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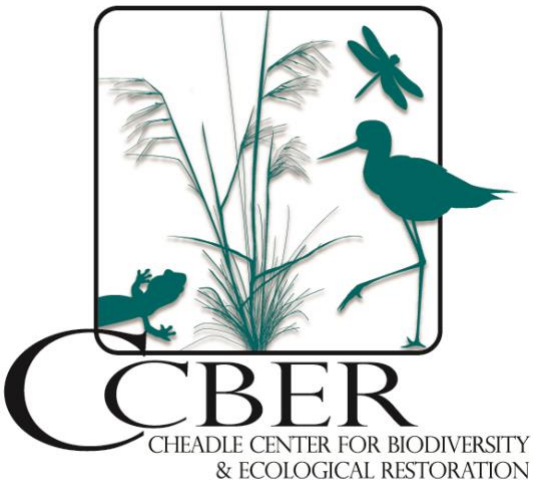

Bird Community Analysis Report

1967 – 2015

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Summary of Bird Survey Data

Prepared for:

Cheadle Center for Biodiversity and Ecological Restoration

Santa Barbara Land Trust

Karen A. Stahlheber

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Contents

Section 1 – Comparison of wetland habitats

Bird surveys covered many different locations over the time period from 1967 – 2014. These locations were assigned to a specific wetland habitat type in the database (TABLE 1.1). Here I compare Shannon-Wiener diversity (BOX 1.1) and bird community composition among the habitat types using a variety of approaches.

BOX 1.1

Shannon-Wiener Diversity (H'): Higher values indicate higher species diversity. Shannon Diversity quantifies the uncertainty/entropy in predicting the species identity of an individual that is taken at random from the dataset.

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

Prior to analysis, I excluded walking surveys that did not report bird counts by each location separately, as wetland habitat couldn't be assigned. Pacific Gas and Electric (PGE), Southern California Edison (SCE) and Delco Area (DA) have no associated habitat type in the database with the data, so these have also been excluded.

For the first approach, I took a monthly average of the numbers counted for each bird species (within locations and years). Sometimes locations were visited multiple times over short date intervals. Then I calculated Shannon-Wiener diversity for monthly average composition at each site, and averaged this by year. Temporal trends in these data were complex (FIG 1.1). Estuarine and/or brackish habitats frequently had higher diversity than coastal or intertidal wetlands, but all habitats fluctuated widely. Some habitat types have data coverage that far exceeds others. For instance, there is only a single 'seasonal wetland' point (from Area I, Goleta Slough).

Excluding the 'seasonal wetland' habitat, I compared the overall mean diversity within each wetland habitat type using a Kruskal-Wallis rank-sum test. All yearly means were included in this analysis, leading to large differences in sample size between habitats, but variances were equal according to Levene's Test ($p = 0.23$). There were highly significant differences between wetland types (FIG 1.2; $\chi^2 = 48.21$, df = 8, $p < 0.001$). Tidal marshes had the highest average diversity, followed by brackish ponds. Coastal strand and rocky intertidal habitats were lowest. To evaluate the temporal consistency of diversity, I calculated the coefficient of variation (CV) within each habitat (TABLE 1.2).

Devereux Slough, Goleta Slough and the UCSB Campus Lagoon are three of the larger wetland locations. Devereux and Goleta contain many different habitat types and water level varies considerably throughout the year, whereas the Campus Lagoon has a very consistent water level, but a smaller number of habitats. Shannon-Wiener diversity was highly variable prior to 1990 (FIG 1.3). I compared mean diversity from 1990 – 2014 among the three locations using an ANOVA, and found no significant differences (FIG 1.4). NOTE – In this analysis areas of Coal

Oil Point Reserve were included as part of the Devereux site, including Devereux Dunes, Devereux Beach, Dune Pond, and West/East Devereux Slough.

I also compared bird communities among wetland habitat types using non-metric multidimensional scaling (NMDS), a type of ordination analysis well-suited to community data. Significance of various factors on NMDS scores can be testing using permutational ANOVA (PERMANOVA). Prior to performing this analysis, I removed bird species that occurred in fewer than 10% of the monthly survey averages. Habitat did significantly influence bird composition (FIG 1.5), although this effect varied over time (Wetland * Year interaction: $F_{8,1562} = 2.33$, $p < 0.001$). Similarity percentage analysis (SIMPER) can be used to generate pairwise comparisons of habitat types (see R code to generate full results). For example, I compared coastal strand and tidal marsh habitats, two wetland types that were significantly different in diversity (TABLE 1.3). Indicator species analysis revealed many species that were positively associated with specific wetland habitat types. Unlike with the NMDS, I included all species in these analyses.

Table 1.1 – Assigned wetland habitat categories found in the bird survey database by broad and specific locations.

Broad Location	Specific Location	Dominant Wetland Habitat	Cowardin (1979) and Ferren (1987) classification
Campus Lagoon	Campus beach	Coastal strand	Coastal strand
	Campus beach areas	Coastal strand	Coastal strand
	Campus Lagoon	Brackish pond	Salt marsh
	Campus Point	Rocky intertidal	Seasonal palustrine wetland
	Manzanita Village	Vernal pool	Seasonal palustrine wetland
Coal Oil Point Reserve	Created vernal pools	Vernal pools	Seasonal palustrine wetland
	Coal Oil Point Reserve (AKA West Devereux)	Brackish pond	Estuarine system
	Devereux beach	Coastal strand	Coastal strand
	Devereux dunes	Coastal strand	Coastal strand
	Devereux slough (AKA East or Lower Devereux)	Brackish pond	Estuarine system
	Dune pond (west of Devereux Slough)	Freshwater marsh	Persistent palustrine emergent wetland
Goleta Slough	Area I	Seasonal wetland	Seasonal palustrine emergent wetland
	Area J	Freshwater marsh	Persistent palustrine emergent wetland
	Area K	Brackish marsh	Persistent palustrine emergent wetland
	Area L	Tidal marsh	Persistent estuarine emergent wetland
	Area M	Tidal marsh	Persistent estuarine emergent wetland
	Basin X	Tidal marsh	Persistent estuarine emergent wetland
	Fish and Game Ecological Reserve	Brackish marsh	Persistent palustrine emergent wetland
	Fish and Game wetlands (Los Carneros Rd)	Brackish marsh	Persistent palustrine emergent wetland
	Goleta Beach	Coastal strand	Coastal strand
	Goleta Sanitary District Ponds	Freshwater marsh	Persistent estuarine emergent wetland
	Goleta Slough (includes airport)	Tidal marsh	Estuarine system
	Goleta Slough mouth	Tidal wetland	Estuarine system
	Goleta Sough (all areas master tally, CBC only)	Tidal marsh	Estuarine system
	North Bluff	Riparian woodland	Forested persistent palustrine wetland
	Santa Barbara Airport	Tidal wetland	Estuarine system
Greater Devereux Area	Ellwood Mesa	Vernal pool	Seasonal palustrine wetland
	Ellwood Mesa beach	Coastal strand	Coastal strand
	North Finger (of Devereux Slough)	Brackish marsh	Persistent palustrine emergent wetland
	North Parcel	Vernal pool	Seasonal palustrine wetland
	Ocean Meadows Golf Course	Freshwater marsh	Persistent palustrine emergent wetland
	Phelp's Ditch (includes Phelps Creek & Encanto Creek)	Riparian woodland	Forested persistent palustrine wetland
	South Finger (of Devereux Slough)	Brackish marsh	Persistent palustrine emergent wetland
	South Parcel	Vernal pool	Seasonal palustrine wetland
	West Campus bluffs	Vernal pool	Seasonal palustrine wetland
Isla Vista	Camino Corto Open Space	Vernal pool	Seasonal palustrine wetland
	Del Sol Open Space	Vernal pool	Seasonal palustrine wetland
	Isla Vista	Vernal pool	Seasonal palustrine wetland
	Isla Vista beach	Coastal strand	Coastal strand
	Isla Vista sewage	Tidal wetland	Persistent estuarine emergent wetland
Storke Campus	East Storke Campus wetland	Brackish marsh	Persistent palustrine emergent wetland
	Francisco Torres wetland	Brackish marsh	Persistent palustrine emergent wetland
	San Clemente Open Space	Freshwater marsh	Persistent palustrine emergent wetland
	Storke Campus	Brackish marsh	Persistent palustrine emergent wetland
	Storke Ranch wetlands	Brackish marsh	Persistent palustrine emergent wetland
	West Storke Campus wetlands (AKA W Storke Campus)	Brackish marsh	Persistent palustrine emergent wetland

Table 1.2 – Coefficient of variation (CV) in Shannon Diversity for each habitat type, calculated over years. Higher values indicate more variation between years.

Wetland habitat	n	CV
Brackish marsh	28	40.82
Coastal strand	31	40.54
Vernal pool	21	40.51
Brackish pond	42	37.22
Tidal marsh	34	34.53
Freshwater marsh	29	34.13
Riparian woodland	11	31.42
Rocky intertidal	22	27.37
Tidal wetland	10	20.33

Table 1.3 – Similarity Percentages (SIMPER) showing species most responsible for the differences between coastal strand and tidal marsh wetland habitats (dissimilarity in the NMDS analysis), across all years. The cumulative proportion of dissimilarity explained by the species shown below is ~75%. Averages are relative proportional abundance of a species.

Bird species	Average – tidal marsh	Average – coastal strand	Proportional contribution to dissimilarity
Western Gull	0.012	0.076	0.051
Sanderling	0.006	0.064	0.044
Rock Pigeon	0.050	0.024	0.043
House Finch	0.035	0.045	0.040
Double-crested Cormorant	0.006	0.047	0.032
Great Blue Heron	0.045	0.008	0.030
American Coot	0.033	0.019	0.030
Brown Pelican	0.001	0.038	0.025
California Gull	0.014	0.027	0.024
Killdeer	0.030	0.014	0.024
Snowy Plover	0.002	0.034	0.024
Heermann's Gull	0.007	0.029	0.022
Song Sparrow	0.020	0.023	0.022
Mallard	0.025	0.015	0.021
Black-bellied Plover	0.004	0.029	0.021
American Crow	0.017	0.019	0.019
Willet	0.006	0.026	0.019
Least Sandpiper	0.026	0.005	0.019
Western Sandpiper	0.019	0.012	0.019
White-crowned Sparrow	0.022	0.009	0.019
Northern Shoveler	0.027	0.001	0.018
Cliff Swallow	0.019	0.008	0.017
Bushtit	0.014	0.015	0.016
European Starling	0.010	0.015	0.015
White-tailed Kite	0.018	0.003	0.014
Savannah Sparrow	0.021	0.001	0.014
Greater Yellowlegs	0.006	0.017	0.013
Snowy Egret	0.010	0.011	0.013
Whimbrel	0.003	0.017	0.013
Marbled Godwit	0.004	0.015	0.012
Black Phoebe	0.008	0.016	0.012
Western Grebe	0.007	0.011	0.012
Black Turnstone	0.001	0.015	0.012
Common Yellowthroat	0.015	0.008	0.012
Canada Goose	0.016	0.001	0.011

Table 1.4 – Indicator species analysis, identifying species whose relative frequency is significantly higher in the listed habitat than all other habitats. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$ after correction for multiple comparisons. Table continues on following page.

Species	Habitat	Species	Habitat	Species	Habitat
Cinnamon Teal	Brackish marsh***	California Gull	Coastal strand***	Pink-footed Shearwater	Rocky intertidal**
Gadwall	Brackish marsh***	Elegant Tern	Coastal strand***	Red-necked Grebe	Rocky intertidal*
Red-winged Blackbird	Brackish marsh***	Greater Yellowlegs	Coastal strand***	American Crow	Seasonal wetland***
Swamp Sparrow	Brackish marsh***	Heermann's Gull	Coastal strand***	Barn Owl	Seasonal wetland***
Cliff Swallow	Brackish marsh**	Least Tern	Coastal strand***	California Quail	Seasonal wetland**
Wilson's Phalarope	Brackish marsh**	Marbled Godwit	Coastal strand***	Song Sparrow	Seasonal wetland**
Cassin's/Western Kingbird	Brackish marsh**	Sanderling	Coastal strand***	California Thrasher	Seasonal wetland*
Northern Shoveler	Brackish marsh**	Surfbird	Coastal strand***	Red-shafted Flicker	Seasonal wetland*
White-eyed Vireo	Brackish marsh*	Western Gull	Coastal strand***	Nuttall's Woodpecker	Seasonal wetland*
American Wigeon	Brackish pond***	Whimbrel	Coastal strand***	Common Yellowthroat	Seasonal wetland*
American White Pelican	Brackish pond***	Willet	Coastal strand***	Swainson's Thrush	Seasonal wetland*
Black-bellied Plover	Brackish pond***	Glaucous-winged Gull	Coastal strand**	Black-headed Grosbeak	Seasonal wetland*
Caspian Tern	Brackish pond***	Herring Gull	Coastal strand**	Bufflehead	Tidal wetland***
Double-crested Cormorant	Brackish pond***	American Coot	Freshwater marsh***	Gull species	Tidal wetland***
Dunlin	Brackish pond***	Canada Goose	Freshwater marsh***	Ring-billed Gull	Tidal wetland***
Eared Grebe	Brackish pond***	Mallard	Freshwater marsh***	Hooded Merganser	Tidal wetland**
Forster's Tern	Brackish pond***	Marsh Wren	Freshwater marsh***	Snowy Egret	Tidal wetland**
Long-billed Dowitcher	Brackish pond***	Sora	Freshwater marsh***	Western x Glaucous-winged Gull	Tidal wetland*
Pacific Golden Plover	Brackish pond***	Virginia Rail	Freshwater marsh***		
Redhead	Brackish pond***	Black-necked Stilt	Freshwater marsh**	Arctic Loon	Tidal marsh***
Short-billed/Long-billed Dowitcher	Brackish pond***	Blackbird species	Freshwater marsh**	Burrowing Owl	Tidal marsh***
Semipalmated Plover	Brackish pond***	European Starling	Freshwater marsh**	Great Blue Heron	Tidal marsh***
Snowy Plover	Brackish pond***	Clay-colored Sparrow	Freshwater marsh*	Green-winged Teal	Tidal marsh***
Western Sandpiper	Brackish pond***	Rusty Blackbird	Freshwater marsh*	Horned Lark	Tidal marsh***
Belted Kingfisher	Brackish pond**	Green Heron	Riparian woodland**	Killdeer	Tidal marsh***
Canvasback	Brackish pond**	Violet-green Swallow	Riparian woodland**	Least Sandpiper	Tidal marsh***
Purple Martin	Brackish pond**	Western Scrub-Jay	Riparian woodland*	Savannah Sparrow	Tidal marsh***
Red-necked Phalarope	Brackish pond**	Cedar Waxwing	Riparian woodland*	Yellow-bellied Sapsucker	Tidal marsh***
Eurasian Wigeon	Brackish pond**	Eastern Phoebe	Riparian woodland*	Audubon's Warbler	Tidal marsh**
Pied-billed Grebe	Brackish pond**	Brant	Rocky intertidal***	Eurasian Sparrowhawk	Tidal marsh**
Olive-sided Flycatcher	Brackish pond**	Black-vented Shearwater	Rocky intertidal***	Lesser Scaup	Tidal marsh**
Ruddy Duck	Brackish pond**	Common Loon	Rocky intertidal***	Rock Pigeon	Tidal marsh**
Northern Pintail	Brackish pond*	Pacific Loon	Rocky intertidal***	Tufted Duck	Tidal marsh**
Black-crowned Night-Heron	Brackish pond*	Surf Scoter	Rocky intertidal***	Belding's Savannah Sparrow	Tidal marsh**
Lesser Yellowlegs	Brackish pond*	House Finch	Rocky intertidal**	Manx Shearwater	Tidal marsh**
Red-breasted Merganser	Brackish pond*	Long-billed Curlew	Rocky intertidal**	Lapland Longspur	Tidal marsh**
Dabbling duck species	Brackish pond*	Pomarine Jaeger	Rocky intertidal**	Oregon Junco	Tidal marsh**
Black Turnstone	Coastal strand***	Royal Tern	Rocky intertidal**	Yellow-shafted Flicker	Tidal marsh**
Brown Pelican	Coastal strand***	Horned Grebe	Rocky intertidal**	Lincoln's Sparrow	Tidal marsh*

Species	Habitat	Species	Habitat	Species	Habitat
Acorn Woodpecker	Vernal pool***	Purple Finch	Vernal pool***	White-crowned Sparrow	Vernal pool**
Anna's Hummingbird	Vernal pool***	Blue-gray Gnatcatcher	Vernal pool***	Downy/Hairy Woodpecker	Vernal pool**
Chestnut-backed Chickadee	Vernal pool***	Black-throated Gray Warbler	Vernal pool***	Great Horned Owl	Vernal pool**
Eurasian Collared-Dove	Vernal pool***	Ruby-crowned Kinglet	Vernal pool***	House Sparrow	Vernal pool**
Goldfinch species	Vernal pool***	Rufous/Allen's Hummingbird	Vernal pool***	Western Grebe	Vernal pool**
Hawk species	Vernal pool***	Townsend's Warbler	Vernal pool***	House Wren	Vernal pool**
Hairy Woodpecker	Vernal pool***	Western Meadowlark	Vernal pool***	American Kestrel	Vernal pool**
Hermit Thrush	Vernal pool***	Willow Flycatcher	Vernal pool***	Lazuli Bunting	Vernal pool*
Lesser Goldfinch	Vernal pool***	Yellow-rumped Warbler	Vernal pool***	Bushtit	Vernal pool*
Oak Titmouse	Vernal pool***	California Towhee	Vernal pool**	Hammond's Flycatcher	Vernal pool*
Orange-crowned Warbler	Vernal pool***	*Empidonax* species	Vernal pool**	Summer Tanager	Vernal pool*

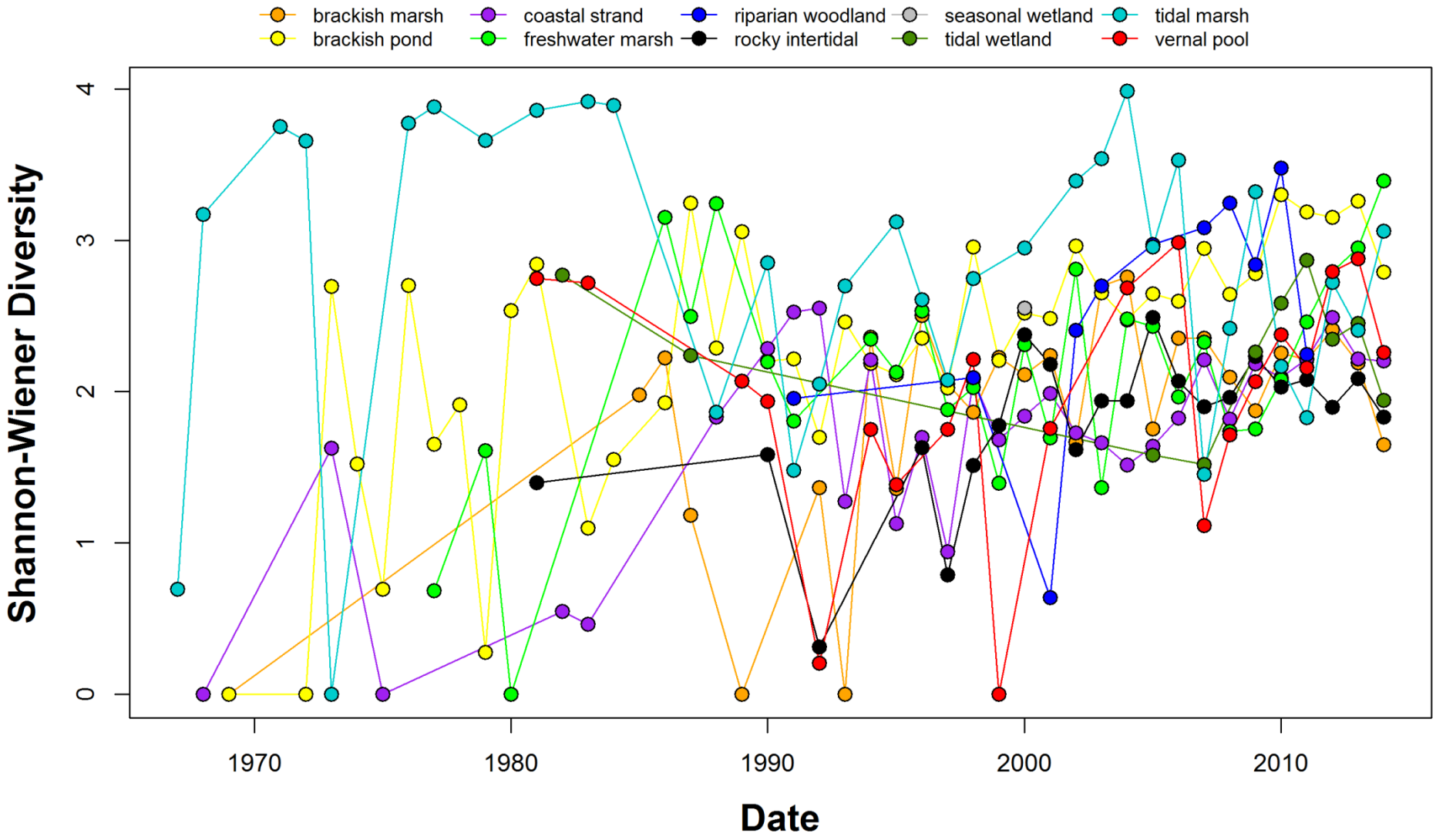

Figure 1.1 – Mean Shannon-Wiener diversity in each year by wetland habitat type. Each data point is the mean of monthly means, therefore could represent a different number of surveys.

