN Post-restoration vs. NLT Post-restoration (species with only one detection removed)	0.035	0.069

Table 2.4. Results of Monte Carlo tests of significance of indicator values for avian species on Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA before and after restoration. Indicator species analysis based on 4999 randomizations of the data show that three avian species (*) could be identified as indicators on the restoration site (NLT) after restoration that could not be considered indicators on the reference site (BMN) before or after restoration. The *p* – value is based on proportion of randomized trials with indicator value equal to or exceeding the observed indicator value. Only species with significant *p* – values at the α = 0.05 level are reported.

				IV from Randomized Groups		
Species	**Transect**	**Max Group Value**	**Observed Indicator Value**	*Mean*	*SD*	***p* – value**
Savannah Sparrow	BMN	Pre	56.0	52.5	1.91	0.049
Brewer's Blackbird	NLT	Pre	60.4	32.5	10.95	0.027
White-tailed Kite	NLT	Pre	61.6	37.9	10.42	0.034
Great Blue Heron*	NLT	Post	79.1	54.5	8.91	0.004
Great Egret*	NLT	Post	84.5	31.6	11.29	0.002
Northern Pintail*	NLT	Post	62.5	29.0	11.04	0.024

2.11 Figures

Figure 2.1. Conceptual diagram of expected outcome of Research Question 1 for avian community after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA when analyzed within a BACI framework. No significant change in community composition was expected on the reference site before versus after restoration and a significant change in community composition was expected on the restoration site before versus after restoration. A significant difference in community composition was expected when the restoration site was compared with the reference site before restoration. No significant difference in community composition was expected when the restoration and reference sites were compared after restoration.

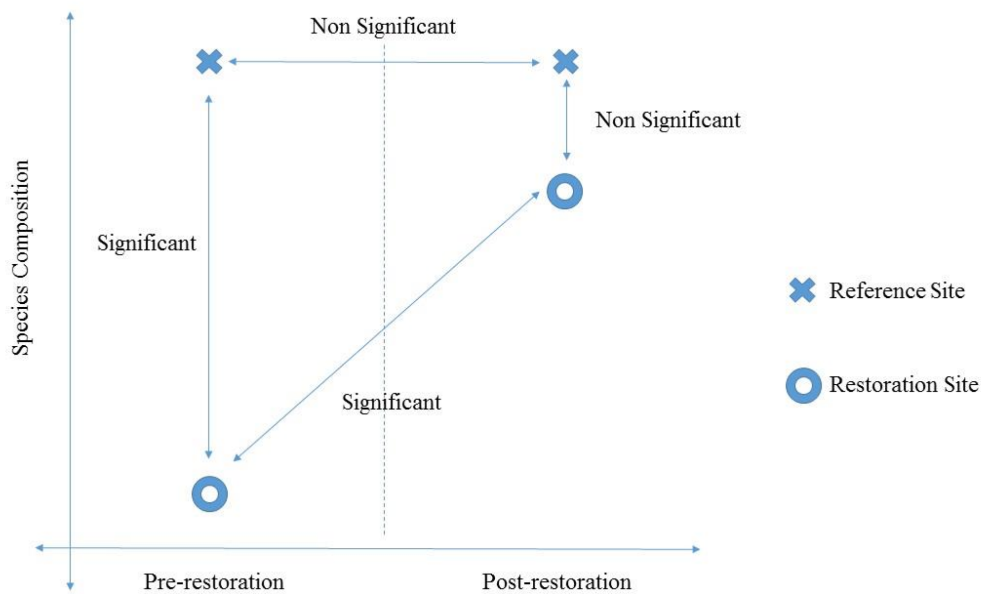

Figure 2.2. Map of study site and transects at Bandon Marsh National Wildlife Refuge in Bandon, Oregon, USA used to assess avian community response to tidal marsh restoration. Each transect leg is designated by a number and demarcated by a yellow box with the corresponding transect leg number.

Bandon Marsh National Wildlife Refuge Avian Monitoring Transects

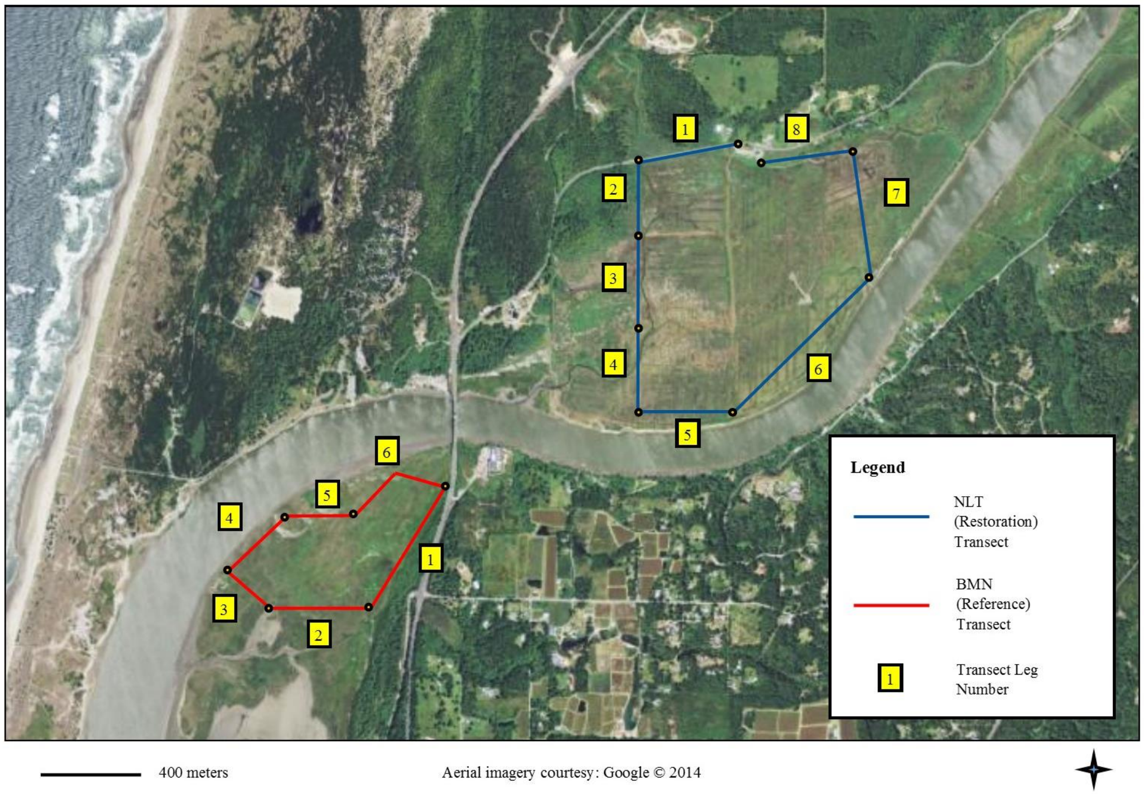

Figure 2.3 Graphical interpretation of a species of lesser (BRCR) and greater (SOSP) abundance in a two-way cluster analysis.

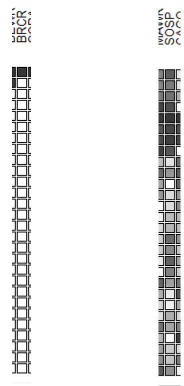

Figure 2.4 Mean avian species richness (S) per transect leg increased on the reference site (BMN) and decreased on the restoration site (NLT) after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. Error bars represent standard error of the mean.

