



Analysis of Trends in Terrestrial Vegetation at Mediterranean Coast Network Parks

Channel Islands National Park



Silver bush lupine (*Lupinus albifrons*) on Santa Rosa Island.

NPS / L.A. STARCEVICH

Analysis of Trends in Terrestrial Vegetation at Mediterranean Coast Network Parks: Channel Islands National Park

Science Report NPS/SR—2025/358

Leigh Ann Starceovich¹, Christopher Murray², Lena F.S. Lee³, Cameron B. Williams⁴,
Kathryn McEachern⁵

¹ Western Ecosystems Technology, Inc.
2725 NW Walnut Blvd.
Corvallis, OR 97330

² Western Ecosystems Technology, Inc.
2121 Midpoint Dr.
Fort Collins, CO 80525

³ National Park Service
Mediterranean Coast Network
401 West Hillcrest Dr.
Thousand Oaks, CA 91360

⁴ National Park Service
Channel Islands National Park
1901 Spinnaker Dr.
Ventura, CA 93001

⁵ U.S. Geological Survey – WERC
Channel Islands Field Station
1901 Spinnaker Dr.
Ventura, CA 93001

Please cite this publication as:

Starceovich, L.A., C. Murray, L.F.S. Lee, C.B. Williams, and K. McEachern. 2025. Analysis of Trends in Terrestrial Vegetation at Mediterranean Coast Network Parks: Channel Islands National Park. Science Report NPS/SR—2025/358. National Park Service, Fort Collins, Colorado.
<https://doi.org/10.36967/2315831>

The National Park Service Science Report Series disseminates information, analysis, and results of scientific studies and related topics concerning resources and lands managed by the National Park Service. The series supports the advancement of science, informed decisions, and the achievement of the National Park Service mission.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

This report is available in digital format from the [National Park Service DataStore](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Contents

	Page
Contents	iii
Figures.....	v
Tables.....	x
Abstract.....	xii
Executive Summary	xiii
Acknowledgments.....	xv
List of Terms.....	xvi
Introduction.....	1
Methods.....	3
Survey Design	3
Index Sites	3
Probability Sites.....	6
Response Design	8
Data Processing Methods	9
Vegetation Metrics	9
Modeling Methods.....	10
Trend Model Selection	11
Covariate Data	12
Data Processing Methods	13
Covariate Model Selection	15
Results.....	17
Trends over Time	18
Trends across Islands.....	18
Trends on Anacapa Island	27
Trends on Santa Barbara Island.....	37
Trends on Santa Cruz Island.....	46
Trends on San Miguel Island.....	58
Trends on Santa Rosa Island	66

Contents (continued)

	Page
Covariate Modeling	72
Covariate Reduction	73
Covariate Modeling across Islands.....	74
Covariate Modeling for Anacapa Island.....	89
Covariate Modeling for Santa Barbara Island	98
Covariate Modeling for Santa Cruz Island	110
Covariate Modeling for San Miguel Island	133
Covariate Modeling for Santa Rosa Island.....	145
Discussion and Conclusions	161
Trends in CHIS Terrestrial Vegetation Metrics	161
Shannon Diversity	161
Density.....	162
Cover	162
Species-Specific Trends	163
Covariate Relationships.....	165
Shannon Diversity	165
Density.....	166
Cover	167
Conclusions.....	170
Literature Cited	171

Figures

	Page
Figure 1. The Channel Islands National Park index sites and Generalized Random Tessellation Stratified (GRTS) sample of probability sites.	7
Figure 2. Schematic representation of the sampling plot.	9
Figure 3. Trend analysis results for CHIS vegetation indicators by index site and year (first of three).	20
Figure 4. Trend analysis results for CHIS vegetation indicators by index site and year (second of three).	21
Figure 5. Trend analysis results for CHIS vegetation indicators by index site and year (third of three).	23
Figure 6. Trend analysis results for CHIS vegetation indicators by probability site and year (first of two).	26
Figure 7. Trend analysis results for CHIS vegetation indicators by probability site and year (second of two).	27
Figure 8. Trend analysis results for CHIS vegetation indicators by index site and year across three regions on Anacapa Island (first of two).	31
Figure 9. Trend analysis results for CHIS vegetation indicators by index site and year across three regions on Anacapa Island (second of two).	33
Figure 10. Trend analysis results for CHIS vegetation indicators by probability site and year across Anacapa Island (first of two).	36
Figure 11. Trend analysis results for CHIS vegetation indicators by probability site and year across Anacapa Island (second of two).	37
Figure 12. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (first of three).	40
Figure 13. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (second of three).	41
Figure 14. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (third of three).	42
Figure 15. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Barbara Island (first of two).	45
Figure 16. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Barbara Island (second of two).	46

Figures (continued)

	Page
Figure 17. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (first of four).	48
Figure 18. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (second of four).	50
Figure 19. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (third of four).	51
Figure 20. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (fourth of four).	52
Figure 21. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (first of three).	55
Figure 22. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (second of three).	56
Figure 23. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (third of three).	57
Figure 24. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (first of three).	60
Figure 25. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (second of three).	61
Figure 26. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (third of three).	62
Figure 27. Trend analysis results for CHIS vegetation indicators by probability site and year across San Miguel Island (first of two).	65
Figure 28. Trend analysis results for CHIS vegetation indicators by probability site and year across San Miguel Island (second of two).	66
Figure 29. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (first of four).	69
Figure 30. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (second of four).	70
Figure 31. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (third of four).	71
Figure 32. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (fourth of four).	72

Figures (continued)

	Page
Figure 33. Marginal effects plots for final covariate models at index sites across more than one island (first of five).....	78
Figure 34. Marginal effects plots for final covariate models at index sites across more than one island (second of five).	80
Figure 35. Marginal effects plots for final covariate models at index sites across more than one island (third of five).....	81
Figure 36. Marginal effects plots for final covariate models at index sites across more than one island (fourth of five).	83
Figure 37. Marginal effects plots for final covariate models at index sites across more than one island (fifth of five).	84
Figure 38. Marginal effects plots for final covariate models at probability sites across all islands (first of two).	86
Figure 39. Marginal effects plots for final covariate models at probability sites across all islands (second of two).	88
Figure 40. Marginal effects plots for final covariate models at index sites across Anacapa Island (first of two).	92
Figure 41. Marginal effects plots for final covariate models at index sites across Anacapa Island (second of two).....	93
Figure 42. Marginal effects plots for final covariate models at probability sites across Anacapa Island (first of two).	96
Figure 43. Marginal effects plots for final covariate models at probability sites across Anacapa Island (second of two).....	97
Figure 44. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (first of four).	101
Figure 45. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (second of four).	103
Figure 46. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (third of four).....	104
Figure 47. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (fourth of four).....	106
Figure 48. Marginal effects plots for final covariate models at probability sites across Santa Barbara Island (first of two).....	109

Figures (continued)

	Page
Figure 49. Marginal effects plots for final covariate models at probability sites across Santa Barbara Island (second of two).	110
Figure 50. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (first of six).	115
Figure 51. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (second of six).	116
Figure 52. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (third of six).	118
Figure 53. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (fourth of six).	120
Figure 54. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (fifth of six).	121
Figure 55. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (sixth of six).	123
Figure 56. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (first of four).	128
Figure 57. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (second of four).	129
Figure 58. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (third of four).	131
Figure 59. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (fourth of four).	132
Figure 60. Marginal effects plots for final covariate models at index sites across San Miguel Island (first of three).	136
Figure 61. Marginal effects plots for final covariate models at index sites across San Miguel Island (second of three).	138
Figure 62. Marginal effects plots for final covariate models at index sites across San Miguel Island (third of three).	139
Figure 63. Marginal effects plots for final covariate models at probability sites across San Miguel Island (first of two).	143
Figure 64. Marginal effects plots for final covariate models at probability sites across San Miguel Island (second of two).	145

Figures (continued)

	Page
Figure 65. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (first of eight).	150
Figure 66. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (second of eight).	151
Figure 67. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (third of eight).	153
Figure 68. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (fourth of eight).	154
Figure 69. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (fifth of eight).	156
Figure 70. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (sixth of eight).	157
Figure 71. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (seventh of eight).	158
Figure 72. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (eighth of eight).	160

Tables

	Page
Table 1. Index sites by island and historic vegetation type (M = Middle, E = East, W = West, N = North, S = South).....	4
Table 2. CHIS original augmented serially alternating panel design showing the annual number of index sites on the left of the slash and annual sample size of probability sites on the right of the slash.	8
Table 3. Suites of water balance covariates with summary statistics and source.....	12
Table 4. Definition of time frames used to summarize water balance covariates for data from Tercek and Thoma.....	13
Table 5. Advantages and disadvantages of the four PET models.	14
Table 6. Total number of transects surveyed per island and first year of data collection.	17
Table 7. Modeling combinations without converging models.	17
Table 8. Trend analysis results for all CHIS vegetation indicators for index sites across islands.	19
Table 9. Trend analysis results for all CHIS vegetation indicators for probability sites across all islands.	25
Table 10. Trend analysis results for all CHIS vegetation indicators for index sites on Anacapa Island.....	29
Table 11. Trend analysis results for all CHIS vegetation indicators for probability sites on Anacapa Island.....	35
Table 12. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Barbara Island.	39
Table 13. Trend analysis results for all CHIS vegetation indicators for probability sites on Santa Barbara Island.	44
Table 14. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Cruz Island.	49
Table 15. Trend analysis results for all CHIS vegetation indicators for probability sites on Santa Cruz Island.	54
Table 16. Trend analysis results for all CHIS vegetation indicators for index sites on San Miguel Island.	59
Table 17. Trend analysis results for all CHIS vegetation indicators for probability sites on San Miguel Island.	64

Tables (continued)

	Page
Table 18. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Rosa Island.	68
Table 19. PET model preferences for three selected vegetation outcomes.	73
Table 20. Covariate models ranked by AICc for all outcomes at index sites across more than one island.	75
Table 21. Covariate models ranked by AICc for all outcomes at probability sites across all islands.	85
Table 22. Covariate models ranked by AICc for all outcomes at index sites across Anacapa Island.	90
Table 23. Covariate models ranked by AICc for all outcomes at probability sites across Anacapa Island.	95
Table 24. Covariate models ranked by AICc for all outcomes at index sites across Santa Barbara Island.	99
Table 25. Covariate models ranked by AICc for all outcomes at probability sites across Santa Barbara Island.	108
Table 26. Covariate models ranked by AICc for all outcomes at index sites across Santa Cruz Island.	112
Table 27. Covariate models ranked by AICc for all outcomes at probability sites across Santa Cruz Island.	125
Table 28. Covariate models ranked by AICc for all outcomes at index sites across San Miguel Island.	134
Table 29. Covariate models ranked by AICc for all outcomes at probability sites across San Miguel Island.	141
Table 30. Covariate models ranked by AICc for all outcomes at index sites across Santa Rosa Island.	147

Abstract

The five islands comprising Channel Islands National Park (CHIS) experience natural gradients in temperature and moisture driven by ocean currents. Additionally, the islands were used as ranchlands and military land before becoming a national park, resulting in widespread erosion and vegetation change. As a result, CHIS spans gradients in climate as well as ranching duration and time since animal removal. Vegetation monitoring was initiated in 1984 on three islands (Anacapa, Santa Barbara, San Miguel), in 1990 on Santa Rosa Island, and in 1998 on Santa Cruz Island, with the goal of documenting the long-term response of island vegetation to ranch animal removal and climate fluctuations. Since that time, monitoring has documented the range of natural fluctuation in island environments over decades and provided insights into vegetation change in ecosystems unencumbered by ongoing development. Long-term vegetation monitoring at CHIS is therefore a rare example of an ecosystem experiment that demonstrates the results of management actions and serves as a baseline for land managers and scientists worldwide.

Terrestrial vegetation data collected between 1984 and 2018 were modeled to estimate trends over time and to characterize relationships with covariates related to site characteristics, nonnative mammal removal programs, and water balance metrics. Data were analyzed for trends in vegetation cover, woody plant density, and plant community diversity grouped by life form and nativity across all islands and within individual islands, as well as for several individual species that dominate plant communities or present challenges to native plant recovery. In all, a total of 162 trend and covariate models were tested in this study, the details of which are provided in this report. Briefly, results reflect a decline in nonnative annual disturbance-thriving species with the reduction in animal grazing and trampling. Increasing trends were observed in native shrub density and native shrub recruitment density, as well as native shrub cover across all islands averaged together and on Santa Cruz Island. However, opposite trends were seen on the smaller islands of Santa Barbara and Anacapa, where increasing seabird activity may be damaging vegetation. Further results indicate the importance of soil moisture, relative humidity, fog, precipitation, site exposure, and solar radiation for vegetation patterns and trends. In many instances, there are apparent interacting effects of environmental variables with trends related to nonnative mammal removal and site location. Vegetation patterns in space and time emerge in the dataset as nuanced responses to interacting drivers.

Executive Summary

Measurements of vegetation cover and plant density are collected annually at Channel Islands National Park (CHIS) under the National Park Service (NPS) Inventory & Monitoring (I&M) Program Vital Signs Monitoring Program. The five park islands were used as ranches and for the military starting in the 1800s, with ground disturbance ranging from island-wide grazing and trampling and road development to discrete emplacements. The result was widespread erosion and type conversion of native perennial shrub-dominated communities to mainly annual grassland, with native stands persisting in refugia inaccessible to grazing animals. The islands also encompass a gradient in maritime climate driven by oceanic currents ranging from cooler, moister and foggier San Miguel Island (SM) in the west across Santa Rosa (SR) and Santa Cruz (SC) Islands to Anacapa Island (AN) in the east, and from the cooler northern islands to much warmer Santa Barbara Island (SB) in the south. Consequently, vegetation change spans gradients in ranching duration, time since animal removal, and climate.

Vegetation monitoring was initiated in 1984 on AN, SB and SM, followed by Santa Rosa Island (SR) in 1990 and Santa Cruz Island (SC) in 1998. Objectives were to document the long-term response of island vegetation to ranch animal removal and climate fluctuation, a rare ecosystem experiment that demonstrates results of management actions and serves as a baseline for land managers and scientists worldwide. The monitoring documents the range of natural fluctuation in island environments across decades and provides insights into vegetation change in ecosystems unencumbered by ongoing development. Two types of sites were selected for the sample design, characterized as index and probability sites. Index sites were selected early in the monitoring program as representative of specific vegetation communities, and probabilistic sites were randomly selected later from the larger population of interest representing all vegetation communities of interest to expand statistical inference island-wide.

Terrestrial vegetation data collected between 1984 and 2018 were modeled to estimate trends over time and characterize relationships with covariates related to site characteristics, nonnative mammal removal programs, and water balance metrics. The data were analyzed for trends in vegetation cover, woody plant density and plant community diversity grouped by life form and nativity across all islands and within individual islands, as well as for several individual species that dominate plant communities or present challenges to native plant recovery. Generalized linear mixed models were used to evaluate trends in vegetation. Then, covariate modeling using metrics related to water balance, individual site characteristics and animal removal was conducted to identify broad relationships among vegetation metrics and environment. A total of 97 environmental variables were considered, including 14 related to animal presence and removal timelines. A suite of water balance metrics derived from published sources were tested for collinearity, and 12 were selected for use in modeling environment and vegetation relationships. In all, a total of 162 trend and covariate models were tested in this analysis. This report provides details of covariate development, model selection and results summarized in graphs and the accompanying narrative, supplemented with charts and

tables provided in a file of [supplemental information](#) (Starcevich et al. 2025). General conclusions summarize vegetation trends and related covariates detected in the samples and analyses.