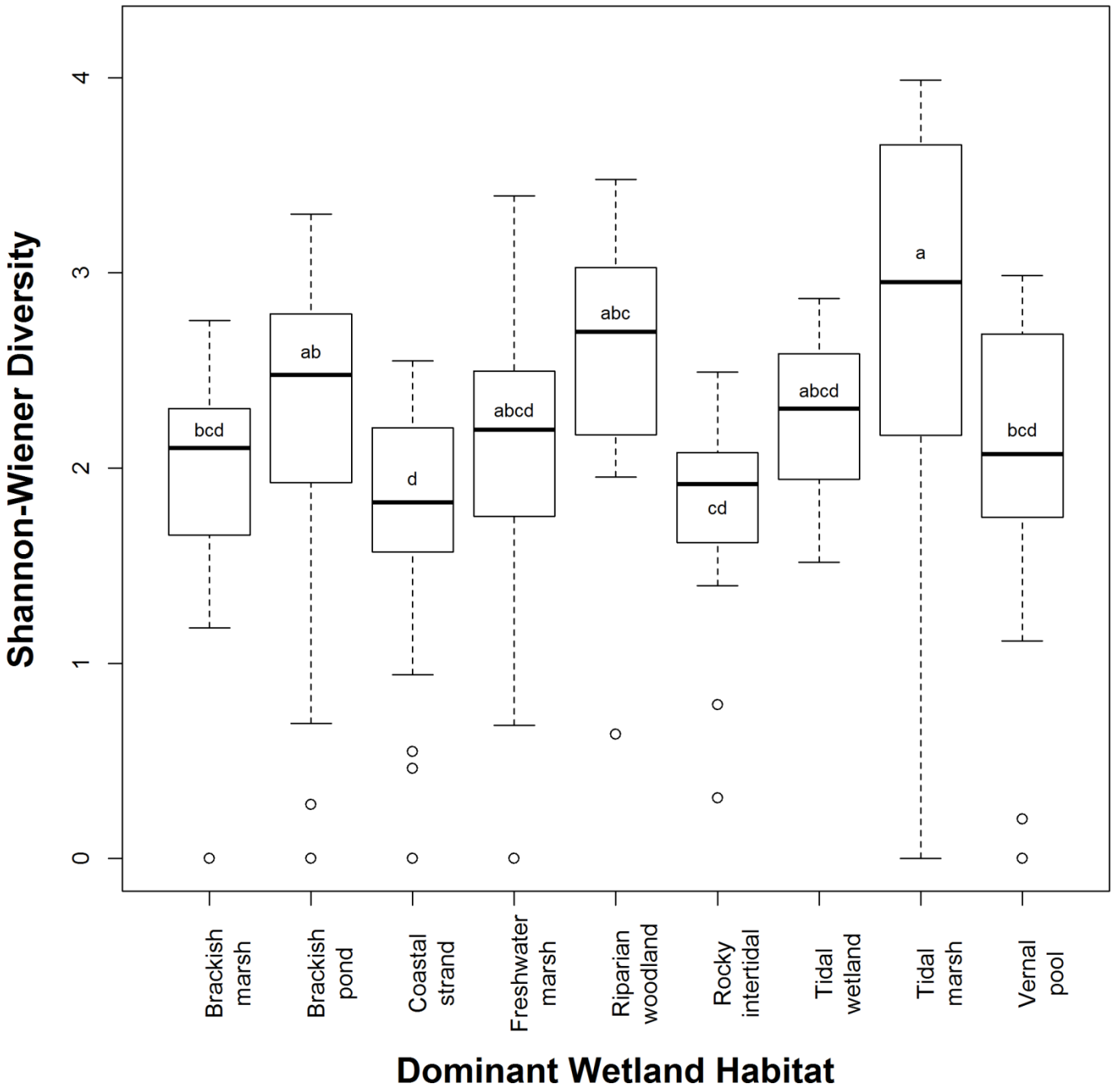

Figure 1.2 – Median Shannon-Wiener diversity by dominant wetland habitat. The top and bottom of the boxes represent the first and third quartiles. The whiskers extend to the most extreme data point that is no more than 1.5 times the interquartile range (the difference between the first and third quartiles). Data shown as hollow points are potential outliers. Habitats are significantly different according to a Kruskal-Wallis test. Letters indicate pairwise test for multiple comparisons of mean rank sums (Nemenyi-Tests).

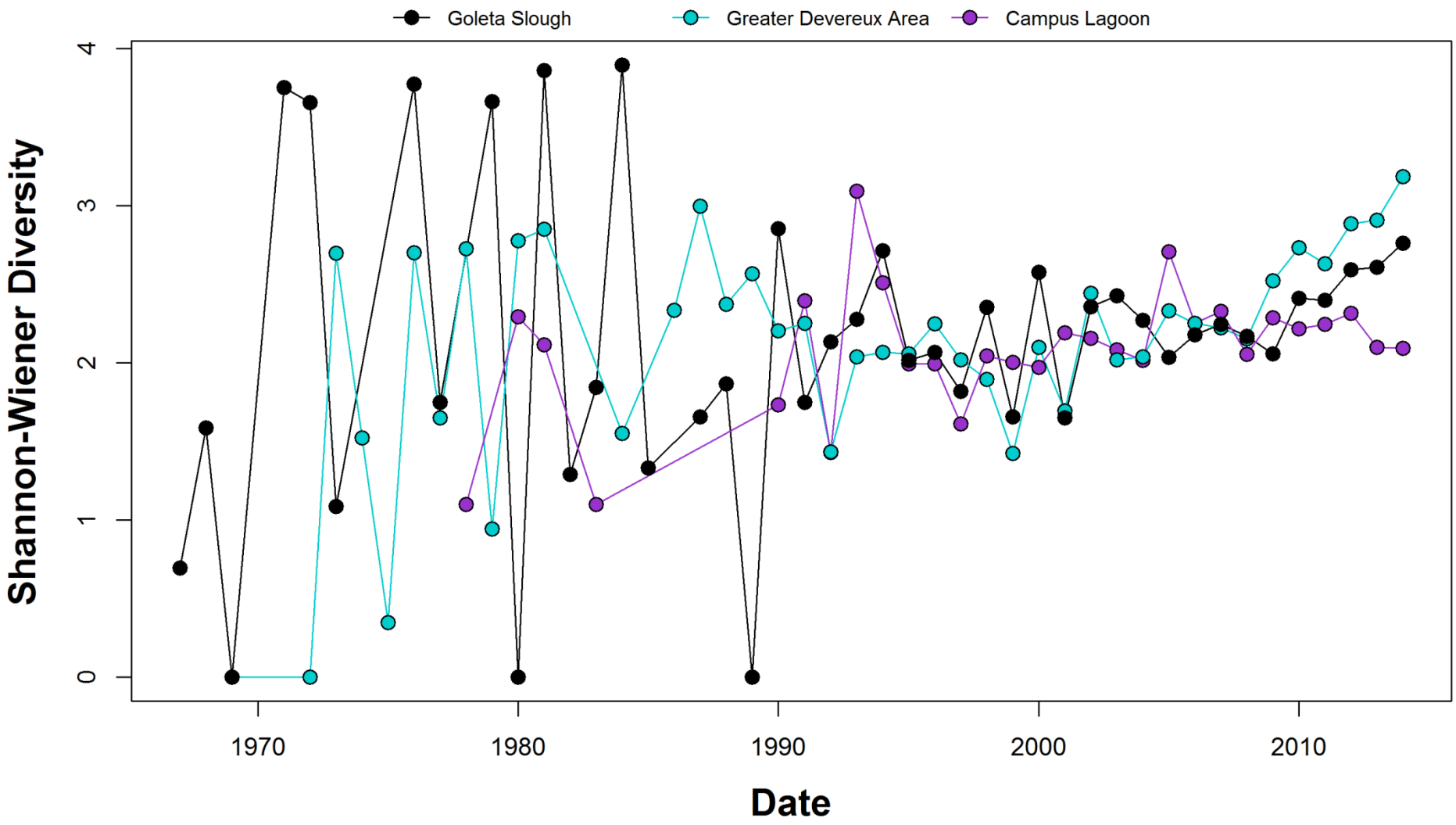

Figure 1.3 – Mean Shannon-Wiener diversity in each year at UCSB Campus Lagoon, Devereux Slough and Goleta Slough. Each data point is the mean of monthly means, therefore could represent a different number of surveys. In this figure, Devereux Slough includes wetland habitats that are part of Coal Oil Point Reserve.

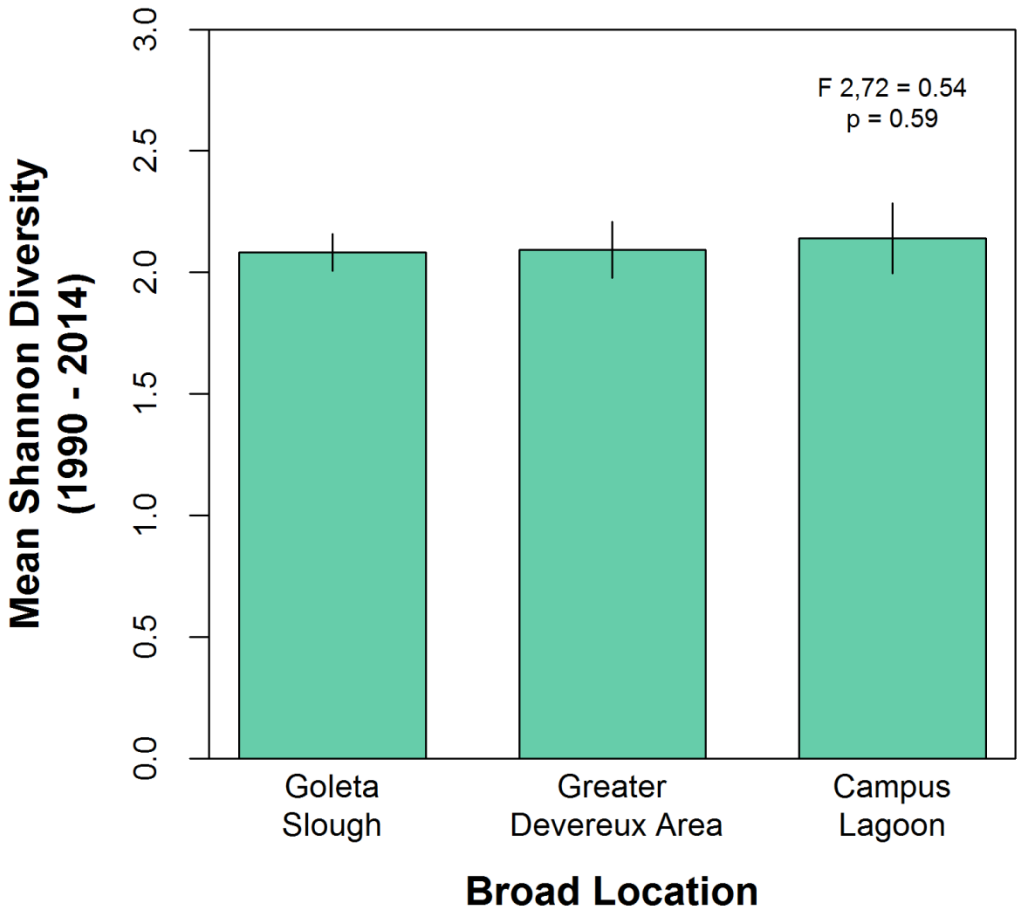

Figure 1.4 – Mean Shannon diversity did not differ among Goleta Slough, the greater Devereux Slough Area and Campus Lagoon. N = 29 for Campus Lagoon, 41 for Devereux and 43 for Goleta Slough.

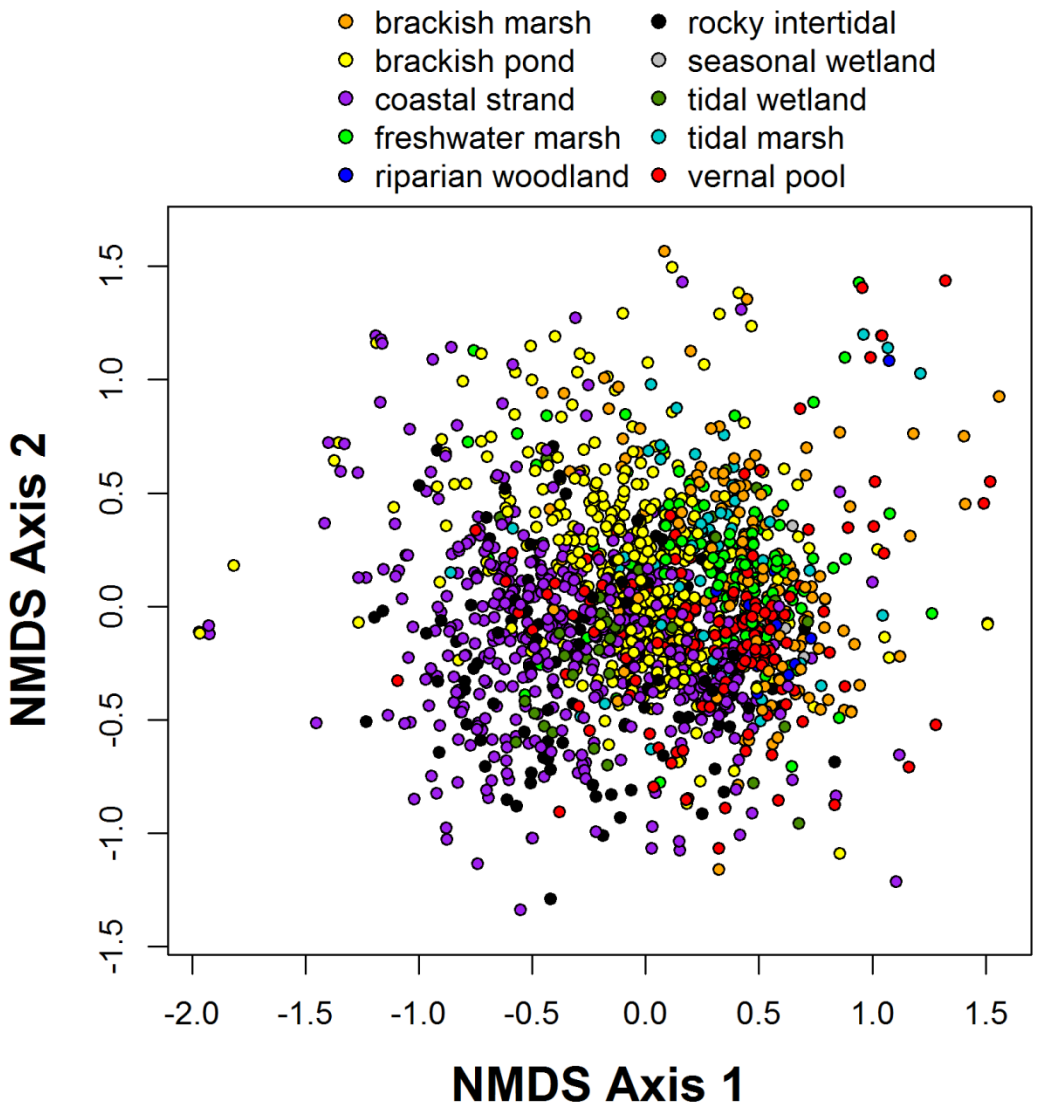

Figure 1.5 – Bird community composition among the wetland habitat types, illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.18 of 3 dimensional solution. Habitats significantly differed from each other according to a PERMANOVA test ($F_{9,1562} = 14.56$, $p < 0.001$, 999 iterations).

Section 2 – Comparison of upland habitats

To compare survey data by upland habitat type, I used similar approaches to the wetland habitat comparison. The surveyed locations covered a broad range of upland habitats, from native t0 exotic dominated communities (TABLE 2.1). Similar to the wetlands, temporal trends in the yearly averages were complex and habitats varied widely (FIG 2.1). Sample sizes varied among the groups, data were not normally distributed and variances were not equal according to a Levene's Test ($F_{9,159} = 3.87$, $p < 0.01$), necessitating a non-parametric approach. Mean Shannon-Wiener diversity, however, did not vary among habitat types according to a Kruskal-Wallis rank-sum test (FIG 2.2; $\chi^2 = 11.09$, df = 9, $p = 0.27$). The coefficient of variation (indicating how much diversity changed over time) was highest in native grassland, and lowest in oak woodlands.

Non-metric multidimensional scaling (NMDS) was also used to examine the composition of the bird community at the different habitats. I used a similar approach to that employed to compare wetlands – excluding the species that occurred in less than 10% of the monthly average surveys. The final, five-dimensional solution had a stress of 0.12. Ruderal habitats appear to cluster in a particular area of the figure, but other patterns are very complex. Habitat did significantly influence bird composition overall (FIG 2.3), although this effect varied over time (Upland * Year interaction: $F_{9,841} = 2.40$, $p < 0.001$). This is very similar to the results comparing wetland habitats.

Similarity percentage analysis (SIMPER) can be used to generate pairwise comparisons of habitat types (see R code to generate full results). As an example, I compared ruderal uplands with coastal sage scrub (TABLE 2.4) and oak woodlands (TABLE 2.5). Interestingly, it seems that many of the species that are more common in the coastal sage scrub habitat are not likely to be within that habitat (ducks, shorebirds, etc.). Since many of the surveys specified locations with both an upland and a wetland habitat type listed, these data may not reliable separate those birds that were from the wetland vs. the upland habitat within a single survey. Thus, I am not sure how much interpretability these differences have. Indicator species analysis also revealed many species that were positively associated with specific upland habitat types (TABLE 2.6). Unlike with the NMDS, I included all species in these analyses.

UPDATE – I repeated the above analysis using only birds categorized as raptors, passerines or waders to exclude birds that aren't using upland habitats. For overall yearly patterns in Shannon Diversity, we see the same trends (FIG 2.4). Again, sample sizes varied among the groups, data were not normally distributed and variances were not equal according to a Levene's Test ($F_{9,159} = 3.16$, $p < 0.01$), necessitating a non-parametric approach. There was no difference in mean Shannon diversity among the upland habitat types (FIG 2.5; Kruskal-Wallis $\chi^2 = 13.54$, df = 9, p

= 0.14). The coefficient of variation in diversity was also similar to the prior results with all bird species (TABLE 2.3).

After repeating the NMDS analysis (excluding aquatic birds and those species that occurred in less than 10% of surveys) ruderal habitats still appeared less compositionally variable (FIG 2.6). According to PERMANVOA, there is also still a significant upland habitat by year interaction ($F_{9,835} = 2.71$, $p = 0.001$). I created new SIMPER tables to illustrate the same comparisons as before which likely better reflect true differences in the upland bird community (TABLE 2.7, 2.8). There were also indicator species that were associated specifically with each upland habitat (TABLE 2.10).

Table 2.1: Assigned upland habitat categories found in the bird survey database by broad and specific locations

Broad Location	Specific Location	Dominant Upland Habitat
Campus Lagoon	Campus Lagoon	Non-native annual grassland
	Campus Lagoon uplands	Coastal sage scrub
	Lagoon Island	Coastal sage scrub
	Manzanita Village	Coastal sage scrub
Coal Oil Point Reserve	Coal Oil Point Reserve (AKA West Devereux)	Coastal sage scrub
	Created Vernal Pools	Non-native annual grassland
	Devereux Dunes	Coastal dunes
	Knoll (Coal Oil Point Reserve)	Eucalyptus woodland
Goleta Slough	Area I	Coastal sage scrub
	Fish and Game Ecological Reserve	Coastal sage scrub
	Fish and Game wetlands (Los Carneros Rd)	Coastal sage scrub
	Goleta Sough (all areas master tally, CBC only)	Eucalyptus woodland
	North Bluff	Oak woodland
	Santa Barbara Airport	Developed
Greater Devereux Area	Ellwood Mesa	Non-native annual grassland
	Family Student Housing (w/ Student Gardens)	Ruderal
	North Finger (of Devereux Slough)	Eucalyptus woodland
	North Parcel	Native grassland
	Ocean Meadows Golf Course	Irrigated Lawn
	Phelp's Ditch (includes Phelps Creek & Encanto Creek)	Coastal sage scrub
	South Finger (of Devereux Slough)	Eucalyptus woodland
	South Parcel	Ruderal
	West Campus bluffs	Non-native annual grassland
Isla Vista	Camino Corto Open Space	Non-native annual grassland
	Del Sol Open Space	Non-native annual grassland
	Isla Vista	Non-native woodland
Pacific Gas & Electric	Pacific Gas & Electric	Eucalyptus woodland
Southern California-Edison	Southern California-Edison	
Storke Campus	CCBER Greenhouses & Nursery (w/ Student Gardens)	Eucalyptus woodland
	East Storke Campus wetland	Eucalyptus woodland
	Francisco Torres Towers	Developed
	Francisco Torres wetland	Non-native woodland
	Storke Campus field	Irrigated Lawn
	San Clemente Open Space	Coastal sage scrub
	West Storke Campus wetlands (AKA W Storke Campus)	Non-native annual grassland
UCSB	UCSB main campus only	Developed

Table 2.2 – Coefficient of variation (CV) in Shannon Diversity for each habitat type, calculated over years. Higher values indicate more variation between years.

Upland habitat	n	CV
Native grassland	4	78.13
Ruderal	12	53.28
Developed	36	45.84
Non-native woodland	11	40.35
Eucalyptus woodland	18	36.65
Irrigated lawn	20	35.97
Coastal dunes	7	24.14
Non-native annual grassland	31	22.16
Coastal sage scrub	27	16.11
Oak woodland	3	9.20

Table 2.3 – Coefficient of variation (CV) in Shannon Diversity for each habitat type, calculated over years. Wetland/ocean birds are excluded here. Higher values indicate more variation between years.

Upland habitat	n	CV
Native grassland	4	78.12
Irrigated lawn	20	43.19
Ruderal	12	41.15
Non-native woodland	11	38.77
Eucalyptus woodland	18	38.10
Developed	36	35.11
Non-native annual grassland	31	25.35
Coastal dunes	7	24.34
Coastal sage scrub	27	19.32
Oak woodland	3	6.76

Table 2.4 – Similarity Percentages (SIMPER) showing species most responsible for the differences between coastal sage scrub and ruderal upland habitats (dissimilarity in the NMDS analysis), across all years. The cumulative proportion of dissimilarity explained by the species shown below is ~75%. Averages are relative proportional abundance of a species within a given survey.

Bird species	Average – coastal sage scrub	Average – ruderal	Proportional contribution to dissimilarity
House Finch	0.065	0.101	0.067
White-crowned Sparrow	0.027	0.041	0.036
Cliff Swallow	0.020	0.037	0.033
Bushtit	0.018	0.050	0.032
European Starling	0.022	0.036	0.032
Sanderling	0.048	0.002	0.031
Double-crested Cormorant	0.048	0.004	0.031
Yellow-rumped Warbler	0.023	0.034	0.031
American Coot	0.041	0.005	0.028
Song Sparrow	0.040	0.025	0.028
Anna's Hummingbird	0.023	0.039	0.026
Western Gull	0.037	0.003	0.025
Red-winged Blackbird	0.021	0.023	0.024
White-tailed Kite	0.004	0.032	0.023
California Towhee	0.014	0.037	0.022
American Crow	0.026	0.020	0.021
Mallard	0.030	0.008	0.021
Mourning Dove	0.005	0.034	0.021
Loggerhead Shrike	0.000	0.032	0.021
Common Yellowthroat	0.024	0.020	0.019
Lesser Goldfinch	0.002	0.027	0.017
Willet	0.020	0.001	0.014
Black Phoebe	0.019	0.012	0.013
Canada Goose	0.005	0.015	0.013
Northern Mockingbird	0.007	0.018	0.012
Western Meadowlark	0.001	0.017	0.012
Black Turnstone	0.017	0.000	0.011
Cassin's Kingbird	0.005	0.015	0.011
American Kestrel	0.001	0.017	0.011
Brown Pelican	0.016	0.001	0.01
Black-bellied Plover	0.016	0.001	0.01
Rock Pigeon	0.008	0.010	0.011
Killdeer	0.012	0.005	0.009
Greater Yellowlegs	0.014	0.001	0.01
Savannah Sparrow	0.001	0.014	0.009
Hooded Oriole	0.006	0.008	0.008

Table 2.5 – Similarity Percentages (SIMPER) showing species most responsible for the differences between oak woodland and ruderal upland habitats (dissimilarity in the NMDS analysis), across all years. The cumulative proportion of dissimilarity explained by the species shown below is ~75%. Averages are relative proportional abundance of a species within a given survey.

Bird species	Average – oak woodland	Average – ruderal	Proportional contribution to dissimilarity
House Finch	0.09	0.101	0.07
Cliff Swallow	0.04	0.037	0.047
California Towhee	0.08	0.037	0.045
Common Yellowthroat	0.068	0.02	0.044
Western Scrub-Jay	0.053	0.002	0.042
Anna's Hummingbird	0.072	0.039	0.037
Black-crowned Night-Heron	0.041	0	0.036
European Starling	0.027	0.036	0.034
White-crowned Sparrow	0	0.041	0.034
Bushtit	0.039	0.05	0.032
Red-winged Blackbird	0.024	0.023	0.029
Yellow-rumped Warbler	0	0.034	0.028
White-tailed Kite	0.004	0.032	0.026
Loggerhead Shrike	0	0.032	0.026
Lesser Goldfinch	0	0.027	0.022
American Crow	0.029	0.02	0.022
Song Sparrow	0.03	0.025	0.021
Bewick's Wren	0.029	0.011	0.02
Mourning Dove	0.035	0.034	0.021
Spotted Towhee	0.026	0.003	0.019
Northern Mockingbird	0.016	0.018	0.016
Great Egret	0.014	0.007	0.015
California Thrasher	0.018	0.002	0.014
Western Meadowlark	0	0.017	0.015
American Kestrel	0	0.017	0.014
Canada Goose	0.002	0.015	0.013
Black Phoebe	0.011	0.012	0.013

Table 2.6 – Indicator species analysis, identifying species whose relative frequency is significantly higher in the listed habitat than all other habitats. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$ after correction for multiple comparisons.