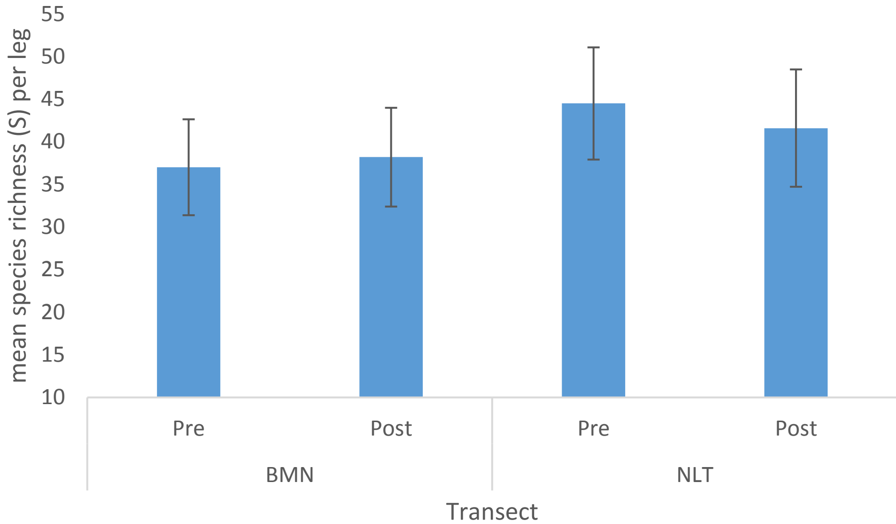

Figure 2.5 Mean avian species evenness (E) per transect leg increased on the reference site (BMN) and decreased on the restoration site (NLT) after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. Error bars represent standard error of the mean.

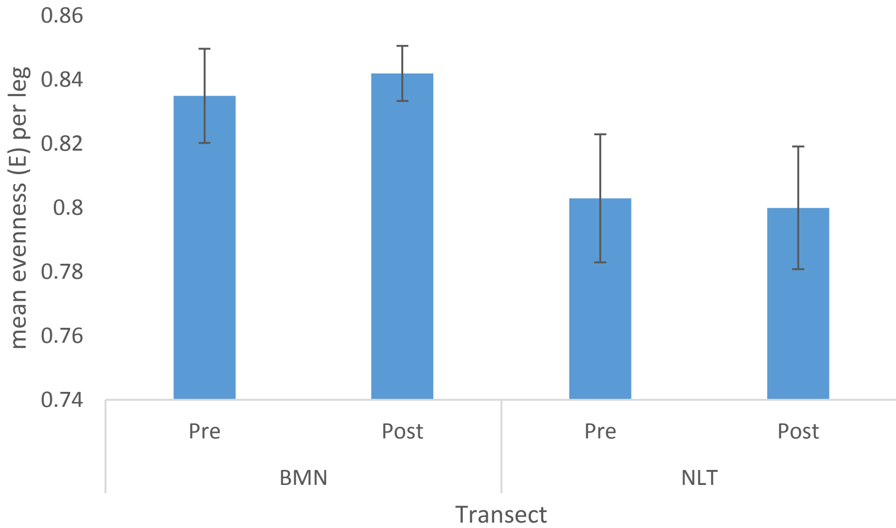

Figure 2.6 Mean Simpson's diversity (D) of avian species per transect leg increased on the reference site (BMN) and decreased on the restoration site (NLT) after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. Error bars represent standard error of the mean.

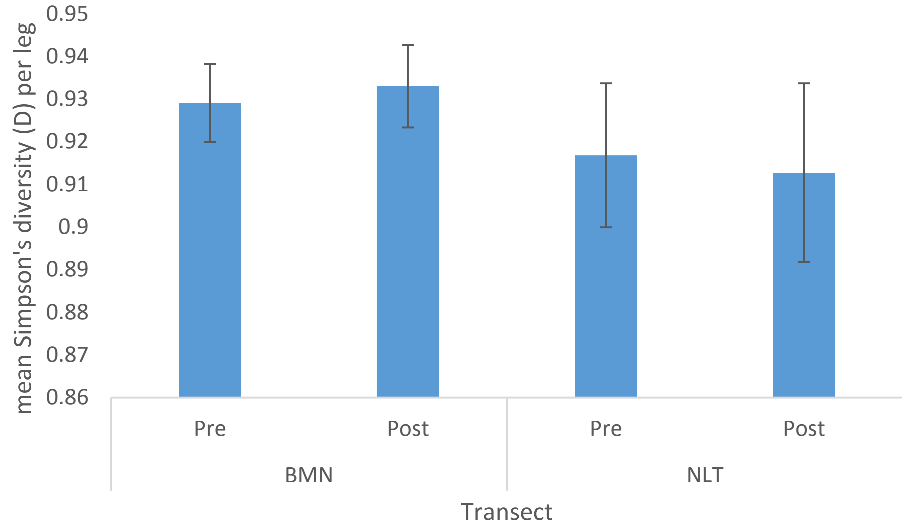

Figure 2.7. Two – way cluster analysis representing similarities of avian species based on transect legs on which they were most abundant and similarities of transect legs based on which species were most abundant before and after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA.

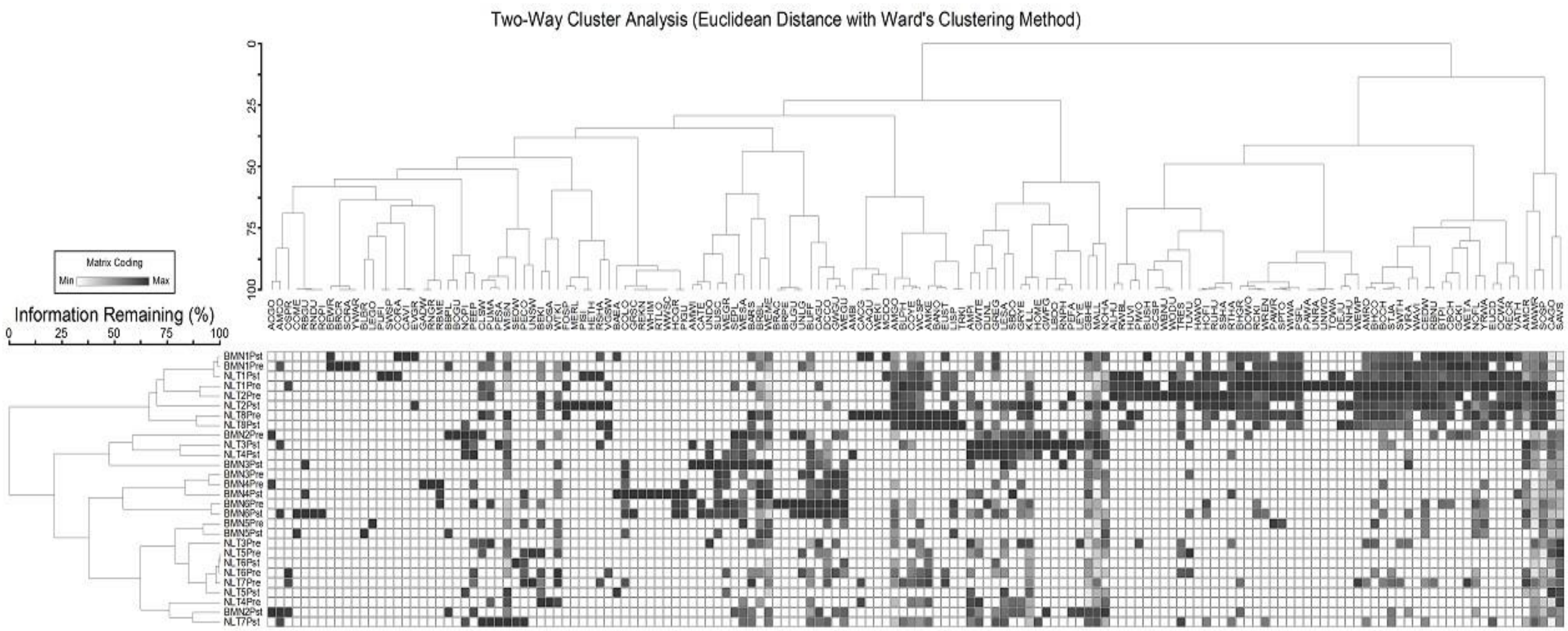

Figure 2.8. Number of detections of avian species identified as indicators on the restoration site (NLT) compared with the reference site (BMN) before and after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. A detection was defined as a group of one or more individuals observed during the surveys.