About half of the Shannon diversity trend models indicate declines in diversity across and within vegetation at index sites, but no trends in diversity were detected at probability sites. This result reflects a decline in nonnative annual disturbance-thriving species with the reduction in animal grazing and trampling seen at index sites that span a longer monitoring period. Increasing trends were observed in native shrub density and native shrub recruitment density as well as native shrub cover across all islands averaged together, and on SC. However, opposite trends were seen on the smaller islands of SB and AN, where increasing seabird activity may be damaging the vegetation. A decline was detected in native tree density across SC and SR, but an increasing trend was found in native tree cover across SC and SR. Native and nonnative forbs and grasses exhibited decreasing cover trends at index sites across all islands.

Thirty-year means of solar radiation and cumulative potential evapotranspiration monthly means were significant predictors in the selected top models of Shannon diversity and native shrub, tree, forb, and grass cover. Water balance covariates summarized for the current year fog season were included in many top models of native tree and shrub density and recruitment density. Monthly water balance variables were included in across-island models of nonnative forb and grass cover. Water balance covariates summarized for the water year or calendar year were included in models as predictors of native and nonnative forb and grass cover, and water balance metrics summarized over the previous two years were important predictors of native shrub and tree recruitment at SC and SR and native shrub density across all islands. Results indicate the importance of soil moisture, relative humidity, fog, precipitation, site exposure, and solar radiation for vegetation pattern and trend. In many instances, there are apparent interacting effects of environmental variables with trends related to nonnative mammal removal and site location. Vegetation patterns in space and time emerge in the dataset as nuanced responses to interacting drivers.

Acknowledgments

The Mediterranean Coast Network would like to thank Dr. Lorraine Flint (EarthKnowledge), Dr. Alan Flint (EarthKnowledge), Dr. Michael Tercek (Walking Shadow Ecology), and Dr. David Thoma (NPS – GRYN) for providing environmental covariate data and guidance for modeling. This report was improved by detailed reviews from Dr. Pat Corry (Consulting Biologist) and Dr. Denise Knapp (Santa Barbara Botanical Garden). Special thanks to Dirk Rodriguez, botanist with Channel Islands National Park for two decades ending in 2019, for collecting and curating much of the field data, and to Dr. Stacey Ostermann-Kelm for long-term administrative support and inspiration for this program and this report. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

List of Terms

Generalized linear mixed model: A general form of the linear mixed model incorporating a link function for discrete outcomes such as binary and count data, fixed effects to model the mean of the linked outcome, and random effects to model the variance composition of the linked outcome.

Membership design: Also called sampling design. Methods used to obtain a set of sampling units from a sampling frame in order to make inference to a target population.

Metric: A measurement representing a parameter of interest; a quantitative assessment of a monitoring characteristic. Also called an “outcome” or “outcome of interest.”

Panel: A collection of sampling units always visited during the same sampling occasion.

Parameter: A population-level outcome of interest estimated by a statistic.

Response design: The method by which measurements are collected at a sampling unit. The response design may specify plot size and shape, the types of measurements taken at a site, and the response units from which measurements are made.

Revisit design: Pattern for which sampling units are returned to for measurement.

Sample: A subset of a population. This may be chosen through a random, probabilistic mechanism (random sampling) or non-randomly (judgment sampling).

Sampling frame: The list of sampling units designed to match the target population as closely as possible.

Sampling unit: The basic unit of replication in the sampling design and the unit selected in the sample from the sampling frame.

Statistic: An estimate of a population parameter.

Survey design: Methods used to draw a sample (sampling design), visit the sampling units over time (revisit design), and collect data from the sampling units (response design) to meet quantitative goals.

Target population: Also called the resource population of interest; the complete collection of units to which inference is made.

Introduction

In the early 2000s, the National Park Service (NPS) Inventory & Monitoring (I&M) Program developed a Vital Signs Monitoring Program to ensure that ecological survey and analysis methods provide scientifically valid information on indices of park health and condition (Fancy et al. 2009). Vital signs in over 270 parks are organized into 32 I&M networks and monitored over time to measure the annual status and long-term trends of ecological indicators, to inform mitigation and management, to obtain baseline information on important indicators in each park, to fulfill legal mandates for park management, and to measure progress toward management goals. The Mediterranean Coast Network (MEDN) identified terrestrial vegetation as one of its Vital Signs. The terrestrial vegetation protocol (Tiszler et al. 2016) outlines the methods used to obtain terrestrial vegetation information from Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO).

The CHIS terrestrial vegetation monitoring program pre-dates the development of the Vital Signs Monitoring Program, with sampling beginning as early as 1984. CHIS is one of the four prototype programs on which the I&M Program was based (Tiszler et al. 2016) and has generated a well-replicated time series of data collected at the same transects for up to 37 years. A vital step in making sound inference for ecological understanding and management use is applying appropriate analytical tools in a structured and transparent framework. This report presents analyses of trends and covariate relations with island vegetation, exploring various metrics and models that could be used in other, younger, Vital Signs datasets. The objective is to present approaches for exploratory analyses of long-term vegetation and environmental data using CHIS as a prototype example for future direction with other I&M datasets. Consequently, this report presents details of transect data preparation, selection of metrics for analysis, development and testing of covariate data, and statistical modeling approaches for general trends and covariate relationships among vegetation, select species and the environment. Ecological interpretations are general and overarching and will be presented elsewhere in greater detail.

Trend analyses have been conducted at CHIS intermittently over the years. Trend plots of data collected between 1984 and 2000 were reported by McEachern (2001), patterns and trends in transect and relevé data from Santa Barbara and San Miguel Islands from 1983 to 2002 were analyzed in a dissertation by Corry (2006), Dow (2008) analyzed trends among native and nonnative vegetation on Santa Rosa Island from 1990 to 2007, and Christian (2007) analyzed browse rates and species composition on Santa Rosa Island chaparral and coastal sage scrub transects between 1997 and 2007. An extensive trend analysis was conducted by Handley et al. (2013) for Santa Barbara and Santa Rosa islands, and covariate analyses for effects of solar radiation, wind speed, fog, soils, and other covariates on CHIS vegetation metrics were conducted. These analyses informed the current work, but this report represents the first all-island analysis of CHIS terrestrial vegetation since the monitoring design was developed in 1988 (Halvorson et al. 1988).

The five islands that comprise CHIS are in the Southern California Bight of the Pacific Ocean (approximately 34.0°N, 119.7°W). They are among the northernmost in the California Islands

archipelago of 18 islands extending southward along the coast of southern California, USA, and Baja California, Mexico (McEachern et al. 2016). The five CHIS islands are at the intersection of two ocean currents; the Davidson (or Humboldt) current that sweeps cold water from the north around Point Conception and the Southern California Counter-current transporting warm waters from the south. These currents meet at the Channel Islands forming strong temperature and wind gradients from the northwestern cold and windy “outer” waters near San Miguel and Santa Rosa Islands, across Santa Cruz Island to the less windy and warmer eastern “inner” islands of Anacapa and Santa Barbara. Island vegetation reflects this gradient, ranging from outer island communities that are more similar to mainland California coastal areas at more northerly latitudes to the inner islands with stronger affinities to more southerly latitudes. The islands also span a gradient of sizes and topographic complexity ranging from Santa Cruz and Santa Rosa at 244 and 217 square kilometers (km^2), to San Miguel at 37 km^2 , and Anacapa and Santa Barbara at 2.9 and 2.6 km^2 .

The islands were home to the Chumash people who may have had permanent settlements there as early as eight thousand years ago (Erlandson et al. 2011; Johnson et al. 2002). Like much of mainland southern California, the islands were used as ranches and military posts beginning in the mid-1800s resulting in increased erosion, the introduction of nonnative plants and a rapid change from perennial grass- and shrub-lands to widespread annual grassland. Ranching ended on the islands beginning in the late 1970s on San Miguel to as recently as 2015 on Santa Rosa. Island vegetation bears the imprint of these strong gradients in space, size and land use in species composition and cover, diversity, woody plant density and fragmentation. CHIS I&M vegetation program transect samples capture island plant communities on the cusp of the transition from ranching land use to management for conservation and recreation. It is the goal of this project to explore and demonstrate analytical approaches that capture vegetation trends and explanatory environmental factors in such variable states across and within islands so that ecologists and managers can be confident in conclusions and further questions presented by the data.

Survey design and trend analysis methods are first discussed. Next, the results of the trend analyses for data collected through 2018 and the modeling assessment of the relationships between CHIS vegetation indicators of terrestrial vegetation cover, density, and diversity and associated covariates are reported. Finally, we synthesize the trend results and covariate analysis results for inference across islands.

Methods

The survey design used for data collection, the trend analysis methods, and the covariate data used for the analysis are described in this section. The survey design was developed to provide the basis for broad inference on vegetation condition and trends by island and across islands. A survey design consists of three main components: the membership design, the temporal revisit design, and the response design (Reynolds 2012). The membership design designates the location of survey sites where monitoring data are collected (Reynolds 2012). The temporal revisit design defines the pattern over time in which sites are visited. The response design outlines the way data are collected during a site visit. The structure of the data informs modeling of CHIS terrestrial vegetation indicators, which are modeled in two ways: as a function of time and as a function of ecological covariates. R code used to conduct the analysis is archived in rNPSVegCHIS (Mitchell et al. 2024). See Section A of the [Supplemental Information](#) for more information.

Survey Design

Vegetation data have been collected at CHIS at two different types of sites. “Index” sites were selected early in the monitoring program as representative of specific vegetation communities, and “probabilistic” (or probability) sites were randomly selected later from the larger population of interest representing all vegetation communities of interest to expand statistical inference island-wide.

Sampling began with subjectively selected transects in 1984 on Anacapa Island (AN), Santa Barbara Island (SB), and San Miguel Island (SM), and in 1990 on Santa Rosa Island (SR). The CHIS vegetation monitoring program only samples transects on the NPS-owned eastern 24% of Santa Cruz Island (SC); The Nature Conservancy (Arlington, VA) owns and independently monitors the western 76%. Sampling began in two stages on the eastern end of SC, as NPS acquired lands there: first in 1998 on the east end of the island, and in 2006 on the isthmus. Probability sites were first sampled in 2013 on all islands except SR, where probability sites were first sampled in 2017.

Below, we summarize the survey design details for the two kinds of sites used for this data analysis at CHIS. Note that the numbers of transects used in this analysis are slightly less than the total design for the program, since probabilistic sampling on Santa Rosa Island began in 2017. Only 2 years of the entire panel rotation had been visited on Santa Rosa at the time of this analysis.

Index Sites

The original monitoring design for CHIS vegetation was developed in 1984 (Halvorson et al. 1988). Annual sampling began in 1984 on AN, SB, and SM. SR was acquired by CHIS in 1987 and vegetation monitoring began there in 1990. Vegetation maps were drawn from aerial photography and ground-truthed with relevé samples (Clark et al. 1990; McEachern 2001) and then transects were located within vegetation communities of interest and across a gradient of topography. On all four islands, transects were selected to represent specific vegetation communities at CHIS (Table 1) where remnant patches of native vegetation occurred. The sample size was limited to the number that could be managed by a single botanist during the growing season each year. Portions of SC were obtained

over time, with east end monitoring beginning in 1998 after completion of a vegetation mapping effort (Johnson and Rodriguez 2001) and isthmus monitoring beginning in 2006. Transect locations at SC were selected randomly from a sampling frame limited to slopes less than 36 degrees with stratification by watershed (Appendix A in Tiszler et al. 2016). Sampling effort was allocated proportionally to the watershed area but with a minimum of three sites per watershed. Shrub and tree monitoring programs were added in 1998 using 30 m × 1 m belt transects to measure shrub stem density, mortality and recruitment of new plants, and using 30 m × 10 m plots centered on the transect to obtain counts, measures of diameter at breast height, mortality and recruitment metrics for trees (McEachern 2000).

Table 1. Index sites by island and historic vegetation type (M = Middle, E = East, W = West, N = North, S = South).

Island	Vegetation Type	Sites
AN	Coastal Sage Scrub	AN-M002, AN-W003, AN-W004
	Coreopsis Scrub	AN-E003, AN-W001, AN-W002
	Perennial Iceplant	AN-E001, AN-E005
	Valley/Foothill Grassland	AN-E002, AN-E004, AN-M001, AN-M003, AN-M004, AN-M005, AN-W005, AN-W006
SB	Boxthorn Scrub	SB-008N, SB-016
	Cactus Scrub	SB-010N, SB-014
	Coastal Scrub	SB-025
	Coreopsis Scrub	SB-009S, SB-010S, SB-011, SB-012, SB-015, SB-017
	Seablite Scrub	SB-002, SB-003, SB-004, SB-005
	Seacliff Scrub	SB-007, SB-008S, SB-013
	Valley/Foothill Grassland	SB-001, SB-006, SB-018, SB-019
SC	Coastal Bluff Scrub	SC-013, SC-014
	Coastal Sage Scrub	SC-037, SC-038, SC-039
	Coastal Scrub	SC-031, SC-035
	Fennel	SC-036, SC-041, SC-042
	Island Chaparral	SC-001, SC-003, SC-006, SC-026, SC-027, SC-032, SC-040
	Lyonothamus Grove	SC-005, SC-008, SC-010
	Mixed Woodland	SC-002, SC-004
	Oak Woodland	SC-007, SC-043
	Riparian	SC-011, SC-021, SC-023, SC-024
	Shrub Savannah	SC-015, SC-016, SC-019
	Valley/Foothill Grassland	SC-012, SC-017, SC-018, SC-020, SC-022, SC-025, SC-028, SC-029, SC-030, SC-033, SC-034, SC-044
SM	Caliche Scrub	SM-001, SM-002
	Coastal Sage Scrub	SM-005, SM-011, SM-018

Table 1 (continued). Index sites by island and historic vegetation type (M = Middle, E = East, W = West, N = North, S = South).