Species	Habitat	Species	Habitat	Species	Habitat
California Quail	Coastal dunes***	Pine Siskin	Developed*	Vermilion Flycatcher	Irrigated lawn***
Red-shafted Flicker	Coastal dunes***	Red-throated Loon	Developed***	Western Bluebird	Irrigated lawn***
Snowy Plover	Coastal dunes*	Ruddy Turnstone	Developed***	Wilson's Snipe	Irrigated lawn***
Song Sparrow	Coastal dunes**	Townsend's Warbler	Developed*	Great Egret	Native grassland**
Warbling Vireo	Coastal dunes**	Varied Thrush	Developed*	White-crowned Sparrow	Native grassland*
Wrentit	Coastal dunes***	Belted Kingfisher	Eucalyptus woodland**	Blackpoll Warbler	Non-native annual grassland**
American Wigeon	Coastal sage scrub***	Black-necked Stilt	Eucalyptus woodland***	Brown Creeper	Non-native annual grassland*
Black-bellied Plover	Coastal sage scrub***	Bufflehead	Eucalyptus woodland***	Chestnut-backed Chickadee	Non-native annual grassland***
Black Turnstone	Coastal sage scrub***	California Gull	Eucalyptus woodland***	Common Murre	Non-native annual grassland*
Double-crested Cormorant	Coastal sage scrub***	Eurasian Wigeon	Eucalyptus woodland***	Heermann's Gull	Non-native annual grassland**
Eared Grebe	Coastal sage scrub***	Great Blue Heron	Eucalyptus woodland***	Horned Grebe	Non-native annual grassland***
Forster's Tern	Coastal sage scrub*	Greater Scaup	Eucalyptus woodland**	MacGillivray's Warbler	Non-native annual grassland***
Greater Yellowlegs	Coastal sage scrub***	Hermit Thrush	Eucalyptus woodland*	Red-breasted Merganser	Non-native annual grassland**
Long-billed Dowitcher	Coastal sage scrub***	House Wren	Eucalyptus woodland*	Redhead	Non-native annual grassland***
Least Sandpiper	Coastal sage scrub**	Lesser Scaup	Eucalyptus woodland***	Western Grebe	Non-native annual grassland***
Mallard	Coastal sage scrub***	Pacific-slope Flycatcher	Eucalyptus woodland***	Willow Flycatcher	Non-native annual grassland***
Pied-billed Grebe	Coastal sage scrub***	Ring-billed Gull	Eucalyptus woodland**	Eurasian Collared-Dove	Non-native woodland***
Sanderling	Coastal sage scrub***	Reddish Egret	Eucalyptus woodland**	Loon species	Non-native woodland**
Semipalmated Plover	Coastal sage scrub***	Ring-necked Duck	Eucalyptus woodland***	Nuttall's x Downy Woodpecker (hybrid)	Non-native woodland**
Western Gull	Coastal sage scrub***	Rock Pigeon	Eucalyptus woodland*	Orchard Oriole	Non-native woodland***
Whimbrel	Coastal sage scrub***	Royal Tern	Eucalyptus woodland***	Red-winged Blackbird	Non-native woodland**
Willet	Coastal sage scrub***	Red-tailed Hawk	Eucalyptus woodland**	Tricolored Blackbird	Non-native woodland***
Arctic Loon	Developed***	Ruddy Duck	Eucalyptus woodland**	Black-crowned Night-Heron	Oak woodland*
Audubon's Warbler	Developed***	Snowy Egret	Eucalyptus woodland***	Blue Grosbeak	Oak woodland*
Black Scoter	Developed**	Spotted Sandpiper	Eucalyptus woodland***	Swainson's Thrush	Oak woodland*
Brown Pelican	Developed***	American Bittern	Irrigated lawn**	Western Scrub-Jay	Oak woodland*
Elegant Tern	Developed*	American Coot	Irrigated lawn***	Bushtit	Ruderal**
Eurasian Sparrowhawk	Developed*	American Crow	Irrigated lawn*	Grasshopper Sparrow	Ruderal***
Killdeer	Developed*	American Pipit	Irrigated lawn**	Lesser Goldfinch	Ruderal***
Least Flycatcher	Developed***	Canada Goose	Irrigated lawn***	Oak Titmouse	Ruderal***
Northern Pintail	Developed*	Eastern Phoebe	Irrigated lawn**	Oriole species	Ruderal**
Painted Redstart	Developed***	Grace's Warbler	Irrigated lawn***	Savannah Sparrow	Ruderal***
Peregrine Falcon	Developed*	Sora	Irrigated lawn***	Tree Swallow	Ruderal*

Table 2.7 – Similarity Percentages (SIMPER) showing species (excluding aquatic birds) most responsible for the differences between coastal sage scrub and ruderal upland (dissimilarity in the NMDS analysis), across all years. The cumulative proportion of dissimilarity explained by the species shown below is ~75%. Averages are relative proportional abundance of a species within a given survey.

Bird species	Average – coastal sage scrub	Average – ruderal	Proportional contribution to dissimilarity
House Finch	0.116	0.109	0.087
White-crowned Sparrow	0.05	0.048	0.052
European Starling	0.038	0.044	0.046
Song Sparrow	0.066	0.027	0.043
Yellow-rumped Warbler	0.042	0.034	0.043
Cliff Swallow	0.031	0.038	0.042
Bushtit	0.033	0.052	0.038
American Crow	0.051	0.025	0.038
Red-winged Blackbird	0.039	0.024	0.037
Black Phoebe	0.055	0.013	0.036
Snowy Egret	0.05	0.003	0.035
Anna's Hummingbird	0.04	0.042	0.032
Common Yellowthroat	0.039	0.02	0.028
California Towhee	0.025	0.038	0.026
White-tailed Kite	0.007	0.032	0.025
Mourning Dove	0.009	0.036	0.023
Rock Pigeon	0.023	0.012	0.022
Loggerhead Shrike	0	0.032	0.021
Lesser Goldfinch	0.003	0.028	0.019
Northern Mockingbird	0.016	0.018	0.018
Cassin's Kingbird	0.01	0.016	0.015
Black-crowned Night-Heron	0.021	0	0.014
Western Meadowlark	0.003	0.018	0.013

Table 2.8 – Similarity Percentages (SIMPER) showing species (excluding aquatic birds) most responsible for the differences between oak woodland and ruderal upland habitats (dissimilarity in the NMDS analysis), across all years. The cumulative proportion of dissimilarity explained by the species shown below is ~75%. Averages are relative proportional abundance of a species within a given survey.

Bird species	Average – oak woodland	Average – ruderal	Proportional contribution to dissimilarity
House Finch	0.093	0.109	0.071
Cliff Swallow	0.043	0.038	0.049
Common Yellowthroat	0.07	0.02	0.044
California Towhee	0.083	0.038	0.045
Western Scrub-Jay	0.054	0.002	0.043
White-crowned Sparrow	0	0.048	0.039
European Starling	0.028	0.044	0.039
Black-crowned Night-Heron	0.046	0	0.038
Anna's Hummingbird	0.075	0.042	0.037
Cedar Waxwing	0.042	0.003	0.035
Bushtit	0.04	0.052	0.032
Red-winged Blackbird	0.027	0.024	0.03
Yellow-rumper Warbler	0	0.034	0.028
White-tailed Kite	0.004	0.032	0.026
Loggerhead Shrike	0	0.032	0.025
Lesser Goldfinch	0	0.028	0.023
American Crow	0.029	0.025	0.022
Song Sparrow	0.032	0.027	0.022
Bewick's Wren	0.03	0.011	0.021
Mourning Dove	0.036	0.036	0.02
Spotted Towhee	0.026	0.003	0.02
Northern Mockingbird	0.016	0.018	0.016
Great Egret	0.016	0.007	0.015
California Thrasher	0.019	0.002	0.015

Table 2.10 – Indicator species analysis (excluding aquatic birds), identifying species whose relative frequency is significantly higher in the listed habitat than all other habitats. Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$ after correction for multiple comparisons.

Species	Habitat	Species	Habitat
California Quail	Coastal dunes*	Marsh Wren	Irrigated lawn**
Red-shafted Flicker	Coastal dunes**	Red-breasted Sapsucker	Irrigated lawn*
Warbling Vireo	Coastal dunes*	Sora	Irrigated lawn***
Wrentit	Coastal dunes***	Vermillion Flycatcher	Irrigated lawn***
Black Phoebe	Coastal sage scrub***	Western Bluebird	Irrigated lawn***
Snowy Egret	Coastal sage scrub***	Common Raven	Native grassland*
Song Sparrow	Coastal sage scrub**	Great Egret	Native grassland***
Audubon's Warbler	Developed***	White-crowned Sparrow	Native grassland*
Least Flycatcher	Developed**	Blackpoll Warbler	Non-native annual grassland***
Oregon Junco	Developed**	Brown Creeper	Non-native annual grassland**
Painted Redstart	Developed***	Bushtit	Non-native annual grassland***
Peregrine Falcon	Developed*	Chestnut-backed Chickadee	Non-native annual grassland***
Red-breasted Nuthatch	Developed***	House Wren	Non-native annual grassland**
Ruby-crowned Kinglet	Developed**	MacGillivray's Warbler	Non-native annual grassland***
Townsend's Warbler	Developed**	Willow Flycatcher	Non-native annual grassland***
Common Ground-Dove	Eucalyptus woodland*	Yellow-rumped Warbler	Non-native annual grassland***
Great Blue Heron	Eucalyptus woodland***	Eurasian Collared-Dove	Non-native woodland**
Hermit Thrush	Eucalyptus woodland*	Nuttall's x Downy Woodpecker (hybrid)	Non-native woodland**
Pacific-slope Flycatcher	Eucalyptus woodland***	Orchard Oriole	Non-native woodland***
Reddish Egret	Eucalyptus woodland***	Red-winged Blackbird	Non-native woodland**
Rock Pigeon	Eucalyptus woodland***	Tricolored Blackbird	Non-native woodland***
Red-tailed Hawk	Eucalyptus woodland***	Black-headed Grosbeak	Oak woodland*
American Bittern	Irrigated lawn***	Swainson's Thrush	Oak woodland*
American Crow	Irrigated lawn*	Western Scrub-Jay	Oak woodland*
American Pipit	Irrigated lawn***	Grasshopper Sparrow	Ruderal***
Eastern Phoebe	Irrigated lawn**	Lesser Goldfinch	Ruderal***
Golden-crowned Kinglet	Irrigated lawn*	Oak Titmouse	Ruderal***
Green-winged Teal	Irrigated lawn***		

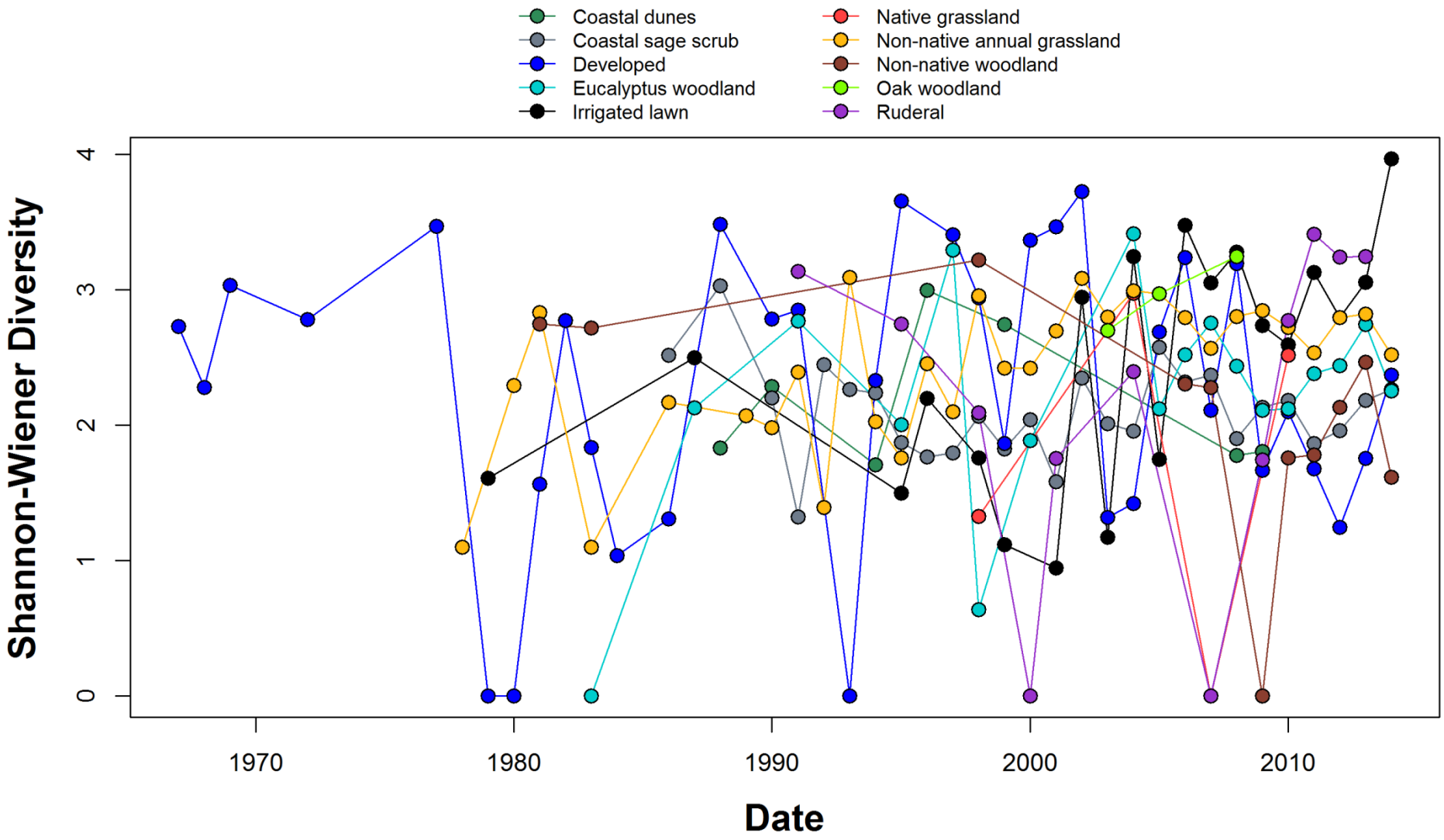

Figure 2.1 - Mean Shannon-Wiener diversity in each year by upland habitat type. Each data point is the mean of monthly means, therefore could represent a different number of surveys.

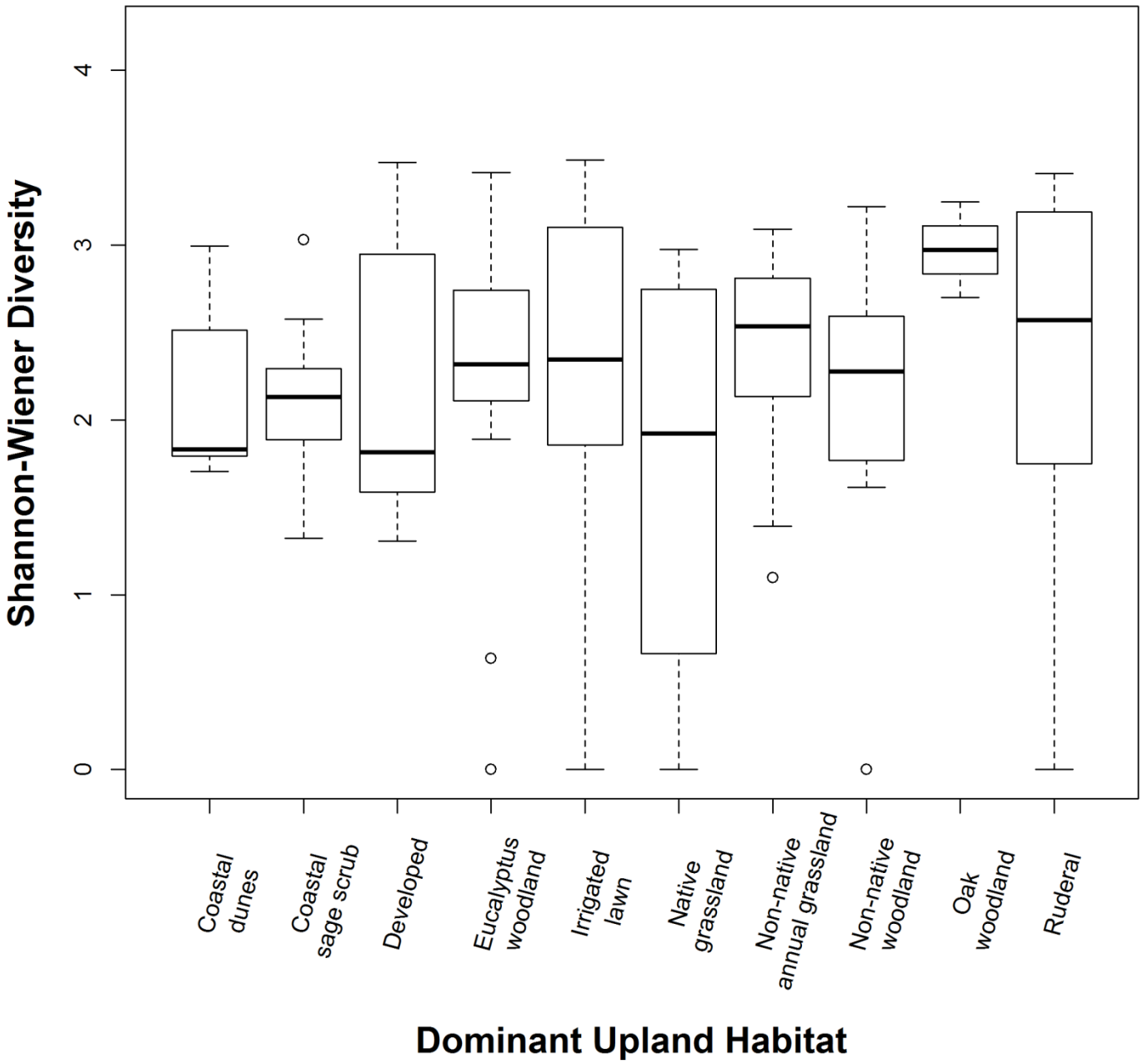

Figure 2.2 – Median Shannon-Wiener diversity by dominant upland habitat. The top and bottom of the boxes represent the first and third quartiles. The whiskers extend to the most extreme data point that is no more than 1.5 times the interquartile range (the difference between the first and third quartiles). Data shown as hollow points are potential outliers. Habitats are not significantly different according to a Kruskal-Wallis test.

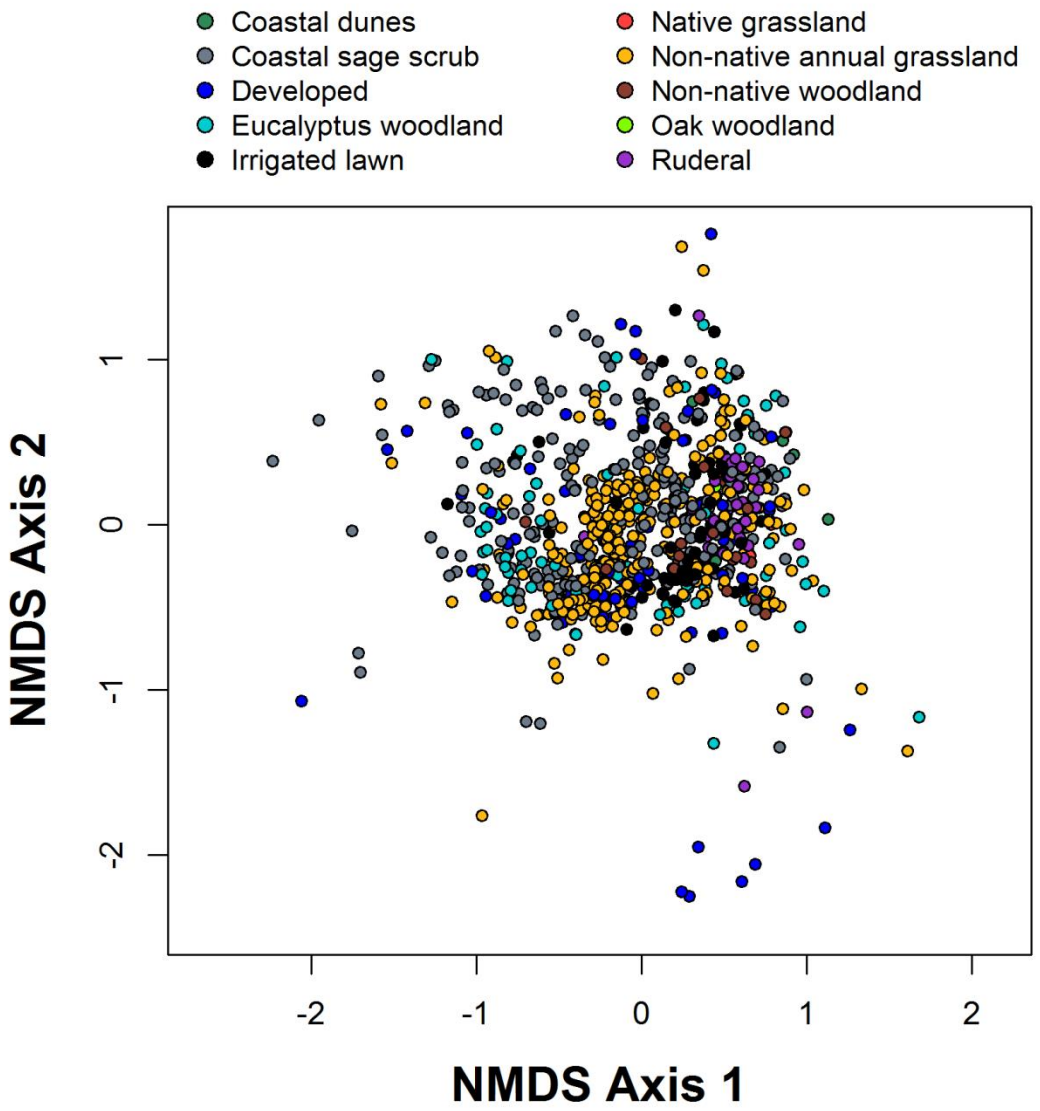

Figure 2.3 – Bird community composition among the upland habitat types, illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.12 of 5 dimensional solution. Habitats significantly differed from each other according to a PERMANOVA test ($F_{9,841} = 5.83$, $p < 0.001$, 999 iterations).