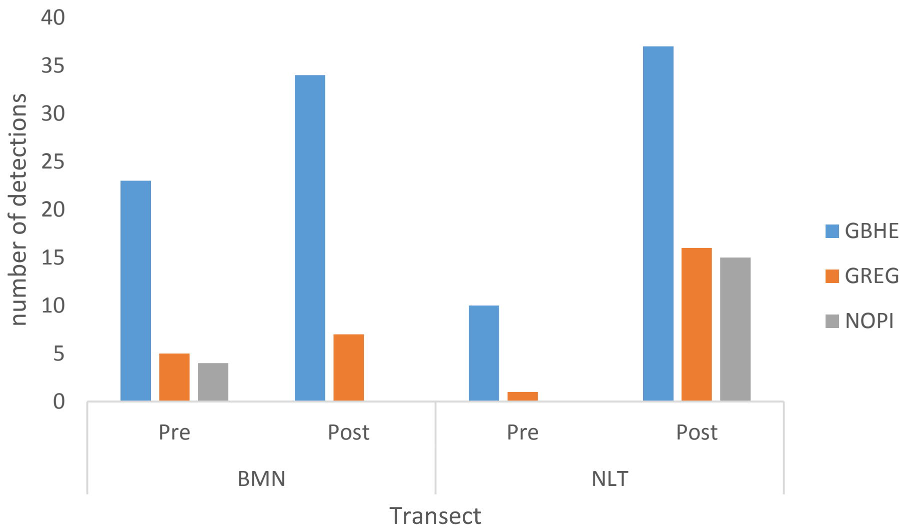

Figure 2.9. Total number of individuals per hectare of avian species identified as indicators on restoration site (NLT) compared with the reference site (BMN) before and after tidal marsh restoration at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA.

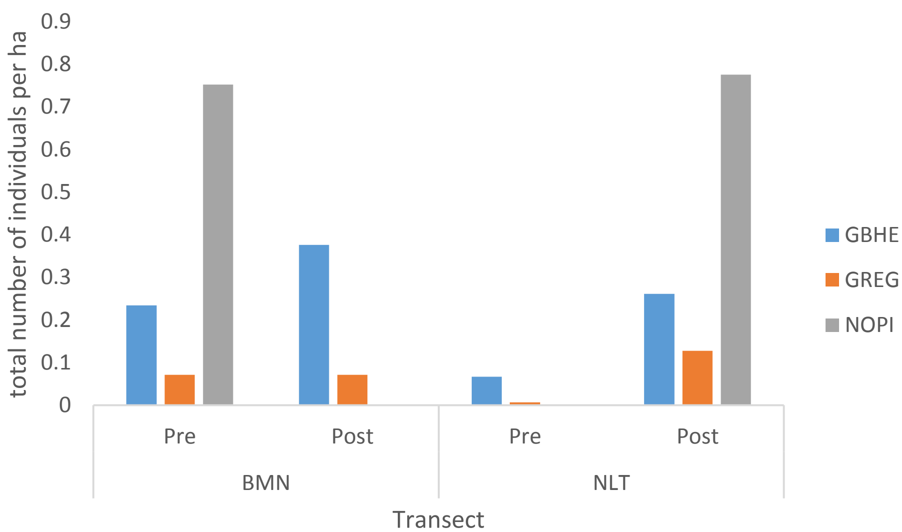

Figure 2.10 Photo showing Wigeongrass at high tide in one of the constructed tidal channels on the Ni-les'tun unit of Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA. Photo taken on 28 September 2014 by B. Wishnek just over three years after restoration of tidal flow to the site.

Chapter 3: Restoring Tidal Marshes: Is it a Practice for the Birds?

3.1 Target Audience

This paper is intended for future publication in a periodical that focuses on Pacific northwest natural resource management and / or birding for the general public. As such, the writing style is geared toward members of the general public that may be interested in these subjects but may not necessarily have the scientific background on the subjects that may be possessed by a researcher or natural resources management professional.

3.2 Introduction

Tides are one of nature's most intriguing forces. Every day movement of water resulting from the movement of the earth, moon and sun rises and falls in tidal marshes without the aid of human intervention. Tides pulse water throughout tidal marshes that gives these habitats life much like the heartbeat of a human pulses blood throughout our bodies to give us life. Pulses of water bring in and out different types of organisms in tidal marshes including birds. As the tide recedes and mudflats become exposed, shorebirds flock to the open mud and search for food on the marsh surface and below the surface that is not available for consumption when the tides are high. At high tides mudflats are covered with large areas of open water that are used by different species, like diving ducks, that need habitats with areas of water deep enough to hunt for food that comes in with higher tides. Some raptor species prey upon waterfowl and shorebirds and have quite spectacular aerial displays while in pursuit of their meals. Graceful long-legged wading birds wait patiently for tides to drop to prey upon small fishes that are more easily caught when the water levels in tidal channels are lower. This suite of bird species found in tidal marshes is well adapted to these habitat conditions. Birds have, however, come under pressure due to reduction in available tidal marsh habitat from large-scale changes in land use in and around tidal marshes (US Fish and Wildlife Service Tidal Marsh Monitoring Website 2014).

Development related to many industries has decreased the worldwide availability of tidal marsh habitats for birds and other species that depend on them for food, shelter and water. This is true on the Oregon Coast where much of the tidal marsh habitat has been restricted from tides during the last 100 years through diking and draining for cattle grazing and other farming practices. One of the most significantly impacted areas with tidal marshes is the Coquille River estuary in southern Oregon, where 94% of the tidal marsh habitat has been converted from tidal marsh to agricultural pasture, this has resulted in reduced habitat for many species of birds that are dependent upon tidal marsh habitats (Good 2000).

The Coquille river estuary is an important stopover for migratory birds in the Pacific Flyway (National Audubon Society 2013). Providing high quality “rest stops” along these migratory “highways” for birds is important to ensure that they get enough food, cover, water and rest. Such drastic amounts of land use change, combined with the importance of the area to migratory birds, has motivated the US Fish and Wildlife Service (USFWS, hereafter) to acquire and restore tidal flows to a portion of the historic tidal marsh habitat in the Coquille River estuary that is a part of Bandon Marsh National Wildlife Refuge (BMNWR, hereafter). This 418 acre portion of land was converted from tidal marsh to pasture for cattle grazing about 100 years ago. Eleven million dollars was spent on completing this project in Bandon which involved filling agricultural ditches, digging pilot tidal channels, removal of levees, removal of tidegates, elevating a local road, putting fish-friendly culverts under the elevated road and relocating an electric transmission line underground between the years 2009-2011 (USFWS 2011).

The USFWS began a bird monitoring program in November 2009. Bird surveys began on the restoration site as well as a nearby unaltered tidal marsh as a reference for comparison in 2009 (two years before the restoration project was completed) and bird surveys finished in 2013 (two years after the restoration project was completed).The goals of the program were to determine (a) if certain species of birds used the restoration site or reference site more before versus after restoration, (b) if the composition of bird species changed after restoration, and (c) to document the accomplishment of bird conservation goals of the restoration project.

In 2011 I was employed as an intern on the restoration project to conduct the bird surveys on the restoration and reference sites. After my internship ended at the end of 2011 I started taking classes to begin working towards my MS degree at Oregon State University with the intent of using the entire bird survey data set, collected by myself and other observers as the basis of my MS research which looked at how birds responded to the restoration.

3.3 What did the Restoration Analysis Show?

In order to determine how the bird community changed after the restoration project, bird surveys were conducted on the restoration site many times before and after tidewater was returned to the former tidal marsh. Bird surveys were also done on an existing tidal marsh before and after the restoration. Doing many surveys on the same areas of the same sites over time allows for greater confidence in the patterns seen in numbers of birds on both sites. I could, therefore, see if there were changes in the numbers and types of birds on the restoration site and compare them to changes on an existing tidal marsh during the same time period.

I found that the numbers and types of birds on the restoration site and the existing tidal marsh were different before restoration and similar after restoration. The differences, however, were small. The data also showed that the numbers and types of birds seen in areas of the restoration site closest to tidal influence were most similar to types of birds seen on areas surveyed on the reference site with similar tidal influence.

Three types of birds observed on the restoration site (great egret, great blue heron and Northern pintail) were identified as being the most important bird species. This was based on how many birds of each type were seen and in how many different parts of the restoration site they were seen after the restoration project compared with before the restoration project. Great blue heron and great egret are wading birds that may have been enticed to the restoration site by greater fluctuations in water levels after tides were reintroduced. Having many of the channels draining to much lower levels during the low tides after restoration may have made hunting for fish easier for great blue heron and great egret.

Lower water level during low tides may have benefitted Northern pintail (a duck species) as well. A plant that Northern pintail have been known to eat colonized many of the tidal channels after restoration and this food source may have been accessed with greater ease by Northern pintail when the tide was low. Two types of birds (white-tailed kite and Brewer's blackbird) were identified as being important on the restoration site before the restoration. These two types of birds are not typical residents of tidal marshes and more likely to be found in other habitats like pastures.