Island	Vegetation Type	Sites
SM (cont.)	Coreopsis Scrub	SM-008, SM-013, SM-015, SM-016
	Island Chaparral	SM-006, SM-007, SM-012
	Seacliff Scrub	SM-009
	Southern Beach and Dune	SM-014
	Valley/Foothill Grassland	SM-003, SM-004, SM-010
SR	Baccharis Scrub	SR-002, SR-005, SR-014, SR-015, SR-026, SR-027, SR-028, SR-029, SR-030
	Caliche Scrub	SR-045, SR-046
	Coastal Bluff Scrub	SR-049, SR-050, SR-051
	Coastal Marsh	SR-006, SR-087
	Coastal Sage Scrub	SR-040, SR-052, SR-053, SR-054, SR-055, SR-056, SR-057, SR-058, SR-059, SR-060, SR-061
	Coastal Strand	SR-003, SR-041
	Island Chaparral	SR-011, SR-013, SR-020, SR-021, SR-034, SR-035
	Lupine Scrub	SR-016, SR-017, SR-018
	Ironwood	SR-070, SR-079
	Mixed Woodland	SR-063, SR-068, SR-069, SR-071, SR-076
	Oak Woodland	SR-074, SR-075, SR-077, SR-078
	Riparian	SR-080, SR-081, SR-082, SR-083, SR-084, SR-085, SR-086
	Santa Cruz Island Pine	SR-072, SR-073
	Torrey Pine Woodland	SR-062, SR-064, SR-065, SR-066, SR-067
	Valley/Foothill Grassland	SR-001, SR-004, SR-008, SR-009, SR-010, SR-012, SR-019, SR-022, SR-023, SR-024, SR-025, SR-031, SR-032, SR-033, SR-036, SR-037, SR-038, SR-039, SR-042, SR-043, SR-044, SR-047, SR-048

Vegetation monitoring occurred from mid-to-late February through mid-July. Most transects were visited during most years, but transects were sometimes missed due to weather, missing markers, and seabird nesting. Data were not collected at all during 1989, 1991, and 1992 due to staffing issues (Johnson and Rodriguez 2001). Vegetation presence was recorded at 100 points on each 30-m line-point intercept transect. Older transects on AN and SB that were established by the Santa Barbara Botanic Garden were 40 m long and extended across canyons. These were split into two short transects that reflected a single aspect (Johnson and Rodriguez 2001).

A program review in 2000 resulted in several recommendations for changes to the vegetation survey methodology used at CHIS (McEachern 2001). In addition to woody plant monitoring for shrubs and trees, the addition of probabilistically selected transects was recommended for island-wide inference. In 2010–2011, CHIS vegetation ecologists developed a new survey design that increased sampling effort at new probability sites. The survey design update included a power analysis to examine

sample sizes of transects needed to detect changes over time in vegetation metrics for cover and species richness (Appendix C in Tiszler et al. 2016). The power analysis was informed by the extensive data record obtained at the index sites, which allowed estimation of variation in trend indicators over time and space. The survey effort for each year was then split between the two plot types to allow a broader spatial scope of inference by addition of the probability sites and to retain continuity over time for long-term trends at index sites. Index sites were allocated to revisit panels based on a set of criteria related to evidence of rapid change, underrepresented vegetation communities, and management concern (Appendix A in Tiszler et al. 2016).

Probability Sites

The target population at CHIS consists of all park-owned lands that have not been developed, maintained, or perpetually disturbed (including areas within 5 m of roads, trails, and development) (Tiszler et al. 2016). Islands served as strata and separate sampling frames were used for each island. Areas with slopes greater than 40 degrees, with dense stands of poison-oak, or that required more than 7.5 hours to access and survey were omitted from the sampling frame for field crew safety. Generalized Random Tessellation Stratified (GRTS) equiprobable samples (Stevens and Olsen 2003, 2004) were drawn within each island (Figure 1). A total of 184 probability sites were added to the 181 existing index sites, and sampling densities ranged from one site per 12 ha on SB to one site per 256 ha on SR.

An augmented serially alternating panel design (Urquhart and Kincaid 1999) was applied at CHIS over a four-year revisit cycle. This revisit design consists of a panel of sites visited every year (“annual panel”) and four serially alternating panels of sites, which are visited once and then rested for the next three years before beginning the cycle again. Both index and probabilistic sites are assigned to each panel with similar numbers represented in each panel. The annual panel augments the remaining panels by providing connected information collected from the same sites every year, improving the power to detect short-term trends. Each year, the annual panel and one of the serially-alternating panels are visited (Table 2). The sampling window at CHIS is scheduled for February through mid-July each year.

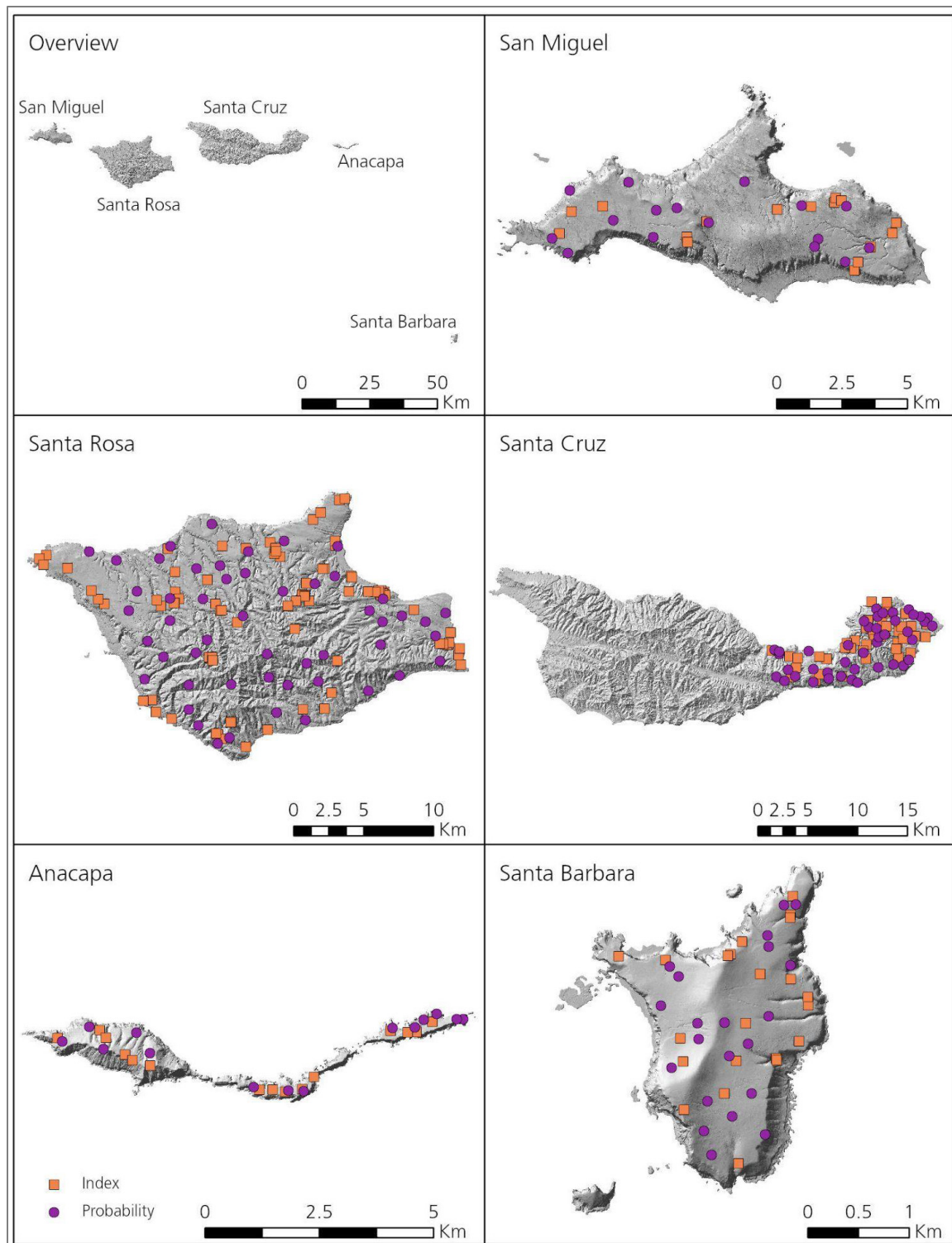


Figure 1. The Channel Islands National Park index sites and Generalized Random Tessellation Stratified (GRTS) sample of probability sites.

NPS / ROCKY RUDOLPH

Table 2. CHIS original augmented serially alternating panel design showing the annual number of index sites on the left of the slash and annual sample size of probability sites on the right of the slash.

Panel	Year 1	Year 2	Year 3	Year 4	Year 5
Annual	39/34	39/34	39/34	39/34	39/34
A	37/36	–	–	–	37/36
B	–	36/37	–	–	–
C	–	–	35/38	–	–
D	–	–	–	34/39	–
Total	76/70	75/71	74/72	73/73	76/70

Response Design

Field data for several types of response metrics were collected at CHIS: percent cover by species and vegetation community, and woody plant density. Cover is measured for all plant species and communities with a point-line intercept response design (Bonham 2013). This approach obtains binary measures of presence/absence at 100 points along a 30 m transect (Figure 2) and calculates cover as the proportion of “hits” (i.e., instances of presence) on the transect. Shrub and tree species were counted in categories of seedlings, saplings, and mature live and dead plants along a 1 m × 30 m belt plot for shrubs and a 10 m × 30 m plot for trees.

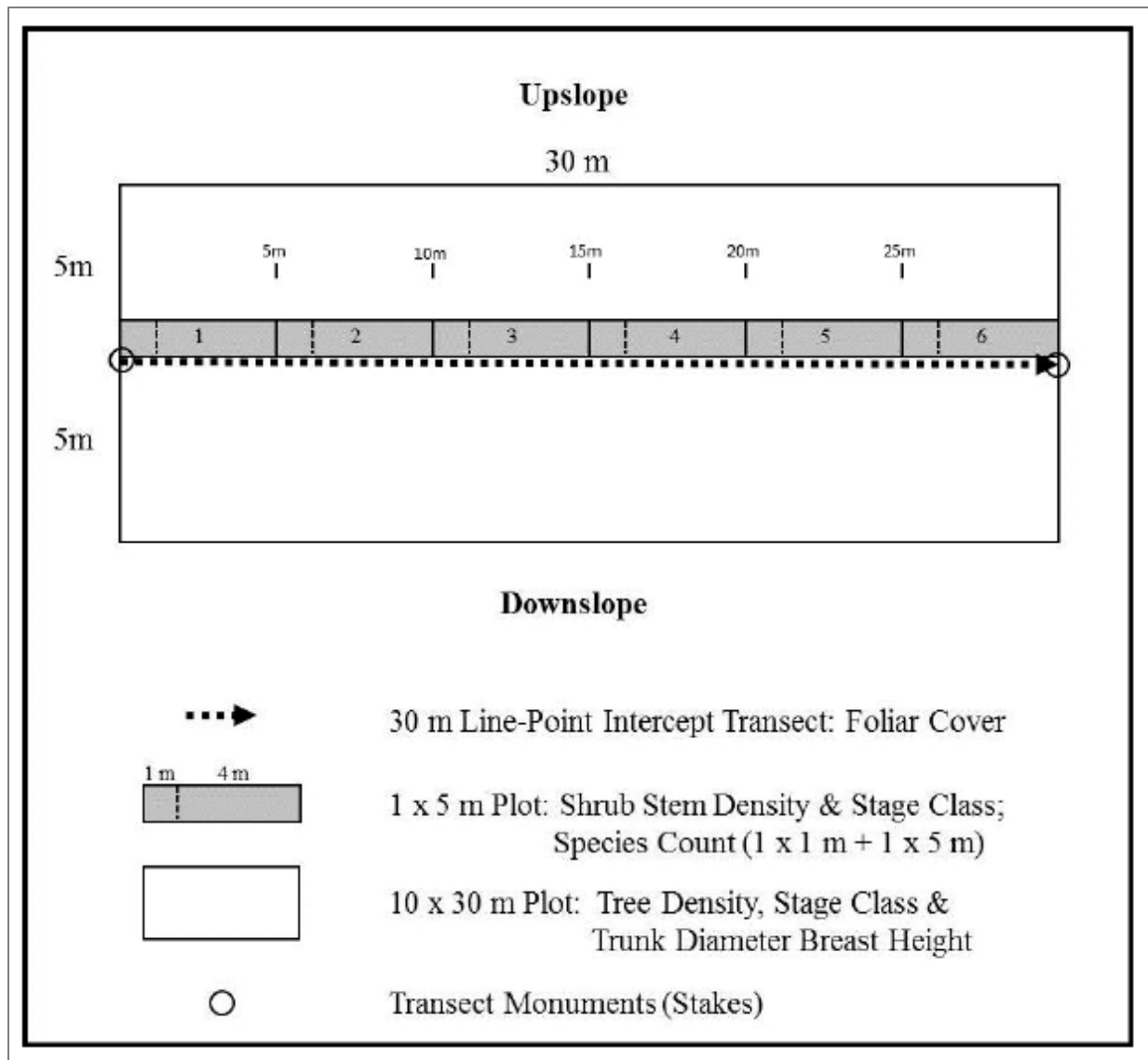


Figure 2. Schematic representation of the sampling plot.

NPS / ADAPTED FROM TISZLER ET AL. (2016)

Data Processing Methods

Vegetation Metrics

Vegetation metrics for trend modeling were calculated from the raw field data. All metrics were calculated by site and year. Absolute percent cover was calculated as the proportion of total points at a given transect where the outcome of interest was recorded. For example, if the outcome of interest was “Native Grasses - Alive” and species belonging to this classification were recorded at 50 of the 100 points on a transect, the absolute cover would be 0.50. Similarly, all shrub and tree density metrics were calculated as the total number of trees (or shrubs) recorded within the respective plot area at a given site divided by the area of the plot.

Species richness was calculated as the number of distinct species observed on a given transect. Shannon-Wiener diversity indices (Fisher et al. 1943; Krebs 1989) also were calculated. For vegetation communities of interest, Shannon diversity metrics were calculated for only the index sites that were selected to represent those communities over time. However, all probability sites were used to calculate community-level Shannon diversity metrics to make inference to the entire island as intended with the probabilistic survey design. Shannon diversity was calculated with the exponentiated form of the estimator, which takes a minimum value of 1. We used the R Community Ecology Package *vegan* (Oksanen et al. 2020) with base e logs to compute these indices. Resulting indices were then exponentiated to determine the number of equally common species which would produce the same given diversity index (MacArthur 1965). This presentation of the index is often preferred because it is considered more meaningful to ecologists. The Shannon-Wiener diversity metric (or “Shannon diversity”) is calculated for a given transect as

$$N_1 = e^H,$$

where

$$H = \sum_{i=1}^s p_i \log(p_i),$$

and i indexes the species, s is the number of species in the group/assembly of interest, and p_i is the total proportion of cover measured at points along the transect for species i .

Modeling Methods

Two modeling exercises were conducted. First, a trend analysis was conducted using the survey year as a predictor for each outcome to estimate the trend over time. Second, the outcome was modeled as a function of environmental covariates. We did not consider trends in time in the covariate modeling exercise. For covariate modeling, the year value was divided by 10 to improve convergence for the long time series. Therefore, estimates of annual proportional trend were also adjusted for this scaling.