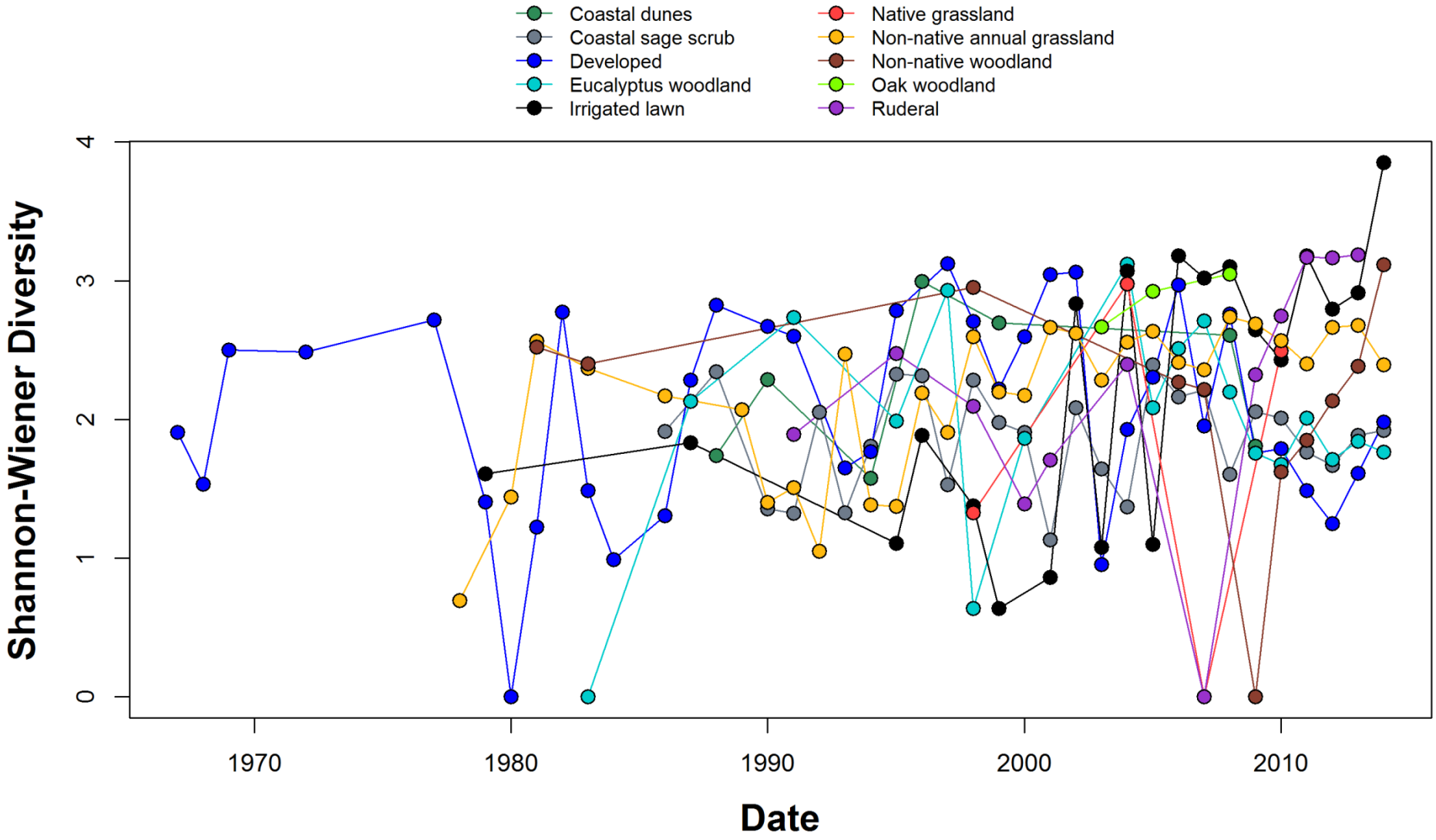

Figure 2.4 - Mean Shannon-Wiener diversity in each year by upland habitat type, excluding aquatic birds. Each data point is the mean of monthly means, therefore could represent a different number of surveys.

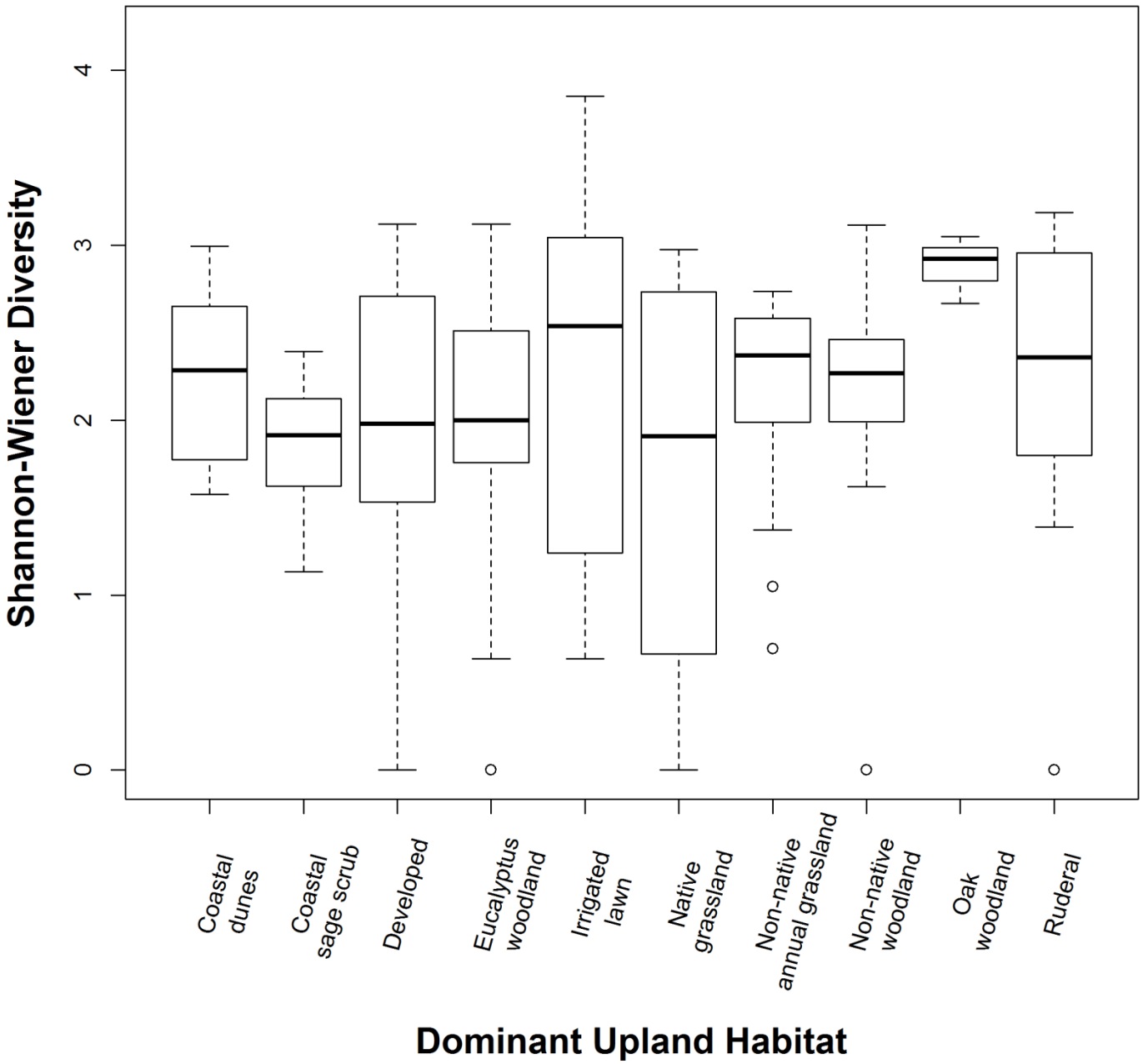

Figure 2.5 – Median Shannon-Wiener diversity by dominant upland habitat, excluding exclusively wetland or ocean-going birds. The top and bottom of the boxes represent the first and third quartiles. The whiskers extend to the most extreme data point that is no more than 1.5 times the interquartile range (the difference between the first and third quartiles). Data shown as hollow points are potential outliers. Habitats are not significantly different according to a Kruskal-Wallis test.

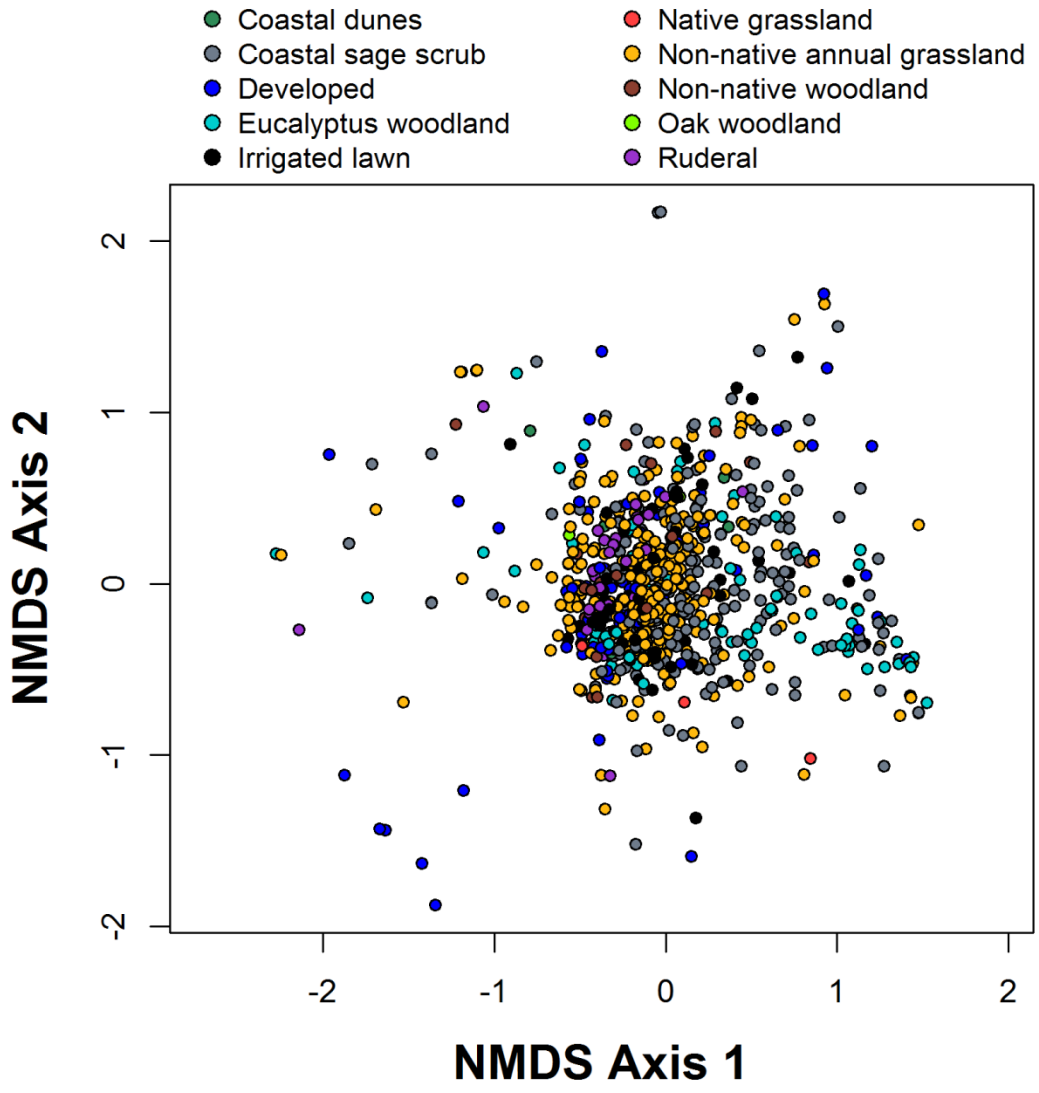

Figure 2.6 – Bird community composition (excluding aquatic birds) among the upland habitat types, illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.12 of 5 dimensional solution. Habitats significantly differed from each other according to a PERMANOVA test ($F_{9,841} = 17.71$, $p < 0.001$, 999 iterations).

Section 3 – Baseline conditions by location

I characterized conditions at Ocean Meadows Golf Course, South Parcel, Devereux Slough, Ellwood Mesa and Coal Oil Point Reserve (COPR) to be used as a baseline for comparison during the restoration process. Prior to analysis of Shannon-Wiener I took monthly averages of birds surveyed within each year, again to better standardize sample size and control for occasional instances of many repeat visits over spans of a few days. For Ellwood Mesa, I excluded Ellwood Mesa Beach and for Devereux Slough I excluded the Devereux Beach and Devereux Dunes locations. I included, however, the upland and brackish/freshwater locations (Dune Pond, Devereux Slough, Phelp's Ditch, North Finger, South Finger, Upper Devereux Slough, and West Campus Bluffs). I excluded Family Student Housing. For Coal Oil Point I included the Reserve (also listed as West Devereux), the created vernal pools and the knoll. I also decided to use data from 1990 to present, since most sites had data coverage during this period, and not all have earlier data.

Shannon Diversity showed an increasing trend in each of the six locations over the 1990 – 2014 time period, except for North Parcel which was surveyed relatively few times (FIG 3.1). On average, however, diversity in these six locations did not differ according to an ANOVA ($p > 0.05$). Considering the average monthly surveys, diversity varied most in North Parcel (where there were the fewest number of samples) and least at Ocean Meadows Golf Course (TABLE 3.1).

Non-metric multidimensional scaling revealed substantial overlap among the sites (FIG 3.1). Site, Year and their interaction were all significant in a PERMANOVA ($p < 0.001$), indicating substantial change over time. Interestingly, there was space in the ordination where Devereux Slough and COPR showed minimal overlap with the other habitats. Some species abundances that were highly correlated ($p < 0.001$) with ordination scores in this region are Semipalmated Plover, Mallard, Northern Shoveler, Black-bellied Plover, Western Sandpiper, Short-billed Dowitcher, American Widgeon, Snowy Egret, Green-winged Teal, and Least Sandpiper. It is also clear in this figure that South Parcel and Ocean Meadows were much less variable than the other sites. There were also many indicator species that were significantly more abundant at one of the sites than the others (TABLE 3.2).

I also calculated the most frequent and most abundant species for each of the six sites (TABLE 3.3). Where multiple different surveys took place on the same day of a given year, I took the mean of the counts for each individual species. The most abundant species differed dramatically between "natural" and disturbed habitats.

Within each site, I used NMDS again to characterize variability by season and over time. In these analyses I did not average surveys within each year. Instead, I defined four seasons as follows: Spring = March, April & May; Summer = June, July & August; Fall = September, October & November; Winter = December, January & February. At Devereux Slough, surveys in the fall had less overlap with the other three seasons in one area of the NMDS ordination space (FIG 3.3). There was also separation among the bird community seasonally at Ellwood Mesa (FIG 3.4). Coal Oil Point Reserve had fewer surveys, but there does appear to be some separation of the summer surveys, especially those from the 1990s (FIG 3.5). By contrast, bird composition at Ocean Meadows Golf Course did not have significant separation among the seasons (FIG 3.6). South Parcel also had few survey points, but did not appear to have much yearly or seasonal variation (FIG 3.7).

Table 3.1 – Coefficient of variation (CV) for each site, calculated using the monthly average surveys (therefore multiple values possible within a single year). Higher values indicate more variation between surveys.

Site	n	CV
North Parcel	4	78.13
Coal Oil Point Reserve	39	59.48
Ellwood Mesa	63	45.95
South Parcel	32	34.17
Devereux Slough	189	32.12
Ocean Meadows Golf Course	52	29.49

Table 3.2 – Indicator species analysis, identifying species whose relative frequency is significantly higher in the listed site than others (among the six tested). Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$ after correction for multiple comparisons. Table continues on next page.

Species	Site	Species	Site	Species	Site
Black Turnstone	COPR**	Least Tern	Devereux**	Chestnut-backed Chickadee	Ellwood Mesa***
Brandt's Cormorant	COPR*	Lesser Yellowlegs	Devereux***	Clark's Grebe	Ellwood Mesa*
Brant	COPR***	Marbled Godwit	Devereux***	Chestnut-sided Warbler	Ellwood Mesa**
Belding's Savannah Sparrow	COPR**	Mallard	Devereux***	Downy/Hairy Woodpecker	Ellwood Mesa**
Black-vented Shearwater	COPR**	Mew Gull	Devereux***	*Empidonax* species	Ellwood Mesa**
California Gull	COPR**	Northern Pintail	Devereux**	Great Horned Owl	Ellwood Mesa**
California Quail	COPR**	Northern Shoveler	Devereux***	Goldfinch species	Ellwood Mesa*
Cinnamon Teal	COPR*	Pied-billed Grebe	Devereux***	Hairy Woodpecker	Ellwood Mesa*
Forster's Tern	COPR**	Pectoral Sandpiper	Devereux***	Hermit Thrush	Ellwood Mesa***
Glaucous-winged Gull	COPR*	Ring-billed Gull	Devereux***	MacGillivray's Warbler	Ellwood Mesa***
Heermann's Gull	COPR**	Red-breasted Merganser	Devereux***	Myrtle Warbler	Ellwood Mesa***
Herring Gull	COPR**	Redhead	Devereux***	Oak Titmouse	Ellwood Mesa**
Snowy Plover	COPR***	Red Knot	Devereux***	Orange-crowned Warbler	Ellwood Mesa***
Western Gull	COPR**	Ring-necked Duck	Devereux**	Cormorant species	Ellwood Mesa*
American Avocet	Devereux***	Red-necked Phalarope	Devereux***	Ruby-crowned Kinglet	Ellwood Mesa**
American Wigeon	Devereux***	Ruddy Duck	Devereux***	Red-shafted Flicker	Ellwood Mesa**
American White Pelican	Devereux**	Ruddy Turnstone	Devereux***	Rufous Hummingbird	Ellwood Mesa***
Baird's Sandpiper	Devereux**	Sandpiper species	Devereux***	Rufous/Allen's Hummingbird	Ellwood Mesa**
Black-bellied Plover	Devereux***	Short-billed Dowitcher	Devereux***	Spotted Towhee	Ellwood Mesa*
Black-crowned Night-Heron	Devereux***	Short/Long-billed Dowitcher	Devereux***	Townsend's Warbler	Ellwood Mesa***
Black-necked Stilt	Devereux***	Semipalmated Plover	Devereux***	Turkey Vulture	Ellwood Mesa***
Bufflehead	Devereux***	Semipalmated Sandpiper	Devereux**	Warbler species	Ellwood Mesa**
Blue-winged Teal	Devereux***	Snowy Egret	Devereux***	White-breasted Nuthatch	Ellwood Mesa**
Caspian Tern	Devereux**	Spotted Sandpiper	Devereux***	Western/Clark's Grebe	Ellwood Mesa**
Common Tern	Devereux*	Western Sandpiper	Devereux***	Western Grebe	Ellwood Mesa***
Double-crested Cormorant	Devereux***	White-faced Ibis	Devereux**	Western Tanager	Ellwood Mesa**
Dunlin	Devereux***	Whimbrel	Devereux***	Western Wood-Pewee	Ellwood Mesa*
Eared Grebe	Devereux***	Willet	Devereux***	Willow Flycatcher	Ellwood Mesa***
Elegant Tern	Devereux**	Wilson's Phalarope	Devereux***	Wilson's Warbler	Ellwood Mesa***
Eurasian Wigeon	Devereux***	Acorn Woodpecker	Ellwood Mesa***	Yellow-rumped Warbler	Ellwood Mesa***
Gadwall	Devereux**	Allen's Hummingbird	Ellwood Mesa***	Great Egret	North Parcel***
Great Blue Heron	Devereux***	American Robin	Ellwood Mesa**	White-crowned Sparrow	North Parcel**
Greater Scaup	Devereux***	Audubon's Warbler	Ellwood Mesa**	American Bittern	Ocean Meadows***
Greater/Lesser Scaup	Devereux**	Blackpoll Warbler	Ellwood Mesa***	American Coot	Ocean Meadows***
Greater Yellowlegs	Devereux***	Barn Owl	Ellwood Mesa***	American Pipit	Ocean Meadows***
Green-winged Teal	Devereux***	Brown Creeper	Ellwood Mesa*	Belted Kingfisher	Ocean Meadows**
Long-billed Curlew	Devereux***	Brown Pelican	Ellwood Mesa**	Brewer's Blackbird	Ocean Meadows***
Least Sandpiper	Devereux***	Black-throated Gray Warbler	Ellwood Mesa***	Canada Goose	Ocean Meadows***
Lesser Scaup	Devereux***	Canada Warbler	Ellwood Mesa**	Clay-colored Sparrow	Ocean Meadows*

Species	Site	Species	Site	Species	Site
Eastern Phoebe	Ocean Meadows***	Virginia Rail	Ocean Meadows**	House Finch	South Parcel**
Grace's Warbler	Ocean Meadows**	Western Bluebird	Ocean Meadows**	House Wren	South Parcel*
Hooded Merganser	Ocean Meadows***	Wilson's Snipe	Ocean Meadows**	Hutton's Vireo	South Parcel**
Killdeer	Ocean Meadows***	Ash-throated Flycatcher	South Parcel**	Lesser Goldfinch	South Parcel***
Marsh Wren	Ocean Meadows***	Bewick's Wren	South Parcel**	Mute Swan	South Parcel**
Red-shouldered Hawk	Ocean Meadows*	Blue-gray Gnatcatcher	South Parcel***	Northern Mockingbird	South Parcel**
Snow Goose	Ocean Meadows***	Bushtit	South Parcel**	Savannah Sparrow	South Parcel***
Sora	Ocean Meadows***	California Towhee	South Parcel***	Song Sparrow	South Parcel*
Vermilion Flycatcher	Ocean Meadows***	Grasshopper Sparrow	South Parcel***	Western Kingbird	South Parcel*

Table 3.3 – Common and abundant species at selected sites in surveys from 1990 to 2014. Highest frequency was calculated by finding those species were at least one individual was sighted on the highest number of surveys. The species with highest daily abundance were those species that had the highest total counts on any single survey. High mean abundance represents the average of daily abundances over the whole survey period (indicates species with consistently high daily abundances). Where multiple surveys occurred on the same date at the same exact location within the site, I took the average of all surveys. The number in parenthesis indicates the frequency (proportion of survey days encountered) and the abundance values.