It is not surprising that the change in the types of birds on the restoration site two years after restoration was small. Previous studies had measured changes in types and numbers of birds on tidal marshes before and after restoration for longer periods of time than this study before large-scale changes were seen in the types of birds on the marsh. The full effect of this restoration project on the birds may not be fully realized two years after the restoration has been complete. It does, however, provide a "report card" that managers can use to measure progress in meeting goals of creating an area with types and numbers of birds on the restoration site similar to an established tidal marsh. If the types and numbers of birds on the restoration site were measured again after more time was allowed for habitat conditions to change, and there was little change in the types and numbers of birds observed, managers might consider taking actions to aid in making the site more suitable for the needs of the types and numbers of birds desired.

Now that some success in restoration of birds in tidal marshes has been seen on the Oregon coast one might ask, “why should ecological restoration for birds in tidal marshes continue? If restoration is to be continued for the benefit of birds in tidal marshes how can interested members of the public become more involved?”

3.4 Why Should we Continue to Work Towards Conservation and Restoration?

Conservation of birds as a group of species is a reason for restoration of tidal marsh habitats to continue. Humans have become disconnected from some other species on the planet and often forget that we are a part of the biodiversity of, and reliant upon, the planet’s biodiversity for goods used in our everyday lives (Bibby 2002). When parts of the planet’s biodiversity are removed or become impaired it weakens the planet’s biodiversity as a whole.

To illustrate, let’s consider the biodiversity of a tidal marsh to be a giant game of “Jenga”. As blocks (in this case, species) are removed from and stacked on top, the structure of Jenga blocks (biodiversity) and stacked on top, more pressure is put on the structure as a whole and less support might be available at the foundation or key parts of the structure. Eventually, after many blocks are removed and placed on the top of the structure, the greater weight of these blocks decreases the integrity of the structure to the point of falling apart.

Scientists cannot predict if removing one of the bird species from a tidal marsh would be a tipping point for causing a collapse in biodiversity on a local or global scale. On the contrary, tidal marshes are changing quickly with changes seen in the climate and land use in and around tidal marshes. Some species in the tidal marsh may not be able to be maintained in their "historic structure." Although some species will be able to withstand the changes, other species may not.

Tidal marsh managers must, therefore, make decisions on where to focus their efforts. Should they focus more of their efforts on species that historically did well in tidal marshes? Or should they focus more of their efforts on species that are able to adapt to change and still serve the roles that are necessary for a functioning tidal marsh ecosystem? Making these management decisions is not an easy task and will require monitoring of bird numbers on many tidal marshes throughout their migratory pathways over time to determine if population size and habitat use patterns are changing.

Tidal marshes and estuaries are some of the most beneficial habitats to conserve in coastal and marine habitats due to the amount and variety of goods and services that they provide to humans and other species (McLeod and Leslie 2009). The soils of tidal marshes can act like a sponge and hold excess carbon from the atmosphere as a buffer against carbon emission-induced climate change. Restoring tidal marshes can act as flood mitigation by reconnecting historic floodplain habitat to the main channel and increasing the watershed's capacity to hold water. In addition, many people consider tidal marshes to be aesthetically pleasing landscapes so conservation is important to those people.

Tidal marshes in the Pacific Northwest also act as nurseries for young salmon and crabs. These two animals are important for their own roles in maintaining the health of the ocean and land, but also as income and food sources for commercial and recreational fishers. Other research teams on the restoration project at BMNWR saw a great increase in salmon as well as the appearance of dungeness crab in newly constructed tidal channels. Young dungeness crab and salmon benefitting from the restoration are also important parts of Oregon's economy. The dungeness crab fishery in Oregon in 2012 was worth $42.2 million and the salmon fishery in that year was worth $4 million (Oregon Department of Fish and Wildlife 2013).

There are additional economic reasons to restore tidal marsh habitats for birds. The popularity of birdwatching as a hobby has grown in recent years. In 2011, 47 million bird watchers (non-hunters alone) created $107 billion in industry output from equipment purchases and travel, which generated 666,000 jobs and contributed $13 billion in local, state and federal income tax revenue (Carver 2013). The spectacle of many migrating shorebirds and waterfowl traversing the Pacific Flyway and stopping in Oregon's tidal marshes draws tourists from all around. It also provides opportunity for the service industries in coastal towns to profit from some of the money brought in by birders (Davis and Radtke 2006).

An additional economic incentive for choosing to restore estuaries is the creation of jobs for restoration contractors, many of which are local. On the southern Oregon coast over $32 million in public and private investments, between 2001 and 2010, have sparked many companies to diversify their businesses in order to compete for bids for restoration work and hire workers that may otherwise be out of jobs (Davis et al. 2011). Furthermore, employees of these companies may never have been exposed to working to improve the condition of natural resources in their communities and this may promote further connection with the places where the companies' employees live.

3.5 Summary of Lessons Learned

Important lessons learned and aspects to consider when looking at the data from this project include:

- It may take more than two years after restoration to see a large change in the bird community as a whole.
- Certain species were identified as important after restoration, based on how many individuals were seen and where on the restoration site they were seen.
- Other pieces of the tidal marsh ecosystem including, but not limited to, plants, fish and tidal flow are changing along with the bird community.
- Reasons beyond birds exist for restoration of tidal marshes.
- There are many avenues for public involvement in conservation and restoration.

3.6 How can you get involved with bird conservation and restoration on the Oregon Coast?

While the challenges of restoring tidal marsh habitats for birds may seem difficult at times, it is important to remember that members of the public can be an invaluable resource. There are many actions the public can take to assist in the conservation and restoration of tidal marsh habitat for birds. The following is a list of possible actions and resources for citizens interested in assisting with these activities on the Oregon Coast.

●Volunteer with a federal land management agency.

Volunteer opportunities exist for members of the public to assist with bird and other wildlife surveys, native plant installation, and educational outreach on the Oregon Coast National Wildlife Refuges, Bureau of Land Management lands, and US Forest Service lands. To learn more see:

-USFWS Website: http://www.fws.gov/oregoncoast/refugevolunteers.htm

-BLM Website: http://www.blm.gov/or/volunteers/index.php

-USFS Website: http://www.fs.usda.gov/main/siuslaw/workingtogether/volunteering

- Volunteer with a state land management agency.

  The Oregon Department of Fish and Wildlife has opportunities similar to those with the federal agencies. The Oregon Department of Land Conservation and Development assists a volunteer board of seven community members (the Land Conservation and Development Commission) that provide input on land use planning issues in the state. Participation in this board could be important in that restoration projects can sometimes involve land ownership issues that may be addressed by this board. Advocates for tidal marshes are needed to let the state planning board know that there is public support for restoration of these habitats. To learn more see:

  -ODFW Website: http://www.dfw.state.or.us/agency/volunteer/

  -ODLCD Website: http://www.oregon.gov/LCD/pages/lcdc.aspx

- Volunteer with a watershed council.

  Watershed councils are place-based organizations that work to restore watersheds in Oregon while taking into account the opinions of other land users and industries that may be impacted by restoration. To learn more see:

  -Oregon Watershed Councils website: http://oregonwatersheds.org/

- Educate yourself and others through reading and attending local educational lectures.

  One of the easiest ways to get informed and involved in bird conservation and restoration is to read up on restoration, tidal marsh or bird conservation issues that matter to you, and to spread the word about these issues to others. Birds do not operate under the same timescales or geographic and political boundaries as humans; it is important to work with others across these boundaries for effective conservation actions.

●Consider how actions you take on your land effect land downstream and upstream.

Maintaining the mindset of connections – to surrounding land and estuaries – is helpful when making wise decisions about the use of your land. The impact of your use of land compounded with others' use of their land in the watershed ultimately impacts the health of estuaries and tidal marshes downstream.

●Inform decision makers of your desires for restoration and conservation.

When a land management agency in your area seeks comments on a proposed project or issue, provide them with feedback. Letting your opinion be heard is an important part of citizen involvement in management of public lands.

●Consider the opinions of others.