Generalized linear mixed models (GLMM) (Bolker et al. 2009; Zuur et al. 2009) were used to evaluate trends in vegetation metrics. Preliminary modeling with the *glmmTMB* package (Brooks et al. 2017) was used to identify the appropriate error distribution for each outcome. Initial modeling indicated that the Shannon diversity index metrics were best modeled with the Tweedie distribution (Tweedie 1984). This distribution is a flexible family of exponential dispersion models that can exhibit characteristics like the Gaussian, Poisson, and gamma distributions based on values of the Tweedie power parameter. Counts of live plants and recruitment for shrub and tree plots were modeled with a Poisson distribution, and an offset term equal to the logged plot area was included so that inference on densities could easily be made. Cover metrics were modeled with the beta-binomial distribution (Skellam 1948) which accounts for underdispersion due to excess zeros. Model selection indicated that the beta-binomial distribution provided a more flexible approach for cover metric modeling than if standard binomial or zero-inflated binomial models were used. The beta distribution was also considered for cover metrics, but the parameterization used in the *glmmTMB* package takes

the open interval (0,1) as the range for beta random variables, so this distribution could not be applied to datasets with site-level cover values of 1. Estimates of baseline status (model intercept), trend, variance components, and dispersion parameters (Tweedie and beta-binomial models) were reported for each trend model.

All GLMMs applied in this trend analysis employ a logarithmic link. By back-transforming the trend coefficient with the *exp* function and subtracting 1, we can obtain a useful interpretation of the effect as the multiplicative change associated with a one-unit increase in the regression predictor. For example, assume that the regression coefficient associated with the scaled time covariate, *WYear*, is 0.05. We can back-transform the unscaled regression coefficient as $\exp(0.05) - 1 = 0.0513$ and interpret the year effect as a 5.13% increase in the outcome of interest for every additional year in the monitoring program. Similarly, the confidence interval limits are computed for the estimated trend on the logarithmic scale and back-transformed to obtain confidence intervals for the annual percentage trend. For Anacapa Island index sites, trends are estimated separately for each islet with the East islet serving as the default value. For estimates of trend in the Middle and West islets, trend estimates are obtained by summing the East trend estimate with the Middle and West trend estimate, respectively, and computing the confidence interval of a sum of regression coefficients before then back-transforming the estimated trend and confidence interval limits to the original scale. Note that, for cover data, the outcome of interest is the odds ratio or the probability of encountering the species or group of interest at a point on the transect divided by the probability of not encountering the species or group of interest. The odds ratio ranges from 0 to 1 when the probability of encountering the species or group of interest at a point is less than or equal to 0.5 and ranges from 1 to infinity when the probability is greater than or equal to 0.5.

Trend Model Selection

Model selection was conducted by comparing the corrected Akaike Information Criterion (AICc; Akaike 1998; Cavanaugh 1997) for models that successfully converged. The appropriate error distribution was identified for models incorporating only a fixed effect for the survey year for trend estimation. Random effects structure followed the form of Piepho and Ogutu (2002) with variance components for year-to-year variation, site-to-site variation, and variation among site-level trend lines over time. For modeling across islands, a random island effect was added. When the model did not converge with the full set of random effects, the random slope effect was removed. For models with overdispersion or underdispersion that could not be accounted for fully by the model, an observation-level random effect (Lee and Nelder 2000) was included to account for the unexplained variation (usually due to excess zeros).

All possible variance components models were compared with AICc and the most parsimonious converging model within two units of the smallest AICc was selected as the final model. Residual diagnostics were assessed with tools from the DHARMA package (Hartig 2021; Hartig and Lohse 2020). Plots with data, trends lines, and 90%-confidence intervals were generated to demonstrate trends and model fit. Program design protocols (Halvorson et al. 1988) envisioned trend detection at the 90% confidence interval. Raw data were jittered in plots so that overlapping values, particularly zeros, could be identified.

Covariate Data

Several covariate datasets were obtained to provide the basis for an assessment of environmental factors that affect CHIS vegetation outcomes. For a complete list of the covariates used for modeling CHIS vegetation indicators and their data sources, see Section B of the [Supplemental Information](#). Site-level covariates such as site elevation, slope, and northness were recorded for each site, and continuous covariates with large magnitudes (latitude, longitude, slope, and elevation) were scaled to improve model convergence. Other covariates considered in the modeling process included the survey month and islet (AN only). Additionally, indicators of nonnative mammal removal (0 for all years prior and 1 for all years after the removal of each species began) and years since nonnative mammal removal began were included to examine the impact of removing elk, deer, pigs, cattle, and sheep from SC and SR. Feral pigs were removed from SR beginning in 1993 and in SC beginning in 2006. Domestic cattle were removed from SR in 1998 and SC in 1999. European mouflon sheep removal began in SC in 2001. On SR, elk removal started in 2011 and mule deer removal in 2013. The removal indicator provides an additional intercept term to account for the nonnative mammal removal, and the number of years since nonnative mammal removal allows the trend over time to change based on nonnative mammal removal.

A large suite of water balance covariates (Table 3) was provided to CHIS from Dr. Lorraine Flint (EarthKnowledge), Dr. Alan Flint (EarthKnowledge), Dr. Michael Tercek (Walking Shadow Ecology; <https://www.yellowstoneecology.com/>), and Dr. David Thoma (National Park Service – Greater Yellowstone Network) for use with the covariate modeling task. Water balance modeling accounts for moisture in the local system by assessing the impacts of factors such as temperature, soil, evaporation, and plant transpiration on precipitation entering the system (Tercek et al. 2018). Water balance systems are important to consider in vegetation modeling because factors such as soil moisture and timing of precipitation can affect both the variability in annual growth and species composition of plant communities (Witwicki et al. 2016). Water balance metrics have been successfully implemented as predictors of wildfire ignition and streamflow (Thoma et al. 2020) as well as modeled greenness indices (Thoma et al. 2016). Handley et al. (2013) found that solar radiation was an important predictor of Simpson’s diversity and species richness on SR. Metrics that reflect long-term drought, solar radiation, precipitation, and other components of water availability will likely continue to be useful in quantifying the impacts of climate change on terrestrial vegetation communities. We collectively refer to the suite of water balance metrics and the variables that inform their calculation as “water balance” metrics in this analysis.

Table 3. Suites of water balance covariates with summary statistics and source.

Covariate	Description	Summary Statistic	Sources
PET	Cumulative potential evapotranspiration	Sum	Flint, Tercek, Thoma
AET	Modeled actual evapotranspiration	Sum	Tercek, Thoma
SOIL	Soil moisture	Mean	Tercek, Thoma
Def (i.e., Deficit)	Accumulated water deficit	Sum	Tercek, Thoma

Table 3 (continued). Suites of water balance covariates with summary statistics and source.

Covariate	Description	Summary Statistic	Sources
Temp	Temperature	Mean	Thoma
GDD	Accumulated growing-degree days	Sum	Thoma
svp	Vapor pressure. Indicator of moisture in the air.	Mean	Thoma
rh	Relative humidity. Indicator of moisture in the air.	Mean	Thoma
vpd	Vapor pressure deficit. Indicator of dryness in the air.	Mean	Thoma
Dew	Dew (binary). Indicator of dew formation given daily weather conditions.	Sum	Thoma
solRad (i.e., rad)	Total clear sky solar radiation. A 30-meter model for all five NPS Channel Islands (a solar radiation model without the blocking ridges).	Mean	Tercek, Flint
rn	Clear sky net solar radiation, long and shortwave energy balance: short-wave is incoming from the sun, long-wave is reflected from the ground surface (also part of the Priestley-Taylor equation).	Mean	Flint

Data Processing Methods

Here, we describe the covariate data from each source and discuss methods to reduce the dimension of the data prior to model selection.

Tercek Data

Dr. Michael Tercek provided modeled water balance values for potential evapotranspiration (PET), actual evapotranspiration, soil moisture, and accumulated water deficit. These metrics were calculated with a gridded water balance model (Tercek et al. 2018) using inputs from the 1-km gridded Daymet data set (Thornton et al. 2016) which included 24-hour precipitation, minimum and maximum 24-hour air temperatures, and vapor pressure. These variables were summarized over several time frames (Table 4), including the current water year, the current fog season, the previous water year (two years before current year to 1 year before current year), and the previous two water years (two years before current year to, and including, the current year).

Table 4. Definition of time frames used to summarize water balance covariates for data from Tercek and Thoma.

Time Frame	AN	SB	SC	SR	SM
Current water year ^A	Oct 1 – Jun 1	Oct 1 – Apr 30	Oct 1 – May 31	Oct 1 – Jun 30	Oct 1 – Jun 30
Previous water year	Oct 1 – Jun 1	Oct 1 – Apr 30	Oct 1 – May 31	Oct 1 – Jun 30	Oct 1 – Jun 30
Previous two water years	Oct 1 – Jun 1	Oct 1 – Apr 30	Oct 1 – May 31	Oct 1 – Jun 30	Oct 1 – Jun 30
Fog season	May 1 – Sep 30	May 1 – Sep 30	May 1 – Sep 30	May 1 – Sep 30	May 1 – Sep 30

^A Water year is October 1 (onset of rain in the Mediterranean climate) to the approximate date of field sampling for each island, capturing the seasonal precipitation that affects the current year's growth.

Thoma Data

Dr. David Thoma provided water balance metrics and climate metrics from Daymet (Thornton et al. 2016) summarized by day, month, and year. The data from Thoma included the same four water balance covariates as Tercek, but the inputs for the Thoma water balance metrics were based on climate data inputs at a single point rather than from a 1-km grid cell. Additionally, Thoma calculated the water balance metrics by month and by year. Thoma also provided modeled metrics such as temperature, accumulated growing-degree days, vapor pressure, relative humidity, vapor pressure deficit, and an indicator of dew formation (Dew).

The Thoma data included four sets of water balance and climate covariates, each based on a different cumulative potential evapotranspiration model: Hamon, Oudin Daymet, Oudin Location, and Penman. The choice of PET model influences how the total precipitation is partitioned into evapotranspiration and runoff. These four variations of the same metrics related to water balance provide various strengths and weaknesses to the computation of the covariate sets (Table 5) relative to prediction, publication, and complexity of the model. The two Oudin (Oudin et al. 2010) models are identical other than the solar radiation inputs which are either based on Daymet measurements or modeled radiation based on location data. The Oudin models perform well for rainfall-runoff models and Penman-Monteith (Penman 1948) works well for evaporative demand (Prudhomme and Williamson 2013).

Table 5. Advantages and disadvantages of the four PET models.

PET Model	Advantages	Disadvantages
Hamon	Performed well for flow modeling in AZ; simple model based on precipitation and temperature which are often easy to obtain, so can be used for prediction.	Performance varies based on location; may mask sources of uncertainty that a more complex PET model could discern (McAfee 2013).
Oudin Daymet	Accounts for low solar radiation on foggy days; solar radiation is obtained from Daymet daily radiation based on measurements of radiation.	Simple model based on solar radiation and temperature; may mask sources of uncertainty that a more complex PET model could discern (McAfee 2013).
Oudin Location	Accounts for solar radiation (useful for fog) obtained from latitude and day of year.	Simple model based on solar radiation and temperature; may mask sources of uncertainty that a more complex PET model could discern (McAfee 2013).
Penman	Considered the standard for publication (David Thoma, NPS ecologist, personal communication); physically based on solar radiation so accounts for low solar radiation on foggy days, wind speed, temperature, and humidity.	Can't be used for projecting into the future; inputs can be difficult to obtain.

Because the complete set of covariates from Thoma was large and mutually correlated, the covariates were reduced to a smaller subset to facilitate model selection. First, correlations between CHIS terrestrial vegetation indicators such as cover, density, and Shannon diversity and the four groups of

water balance and climate metrics from Thoma were examined to reduce those metrics to a subset based on a single PET model. Then covariate suites from all sources were examined and reduced further to obtain a succinct modeling subset.

For each of the four Thoma covariate groups calculated with a different PET model and summarized for a given time period, the correlation of each covariate with each of three selected vegetation outcomes (overall Shannon diversity, native tree cover, and native tree density) was calculated. The covariate group for the PET model exhibiting the strongest correlation overall with the selected vegetation outcomes was chosen as the preferred PET model, and the covariates related to the other three PET equations were eliminated from further consideration for this modeling exercise.

Flint Data

The data provided by Dr. Lorraine Flint and Dr. Alan Flint included potential clear sky evapotranspiration, total clear sky solar radiation, and clear sky net radiation. Potential clear sky evapotranspiration is determined from simulated solar radiation where the water balance for every grid cell is calculated using topographic shading (Flint and Flint 2012). This metric is calculated in part using the Priestley-Taylor equation (Priestley and Taylor 1972) for actual evapotranspiration. Note that Weiland et al. (2012) did not find extreme differences among modeled discharge for the four PET equations they examined (Penman-Monteith, Priestley-Taylor, and two others). Total clear sky solar radiation was obtained from a 30-meter solar radiation model for all five islands in CHIS and did not account for any blocking ridges. Clear sky net radiation, also a factor in the Priestley-Taylor equation, balances longwave energy reflected from the ground surface and shortwave energy from the sun. These metrics are computed as site-level 30-year means computed for three specific time periods: October 1 to the survey month, only the survey month, and all months. These 30-year means are site-level covariates as they do not vary over time.

Covariate Model Selection

The error distributions and variance form identified for each outcome in each trend analysis were used as the basis for modeling the outcome as a function of environmental covariates. Many of the covariates provided are correlated and will not be able to enter the same model due to multicollinearity, which affects the interpretation of covariates. Multicollinearity occurs when one model predictor is essentially a linear function of other model predictors. This linear dependence results in biased regression coefficients and standard errors. Multicollinearity among sets of model predictors was assessed with the condition number (Belsley et al. 1980), which ranges from 1 to infinity and provides an index of correlation among a set of model covariates. The condition number may be applied to sets of model predictors containing both categorical and numeric predictors. While some research suggests incorporating condition number cutoffs of 10 (Dormann et al. 2013) to 30 (Douglass et al. 2003), we required a condition number of five or less for model consideration for model parsimony and to avoid moderate-to-extreme collinearity issues.

The model selection entailed several steps given the high dimension of covariate data. All covariates were available for SC, SM, and SR, so initial comparisons were made for this subset of islands. The correlation among each set of covariate groups (PET, AET, soil water, etc.) was calculated and

subgroups of highly correlated covariates were defined (see Section C of the [Supplemental Information](#)). Then for each covariate analysis (defined by the combination of outcome, island, and plot type), the correlation between the outcome of interest and each covariate in a subgroup was calculated. The covariate most strongly correlated with the outcome of interest (on the linked scale of log or logit) was selected from the subgroup for model selection. All possible covariate combinations of up to 6 covariates per model were enumerated for model selection. Further correlation among covariates within a model was identified by calculating the condition number and removing covariate combinations with condition numbers greater than 5. The set of converging models meeting the condition number requirement was compared with AICc (Cavanaugh 1997). The final model was selected as the most parsimonious model within the set of “top models,” defined as models within two AICc units of the smallest AICc value among all converging models.

Results

The total number of index sites monitored by island ranged from 16 to 87 and surveys began as early as 1984 (Table 6). For probability surveys, the number of sites ranged from 14 to 51. Probability surveys began in 2013 for all islands except SR, for which surveys started in 2017. Because the data available at the time of analysis included only 2017 and 2018 SR survey data, no island-level probability analyses were conducted for SR due to the small sample size. The combination of island, plot type, and outcome resulted in 162 different trend modeling scenarios. Of these, converging trend models were not obtained for 11 combinations (Table 7). In these cases, either a lack of replication, a lack of species diversity in a particular vegetation community for a given island, or a paucity of non-zero cover values contributed to the inability to obtain a suitable model for inference. These 11 combinations were not explored for trend or covariate modeling. Additionally, 1998 and 1999 were omitted from SC analyses because these surveys were preliminary and data are potentially not comparable to data collected in subsequent years (L.F.S. Lee, personal observation). The sample size of probability sites on AN was too small to estimate separate trends by islet area (East, Middle, or West), but the Islet effect was included in models of index sites. In this section, trends in time for each outcome, island, and plot type combination are discussed, and then the covariate modeling results are reviewed.