Site	Species with highest frequency	Species with highest single-day abundance	Species with highest mean abundance
Coal Oil Point Reserve	Anna's Hummingbird (0.48) California Towhee (0.46) Common Yellowthroat (0.46) House Finch (0.44) Snowy Egret (0.44) Song Sparrow (0.44)	Brown Pelican (900) Brandt's Cormorant (400) Heermann's Gull (400) Sanderling (400) Snowy Plover (368) Western Gull (325)	Snowy Plover (30.5) Sanderling (27.9) Brown Pelican (24.4) Brandt's Cormorant (17.1) Western Gull (17.0) Heermann's Gull (12.9)
Devereux Slough	Mallard (0.46) Great Egret (0.45) Snowy Egret (0.42) Black-necked Stilt (0.38) Black Phoebe (0.37) Killdeer (0.37)	Red-necked Phalarope (2500) Cedar Waxwing (1000) Western Sandpiper (770) Elegant Tern (580) American Coot (520) Black-bellied Plover (434)	Western Sandpiper (12.4) Black-bellied Plover (11.8) Red-necked Phalarope (11.2) Snowy Plover (8.5) Semipalmated Plover (8.2) American Widgeon (7.0)
Ellwood Mesa	California Towhee (0.73) House Finch (0.68) Anna's Hummingbird (0.66) Black Phoebe (0.63) Song Sparrow (0.60) Turkey Vulture (0.53)	Clark's/Western Grebe (500) Western Grebe (400) Sanderling (275) Yellow-rumped Warbler (250) Ancient Murrelet (200) White-crowned Sparrow (200)	Bushtit (5.9) House Finch (5.9) Yellow-rumped Warbler (5.7) Western Grebe (5.1) Sanderling (3.9) Anna's Hummingbird (3.7)
North Parcel	Black Phoebe (0.75) House Finch (0.75) White-crowned Sparrow (0.75) American Crow (0.50) Anna's Hummingbird (0.50) Cassin's Kingbird (0.50)	White-crowned Sparrow (50) Bushtit (20) House Finch (20) Rock Pigeon (16) Yellow-rumped Warbler (7) American Crow (6)	White-crowned Sparrow (22.8) House Finch (8.3) Bushtit (5) Rock Pigeon (4.5) Yellow-rumped Warbler (2.5) Black Phoebe (2)
Ocean Meadows Golf Course	Black Phoebe (0.69) House Finch (0.58) Western Bluebird (0.57) Anna's Hummingbird (0.56) Song Sparrow (0.56) American Crow (0.55)	American Crow (506) Red-winged Blackbird (168) Canada Goose (162) Cliff Swallow (135) Gull species (120) White-crowned Sparrow (110)	American Crow (26) Canada Goose (18.8) White-crowned Sparrow (12.9) House Finch (11.5) Red-winged Blackbird (7.4) Yellow-rumped Warbler (6.4)
South Parcel	House Finch (0.89) California Towhee (0.87) Mourning Dove (0.85) Anna's Hummingbird (0.84) Black Phoebe (0.84) Red-tailed Hawk (0.84)	Cliff Swallow (139) House Finch (102) Red-winged Blackbird (91) White-crowned Sparrow (68) Bushtit (54) Anna's Hummingbird (52)	House Finch (30.5) Bushtit (18) Anna's Hummingbird (14.5) Cliff Swallow (14.1) California Towhee (11.8) Mourning Dove (9.5)

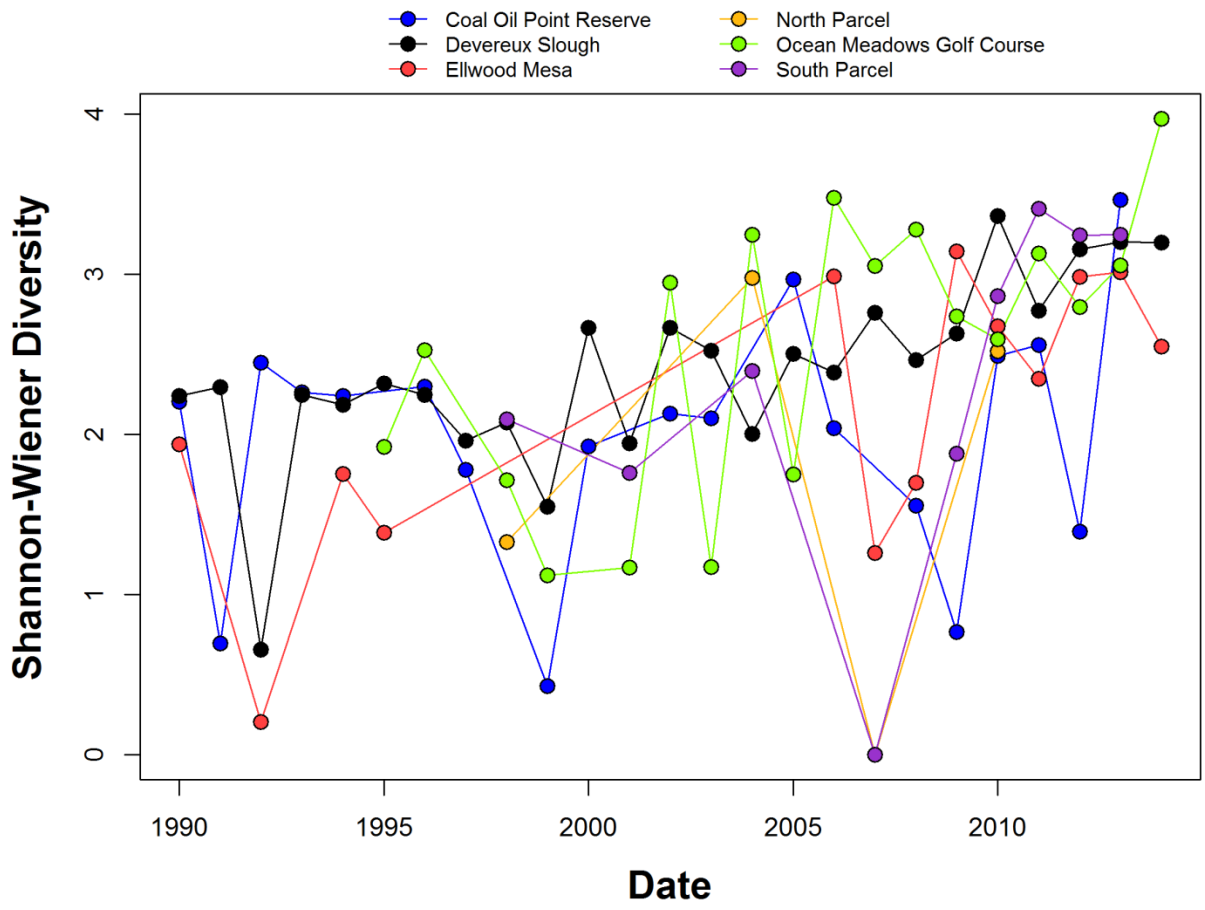

Figure 3.1 - Mean Shannon-Wiener diversity in each year for the six baseline locations. Each data point is the mean of monthly means, therefore could represent a different number of surveys.

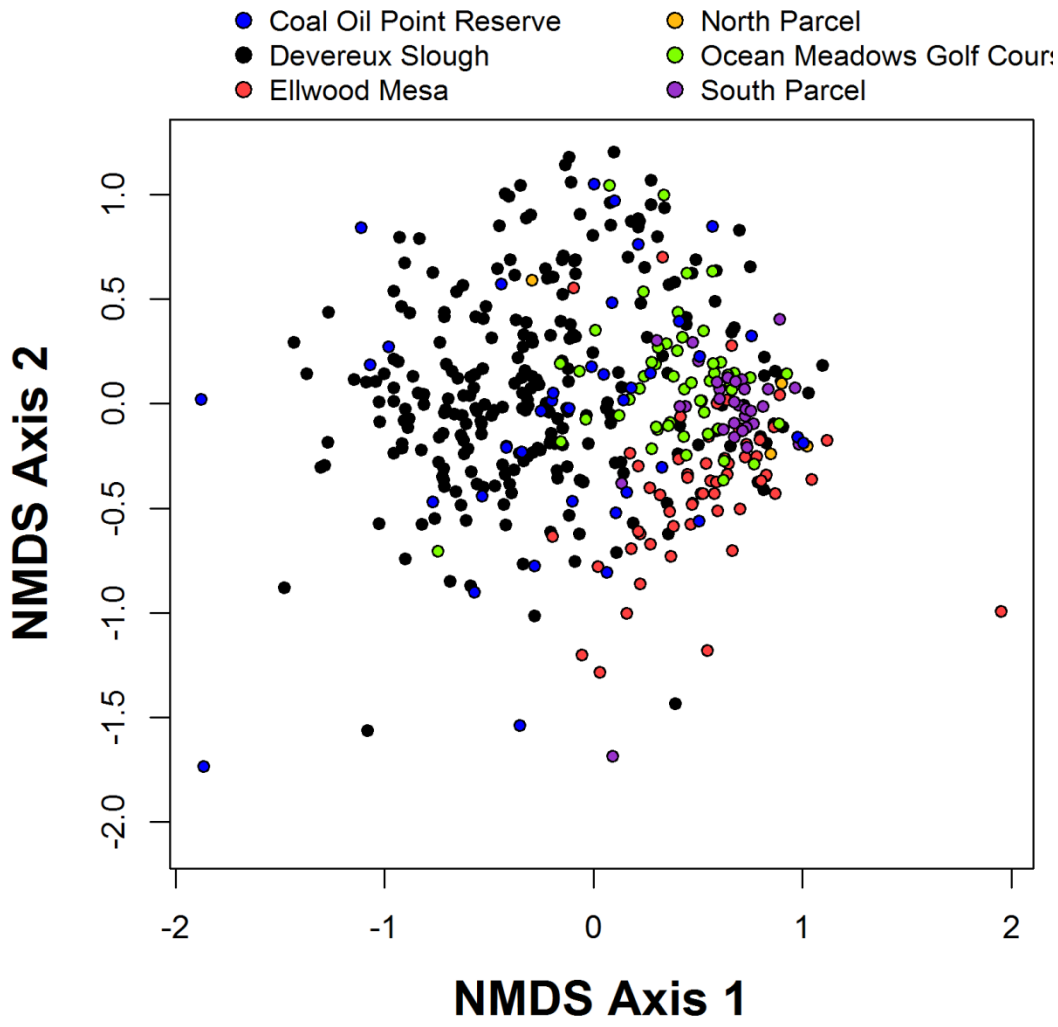

Figure 3.2 – Bird community composition among the sites, illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.11 of 5 dimensional solution. Sites significantly differed from each other according to a PERMANOVA test ($F_{5,418} = 9.78$, $p < 0.001$, 999 iterations).

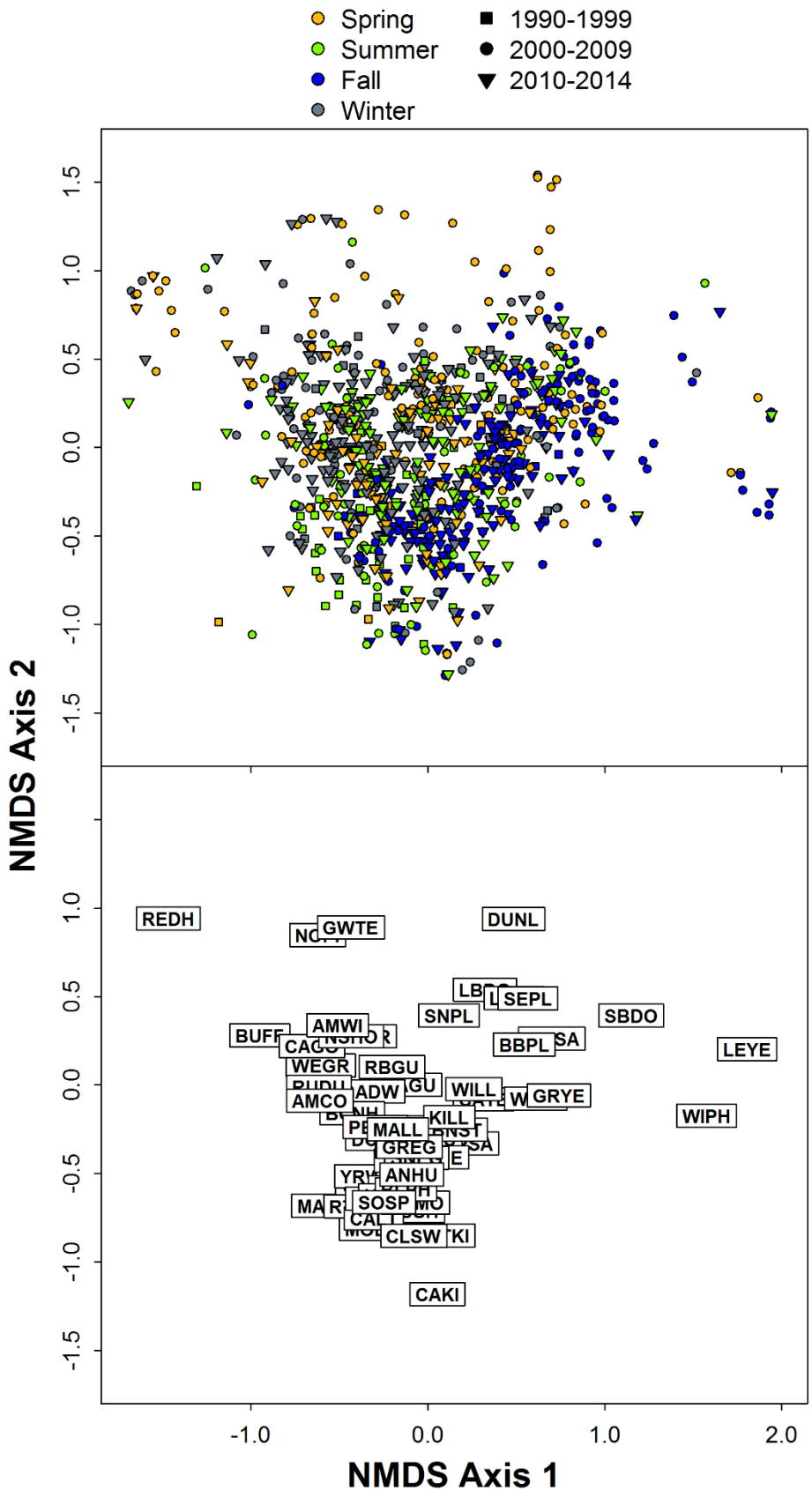

Figure 3.3 – Bird community composition at Devereux Slough illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.11 of 5 dimensional solution. Top panel shows dissimilarity of the surveys, bottom panel shows species scores in the same ordination space, with labeling priority in clusters given to more abundant and frequent species. See full database for species names corresponding to codes used.

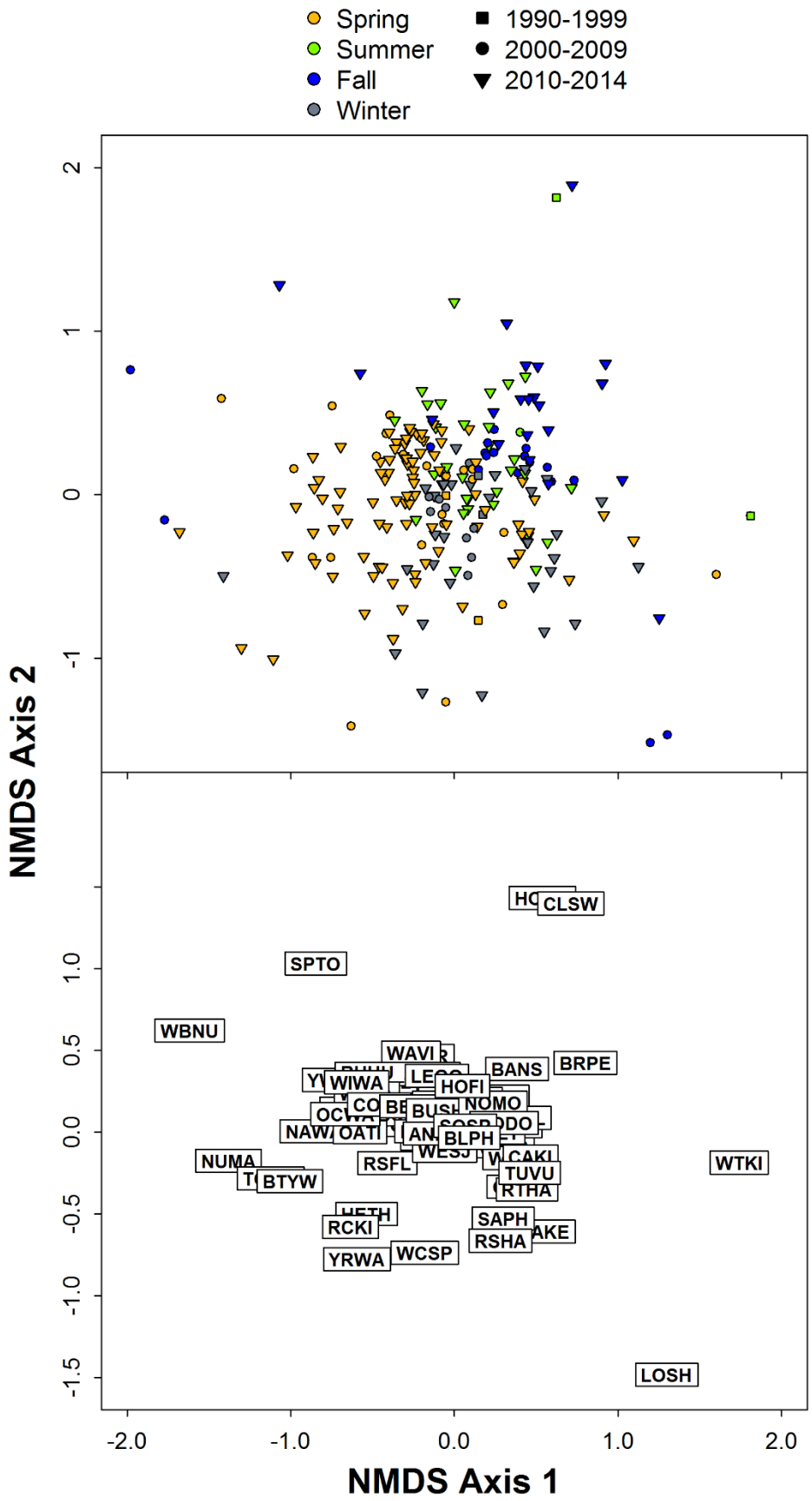

Figure 3.4 – Bird community composition at Ellwood Mesa illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.11 of 5 dimensional solution. Top panel shows dissimilarity of the surveys, bottom panel shows species scores in the same ordination space, with labeling priority in clusters given to more abundant and frequent species. See full database for species names corresponding to codes used.

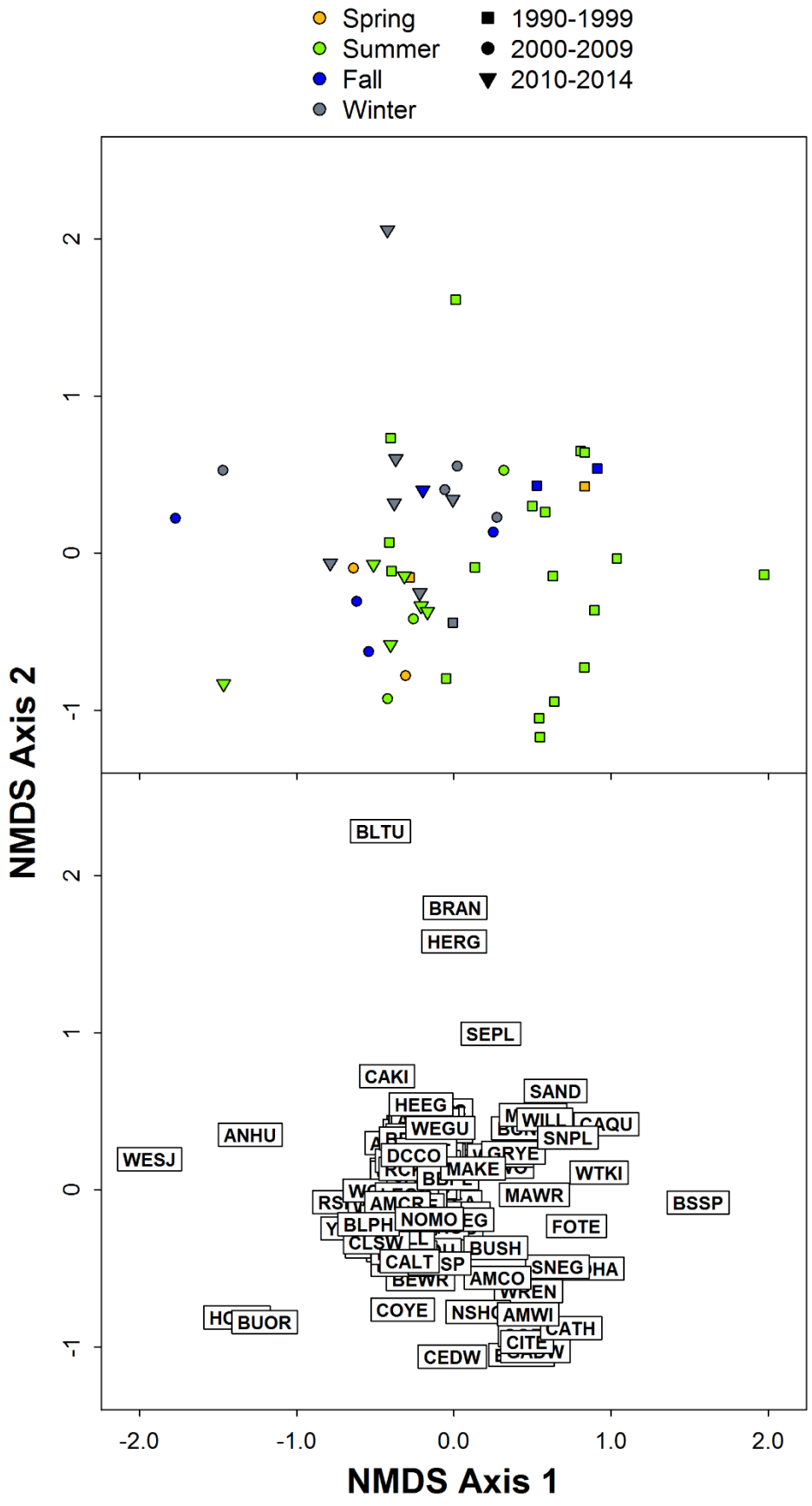

Figure 3.5 – Bird community composition at Coal Oil Point Reserve illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.11 of 3 dimensional solution. Top panel shows dissimilarity of the surveys, bottom panel shows species scores in the same ordination space, with labeling priority in clusters given to more abundant and frequent species. See full database for species names corresponding to codes used.