Although you may not share your opinion or see eye-to-eye on natural resource management issues, it is important to share your opinion and listen to the opinions of others. Ultimately, it's critical to find out what is important to you both and use these similarities as points to work towards a shared understanding of how natural resource management issues affect fellow citizens.

3.7 Conclusion

The title of this article poses the question "Is tidal marsh restoration a practice for the birds?" I believe it is a practice that has great potential to benefit birds, other species and humans. Many avenues are available for your participation in this practice and many groups that work on these issues welcome your participation.

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Chapter 4: Management Implications

4.1 Introduction

Research must be done in a manner that effectively answers the questions about the effects of the restoration on resources of interest. Scientific research and results must be communicated clearly to stakeholders and people who are making management decisions about the resources. Ideally, it may also provoke deeper scientific questions that address important questions in the relatively nascent field of restoration ecology (Nichols and Williams 2006). Connecting the public to restoration projects and the science behind monitoring abiotic and biotic response to the projects allows deeper connection to place, which is one of the fundamental tenets of ecosystem-based management (McLeod and Leslie 2009, McNutt 2013). This connection of people and place in coastal habitats is important now and in the future, as managers work across political and social boundaries to gain support for further restoration projects (Weinstein 2008). Managers of restoration projects need many pieces of information to be communicated to them to make decisions regarding resources under their jurisdiction that are informed by the best available science (Rosenberg and Sandifer 2009).

Rosenberg and Sandifer (2009) identified five principles to guide the development of an ecosystem-based approach to natural resources management. These are: (1) setting goals to encompass all ecosystem services, (2) determining the spatial scale for management planning, (3) integrating human activity, (4) accounting for cumulative impacts and (5) making decisions with regards to uncertainty. These principles are incorporated here to produce a set of management recommendations for tidal marsh restoration planning and monitoring with an avian emphasis. Recommendations for improving avian survey design are included first as the avian surveys are the basis of this project.

4.2 Management Recommendations

Avian Survey Design

- A more involved training program for observers could include:
    - Use of decoys at known distances to improve estimates of observers (Buckland et al. 2001).
    - Hearing and vision tests prior to hiring observers to ensure that inter-observer aural and visual acuity is similar (Fannes and Bystrak 1981, Buckland et al. 2001).
    - Employing double observer methodology to quantify inter-observer variation for better density estimates (Nichols et al. 2000).
- Use of different survey methods to account for variability in detection probabilities of different species at different tidal stages.
    - Different species are more prevalent at different stages of tide and the use of different survey techniques would allow for more holistic response of community. For example, boat-based surveys at higher tides may better account for abundances of waterfowl and wading birds which may be less detectable during lower tides, as they may be hidden in tidal channels (Woo et al. 2011).
- Include more than one reference site to avoid pseudoreplication issues.
    - Brophy et al. (2014) used a site in the Siuslaw River estuary as a reference for BMNWR for their flowpath profiles. Avian surveys done on the Siuslaw site or possibly a high marsh site, such as the South Slough National Estuarine Research Reserve in Charleston, in addition to the surveys on the Bandon Marsh unit reference site, could provide at least some semblance of replication if more tidal

marsh restoration is done in the Coquille river estuary. Spatial separation between restoration and reference sites assures that the parameters of interest are beyond each other's influence but in similar ranges of natural phenomena (Stewart-Oaten et al. 1986).

- Specific, quantifiable goals for the avian community's progression (e.g. X% increase in waterfowl use on site within Y number of years) would have facilitated formulating research questions as well as deciding on analysis techniques for this project. The need for specific and quantifiable goals is important in being able to define restoration success as well as incorporate the management goals for the avian community into that of the refuge as a whole (Howell et al. 2012, Conroy and Peterson 2013). Changes in target species use of restored sites after restoration seen in other studies may be used as guides to assist in formulating these goals. If uncertainty exists about expected response of some groups or species, the goals can be stated within a range of values concordant with the amount of uncertainty.
- Break transect legs up into independent sections that account for both edge and interior species. The sampling scheme that was used had many transect legs that abutted edge forest and river habitat. Having a better balance of transect legs through the interior of both sites may have picked up more tidal marsh-dependent species. Additionally, having transect legs that are independent reduces the possibility of birds being assigned to transect legs that adjoined on corners of the transect. Examples of adjoining corners where birds could have been assigned to different transect legs are seen in figure 2.1 where NLT legs 4 and 5 meet and where BMN legs 1 and 6 meet.

Setting Goals to Encompass all Ecosystem Services

- Develop a set of microhabitat type designations and record the habitat type in which each bird or group of birds was observed, behavior, and prey abundance, as done by Armitage et al. (2007) and Miller (2012). This data would help answer the question of how different species use the habitats, and if this changes before and after restoration. This will make inferences drawn from community analysis more substantive because it gets at habitat use at a finer scale than the transect leg. This data combined with the data from Brophy et al. (2014) would allow for a wider range of analyses. At the species level and guild level, modeling could be used to determine if microhabitat type, tidal stage, salinity, behavior or other covariates most influenced the response of species or guilds.
- Once the responses of species of interest to the aforementioned biotic and abiotic covariates are analyzed, the various ecosystem services provided by each covariate, including birds, can be quantified and connected to the restoration project (Farber et al. 2006, Beaumont et al. 2007, Wenny et al. 2011). Quantification of ecosystem services at BMNWR may be used as justification for funding further research on the site.

Determining Spatial Scale for Management Planning

- Monitoring plans for future restoration projects should be devised to continue to contribute to flyway-scale data of highly migratory species like the Pacific Flyway Shorebird Survey (Point Blue Conservation Science 2014). This will assist managers at BMNWR and other estuaries by having data at local, regional and flyway scales to assess abundances of species of management concern at a flyway scale. While the trends may not be strictly comparable between sites due to differences in sampling methodologies, they offer a rough idea of population size and site selection at a larger scale.

Integrating Human Activity Across Sectors

- Tidal marsh ecosystems are ecologically complex. Adding the societal dimensions and ideals that drive patterns of land use and recreation in and around tidal marshes complicates their management. Given the task of managing tidal marshes (and natural resources therein) on public land under the public trust doctrine and the coupled nature of social and ecological domains, the public should have input into how their marshes are managed. In the case of the avian component of tidal marshes, the public's opinion should be considered in conjunction with agency management goals to establish areas for hunting and areas for birdwatching, and protecting areas from disturbance. Finally, inclusion of citizen involvement in management plans is concordant with goal 1 of the Oregon Department of Land Conservation and Development, which looks to increase citizen involvement in land use planning (Oregon Department of Land Conservation and Development 2014). The OCNWRC has incorporated citizen feedback in its Comprehensive Conservation Plan through public meetings, as well as including local stakeholders in planting of native plants on the restoration site. These practices should continue and be augmented with other methods of citizen involvement discussed below.
- Incorporating the opinion of members of the public regarding the management of the avian component of tidal marshes can be done in many ways. Cohen (1988) and Vaske (2008) are useful starting places for methodology to assess public perception and opinion of natural resource management issues in a systematic manner.
- Collaborative learning can be useful for incorporating public opinion. This is a formal process whose goal is shared understanding of conflicting natural resource management objectives (Schusler et al. 2003). A neutral third party often facilitates discussions where

participants share their opinions on the matter at hand to work towards a common vision of appropriate management. Having a neutral third party helps with facilitating effective communication, which is paramount in creating meaningful dialogue that works towards change (Conway 1999). If restoration projects are planned in the future in the area of BMNWR, incorporating the community as much as possible from the beginning of the process to work towards shared goals for the avian and all other components of the coupled socio-ecological system may contribute to a better project in the long run.

Accounting for Cumulative Impacts and Tradeoffs Among Services

- Tidal marshes along the Oregon Coast have been highly impacted by cumulative impacts of human development (Good 2000). Methods for assessing the degree of tidal wetland functionality on the Oregon Coast have been developed (Adamus 2006). Assessing the functionality of tidal marshes and the degree to which cumulative impacts have impaired tidal marsh structure, function, processes and products (including the avian component) will assist managers in prioritizing areas for future restoration based on their current level of functionality.
- Potential costs of restoring future areas for birds versus other species and deciding the importance of birds versus other species can be used as criteria to assess tradeoffs of different restoration strategies.