Table 6. Total number of transects surveyed per island and first year of data collection.

Island	Index Sites		Probability Sites	
	Number of Transects	First Year	Number of Transects	First Year
AN	16	1984	14	2013
SB	25	1984	21	2013
SC	43	1998	42	2013
SM	17	1984	16	2013
SR	87	1990	51	2017

Table 7. Modeling combinations without converging models.

Outcome	Island	Plot Type
Overall Shannon Diversity	AN	Probability
Overall Shannon Diversity	SM	Probability
Native Shannon Diversity	SB	Probability
Island Chaparral Shannon Diversity	SC	Index
Island Chaparral Shannon Diversity	SR	Index
Oak Shannon Diversity	SC, SR	Index
Oak Shannon Diversity	SR	Index

Table 7 (continued). Modeling combinations without converging models.

Outcome	Island	Plot Type
Torrey Pine Shannon Diversity	SR	Index
Ironwood Shannon Diversity	SC	Index
Native Grass Cover	SB	Probability
<i>Eriogonum giganteum</i> Cover	SB	Probability

Trends over Time

Initial trend modeling was conducted with the Tweedie distribution for the Shannon diversity index, the Poisson distribution for density metrics, and the beta-binomial model for cover outcomes. Note that, for patchy distributions where many sites have no cover, the dispersion parameter is large as is the site-to-site variation. Trend results are provided by island, then plot type, and then outcome and include tables of estimated regression coefficients (with associated standard errors and significance tests), variance components, and dispersion parameters when applicable. Trend plots display estimated trend lines with 90%-confidence intervals (CI). Confidence intervals were calculated on the conditional model and did not account for random effects variances.

Regression coefficients are reported for all models and back-transformed annual proportional trend estimates (i.e., the one-year trend expressed as a proportional change where -0.045 represents an annual decline of -4.5%). However, please note that the comparison of p-values to a Type I error level of 0.10 should be interpreted liberally so as not to fail to consider a true trend or to act unnecessarily based on an erroneous assumption of trend (Wasserstein et al. 2019). Back-transformed trend estimates expressed as an annual percent change are provided in Section D of the [Supplemental Information](#).

Trends across Islands

Index Sites

Trend modeling results for trends across islands at index sites are presented in Table 8. Declining trends were observed for index sites across islands in all Shannon diversity metrics, but not all trends were statistically significant. Back-transforming the trend regression coefficient to interpret trend as an annual proportional change (as discussed in the methods section), we find that overall Shannon diversity (Figure 3A) had an estimated annual trend of -1.43% (90%-CI: -1.91% , -0.95%), but the trend in native Shannon diversity (Figure 3B) was not found to be different from zero ($p = 0.4452$). Decreasing trends were observed in index sites for island chaparral Shannon diversity at SC and SR (Figure 3C, annual trend: -3.98% , 90%-CI: -5.26% , -2.67%); coastal sage scrub Shannon diversity at AN, SC, SM, and SR (Figure 3D, annual trend: -1.54% , 90%-CI: -2.53% , -0.55%); and grassland Shannon diversity across all islands (Figure 3E, annual trend: -1.80% , 90%-CI: -2.44% , -1.16%). No significant trend ($p = 0.5084$) was observed in riparian Shannon diversity in SC and SR (Figure 3F), but ironwood Shannon diversity (Figure 4A, annual trend: -1.80% , 90%-CI: -2.81% , -0.79%) exhibited a decreasing trend at SC and SR. No significant trend ($p = 0.3466$) was observed for Shannon diversity of mixed woodland species at SC and SR (Figure 4B).

Table 8. Trend analysis results for all CHIS vegetation indicators for index sites across islands.

Outcome	Islands	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Island Variation	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	All	1.8552	0.0716	-0.0144	0.0030	<0.0001	–	0.3852	0.0201	0.0003	–
Native Shannon Diversity	All	1.1156	0.0999	-0.0020	0.0026	0.4452	0.0228	0.4840	0.0122	0.0004	–
Island Chaparral Shannon Diversity	SC,SR	2.3337	0.2525	-0.0406	0.0082	<0.0001	–	0.6096	0.0328	0.0005	–
Coastal Sage Scrub Shannon Diversity	AN,SC, SM,SR	2.0321	0.1504	-0.0156	0.0061	0.0107	–	0.2420	0.0525	0.0003	–
Grassland Shannon Diversity	All	1.9106	0.1176	-0.0182	0.0040	<0.0001	0.0346	0.0997	0.0237	0.0003	–
Riparian Shannon Diversity	SC,SR	1.6199	0.2396	-0.0061	0.0092	0.5084	–	0.4790	0.0150	0.0007	–
Ironwood Shannon Diversity	SC,SR	1.3562	0.1417	-0.0182	0.0063	0.0036	–	–	0.0000	–	–
Mixed Woodland Shannon Diversity	SC,SR	1.9075	0.0959	-0.0040	0.0042	0.3466	–	–	0.0000	–	–
Native Tree Density	SC,SR	-2.8756	0.2119	-0.0292	0.0152	0.0555	–	0.8437	0.0701	0.0009	0.0699
Native Tree Recruitment Density	SC,SR	-4.8403	0.8376	0.0712	0.0645	0.2698	–	9.6308	1.4434	0.0237	1.1382
Native Shrub Density	All	-1.7037	0.3537	0.0344	0.0137	0.0119	0.3337	3.5270	0.0186	0.0091	0.1613
Native Shrub Recruitment Density	SC,SR	-3.1286	0.3585	-0.0245	0.0276	0.3759	–	3.1866	0.1347	0.0099	1.9503
Native Tree Cover	SC,SR	-12.2672	0.8212	-0.0154	0.0057	0.0070	–	129.6940	0.0280	–	–
Native Shrub Cover	All	-4.4639	0.4096	0.0304	0.0118	0.0099	–	21.6789	0.0653	0.0116	0.1464
Native Forb Cover	All	-1.6935	0.4404	-0.0457	0.0113	<0.0001	0.5951	4.4385	0.2566	0.0061	0.6019
Nonnative Forb Cover	All	-1.5399	0.3221	-0.1111	0.0154	<0.0001	–	3.7460	0.5425	0.0072	1.1752
Native Grass Cover	All	-3.6923	0.7998	-0.0391	0.0131	0.0030	2.5665	9.0001	0.2702	0.0084	0.3252
Nonnative Grass Cover	All	0.5130	0.3279	-0.0784	0.0142	<0.0001	–	5.4898	0.5506	0.0033	–

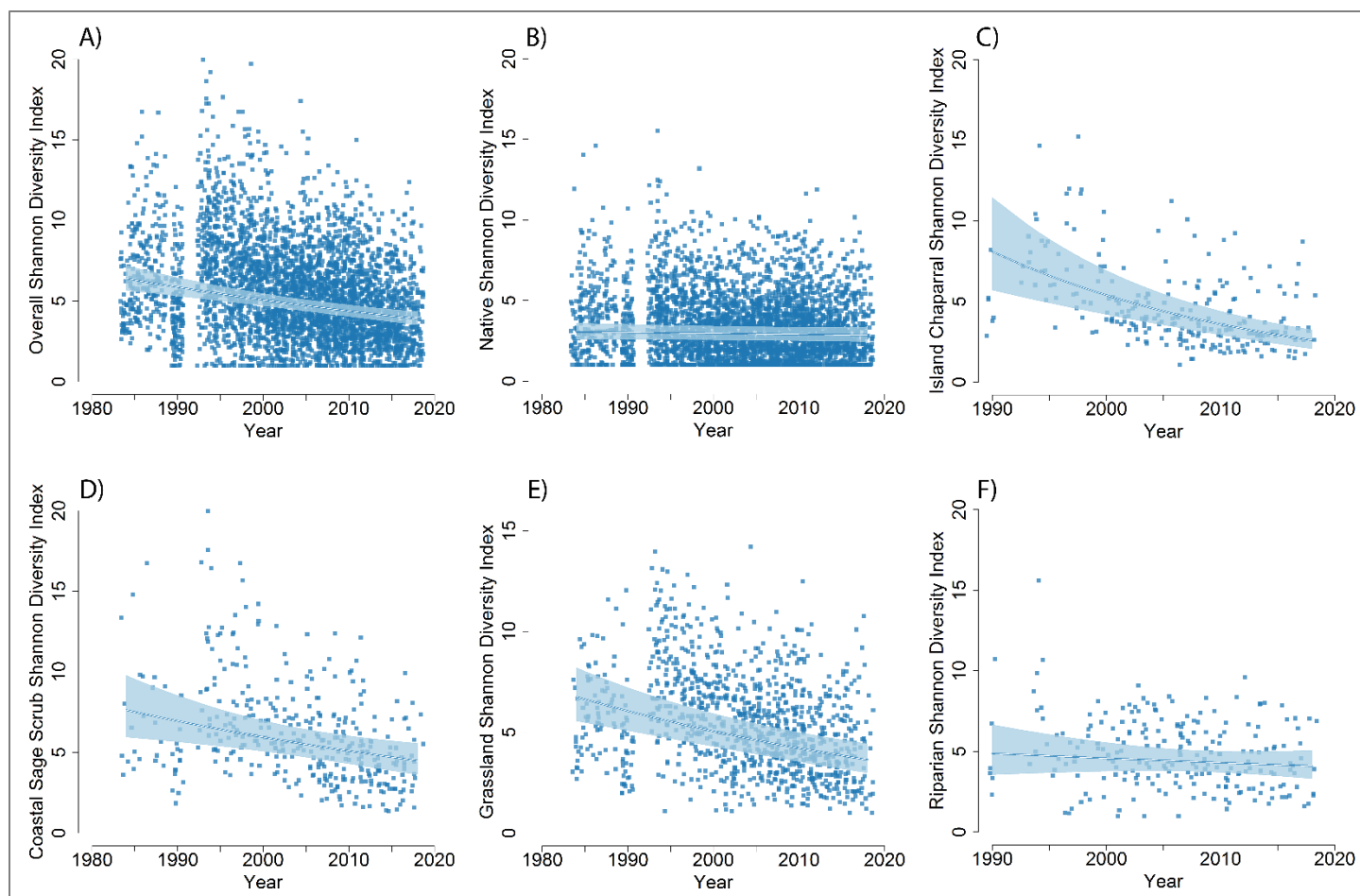


Figure 3. Trend analysis results for CHIS vegetation indicators by index site and year (first of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index across all islands ($p < 0.0001$). B) Native Shannon diversity index across all islands ($p = 0.4452$). C) Island chaparral Shannon diversity index across Santa Cruz and Santa Rosa islands ($p < 0.0001$). D) Coastal sage scrub Shannon diversity index across Anacapa, Santa Cruz, San Miguel, and Santa Rosa islands ($p = 0.0107$). E) Grassland Shannon diversity index across all islands ($p < 0.0001$). F) Riparian Shannon diversity index across Santa Cruz and Santa Rosa islands ($p = 0.5084$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

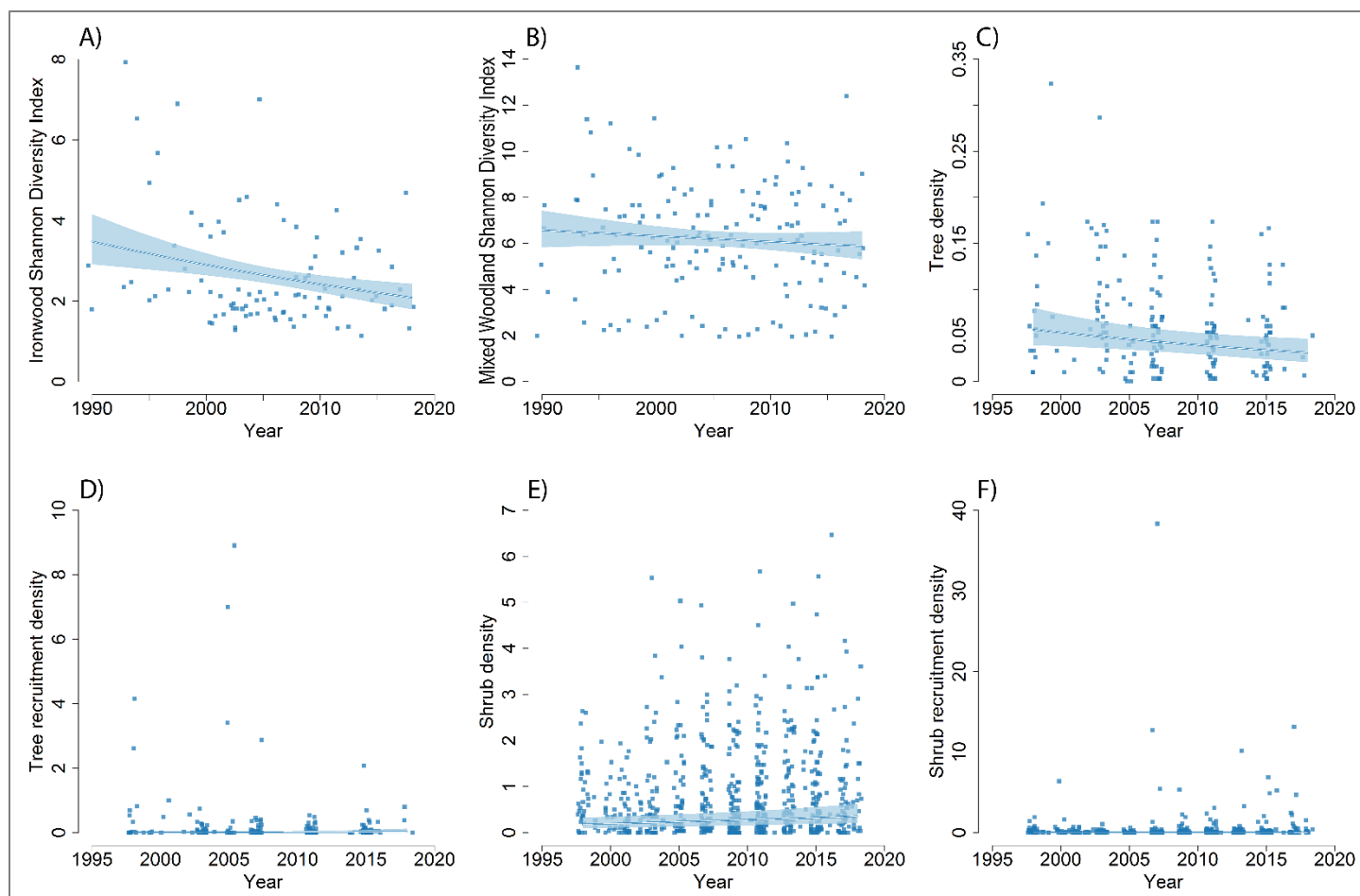


Figure 4. Trend analysis results for CHIS vegetation indicators by index site and year (second of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Ironwood Shannon diversity index across Santa Cruz and Santa Rosa islands ($p = 0.0036$). B) Mixed woodland Shannon diversity index across Santa Cruz and Santa Rosa islands ($p = 0.3466$). C) Native tree density across Santa Cruz and Santa Rosa islands ($p = 0.0555$). D) Native tree recruitment density across Santa Cruz and Santa Rosa islands ($p = 0.2698$). E) Native shrub density across all islands ($p = 0.0119$). F) Native shrub recruitment density across Santa Cruz and Santa Rosa islands ($p = 0.3759$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

For density estimates, native tree density demonstrated a negative trend over time in SC and SR (Figure 4C, annual trend: -2.87% , 90%-CI: -5.28% , -0.41%), but no trend ($p = 0.2698$) was observed in native tree recruitment on SC and SR (Figure 4D). For shrubs, an increasing trend was observed in native shrub density (Figure 4E, annual trend: 3.50% , 90%-CI: 1.20% , 5.85%), but no trend was observed ($p = 0.3759$) in native shrub recruitment density (Figure 4F).