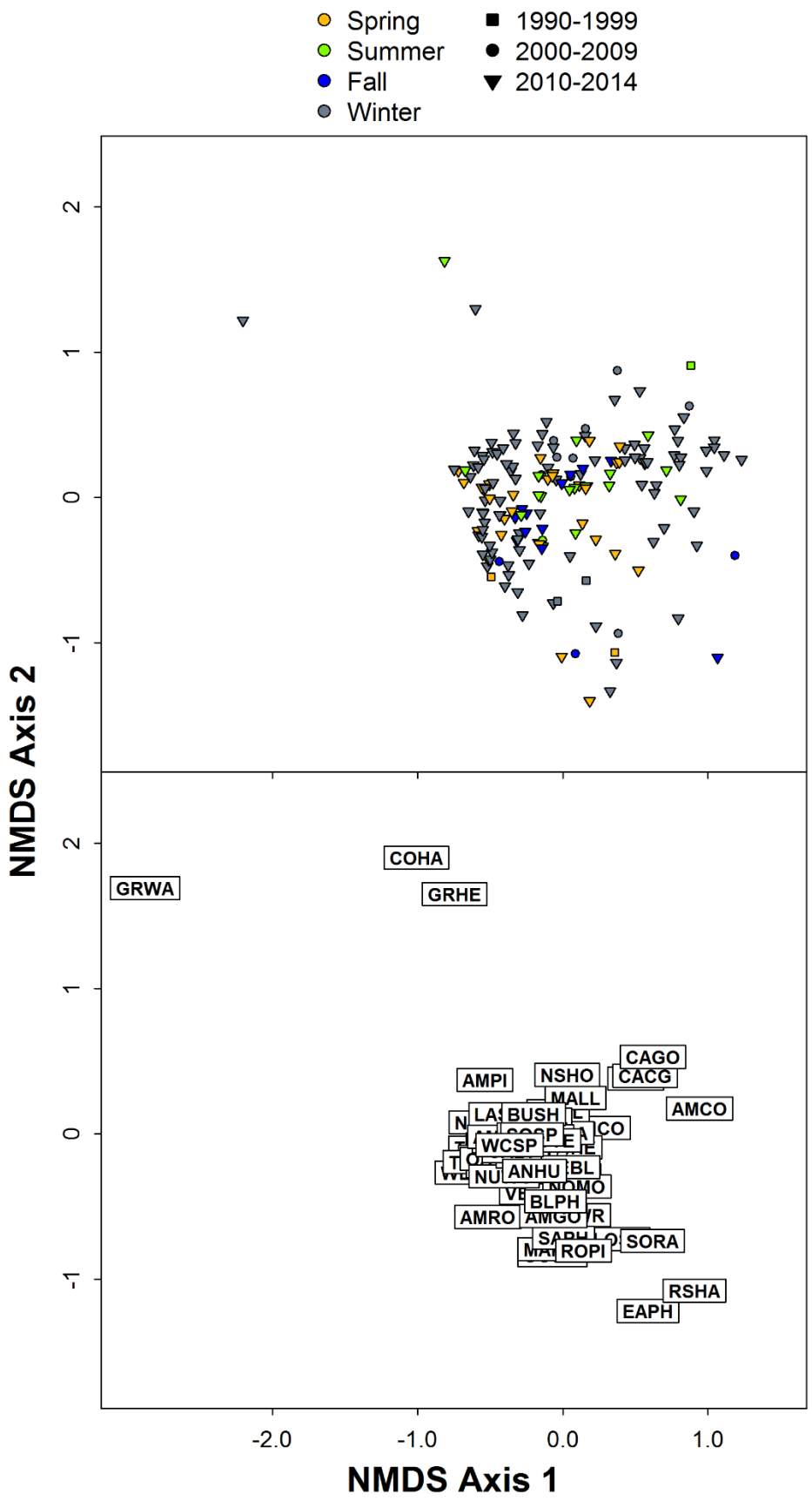

Figure 3.6 – Bird community composition at Ocean Meadows Golf Course illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.11 of 5 dimensional solution. Top panel shows dissimilarity of the surveys, bottom panel shows species scores in the same ordination space, with labeling priority in clusters given to more abundant and frequent species. See full database for species names corresponding to codes used.

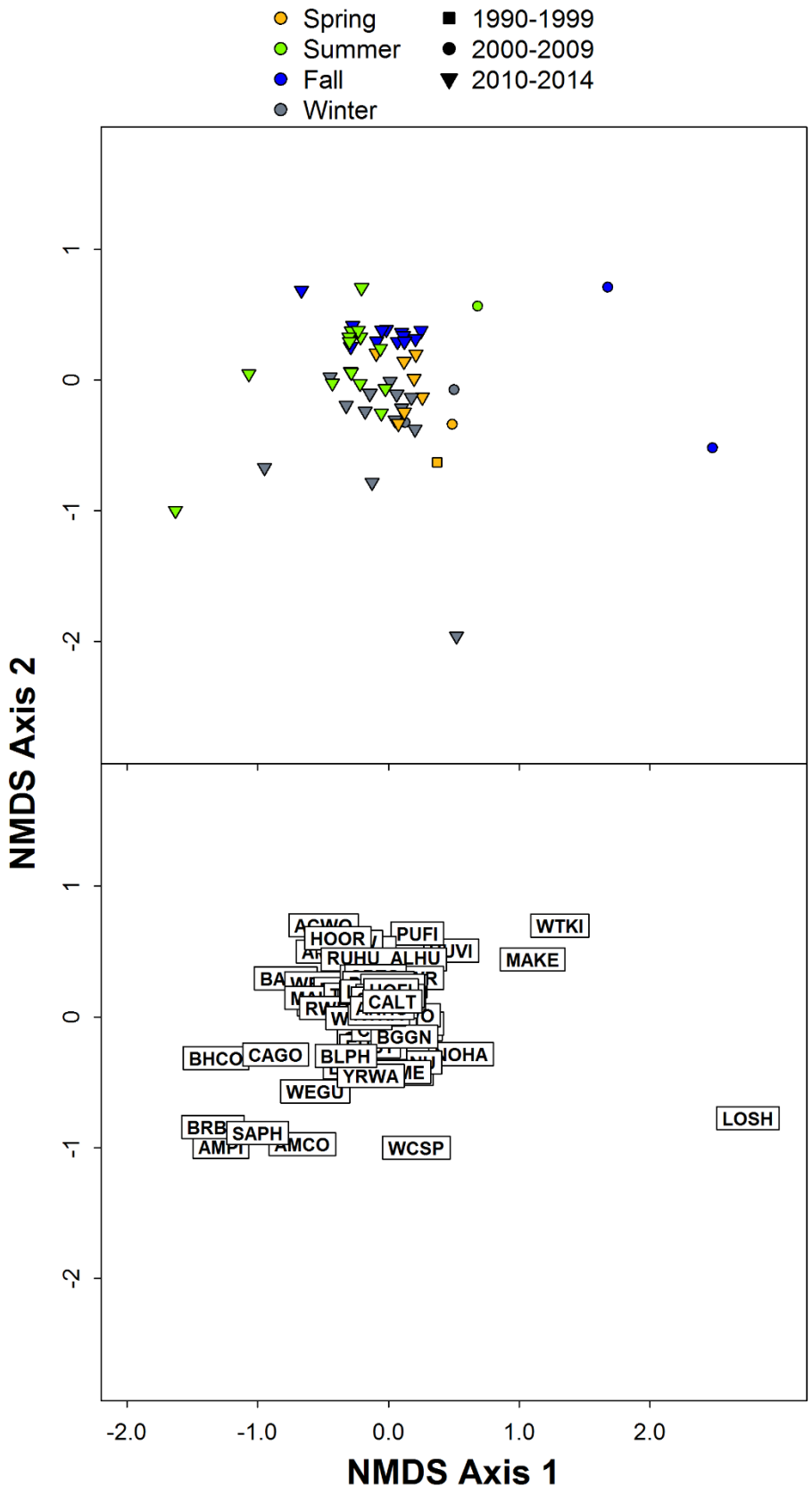

Figure 3.7 – Bird community composition at South Parcel illustrated using non-metric multidimensional scaling (NMDS). Distance between the points indicates their dissimilarity in composition, using Bray-Curtis dissimiliarity index. Species that occurred in < 10% of the surveys were excluded. Ordination shows the best solution after 20 iterations. Final stress = 0.10 of 3 dimensional solution. Top panel shows dissimilarity of the surveys, bottom panel shows species scores in the same ordination space, with labeling priority in clusters given to more abundant and frequent species. See full database for species names corresponding to codes used.

Section 4 – Individual Species Exploratory Analysis

I compared a few select species to evaluate any possible patterns over time and usage of different habitats. To use the same analysis for any additional species, see the associated R code.

White tailed Kite did not appear to increase or decrease in abundance over time (FIG 4.1). They do, however, appear to occur at higher abundance around tidal marsh and brackish pond wetland habitats, and non-native annual grassland and irrigated lawn uplands (FIG 4.2). Sightings of White-tailed Kites in developed upland habitats, however, have been very consistent over the surveys. Another raptor, Red-tailed Hawk, also did not show an obvious pattern over time (FIG 4.3). They were most abundant in tidal marsh, developed and eucalyptus woodland (FIG 4.4).

Green Heron and Sora are both hard to detect species, and I examined abundance over time for each in a similar fashion (FIG 4.5). Green heron were never particularly abundant and appeared to prefer tidal marsh and brackish pond habitats. Sora were consistently observed in tidal marsh also, and reached high abundance occasionally in brackish ponds.

Belding's Savannah Sparrow was observed at high abundance only in surveys prior to 2005 (FIG 4.6). They were consistently observed in coastal strand and brackish ponds, but were at higher abundance in tidal marsh and vernal pools in the 1990s (FIG 4.7). For upland habitats, they were only consistently observed in coastal sage scrub (FIG 4.7).

UPDATE: I also created graphs that showed the actual location instead of the habitat types. The code for doing this will be provided to generate graphs for any birds of interest. In this case, Devereux Slough refers only to those locations that are listed as part of the Greater Devereux Area in Table 1.1 and Table 2.1. Other Devereux Slough locations are considered part of Coal Oil Point Reserve.

White-tailed kites occurred consistently at Goleta Slough, Devereux Slough and Coal Oil Point (Fig 4.8). As, expected given the pattern for habitat use, Belding's Savanna Sparrow was most abundant at Goleta Slough (Fig 4.9). Snowy Plover increased dramatically over the survey period (4.10), especially at Coal Oil Point (Fig 4.11).

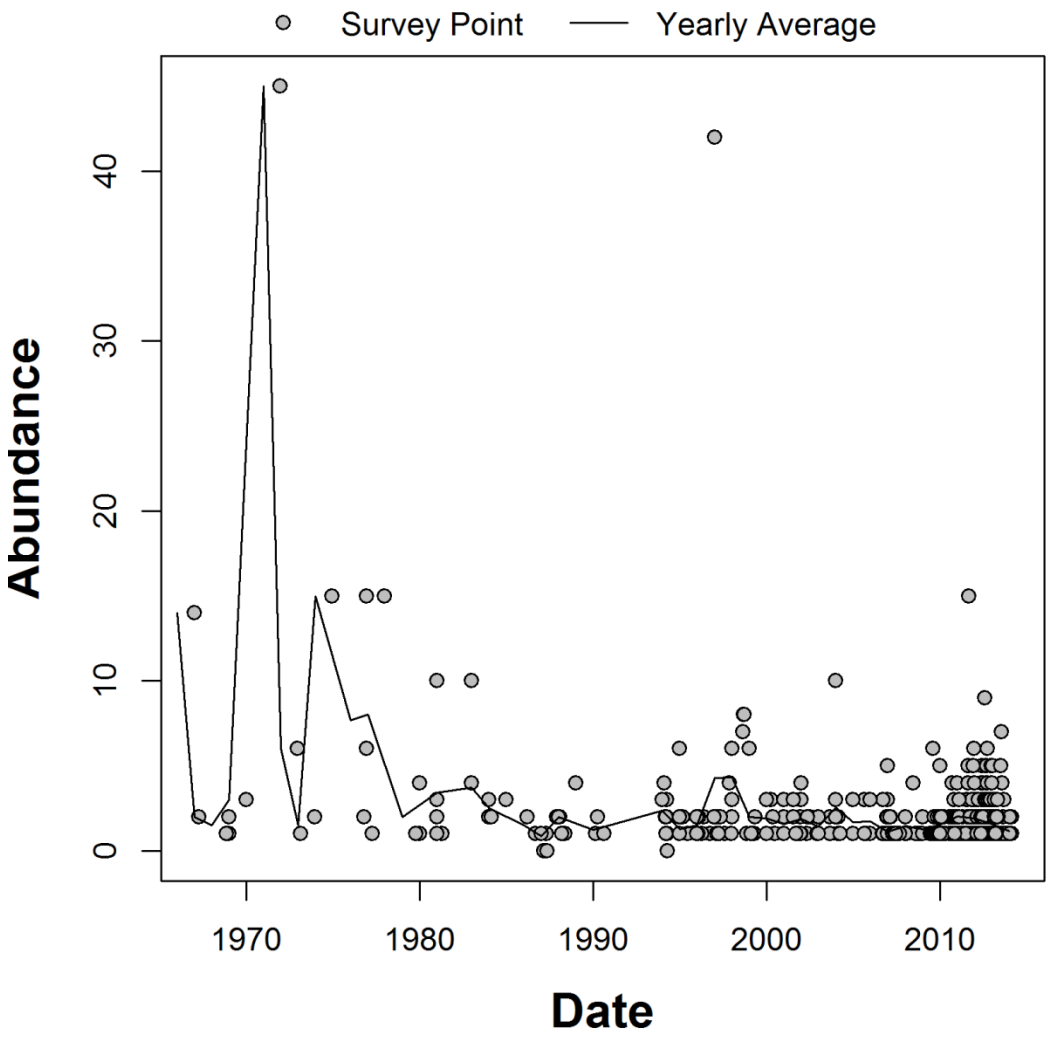

Figure 4.1 – White-tailed Kite abundance over time. Each point represents a single survey, and the line a running yearly average count.

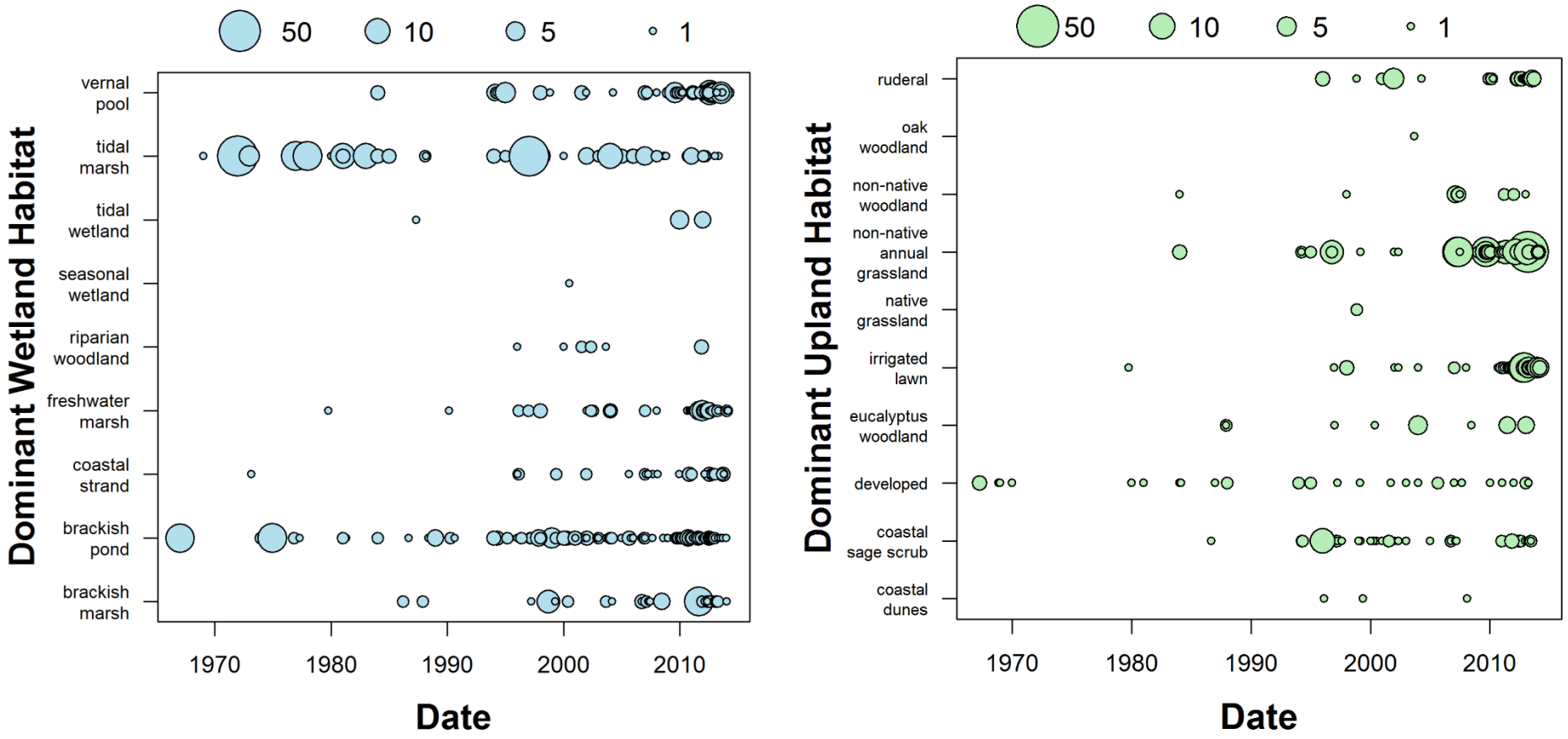

Figure 4.2 – White-tailed Kite abundance and habitat use over time for wetlands (left) and uplands (right). Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

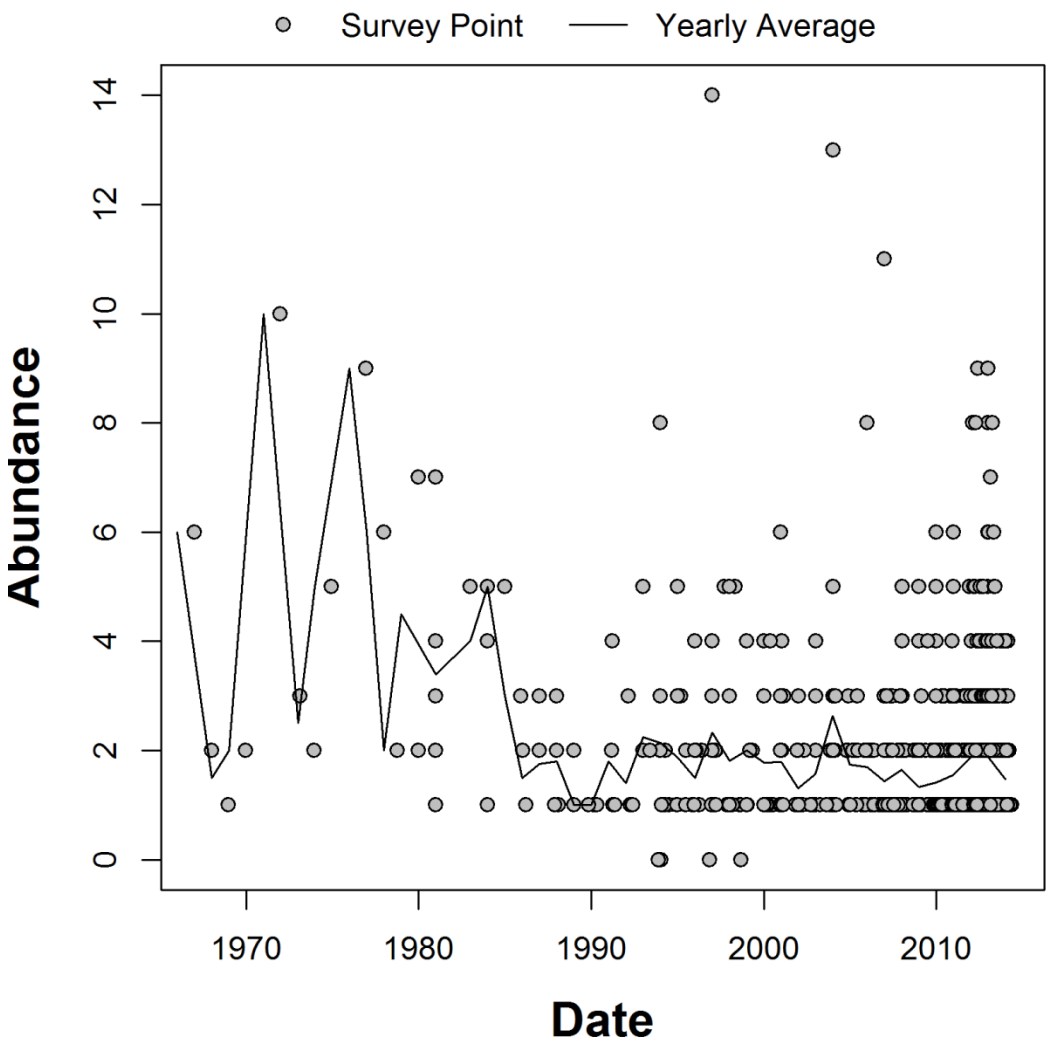

Figure 4.3 – Red-tailed Hawk abundance over time. Each point represents a single survey, and the line a running yearly average count.

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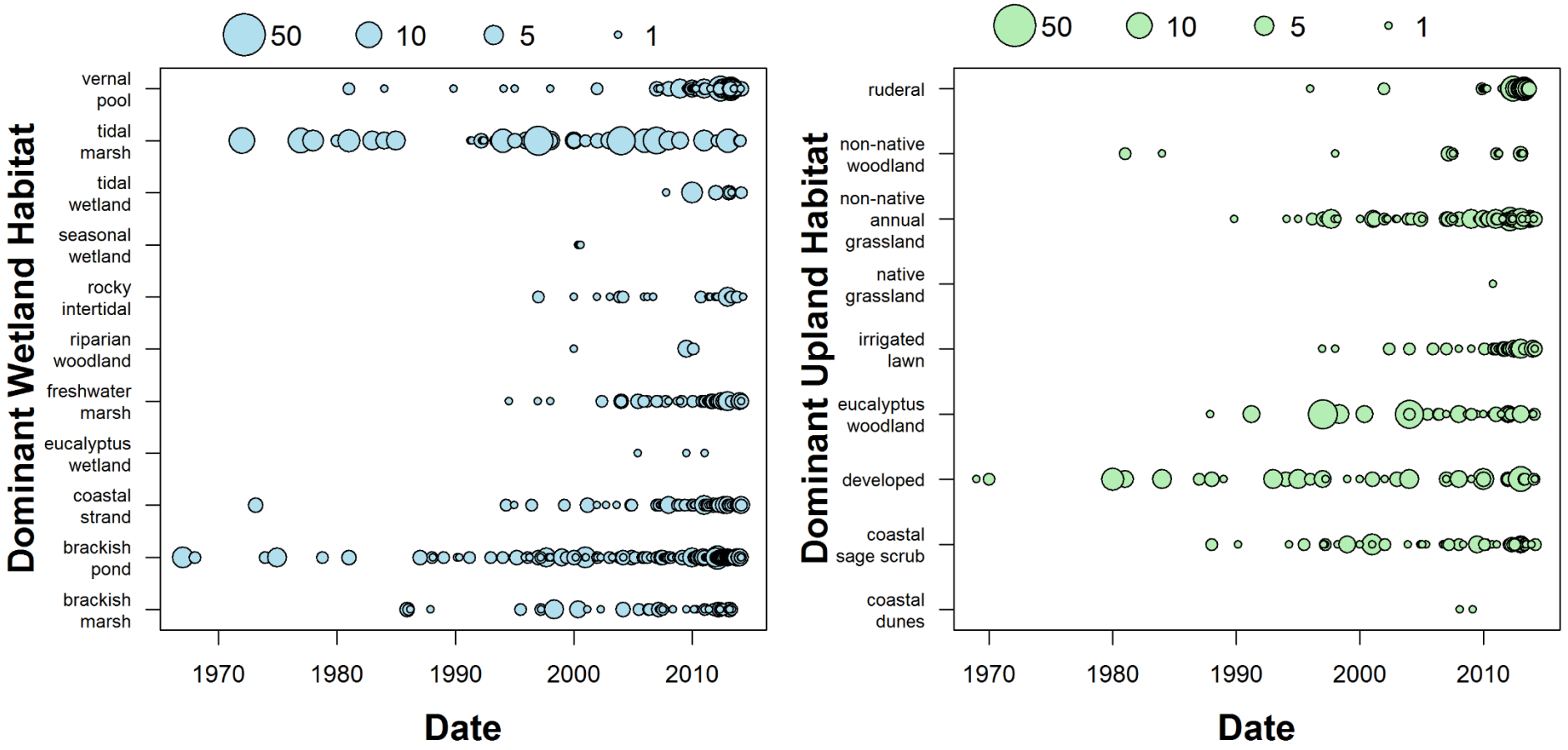

Figure 4.4 – Red-tailed Hawk abundance and habitat use over time for wetlands (left) and uplands (right). Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