Making Decisions Under Uncertainty

- Although some studies have examined avian response to tidal marsh restoration, much information is unknown about how birds respond to restoration in many geographic regions (Ortega-Alvarez and Lindig-Cisneros 2012). When compounded with uncertainty regarding the dynamics of the social side of the socio ecological system, the management of tidal marsh birds and restoration projects can seem daunting. Structured decision making techniques exist that can confront these issues by recognizing the uncertainty of information while guiding management decisions based on connections between the social and ecological systems (Conroy and Peterson 2013). Employing such techniques can lead to management decisions that reflect the interrelationships of all components of the socio ecological system in a transparent and accountable manner, clearly state connections between decisions and stated management objectives, contribute to institutional memory of the decision making process and integrate resources used for monitoring (Conroy and Peterson 2013).

4.3 Lessons learned about avian response to restoration

After embarking on a research project it is critical to assess the project outcomes and provide suggestions for improvement of similar projects in the future. Two overarching lessons learned from this project are of time and unintended consequences.

Time

It may take more time than was encompassed by the surveys in this project to see a community response to the restoration with a great effect size. Although the degree of change in the community was not great, this does not mean that the project has not achieved its goals of increased avian use of the restoration site. Some species such as great blue heron, great egret and Northern pintail were identified as significant indicators of the avian community on the site that were not seen as such before the restoration. Others, like green-winged teal, least Sandpiper and mallard saw increases in abundance and detection frequency on the restoration site and also to a lesser extent on the reference site. Given observed shifts in other abiotic and biotic parameters measured on the restoration site towards those parameters' functionality on the reference site it may not be long before a community response to the restoration project with a great effect size in the avian community is seen.

This restoration project was also designed to increase Sitka spruce swamp habitat. The time scale of forested wetland recovery compared with tidal marsh wetland development is much greater (Brophy 2009). As such, species more associated with forested wetlands like Hooded Merganser and Wood Duck, as well as the neotropical migratory songbirds that may use the adjacent spruce swamp, may become more prevalent if the structure and function of the spruce-swamp habitat increases, but their responses may take longer to see than the avian species that use the faster-maturing tidal marsh.

The factor of time in observing community change is at odds with the budgetary constraints placed on the monitoring program in only having funds for two years of post-restoration avian monitoring. Limited monitoring budgets are common in the field of ecological restoration so it will be important for practitioners on future tidal marsh monitoring efforts to seek funding that allows for adequate measurement of response of the avian community and all other parameters to the projects (Shriver and Greenberg 2012). Time is also important to gaining greater acceptance of the project in Coos County. Proactive community involvement beyond the requirements of NEPA may aid in gaining greater community acceptance. Strategies to assimilate the positive and negative feedback from the community combined with enhanced restoration strategies will be important to increase resilience in the coupled socioecological system of Coos County (Walker et al. 2004, McLeod and Leslie 2009).

Unintended consequences

When conducting ecological restoration projects there is the potential for unintended consequences to occur as a result of the restorative actions (Hobbs et al. 2011). An unintended consequence of the restoration at BMNWR was the increase in mosquito production on the site after the project had been completed. Pools of standing water left from higher tides on the site were densely colonized by mosquitos in spring and summer 2013. The density of mosquitos on the site, which affected surrounding residential areas, ignited a public push for corrective action. An integrated marsh management plan (IMM) was developed to include larvicide application and digging of additional tidal channels to facilitate drainage of some of the largest pools (U.S. Fish and Wildlife Service 2014).

Clarke et al. (1984) found that ditching for pool drainage did not significantly decrease the amount of invertebrate and fish prey available to birds. However, the prey is less accessible after ditching due to the decrease in pools which make the prey easier to catch for birds. This resulted in less abundant and diverse avian populations on ditched sites than sites with pools. In a newer IMM project design with more heterogeneity in channel shape, Rochlin et al. (2012) saw greatest increases in shorebird, waterfowl, and wading birds after the project had been implemented. Contrasting the two approaches of straight ditching versus sinuous ditching it appears that sinuous or branched ditching that creates more heterogeneity in the marsh and may be the best alternative for maintaining a more diverse avian community on the site.

Most of the groundwork for the IMM project at BMNWR has been completed as of October 2014. Nonetheless, design features of IMM projects such as the one discussed in Rochlin et al. (2012) should be considered if additional IMM is needed at BMNWR and/or in future restoration plans for other tidal marshes in Oregon, where consistent with natural geomorphic processes and if mosquitos may present a problem. Reducing mosquito use of NLT through physical manipulation warrants future study of impacts on other organisms, such as birds. Monitoring of the avian community after the IMM project is complete will inform managers of the effectiveness of their efforts to control mosquito populations while maintaining habitat for the avian community. The USFWS is planning to conduct avian surveys on the site beginning in 2015. Response to the mosquito issue has taken significant financial and human capital and will continue to require time and attention. Organizations implementing tidal marsh restoration projects may want to set aside discretionary funding at the outset of the project in the event that unintended consequences require corrective action in the future.

4.4 Possible future concerns to address

Several other factors must be considered when looking into the future of the avian community and tidal marsh restoration at BMNWR and the Coquille river estuary. One is sea level rise. If the marshes on BMNWR are not able to accrete at a faster rate than the sea level is rising, loss of habitat could eliminate some of the critical areas of the refuge for birds (Hughes 2004) and nullify the gains made by restoration. This underscores the need to consider restoration on properties that are upriver that are historical tidal marshes, assuming they are less susceptible to the impacts of sea level rise. At odds with the need to restore habitat less at risk of sea level rise effects is the current sociopolitical climate that is not in favor of many actions taken by the USFWS. If the trends of decreasing USFWS budgets continue, lack of funding for both restoration and monitoring may hamper the efforts to acquire, restore and monitor more tidal marsh habitat in the Coquille River estuary. Finally, the cumulative effects of climate change, land use change and other drivers of change at unprecedented scales may result in the appearance of ecosystem structures that are outside of the range of historical variation, and thus pose new management challenges (Hulvey et al. 2013).

4.5 Conclusion

The perpetual interplay of avian communities, ecosystem structure and function and human desire to manage ecological systems, poses interesting challenges. The ability of current and future leaders in the natural resources management field to communicate management and research to multiple parties does so as well. This project and my coursework at Oregon State have prepared me for the task of multifaceted communication and I look forward to implementing and further refining these skills as a natural resources management professional.

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APPENDICES

Appendix A. Observer and weather data summary for avian surveys conducted on the restoration site (NLT) and reference site (BMN) at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA from December 2009 – August 2013.

	NLT		**BMN**	
Condition	*# Surveys Pre*	*# Surveys Post*	*# Surveys Pre*	*# Surveys Post*
Observer				
WTB	16	28	12	27
WTB & RR	4	0	5	0
WTB & CMB	3	0	2	0
CMB	10	0	10	0
WTB & BKW	4	0	3	0
BKW	14	6	16	6
BKW + 2	1	1	1	1
BKW + 3	1	0	0	0
WTB & JPM	0	2	0	1
JPM	0	18	0	20
KC & WTB	0	0	1	0
Times				
Mean Start Time	7:29	9:29	9:06	9:27
Mean End Time	10:19	11:46	11:01	10:56
Mean Total Time Surveyed	2:49	2:17	1:55	1:29
Sky Cover[1]				
0	7	17	14	12
1	12	18	17	20
2	34	20	19	23
Precipitation[1]				
0	43	50	41	43
4	2	3	2	5
5	3	1	4	5
8	4	1	3	1
4 & 8	0	0	0	1
4, 5 & 8	1	0	0	0
Beaufort Number[2]				
0	20	10	14	9
0.5	17	11	8	14
1	7	17	9	19
0-1	1	0	0	0
1.5	5	15	6	6
2	3	2	9	3
2.5	0	0	0	4
3	0	0	2	0
3.5	0	0	1	0

Noise Interference[3]				
Missing	5	0	0	0
0	14	17	0	0
0.5	0	1	0	0
0-1	3	0	0	0
0-3	1	0	0	0
1	11	31	0	18
1.5	3	0	8	1
1-2.5	2	0	0	0
1-3	6	1	0	0
1-4	1	0	0	0
2	3	5	40	32
2.5	0	0	1	3
2-3	2	0	0	0
2-4	1	0	0	0
3	0	0	1	1
4	1	0	0	0
Temperature (Celsius)				
mean	11.194	13.947	13.282	13.489
SE	0.568	0.534	0.547	0.498
Tide Height (m)				
mean	0.222	0.212	0.155	0.217
SE	0.071	0.061	0.068	0.057