For cover metrics, a decreasing trend across index sites at SC and SR was estimated for native tree cover (Figure 5A, annual trend in odds: -1.53% , 90%-CI: -2.45% , -0.60%), but there was an increasing trend in native shrub cover (Figure 5B, annual trend in odds: 3.09% , 90%-CI: 1.11% , 5.11%). Declining trends for index sites were detected for the odds of native forb cover (Figure 5C, annual trend: -4.47% , 90%-CI: -6.23% , -2.68%), nonnative forb cover (Figure 5D, annual trend: -10.52% , 90%-CI: -12.76% , -8.21%), native grass cover (Figure 5E, annual trend: -3.83% , 90%-CI: -5.89% , -1.73%), and nonnative grass cover (Figure 5F, annual trend: -7.54% , 90%-CI: -9.66% , -5.36%).

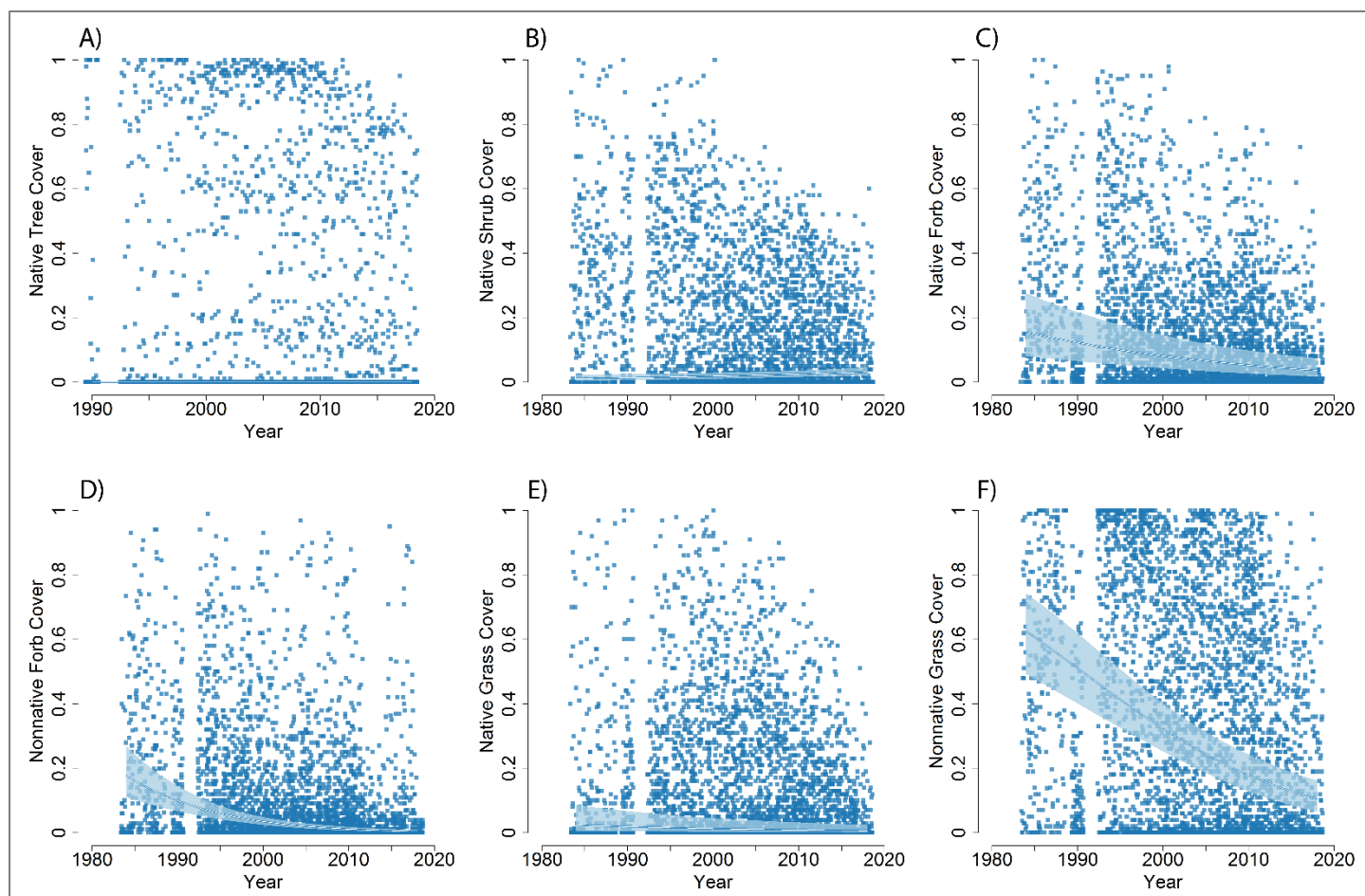


Figure 5. Trend analysis results for CHIS vegetation indicators by index site and year (third of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native tree cover across Santa Cruz and Santa Rosa islands ($p = 0.0070$). B) Native shrub cover across all islands ($p = 0.0099$). C) Native forb cover across all islands ($p < 0.0001$). D) Nonnative forb cover across all islands ($p < 0.0001$). E) Native grass cover across all islands ($p = 0.0030$). F) Nonnative grass cover across all islands ($p < 0.0001$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Probability Sites

Trends since 2013 in vegetation metrics across all islands for probability sites were not significantly different from zero for any of the indicators examined (Table 9), including overall Shannon diversity (Figure 6A, $p = 0.8467$), native Shannon diversity (Figure 6B, $p = 0.6046$), and native shrub density (Figure 6C, $p = 0.2214$). Similarly, no trends were detected in the odds of native shrub cover (Figure 6D, $p = 0.2504$), native forb cover (Figure 7A, $p = 0.5001$), nonnative forb cover (Figure 7B, $p = 0.1429$), native grass cover (Figure 7C, $p = 0.3313$), and nonnative grass cover (Figure 7D, $p = 0.5153$).

Table 9. Trend analysis results for all CHIS vegetation indicators for probability sites across all islands.

Outcome	Islands	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Island Variation	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	All	1.1767	0.8806	0.0054	0.0277	0.8467	0.0294	0.1295	0.0104	–	–
Native Shannon Diversity	All	1.1649	0.6166	–0.0099	0.0192	0.6046	0.0434	0.2297	0.0042	–	–
Native Shrub Density	All	–0.3494	0.7917	–0.0521	0.0426	0.2214	–	2.0428	0.0000	–	0.3193
Native Shrub Cover	All	–4.5877	0.6103	0.0198	0.0173	0.2504	–	6.0529	0.0000	–	–
Native Forb Cover	All	–5.3052	3.1014	0.0659	0.0977	0.5001	0.2384	1.0818	0.1411	–	–
Nonnative Forb Cover	All	–2.9814	4.5343	0.0047	0.1429	0.9738	0.6864	0.4196	0.3071	–	–
Native Grass Cover	All	–2.1655	3.3674	–0.0977	0.1006	0.3313	3.0291	96.1001	0.0000	0.0663	0.2033
Nonnative Grass Cover	All	1.3677	5.0169	–0.1027	0.1578	0.5153	0.6667	148.7224	0.3582	0.1389	–

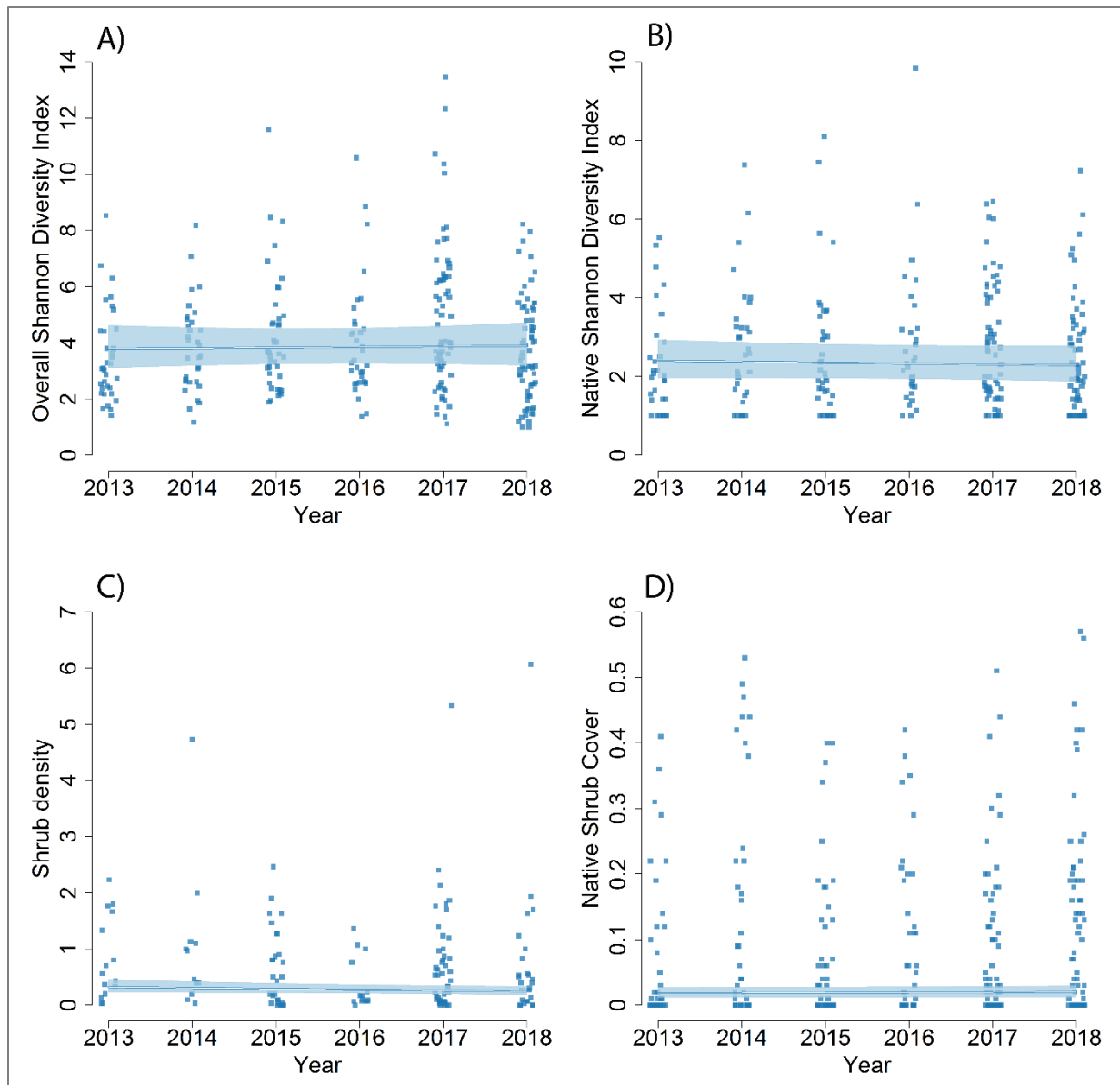


Figure 6. Trend analysis results for CHIS vegetation indicators by probability site and year (first of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index across all islands ($p = 0.8467$). B) Native Shannon diversity index across all islands ($p = 0.6046$). C) Native shrub density across all islands ($p = 0.2214$). D) Native shrub cover across all islands ($p = 0.2504$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

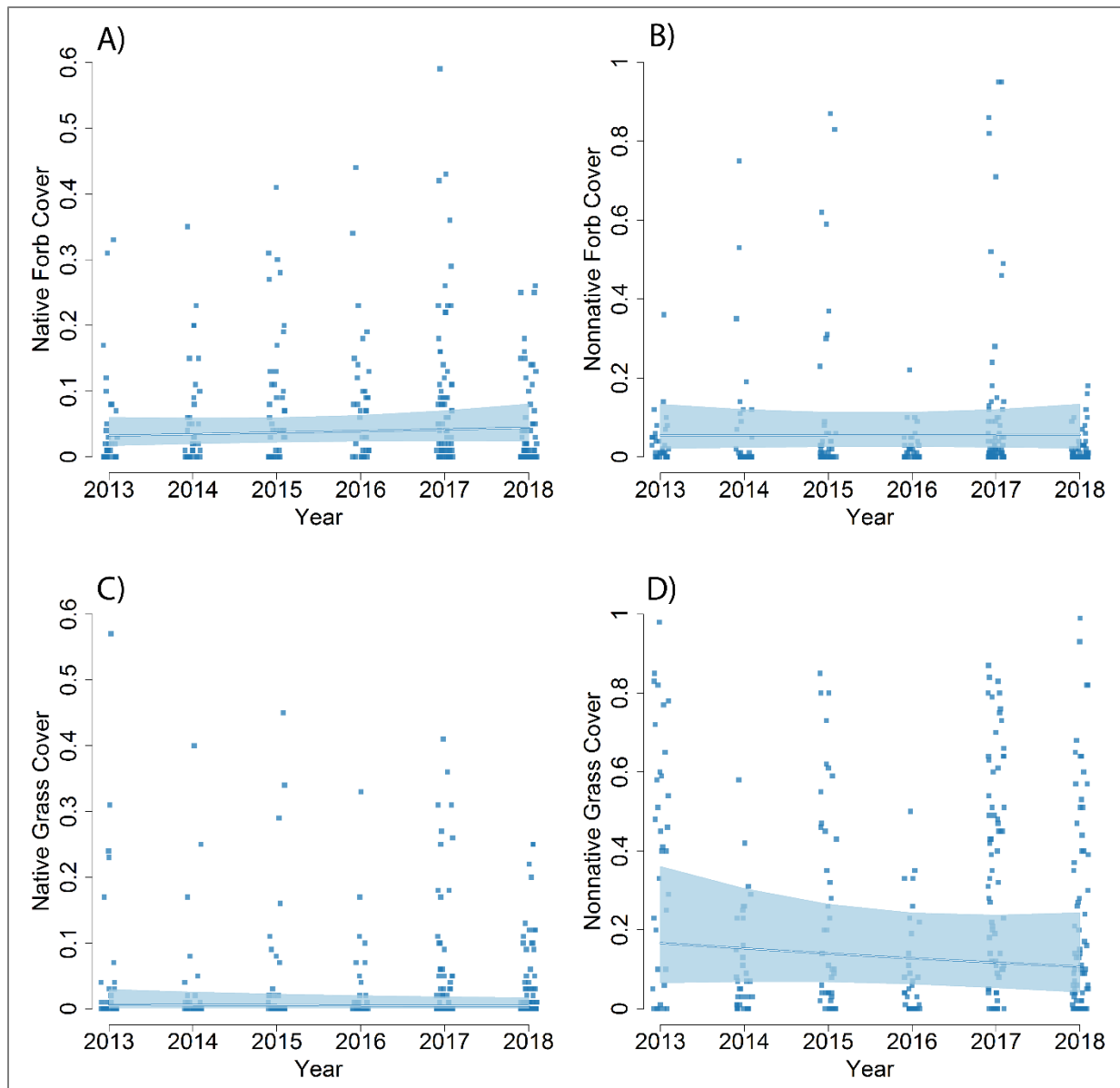


Figure 7. Trend analysis results for CHIS vegetation indicators by probability site and year (second of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native forb cover across all islands ($p = 0.5001$). B) Nonnative forb cover across all islands ($p = 0.9738$). C) Native grass cover across all islands ($p = 0.3313$). D) Nonnative grass cover across all islands ($p = 0.5153$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Trends on Anacapa Island

Anacapa Island Index Sites

Trend models for index sites at AN include an interaction term for the year and islet to assess trends within each of the three regions of AN (East, Middle, and West). Trend modeling results are organized by islet in Table 10, with the results from a single model presented on three lines with one

line per islet. Therefore, the variance components estimates are repeated on the three lines but originate from the same model.