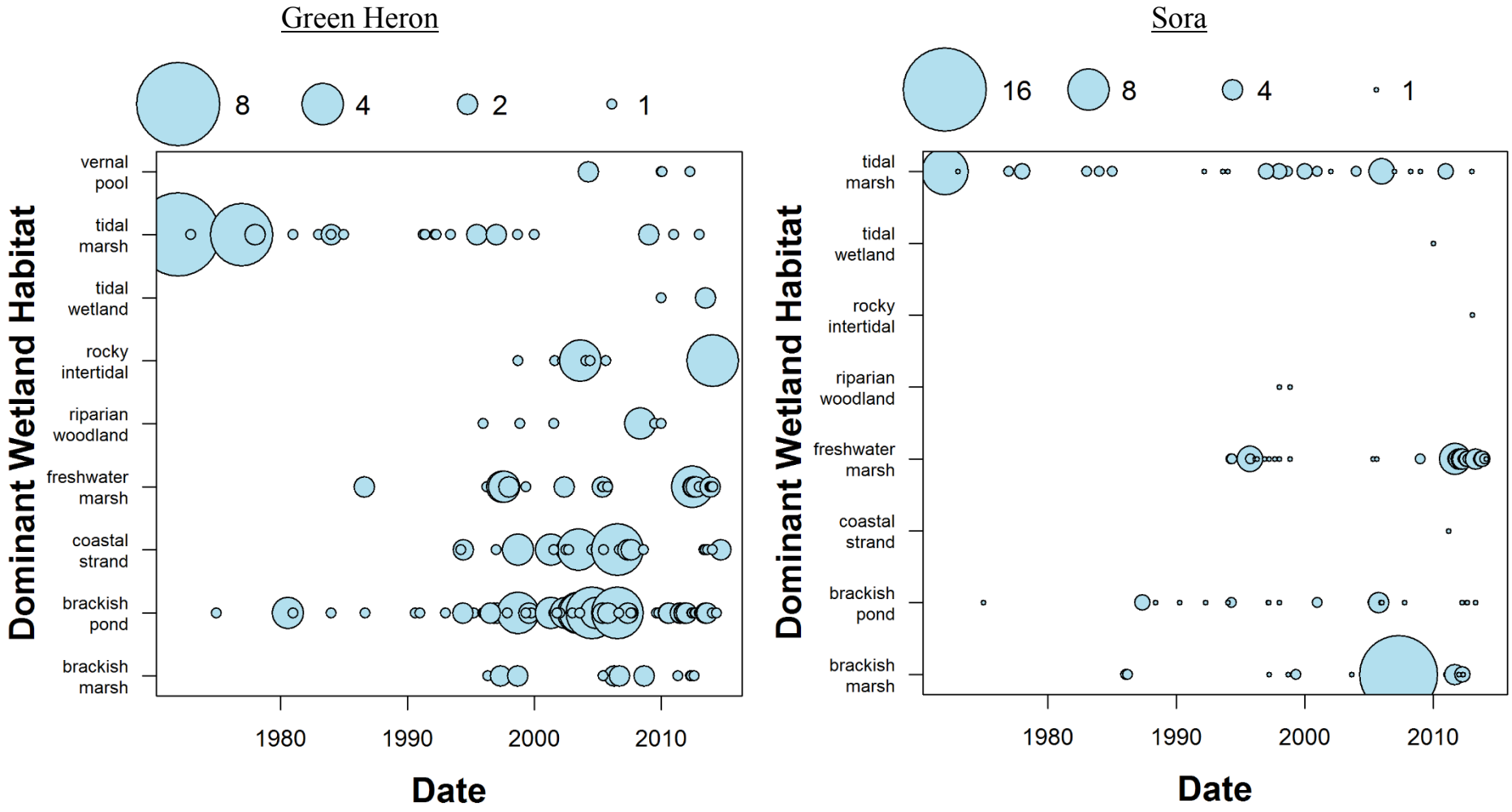

Figure 4.5 – Abundance and wetland habitat use over time for the Green Heron and Sora. Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

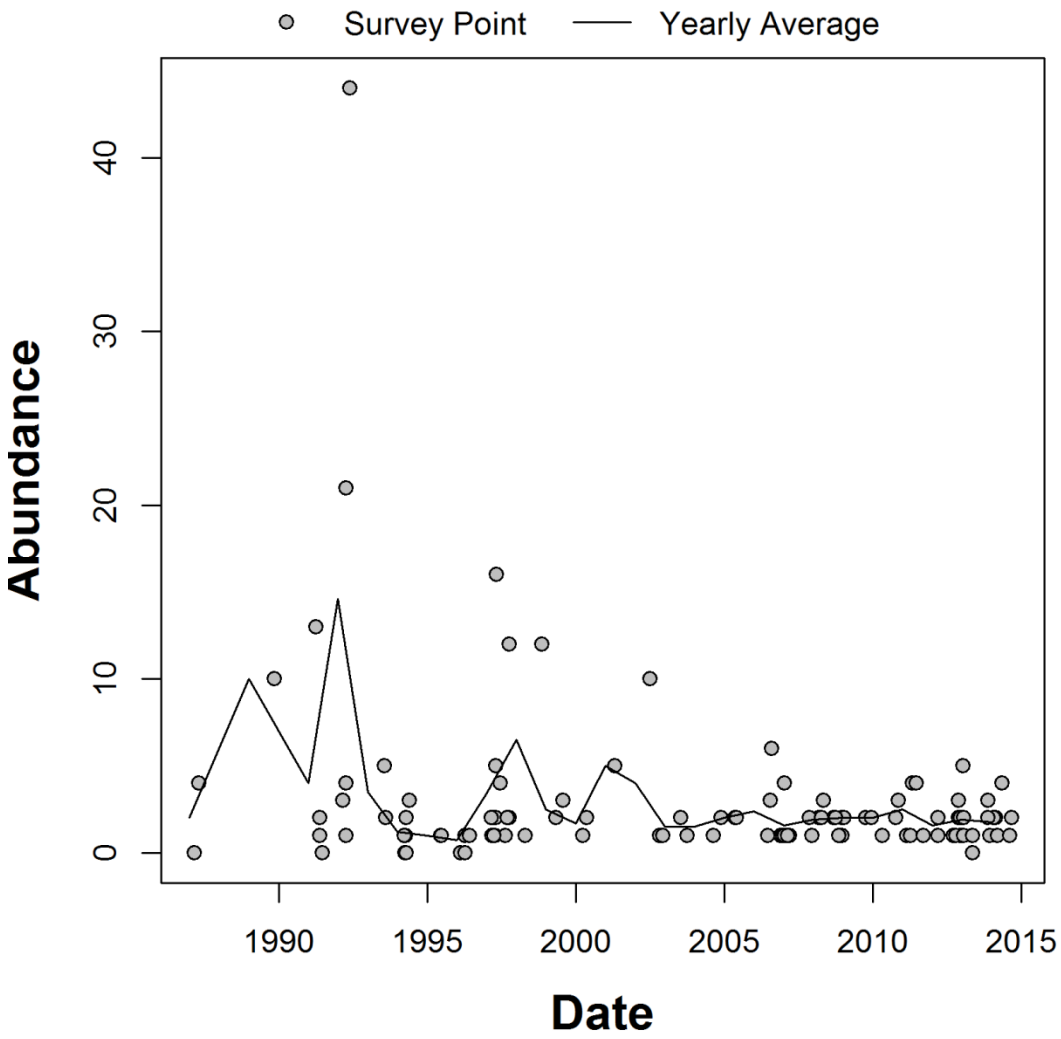

Figure 4.6 – Belding's Savannah Sparrow abundance over time. Each point represents a single survey, and the line a running yearly average count.

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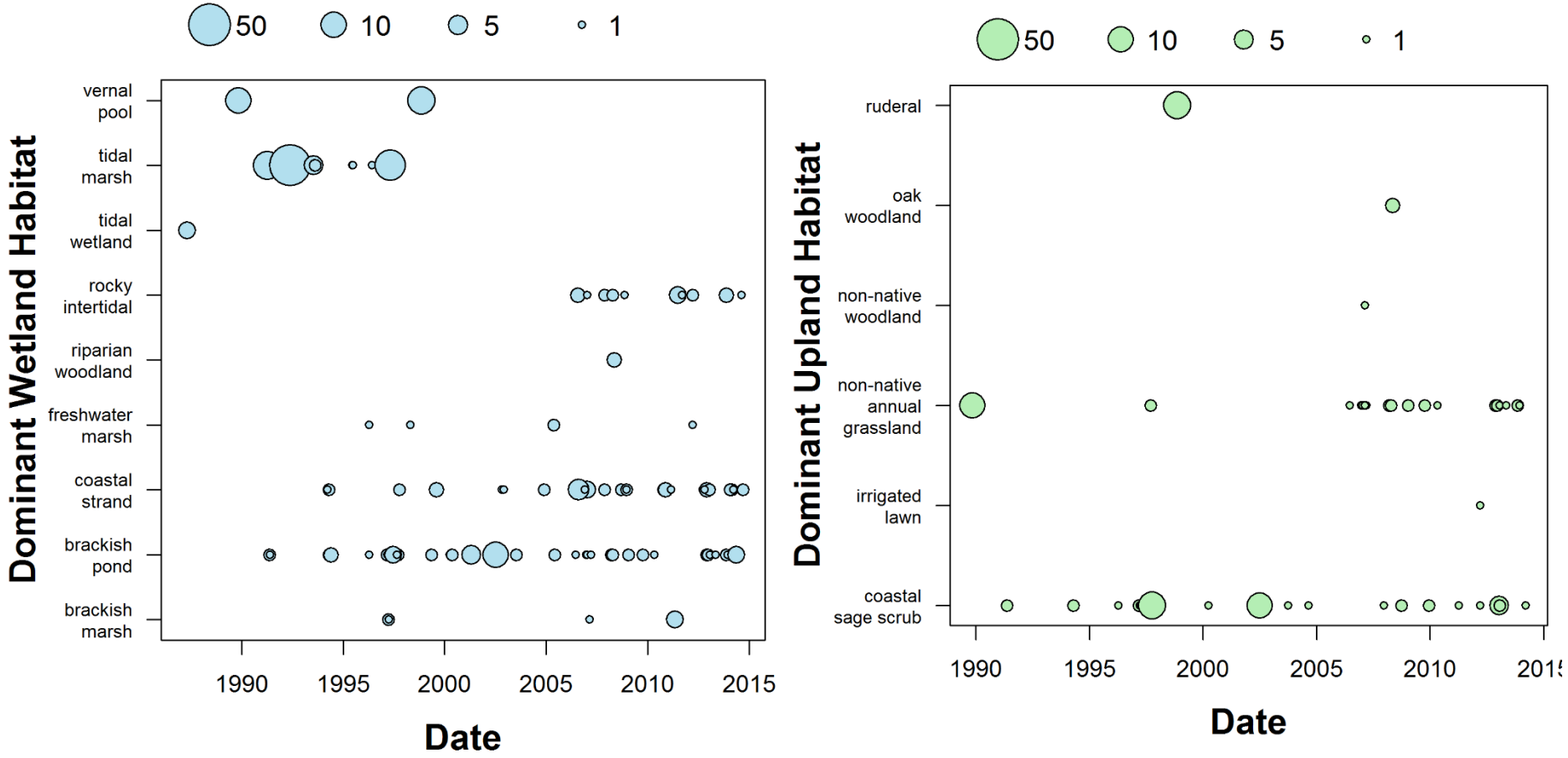

Figure 4.7 – Belding's Savannah Sparrow abundance and habitat use over time for wetlands (left) and uplands (right). Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

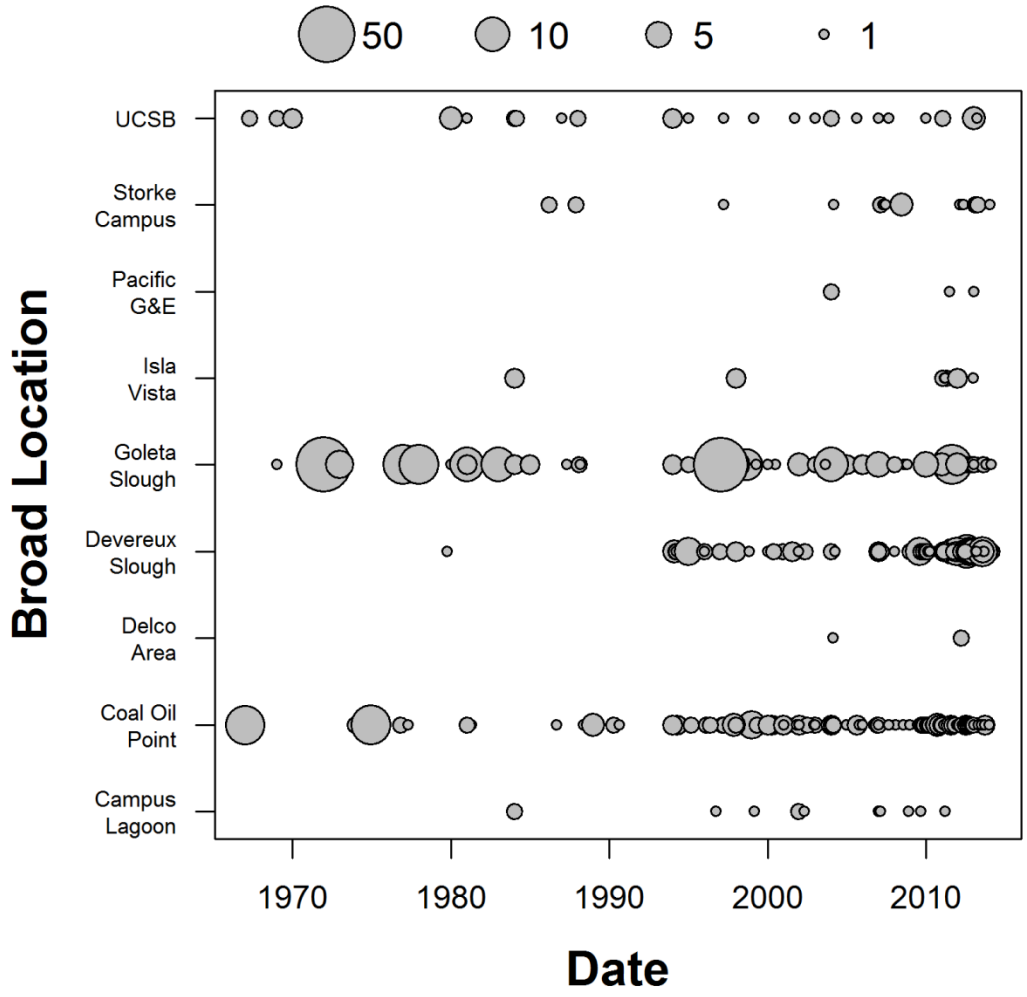

Figure 4.8 - White-tailed Kite abundance and presence at each broad location. Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

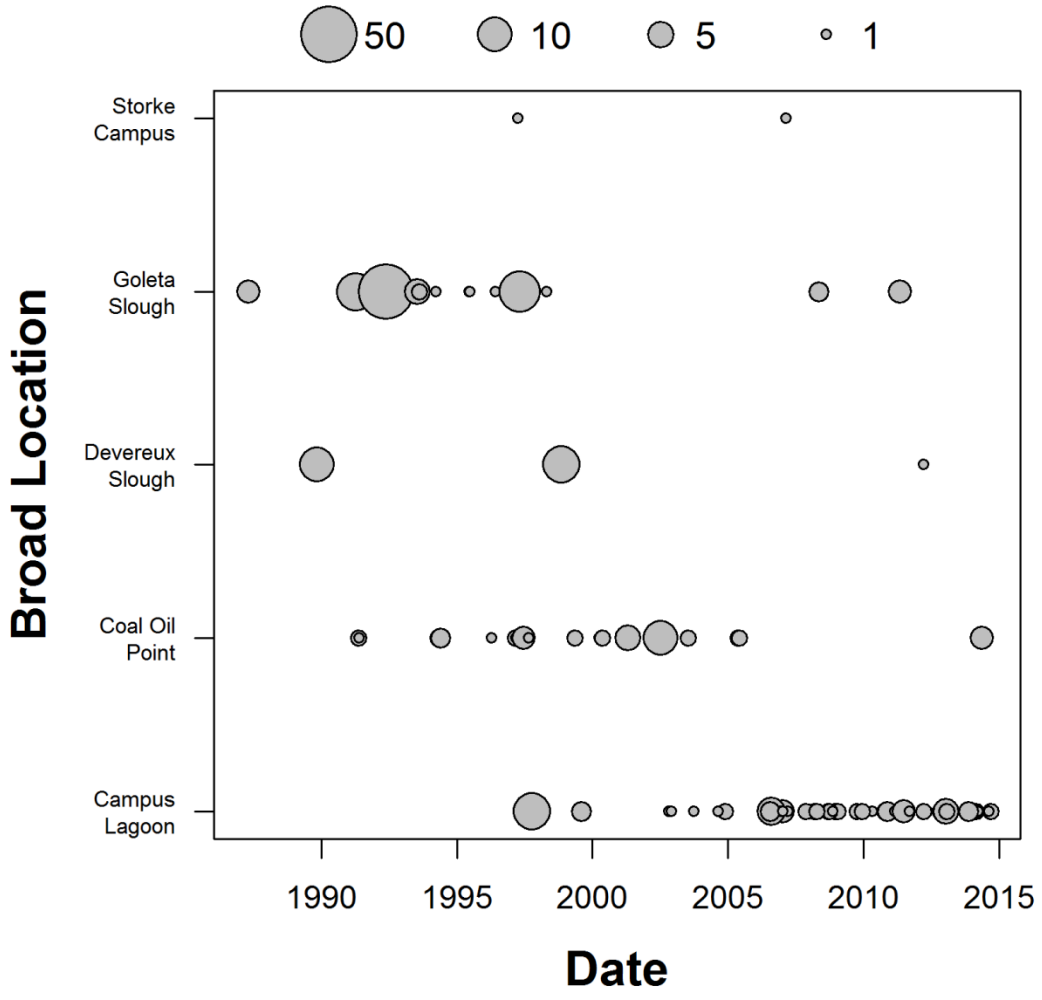

Figure 4.9 – Belding's Savanna Sparrow abundance and presence at each broad location. Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

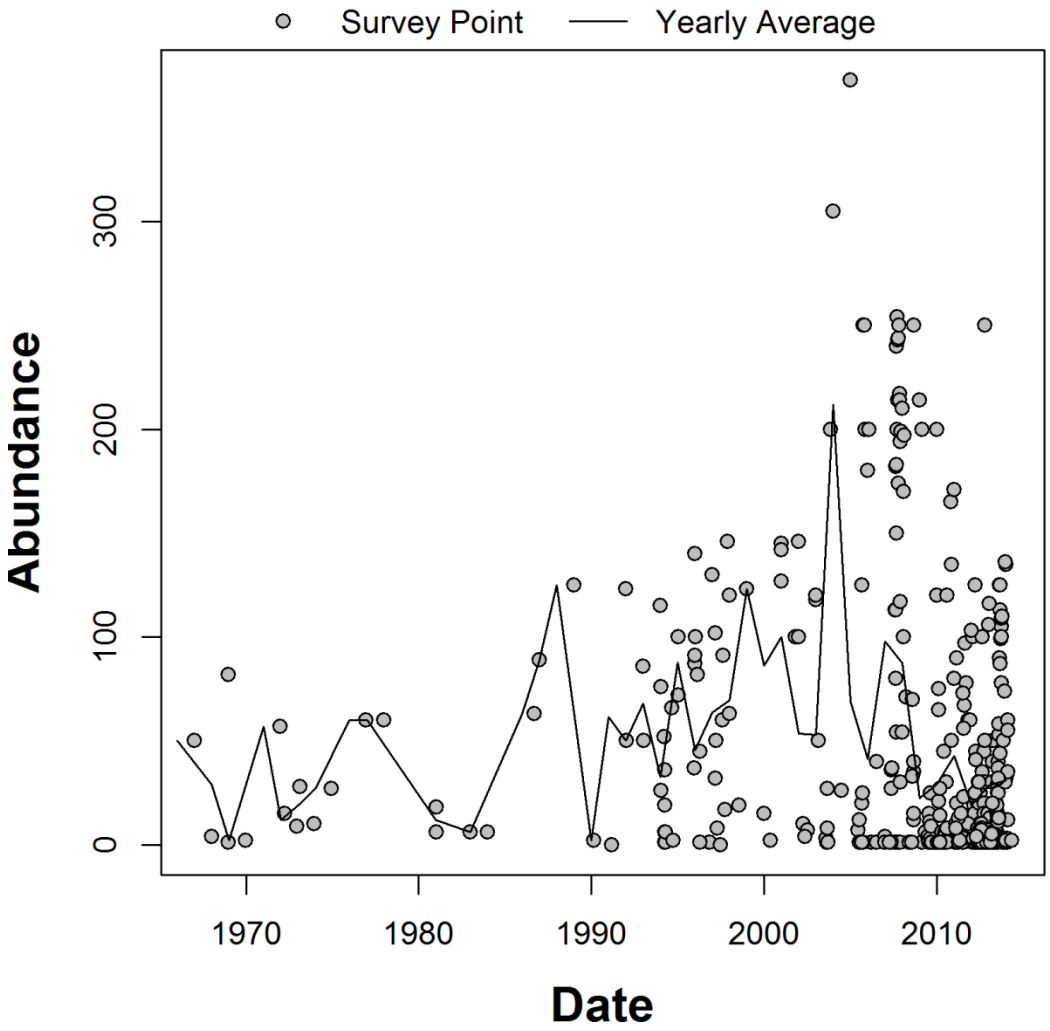

Figure 4.10 – Snowy Plover abundance over time. Each point represents a single survey, and the line a running yearly average count.

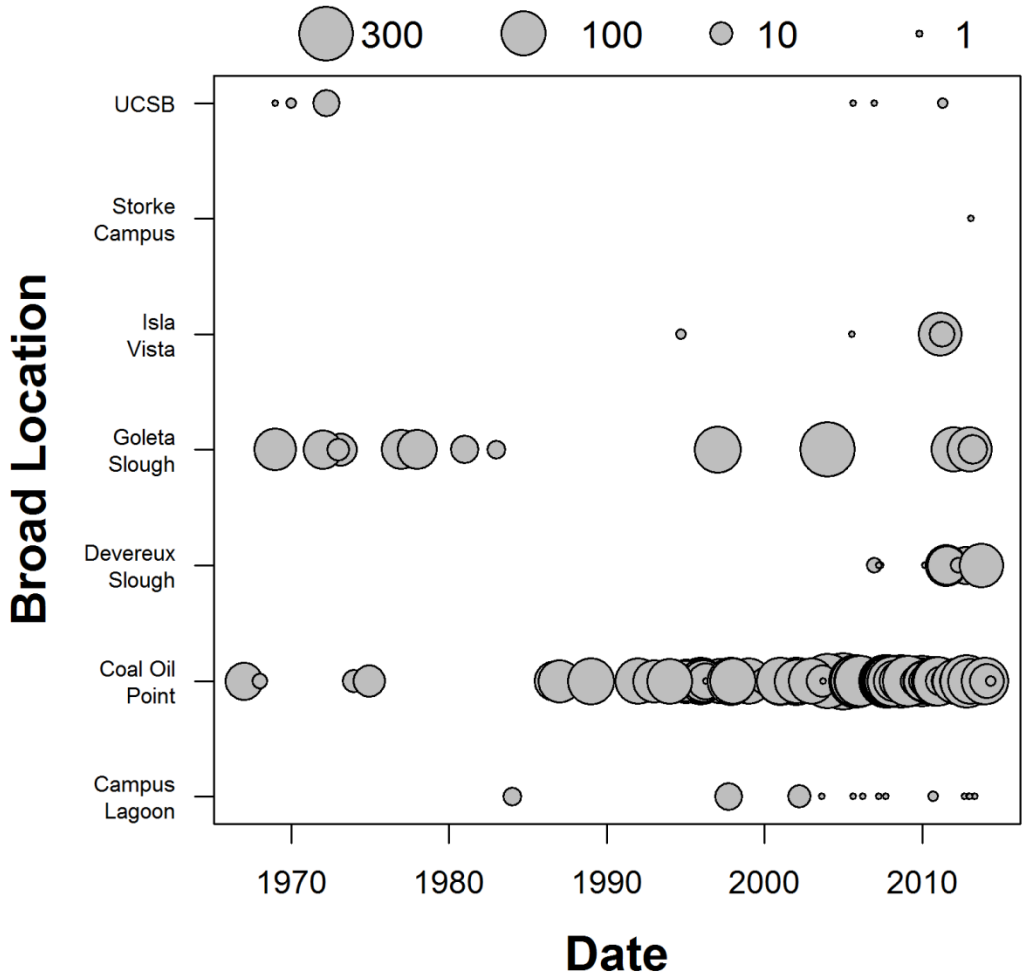

Figure 4.11 – Snowy Plover abundance and presence at each broad location. Each point represents a single survey. The size of the points is scaled relative to the abundance, as indicated by the legend.