Appendix A footnotes

[1]*Sky cover and precipitation code definitions*

Code	Condition
	Sky Cover
0	clear or a few clouds
1	partly cloudy (scattered) or variable sky
2	cloudy (broken) or overcast
	Precipitation
0	no precipitation
4	fog or smoke
5	Drizzle
7	Snow
8	showers

[2]*Wind speed code definitions*

Beaufort Number	Wind Speed Indicators	Wind Speed (mph/kph)
0	smoke rises vertically	< 1 / < 2
1	wind direction shown by smoke drift	1 - 3 / 2 - 5
2	wind felt on face; leaves rustle	4 - 7 / 6 - 12
3	leaves, small twigs in constant motion; light flag extended	8 - 12 / 13 - 19
4	raises dust and loose paper; small branches are moved	13 - 18 / 20 - 29
5	small trees in leaf sway; crested wavelets on inland waters	19 - 24 / 30 - 38

[3]*Noise interference code definitions*

Noise Interference Code	Definition
0	no noise
1	faint noise
2	moderate noise (probably cannot hear birds beyond 100m)
3	loud noise (probably cannot hear birds beyond 50m)
4	intense noise (probably cannot hear birds beyond 25m)

Appendix B. Summary of raw observations by species on each transect pre (December 2009 – August 2011) and post restoration (December 2011 – August 2013). Observations greater than 200 meters from the transect and fly-overs were not included in these numbers. A detection was defined as a group of one or more individuals. Total number of individuals was defined as the sum of the individuals in all detections. Four letter species codes are listed after the species name in parenthesis.

	NLT				**BMN**			
	# Detections		Total # Individuals		# Detections		Total # Individuals	
Species	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Aleutian Canada Goose (ACGO)	0	0	0	0	2	2	32	160
Allen's Hummingbird (ALHU)	2	3	2	3	0	0	0	0
American Bittern (AMBI)	1	1	1	1	0	0	0	0
American Coot (AMCO)	0	2	0	2	1	4	1	11
American Crow (AMCR)	39	19	94	62	20	16	29	42
American Goldfinch (AMGO)	97	57	210	150	26	15	33	27
American Kestrel (AMKE)	15	6	15	6	0	0	0	0
American Pipit (AMPI)	14	33	122	315	0	6	0	34
American Robin (AMRO)	143	50	178	80	7	10	13	14
American Wigeon (AMWI)	0	1	0	4	0	2	0	14
Bald Eagle (BAEA)	0	1	0	1	0	2	0	2
Band-tailed Pigeon (BTPI)	4	3	17	4	4	4	5	14
Barn Owl (BANO)	1	1	1	1	0	0	0	0
Barn Swallow (BARS)	23	10	161	19	6	7	39	49
Belted Kingfisher (BEKI)	15	5	16	5	4	0	4	0
Bewick's Wren (BEWR)	0	0	0	0	2	1	2	1
Black Brant (BLBR)	0	0	0	0	0	1	0	100
Black Phoebe (BLPH)	23	16	24	16	0	0	0	0
Black Turnstone (BLTU)	0	0	0	0	1	0	7	0
Black-bellied Plover (BBPL)	0	0	0	0	4	3	10	3
Black-capped Chickadee (BCCH)	115	45	256	88	50	19	70	31
Black-headed Grosbeak (BHGR)	25	13	27	13	13	6	13	6
Bonaparte's Gull (BOGU)	0	0	0	0	1	0	1	0
Brandt's Cormorant (BRAC)	0	0	0	0	1	0	3	0
Brewer's Blackbird (BRBL)	12	2	18	4	14	13	85	213
Brown Creeper (BRCR)	0	0	0	0	1	0	1	0
Brown Pelican (BRPE)	0	0	0	0	1	0	3	0
Brown-headed Cowbird (BHCO)	36	12	49	12	6	3	11	3
Bufflehead (BUFF)	14	34	27	106	48	45	128	165

Bushtit (BUSH)	2	0	14	0	0	1	0	20
Cackling Goose (CACG)	3	0	7	0	0	1	0	2
California Gull (CAGU)	4	2	63	3	8	16	189	192
California Quail (CAQU)	3	0	3	0	0	1	0	2
Canada Goose (CAGO)	66	100	850	996	115	95	381	266
Caspian Tern (CATE)	0	0	0	0	1	2	2	6
Cassin's Vireo (CAVI)	0	0	0	0	0	1	0	1
Chestnut-backed Chickadee (CBCH)	30	7	43	17	26	12	54	29
Cedar Waxwing (CEDW)	70	29	149	136	64	17	136	104
Cliff Swallow (CLSW)	11	2	29	33	3	0	7	0
Common Loon (COLO)	2	0	2	0	6	11	6	18
Common Merganser (COME)	0	0	0	0	0	2	0	6
Common Raven (CORA)	0	2	0	2	0	2	0	3
Common Yellowthroat (COYE)	165	152	123	141	8	3	8	3
Dark-eyed Junco (DEJU)	3	3	13	7	0	0	0	0
Double-crested Cormorant (DCCO)	27	18	47	21	52	40	377	393
Downy Woodpecker (DOWO)	28	20	31	22	1	2	1	2
Dunlin (DUNL)	0	2	0	10	3	0	22	0
Eurasian Collared-dove (EUCD)	5	7	5	11	0	3	0	3
European Starling (EUST)	12	7	38	21	0	2	0	8
Evening Grosbeak (EVGR)	0	1	0	2	0	1	0	50
Fox Sparrow (FOSP)	2	2	2	2	1	0	1	0
Gadwall (GADW)	0	0	0	0	1	0	2	0
Glaucous Gull (GLGU)	0	0	0	0	2	1	5	1
Glaucous-winged Gull (GWGU)	2	0	7	0	12	5	269	28
Golden-crowned Kinglet (GCKI)	6	1	7	1	9	2	9	3
Golden-crowned Sparrow (GCSP)	2	0	2	0	0	0	0	0
Great Egret (GREG)	1	16	1	19	5	7	8	7
Great Blue Heron (GBHE)	10	37	10	39	23	34	23	37
Greater Scaup (GRSC)	0	0	0	0	0	2	0	4
Greater Yellowlegs (GRYE)	5	12	15	30	6	4	10	4
Greater White-fronted Goose (GWFG)	0	3	0	21	1	2	1	17
Green-winged Teal (GWTE)	8	66	754	1826	4	7	20	82
Hairy Woodpecker (HAWO)	3	4	3	4	0	0	0	0
Hermit Thrush (HETH)	0	4	0	4	0	0	0	0
Hooded Merganser (HOME)	0	6	0	21	1	0	4	0
Horned Grebe (HOGR)	0	0	0	0	1	3	1	4
House Finch (HOFI)	11	14	19	32	4	3	5	3
Hutton's Vireo (HUVI)	5	7	5	7	0	0	0	0