Note that fixed intercept and trend effects for Middle and West islets are additive relative to the East islet estimates. For example, the trend estimate for logged overall Shannon diversity for the East islet is -0.0252 , but for the Middle islet the trend estimate of logged overall Shannon diversity is -0.0269 (calculated as $-0.0252 - 0.0017 = -0.0269$). Therefore, the trend p-values from Table 10 cannot be directly used to assess the significance of a trend estimate for Middle and West islets because the p-values reflect tests of the differences between trends in the Middle or West islets from the trend in the East islet. We use the confidence intervals of the estimated annual percent trends for each islet to assess statistical significance.

Overall Shannon diversity (Figure 8A) declined at AN index sites by -2.49% annually (90%-CI: -3.28% , -1.69%) for the East islet and by -2.66% annually (90%-CI: -3.54% , -1.77%) for the Middle islet, but the confidence interval for the trend in the West islet overlapped zero implying no significant trend at the 0.10 level (annual trend: -0.40% , 90%-CI: -1.21% , 0.42%). Similarly for native Shannon diversity (Figure 8B), decreasing trends were observed for the East islet (annual trend: -2.94% , 90%-CI: -3.93% , -1.93%) and the Middle islet (annual trend: -2.91% , 90%-CI: -3.97% , -1.84%) but no significant trend was observed for the West islet (annual trend: -0.38% , 90%-CI: -1.41% , 0.65%). Coastal sage scrub Shannon diversity (Figure 8C) demonstrated a decreasing trend in the East islet (annual trend: -3.85% , 90%-CI: -5.37% , -2.30%) but no significant trend was observed in the West islet (annual trend: -0.09% , 90%-CI: -1.71% , 1.55%). Only one transect in the Middle islet contained coastal sage scrub species, so trend was not estimable for this islet. Similarly to the other Shannon diversity metrics, negative trends were estimated for grassland Shannon diversity (Figure 8D) in the East islet (annual trend: -2.23% , 90%-CI: -3.23% , -1.23%) and the Middle islet (annual trend: -2.74% , 90%-CI: -3.77% , -1.70%) but not the West islet (annual trend: 0.22% , 90%-CI: -0.74% , 1.20%).

For native shrub density (Figure 8E), a negative trend was detected at AN index sites in the Middle islet (annual trend: -20.50% , 90%-CI: -34.27% , -3.83%). However, note that the wide confidence interval is due to the small sample size of index sites in the Middle islet. Trends for the East islet (annual trend: -0.31% , 90%-CI: -11.25% , 11.98%) and the West islet (annual trend: -13.21% , 90%-CI: -42.16% , 30.25%) were not significantly different from zero.

Table 10. Trend analysis results for all CHIS vegetation indicators for index sites on Anacapa Island.

Outcome	Islet	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	East	2.0312	0.1744	-0.0252	0.0050	<0.0001	0.1046	0.0513	–	–
Overall Shannon Diversity	Middle ^A	0.2623	0.2155	-0.0017	0.0046	0.7068	0.1046	0.0513	–	–
Overall Shannon Diversity	West ^A	0.2705	0.2071	0.0213	0.0041	<0.0001	0.1046	0.0513	–	–
Native Shannon Diversity	East	1.6999	0.2449	-0.0298	0.0063	<0.0001	0.2664	0.0368	0.0001	–
Native Shannon Diversity	Middle ^A	0.0176	0.3315	0.0003	0.0077	0.9740	0.2664	0.0368	0.0001	–
Native Shannon Diversity	West ^A	0.1463	0.3175	0.0260	0.0074	0.0005	0.2664	0.0368	0.0001	–
CSS Shannon Diversity	East	–	–	–	–	–	–	–	–	–
CSS Shannon Diversity	Middle ^A	2.5449	0.4364	-0.0393	0.0097	<0.0001	0.1584	0.0934	–	–
CSS Shannon Diversity	West ^A	-0.2111	0.5328	0.0383	0.0115	0.0009	0.1584	0.0934	–	–
Grassland Shannon Diversity	East	1.9520	0.1382	-0.0226	0.0062	0.0003	0.0091	0.0755	–	–
Grassland Shannon Diversity	Middle ^A	0.3091	0.1137	-0.0052	0.0054	0.3330	0.0091	0.0755	–	–
Grassland Shannon Diversity	West ^A	-0.0096	0.1298	0.0248	0.0051	<0.0001	0.0091	0.0755	–	–
Native Shrub Density	East	-1.4253	1.1170	-0.0031	0.0707	0.9650	0.8853	0.2974	–	0.4883
Native Shrub Density	Middle ^A	3.0847	2.0978	-0.2263	0.1309	0.0838	0.8853	0.2974	–	0.4883
Native Shrub Density	West ^A	1.6437	4.0227	-0.1386	0.2583	0.5916	0.8853	0.2974	–	0.4883
Native Shrub Cover	East	-0.7221	0.8003	-0.0920	0.0203	<0.0001	2.7186	0.4014	0.0005	–
Native Shrub Cover	Middle ^A	0.3789	1.0698	-0.0143	0.0214	0.5051	2.7186	0.4014	0.0005	–
Native Shrub Cover	West ^A	1.1835	1.0290	-0.0068	0.0229	0.7658	2.7186	0.4014	0.0005	–
Native Forb Cover	East	0.0077	0.4176	-0.0964	0.0233	<0.0001	0.6214	0.2528	0.0019	–
Native Forb Cover	Middle ^A	0.1405	0.5266	-0.0329	0.0310	0.2890	0.6214	0.2528	0.0019	–
Native Forb Cover	West ^A	0.1386	0.5064	0.0457	0.0296	0.1224	0.6214	0.2528	0.0019	–
Nonnative Forb Cover	East	-1.2182	0.6856	-0.0067	0.0266	0.8016	1.4893	0.9872	0.0014	–
Nonnative Forb Cover	Middle ^A	-1.4626	0.8245	0.0225	0.0295	0.4469	1.4893	0.9872	0.0014	–
Nonnative Forb Cover	West ^A	-1.3115	0.8074	-0.0219	0.0316	0.4881	1.4893	0.9872	0.0014	–

^A Intercept and trend estimates for Middle and West islets are additive effects relative to the effects of the East islet.

Table 10 (continued). Trend analysis results for all CHIS vegetation indicators for index sites on Anacapa Island.

Outcome	Islet	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Native Grass Cover	East	-1.4282	0.9582	-0.0738	0.0301	0.0142	4.1495	0.2124	0.0031	–
Native Grass Cover	Middle ^A	0.5076	1.3224	-0.0561	0.0406	0.1671	4.1495	0.2124	0.0031	–
Native Grass Cover	West ^A	0.4871	1.2680	0.0109	0.0391	0.7802	4.1495	0.2124	0.0031	–
Nonnative Grass Cover	East	-0.7369	0.7110	-0.0535	0.0266	0.0441	1.5912	1.1544	0.0012	–
Nonnative Grass Cover	Middle ^A	1.7345	0.8308	0.0255	0.0268	0.3416	1.5912	1.1544	0.0012	–
Nonnative Grass Cover	West ^A	0.6283	0.7987	0.0014	0.0271	0.9579	1.5912	1.1544	0.0012	–

^A Intercept and trend estimates for Middle and West islets are additive effects relative to the effects of the East islet.

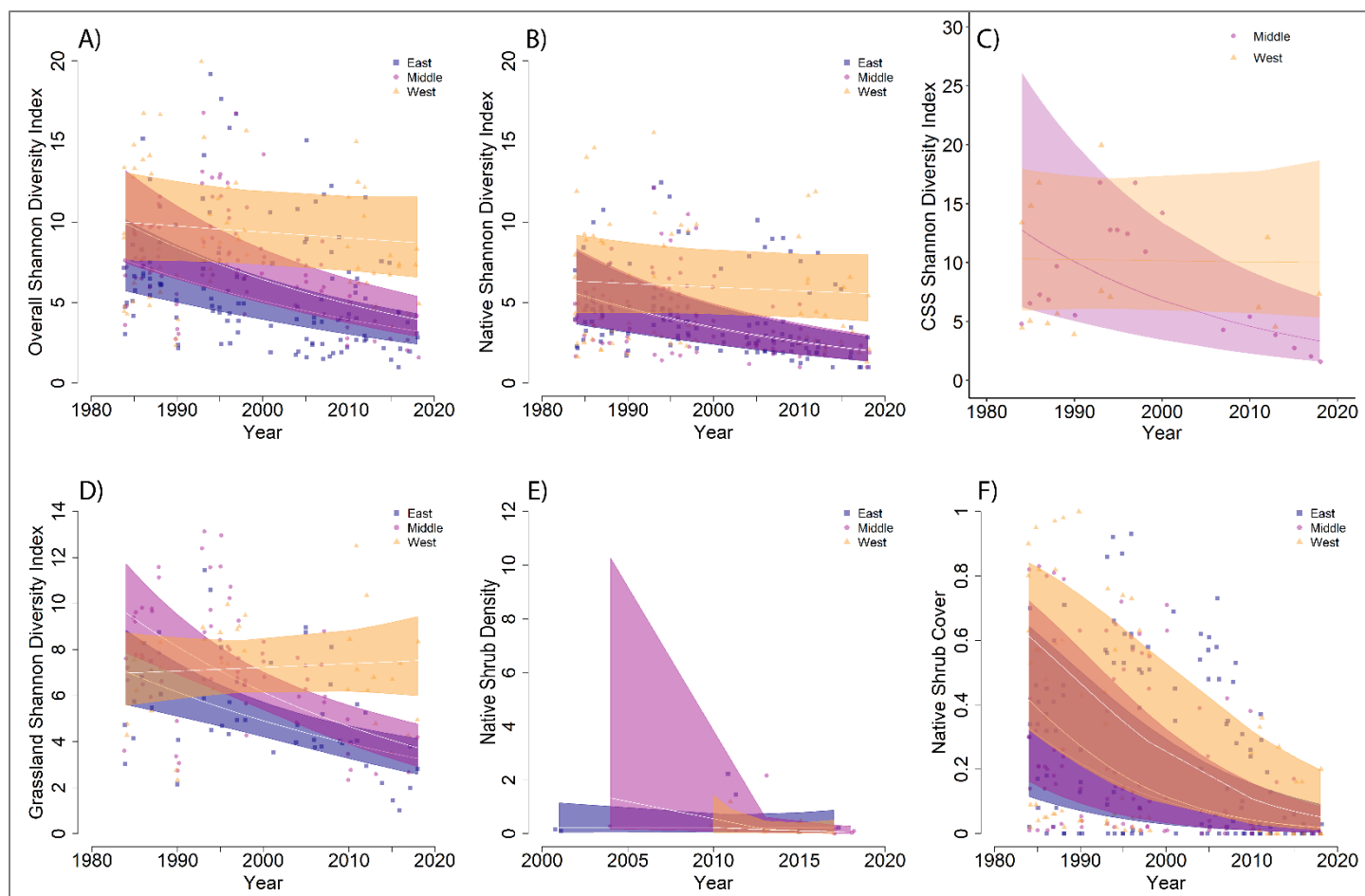


Figure 8. Trend analysis results for CHIS vegetation indicators by index site and year across three regions on Anacapa Island (first of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index (East, $p < 0.0001$; Middle, $p = 0.7068$; West, $p < 0.0001$). B) Native Shannon diversity index (East, $p < 0.0001$; Middle, $p = 0.9740$; West, $p = 0.0005$). Note that the East (blue) and Middle (pink) trend lines and confidence intervals completely overlap. C) Coastal sage scrub (CSS) Shannon diversity index (Middle, $p < 0.0001$; West, $p = 0.0009$). D) Grassland Shannon diversity index (East, $p = 0.0003$; Middle, $p = 0.3330$; West, $p < 0.0001$). E) Native shrub density (East, $p = 0.9650$; Middle, $p = 0.0838$; West, $p = 0.5916$). F) Native shrub cover (East, $p < 0.0001$; Middle, $p = 0.5051$; West, $p = 0.7658$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Native shrub cover (Figure 8F) demonstrated a negative trend at all AN islets, with decreasing annual trends in the odds of -8.79% (90%-CI: -11.78% , -5.70%) in the East islet, -10.09% (90%-CI: -13.11% , -6.95%) in the Middle islet, and -9.41% (90%-CI: -12.48% , -6.24%) in the West islet. Similarly for the odds of native forb cover (Figure 9A), negative trends were observed for index sites at all islets with annual declines of -9.19% (90%-CI: -12.61% , -5.65%) in the East islet, -12.13% (90%-CI: -15.67% , -8.45%) in the Middle islet, and -4.95% (90%-CI: -8.39% , -1.39%) in the West islet. However, nonnative forb cover (Figure 9B) showed no change at AN index sites over the monitoring period. Trends in the odds of nonnative forb cover at the East islet (annual trend: -0.66% , 90%-CI: -4.91% , 3.77%), Middle islet (annual trend: 1.59% , 90%-CI: -3.06% , 6.47%), and West islet (annual trend: -2.82% , 90%-CI: -7.51% , 2.10%) were not significantly different from zero at the 0.10 level. Similarly to other native cover metrics at AN, native grass cover (Figure 9C) exhibited negative trend at all three AN islets. Annual declines of -7.12% (90%-CI: -11.60% , -2.40%) in the East islet, -12.18% (90%-CI: -16.66% , -7.46%) in the Middle islet, and -6.10% (90%-CI: -10.49% , -1.48%) in the West islet were observed at AN index sites in the odds of native grass cover. Significant trends in the odds of nonnative grass cover (Figure 9D) were observed in the East islet (annual trend: -5.21% , 90%-CI: -9.27% , -0.97%) and the West islet (annual trend: -5.08% , 90%-CI: -9.31% , -0.65%), but no significant trend was observed in the Middle islet (annual trend: -2.77% , 90%-CI: -7.04% , 1.70%) for AN index sites.