Section 5 – Diversity and Abundance by Location

For a more in-depth look at Goleta Slough, Devereux Slough and Campus Lagoon, I examined patterns in mean Shannon diversity and bird abundances over the course of the year. First, I calculated a monthly mean of the total counts for each species (within locations and years). In this case, as in sections 1 and 2, Devereux Slough includes locations within Coal Oil Point Reserve. Then I separated the data by season, as in section 3. Spring = March, April & May; Summer = June, July & August; Fall = September, October & November; Winter = December, January & February. Within each of these seasons, I took an average of the monthly mean counts for every year. Then, I calculated diversity for this average yearly community.

In spring, mean Shannon diversity appears higher at the two slough locations compared to Campus Lagoon prior to the 2000s (Fig 5.1A). Since then, values have been more similar. I used a linear SLS model to test the effect of year and site on diversity, along with their interaction. This analysis looks for any linear relationships between diversity and year (but wouldn't account for any nonlinear relationships)[1]. This model explained ~42% of the variation in diversity, and was highly significant ($F_{5,71} = 11.88$, $p < 0.001$). The residuals were normally distributed. On average, Goleta Slough and Devereux Slough had higher diversity than Campus Lagoon, according to a post-hoc Tukey test ($F_{2,71} = 3.33$, $p = 0.04$), although there was a significant interaction between year and site ($F_{2,71} = 3.21$, $p = 0.05$). The slope of the relationship with year was positive at all three sites, but was lowest at Devereux Slough, and higher at the other two sites. F test of the pairwise contrasts between the slopes, adjusted using Holm's method, showed that there was a trend toward a difference between Devereux and Campus Lagoon ($p < 0.1$).

Also in spring, I compared the abundance of shorebirds (Fig 5.1B), ducks (Fig 5.1C) and wading birds (Fig 5.1D) over time among the three sites. Using a similar statistical method to that described above, I compared the three types of wetland birds. In all cases, the counts had to be transformed to meet the assumptions of normal residuals ($\sqrt[n]{abundance}$; n depended on the functional group). For shorebirds, there was a trend toward a significant difference between the sites($F_{2,60} = 3.02$, $p = 0.06$), and this did not interact with year. Devereux had significantly higher abundance compared to Goleta Slough, according to a post-hoc Tukey test ($p = 0.04$). For ducks, there was also a significant difference among sites ($F_{2,66} = 12.65$ $p < 0.001$), and the slope of the year effect differed between sites ($F_{2,66} = 4.26$, $p = 0.02$). Both Devereux and Goleta Slough had lower duck abundance compared to Campus Lagoon. The slope of the year effect was negative at the Campus Lagoon, and positive at Goleta Slough. The slope was approximately zero at

[1]It is possible that a repeated-measures model should be used and not take the means within a year prior to analysis, but, this could be problematic since the sample sizes would be wildly different across years and sites. I am also not sure to what extent these data might be repeated-measures (i.e. did the person go to the exact same spot from year to year, etc). I think it is at least somewhat reasonable to make the assumption that the years are independent from each other, esp. if they are averages across many surveys, taken for many different purposes by different observers.

Devereux. Wading birds did not differ among sites, and had no significant linear relationship with year.

In summer, 46% of the variation in Shannon diversity was explained by a model with site, year and their interaction ($F_{5,62} = 12.54$, $p < 0.001$). However, only the relationship with year was significant (F1,62 = 57.61, $p < 0.001$), and the sites did not differ. Shannon diversity increased over the time period (Fig 5.2A). For shorebird abundance, there were differences among sites (F2,52 = 7.32, $p < 0.001$), and there was no effect of year or an interaction. Devereux Slough had significantly more summer shorebirds than the other sites, according to a post-hoc Tukey test (Fig 5.2B). Duck abundance did not differ among the sites, but increased over time (Fig 5.2C, $F_{1,52} = 6.55$, $p = 0.01$). Our model revealed no significant effects on site or year on the abundance of wading birds (Fig 5.2D).

Fall bird diversity also increased over time (Fig 5.3A; $F_{1,63} = 89.53$, $p < 0.001$), but was not different among the sites. Fifty-six percent of the variation in diversity was explained by this model with site, year and their interation ($F_{5,63} = 18.52$, $p < 0.001$). Approximately 33% of the variation in shorebird numbers was explained by the linear model with site, year and their interaction ($F_{5,57} = 7.07$, $p < 0.001$). Shorebird numbers increased over time at all sites ($F_{1,57} = 13.79$, $p < 0.001$), although they were higher at Devereux than the other two sites (Fig 5.3B, $F_{2,57} = 10.76$, $p < 0.001$) according to a *post-hoc* Tukey test. The model of ducks was significant, although it only explained 13% of the variance in numbers ($F_{5,48} = 2.55$, $p = 0.04$). Site was the only significant term ($F_{2,48} = 3.65$, $p = 0.03$); Campus Lagoon had higher mean duck abundance relative to Goleta Slough, and Devereux was intermediate (Fig 5.3C). Wader abundance increased over time ($F_{1,50} = 10.31$, $p = 0.002$) and differed among the sites (Fig 5.3D; $F_{2,50} = 4.52$, $p = 0.02$). The model explained 21% of the variance in wader numbers ($F_{5,50} = 3.91$, $p = 0.005$).

In winter, there was a significant interaction between site and year ($F_{2,88} = 10.42$, $p < 0.001$), and the model itself was highly significant ($F_{5,88} = 10.26$, $p < 0.001$). According to a post-hoc test of the regression slopes, at Goleta Slough there was not much of a trend over time, but diversity increased at Devereux and Campus Lagoon (Fig 5.4A). Shorebird abundance variance was not explained significantly by the model with site, year and their interaction, although there was a significant negative temporal trend (Fig 5.4B; $F_{1,79} = 5.37$, $p = 0.02$). There was a significant site by year interaction in the model of winter duck abundance ($F_{2,85} = 4.99$, $p = 0.009$), as well as a difference among site means ($F_{2,85} = 6.90$, $p = 0.002$). There were significantly more ducks at Goleta Slough relative to Devereux, and Campus Lagoon was intermediate (Fig 5.4C). At Goleta Slough, there was a negative trend over time, whereas there was a positive trend at the other two locations. There were no effects of site or year on wader abundance (Fig 5.4D).

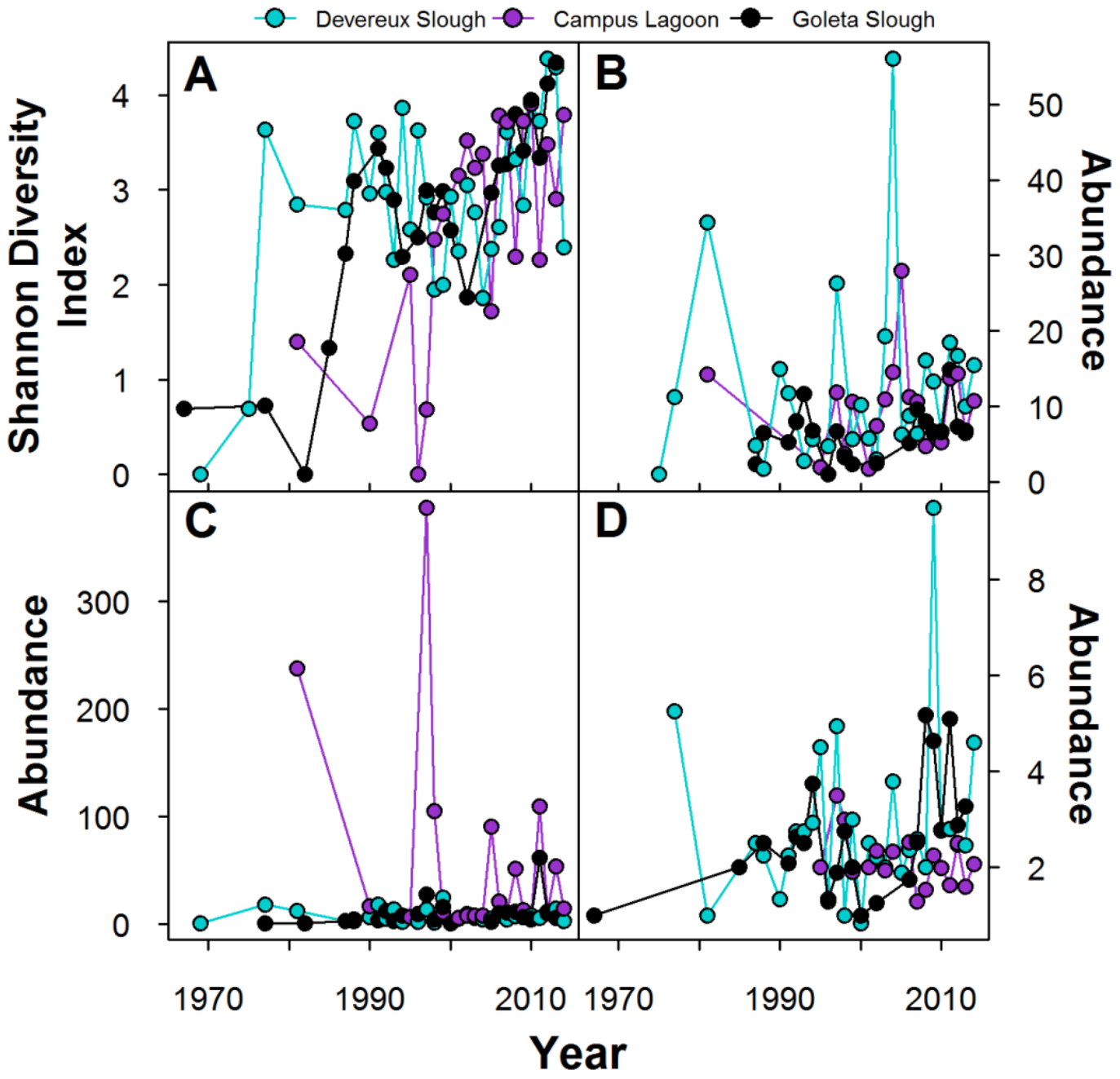

Figure 5.1 – Spring (Mar, Apr & May) patterns over the survey period in species abundance and diversity at three large wetland sites. (A) Mean Shannon-Wiener diversity, (B) shorebird abundance, (C) duck abundance and (D) wader abundance.

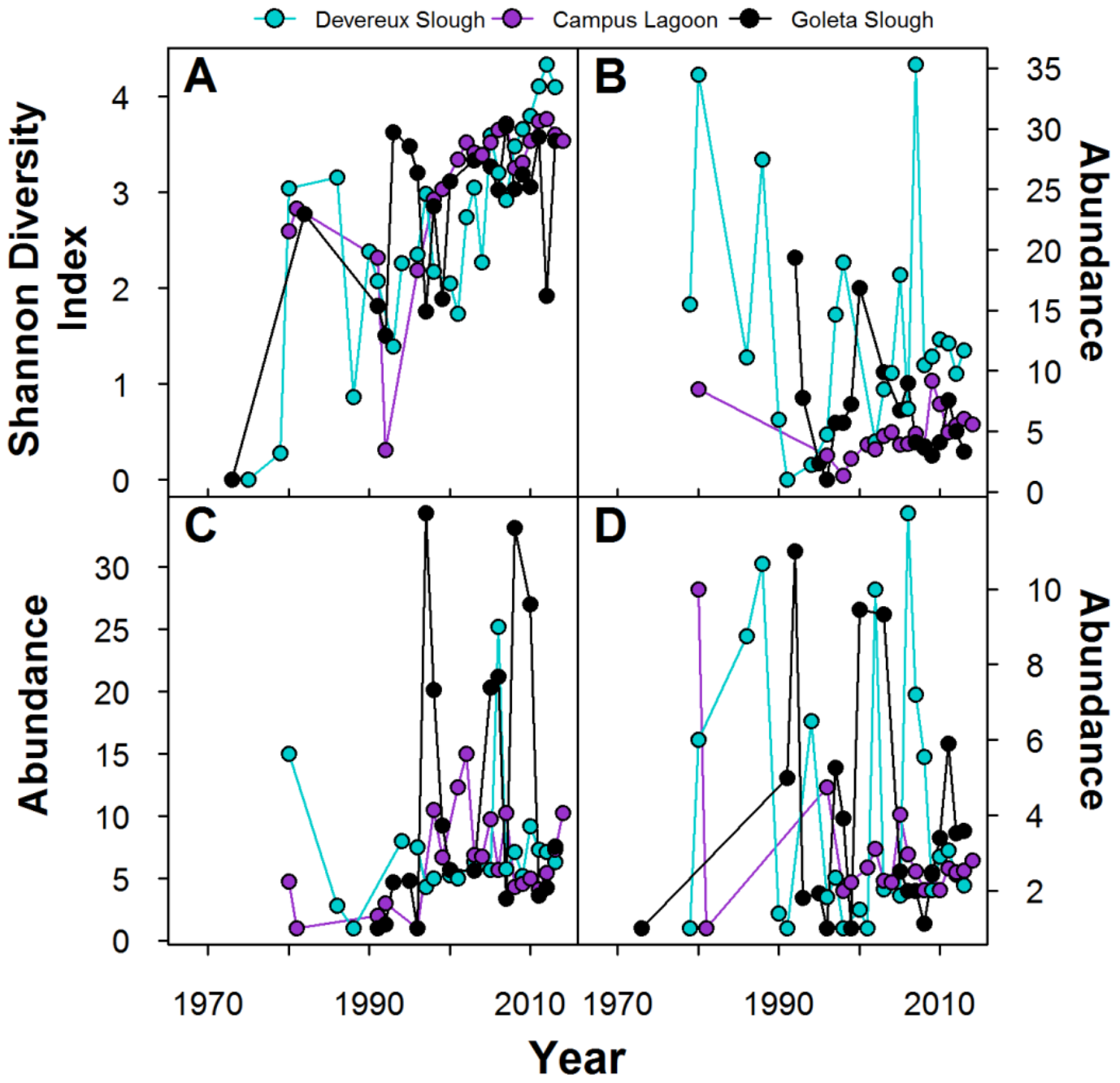

Figure 5.2 – Summer (June, July & Aug) patterns over the survey period in species abundance and diversity at three large wetland sites. (A) Mean Shannon-Wiener diversity, (B) shorebird abundance, (C) duck abundance and (D) wader abundance.

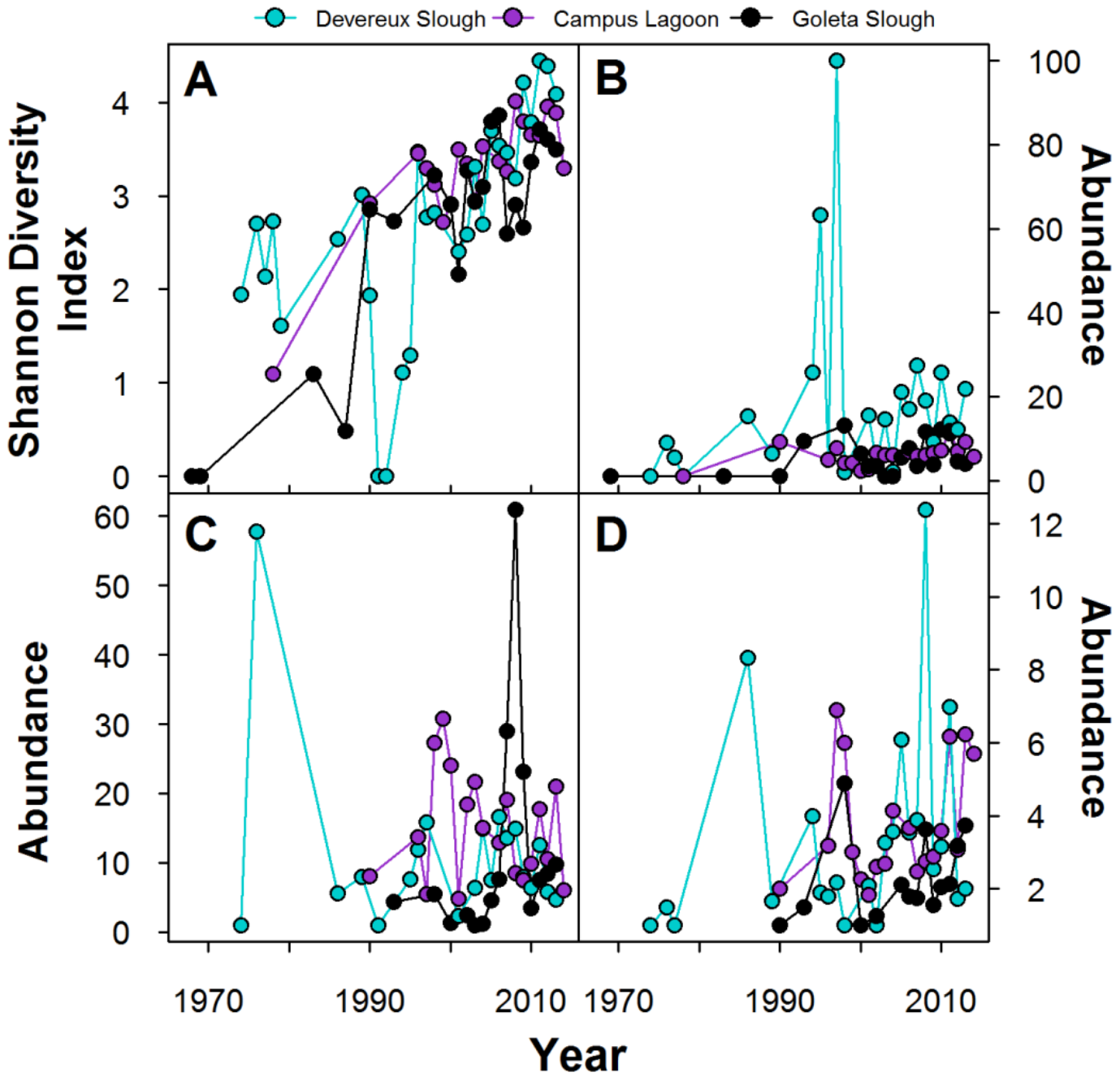

Figure 5.3 – Fall (Sept, Oct & Nov) patterns over the survey period in species abundance and diversity at three large wetland sites. (A) Mean Shannon-Wiener diversity, (B) shorebird abundance, (C) duck abundance and (D) wader abundance.

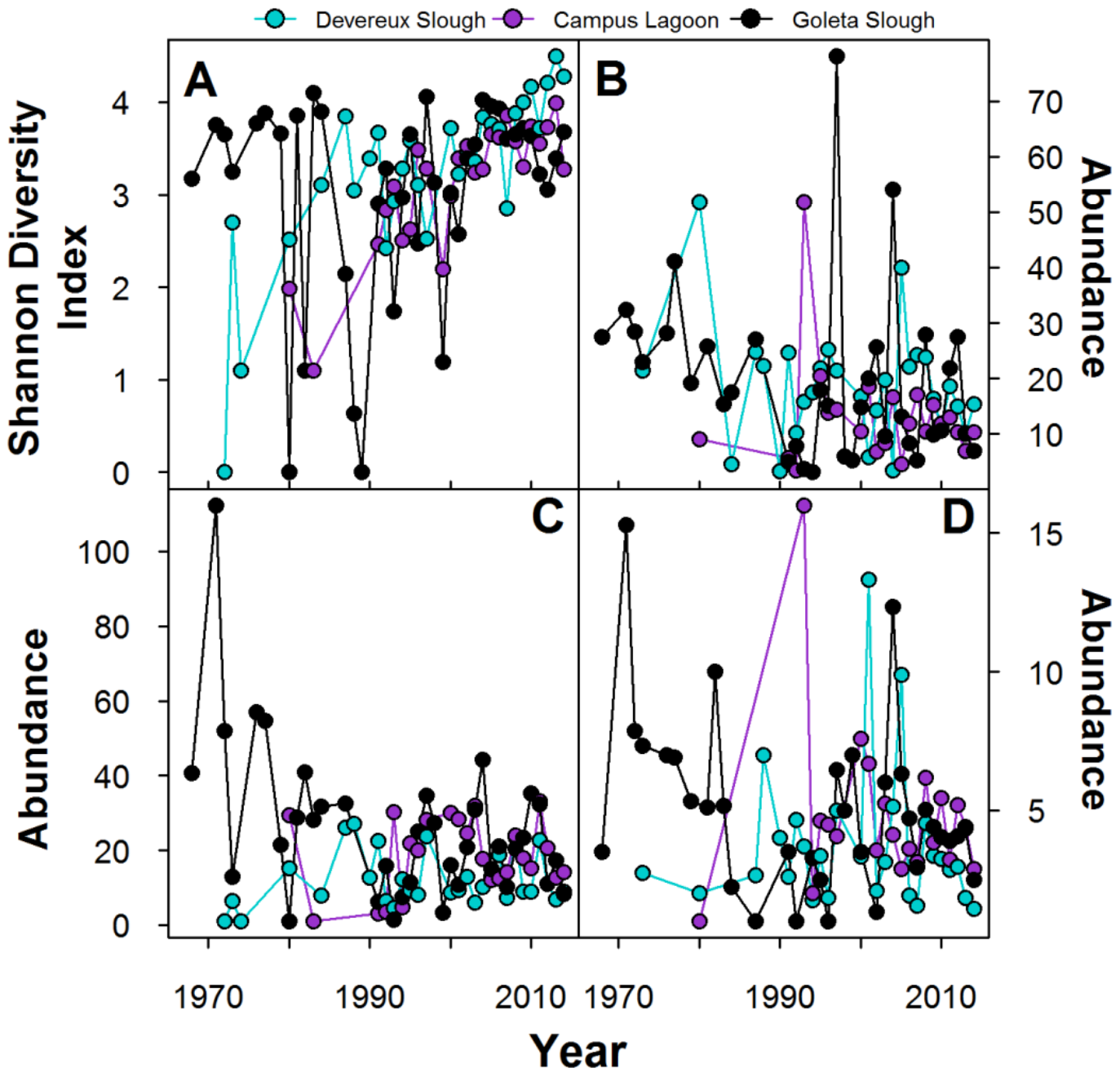

Figure 5.4 – Winter (Dec, Jan & Feb) patterns over the survey period in species abundance and diversity at three large wetland sites. (A) Mean Shannon-Wiener diversity, (B) shorebird abundance, (C) duck abundance and (D) wader abundance.