Killdeer (KILL)	36	49	81	131	4	2	15	3
Least Sandpiper (LESA)	6	45	38	1052	6	5	110	403
Lesser Goldfinch (LEGO)	0	0	0	0	1	0	1	0
Lesser Yellowlegs (LEYE)	1	1	1	1	0	1	0	1
Lincoln’s Sparrow (LISP)	7	17	8	24	1	2	2	2
Long-billed Dowitcher (LBDO)	0	5	0	16	0	0	0	0
Mallard (MALL)	43	128	181	1039	56	39	478	273
Marsh Wren (MAWR)	1225	1119	1494	1399	315	364	361	405
Merlin (MERL)	0	1	0	1	0	0	0	0
Mourning Dove (MODO)	2	1	2	2	0	4	0	4
Northern Flicker (NOFL)	44	27	55	28	31	30	42	34
Northern Harrier (NOHA)	8	16	8	17	4	14	4	14
Northern Pintail (NOPI)	0	15	0	116	4	0	74	0
Orange-crowned Warbler (OCWA)	24	29	28	33	7	11	7	11
Osprey (OSPR)	5	0	5	0	0	1	0	1
Pacific Wren (PAWR)	7	1	7	1	2	0	2	0
Pacific-slope Flycatcher (PSFL)	26	12	26	13	9	1	9	1
Palm Warbler (PAWA)	1	0	1	0	0	0	0	0
Pectoral Sandpiper (PESA)	0	2	0	13	0	0	0	0
Peep Sandpipers (PEEPs)	3	5	33	349	8	3	316	18
Pelagic Cormorant (PECO)	6	10	10	12	2	1	2	3
Peregrine Falcon (PEFA)	1	4	1	4	0	1	0	1
Pigeon Guillemot (PIGU)	0	0	0	0	2	3	2	8
Pileated Woodpecker (PIWO)	6	4	6	4	0	0	0	0
Pine Siskin (PISI)	0	3	0	70	0	0	0	0
Purple Finch (PUFI)	0	2	0	3	0	0	0	0
Purple Martin (PUMA)	7	7	7	12	2	1	3	2
Red Crossbill (RECR)	3	12	40	117	0	3	0	154
Red Knot (REKN)	0	0	0	0	0	1	0	22
Red-breasted Merganser (RBME)	0	0	0	0	3	1	6	1
Red-breasted Nuthatch (RBNU)	9	6	9	7	5	3	5	5
Red-necked Grebe (RNGR)	0	0	0	0	1	0	1	0
Red-necked Phalarope (RNPH)	0	2	0	72	1	1	1	3
Red-shouldered Hawk (RSHA)	1	12	1	12	0	1	0	1
Red-tailed Hawk (RTHA)	17	19	17	19	1	4	1	4
Red-throated Loon (RTLO)	0	0	0	0	0	1	0	1
Red-winged Blackbird (RWBL)	4	7	5	14	0	0	0	0
Ring-billed Gull (RBGU)	0	0	0	0	0	5	0	32
Ring-necked Duck (RNDU)	0	0	0	0	0	1	0	2
Rock Pigeon (ROPI)	0	0	0	0	0	1	0	1
Rufous Hummingbird (RUHU)	4	9	6	11	0	0	0	0

Ruby-crowned Kinglet (RCKI)	18	29	37	44	10	6	11	6
Savannah Sparrow (SAVS)	1451	767	1856	1089	654	369	765	443
Semipalmated Plover (SEPL)	1	2	4	21	3	4	171	139
Sharp-shinned Hawk (SSHA)	2	2	2	2	0	0	0	0
Short-billed Dowitcher (SBDO)	1	7	1	29	1	3	7	23
Short-eared (SEOW)	0	3	0	3	0	0	0	0
Solitary Sandpiper (SOSA)	1	0	1	0	0	0	0	0
Song Sparrow (SOSP)	1335	832	1790	1137	535	388	649	464
Sora (SORA)	0	0	0	0	2	0	2	0
Spotted Towhee (SPTO)	20	3	21	3	6	1	6	1
Steller’s Jay (STJA)	97	54	127	64	17	15	27	21
Surf Scoter (SUSC)	0	0	0	0	27	20	72	81
Swainson’s Thrush (SWTH)	64	38	65	41	30	22	31	23
Swamp Sparrow (SWSP)	0	1	0	1	0	0	0	0
Townsend’s Warbler (TOWA)	2	1	2	2	0	0	0	0
Tree Swallow (TRES)	41	18	81	47	3	0	4	0
Tropical Kingbird (TRKI)	0	1	0	1	0	0	0	0
Turkey Vulture (TUVU)	8	1	31	2	1	2	1	7
Unidentified Dowitcher (UNDO)	1	2	100	32	0	2	0	255
Unidentified Hummingbird (UNHU)	2	2	2	2	0	0	0	0
Unidentified Larid Gull (UNLG)	3	0	6	0	17	1	59	10
Unidentified Rail (UNRA)	1	0	3	0	0	0	0	0
Unidentified Swallow (UNSW)	2	0	21	0	0	0	0	0
Unidentified Woodpecker (UNWO)	1	0	1	0	0	0	0	0
Varied Thrush (VATH)	4	7	4	7	0	3	0	3
Violet-green Swallow (VGSW)	2	3	2	4	2	0	2	0
Virginia Rail (VIRA)	27	31	33	41	12	13	12	14
Warbling Vireo (WAVI)	3	4	3	4	2	0	2	0
Western Grebe (WEGR)	2	2	2	2	6	6	17	7
Western Gull (WEGU)	1	4	1	17	47	45	608	487
Western Kingbird (WEKI)	1	0	1	0	0	0	0	0
Western Meadowlark (WEME)	15	13	139	67	33	37	175	276
Western Sandpiper (WESA)	2	9	3	430	8	6	524	1343
Western Tanager (WETA)	6	7	7	8	8	1	8	1
Western Wood-pewee (WEWP)	9	3	9	3	0	0	0	0
Whimbrel (WHIM)	0	0	0	0	0	1	0	31
White-breasted Nuthatch (WBNU)	1	0	1	0	0	0	0	0
White-crowned Sparrow (WCSP)	94	44	102	104	13	1	13	1
White-tailed Kite (WTKI)	16	3	18	3	4	3	4	3

White-winged Scoter (WWSC)	0	0	0	0	0	1	0	2
Wilson's Snipe (WISN)	18	50	31	88	12	7	15	7
Wilson's Warbler (WIWA)	31	9	36	10	8	3	8	3
Wood Duck (WODU)	3	1	13	5	0	0	0	0
Wrentit (WREN)	68	39	74	41	9	3	9	3
Yellow Warbler (YWAR)	0	0	0	0	2	0	2	0
Yellow-rumped Warbler (YRWA)	30	26	61	59	21	15	88	56

Appendix C. Comparison of diversity measures between transects on the restoration (NLT) and reference (BMN) sites at Bandon Marsh National Wildlife Refuge, Bandon, Oregon, USA before and after tidal marsh restoration.

	S (Richness)		**E (Evenness)**		**H (Shannon's Diversity)**		**D (Simpson's Diversity)**	
Transect Leg	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
BMN 1	54	58	0.845	0.849	3.372	3.446	0.951	0.956
BMN 2	46	35	0.804	0.839	3.076	2.983	0.938	0.934
BMN 3	20	30	0.886	0.865	2.654	2.941	0.916	0.931
BMN 4	30	36	0.857	0.863	2.914	3.091	0.932	0.943
BMN 5	25	19	0.787	0.817	2.532	2.407	0.891	0.888
BMN 6	47	51	0.829	0.818	3.192	3.218	0.947	0.945
Mean	37	38.2	0.835	0.842	2.957	3.014	0.929	0.933
SE	5.633	5.793	0.015	0.009	0.131	0.142	0.009	0.010
NLT 1	73	69	0.869	0.825	3.730	3.494	0.967	0.955
NLT 2	62	66	0.843	0.855	3.479	3.582	0.954	0.960
NLT 3	35	42	0.823	0.836	2.925	3.126	0.928	0.944
NLT 4	26	33	0.740	0.807	2.412	2.823	0.867	0.927
NLT 5	23	17	0.704	0.741	2.207	2.101	0.830	0.839
NLT 6	38	17	0.782	0.700	2.845	1.983	0.904	0.800
NLT 7	37	42	0.820	0.841	2.962	3.043	0.929	0.938
NLT 8	62	47	0.842	0.823	3.475	3.170	0.956	0.940
Mean	44.5	41.6	0.803	0.800	3.004	2.915	0.917	0.913
SE	6.571	6.892	0.020	0.019	0.189	0.209	0.017	0.021

Appendix D. Summary of abbreviations used in the text

BACI – Before-After Control-Impact study design

BMN – Bandon Marsh North unit (reference site) avian monitoring transect

BMS – Bandon Marsh South unit (reference site) avian monitoring transect (not included in analyses)

BMNWR – Bandon Marsh National Wildlife Refuge

FHWA – Federal Highway Administration (Western Federal Lands Division)

ha - hectare

IMM – Integrated Marsh Management

ISA – Indicator Species Analysis

m - meter

MRPP – Multi-response Permutation Procedures

NLT – Ni-les'tun unit (restoration site) avian monitoring transect

NMDS – Non-metric Multidimensional Scaling

OCNWRC – Oregon Coast National Wildlife Refuge Complex

PSU – Practical Salinity Units

USFWS – U.S. Fish and Wildlife Service