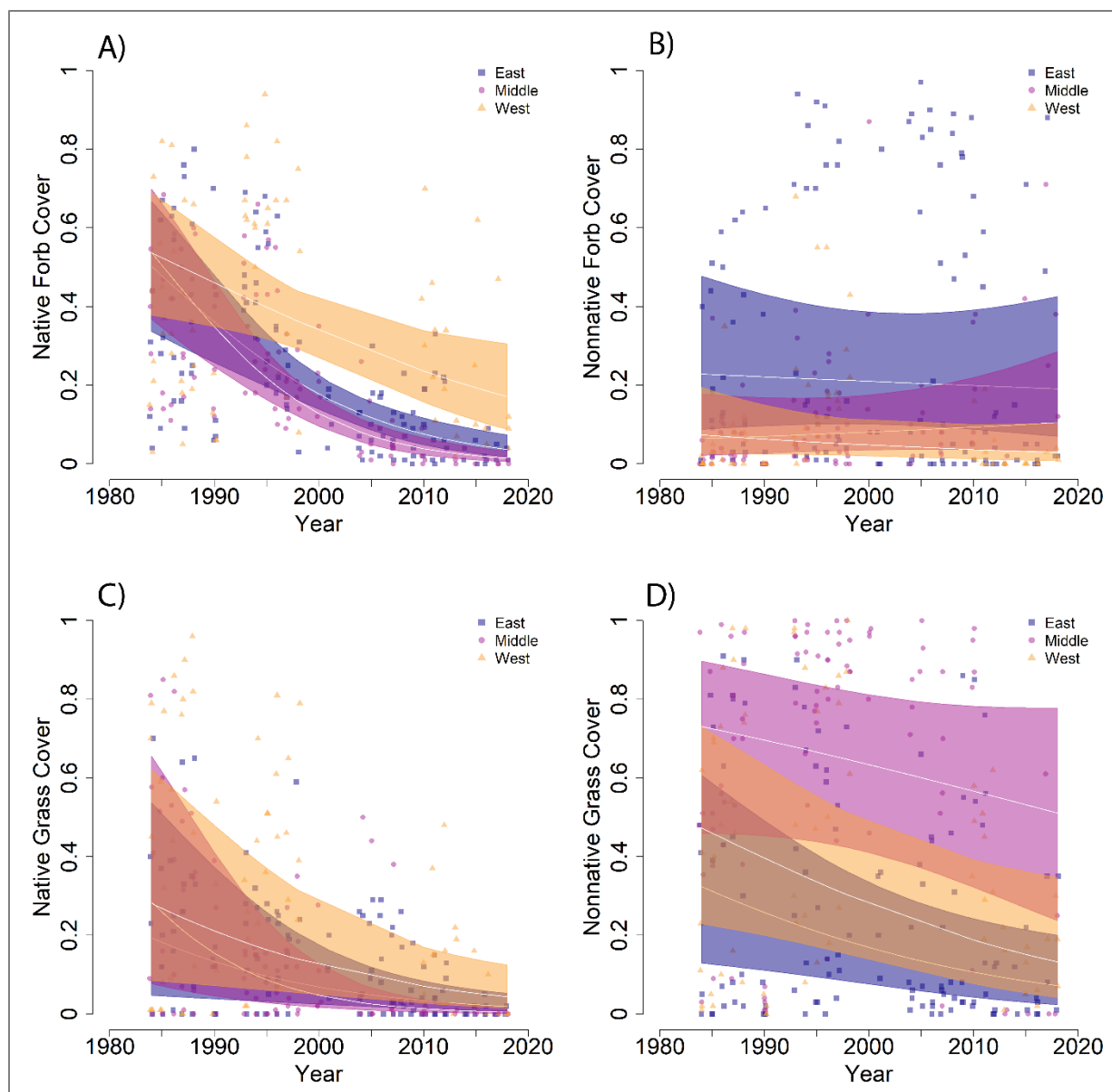


Figure 9. Trend analysis results for CHIS vegetation indicators by index site and year across three regions on Anacapa Island (second of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native forb cover (East, $p < 0.0001$; Middle, $p = 0.2890$; West, $p = 0.1224$). B) Nonnative forb cover (East, $p < 0.8016$; Middle, $p = 0.4469$; West, $p = 0.4881$). C) Native grass cover (East, $p = 0.0142$; Middle, $p = 0.1671$; West, $p = 0.7802$). D) Nonnative grass cover (East, $p = 0.0441$; Middle, $p = 0.3416$; West, $p = 0.9579$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Anacapa Island Probability Sites

For AN probability sites (Table 11), no significant trends were observed for native Shannon diversity (Figure 10A, $p = 0.9430$), native shrub density (Figure 10B, $p = 0.2176$), native shrub cover (Figure 10C, $p = 0.8829$), or native forb cover (Figure 10D, $p = 0.9491$). A significant increasing trend of 67.23% per year (90%-CI: 27.31%, 119.67%) was estimated for the odds of nonnative forb cover, but

note in Figure 11A that the initial cover in 2013 was near zero. Neither native grass cover (Figure 11B, $p = 0.8166$) nor nonnative grass cover (Figure 11C, $p = 0.2444$) exhibited a significant trend since probability surveys began in 2013. For all trend models from AN probability sites, the site-level slope random effect was inestimable and the year-to-year variance term was near zero. This may be due to a small sample size of years.

Table 11. Trend analysis results for all CHIS vegetation indicators for probability sites on Anacapa Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Native Shannon Diversity	0.7099	2.3608	0.0053	0.0742	0.9430	–	0	–	–
Native Shrub Density	2.1151	3.2332	–0.2270	0.1841	0.2176	–	0	–	1.1179
Native Shrub Cover	–3.7276	3.8525	–0.0178	0.1205	0.8829	3.7546	0	–	–
Native Forb Cover	–3.7149	4.2181	0.0085	0.1331	0.9491	1.2060	0	–	–
Nonnative Forb Cover	–20.2171	5.4742	0.5142	0.1658	0.0019	3.8102	0	–	–
Native Grass Cover	–3.3076	4.9193	–0.0362	0.1561	0.8166	4.3622	0	–	–
Nonnative Grass Cover	–10.3521	6.6183	0.2388	0.2051	0.2444	2.3347	0	–	–

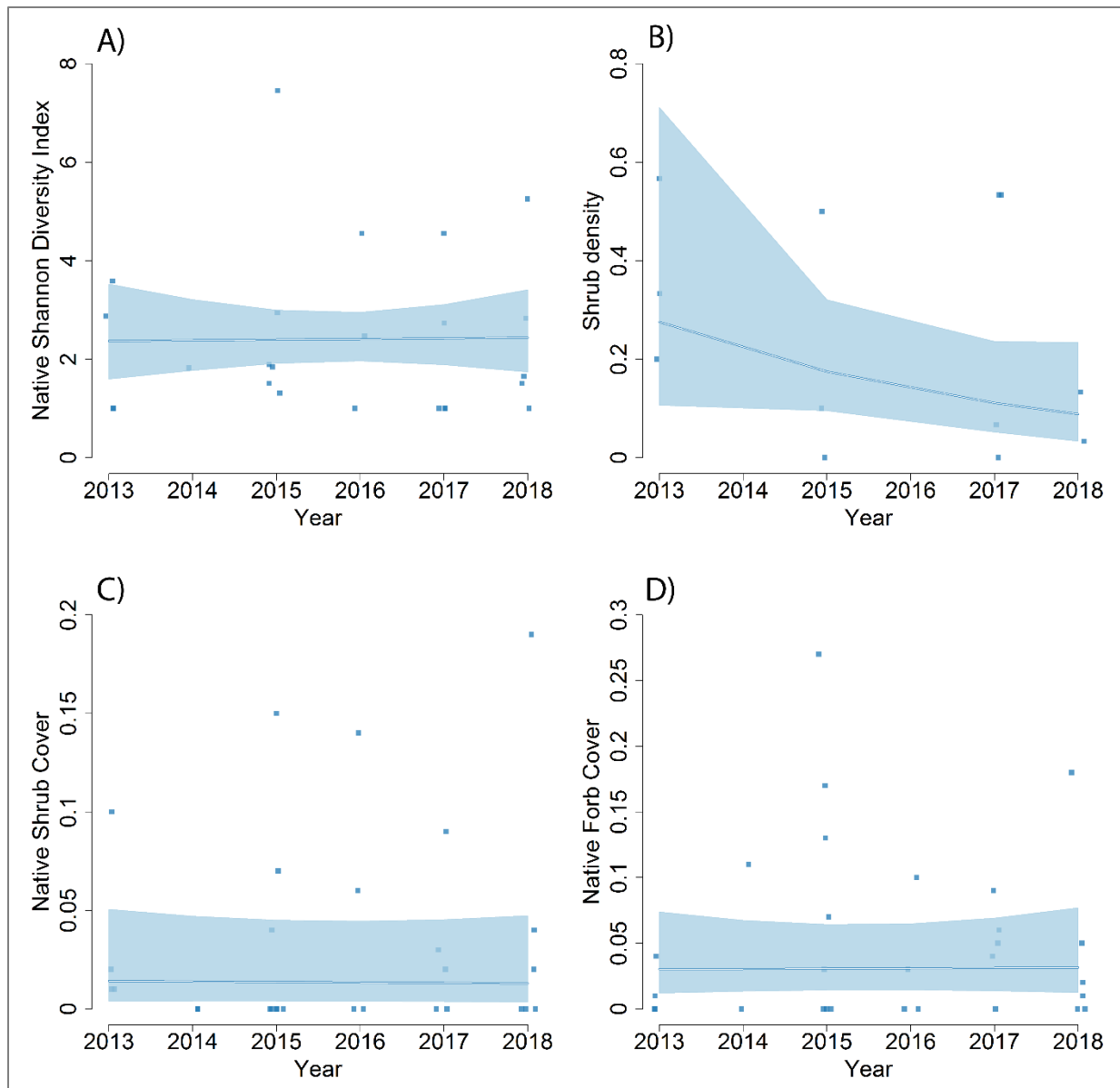


Figure 10. Trend analysis results for CHIS vegetation indicators by probability site and year across Anacapa Island (first of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native Shannon diversity index ($p = 0.9430$). B) Native shrub density ($p = 0.2176$). C) Native shrub cover ($p = 0.8829$). D) Native forb cover ($p = 0.9491$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

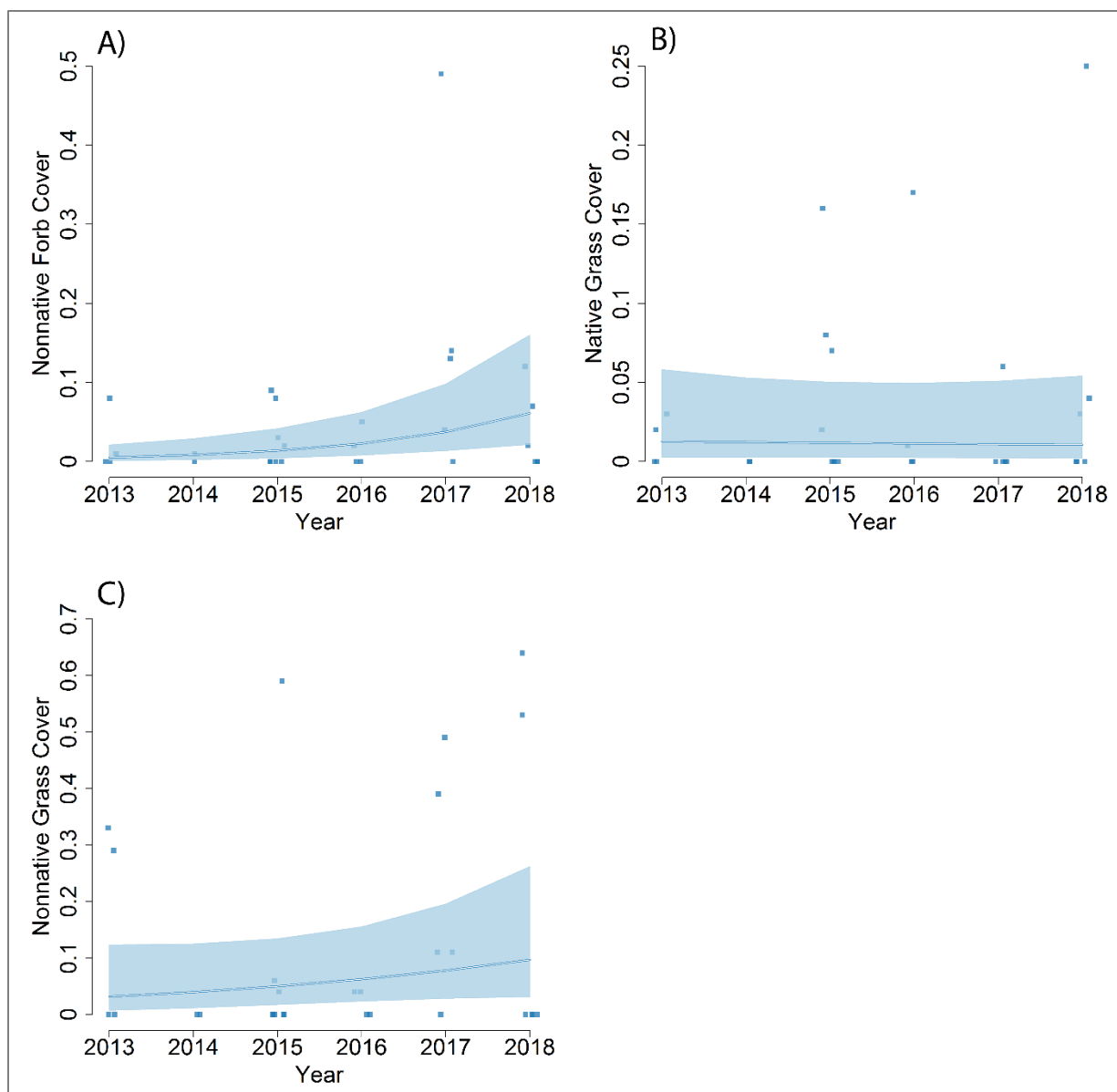


Figure 11. Trend analysis results for CHIS vegetation indicators by probability site and year across Anacapa Island (second of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Nonnative forb cover ($p = 0.0019$). B) Native grass cover ($p = 0.8166$). C) Nonnative grass cover ($p = 0.2444$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Trends on Santa Barbara Island

Santa Barbara Index Sites

Negative trends in Shannon diversity metrics were observed for index sites on SB (Table 12). Overall Shannon diversity (Figure 12A) declined by an estimated -1.52% per year (90%-CI: -2.24% , -0.80%), native Shannon diversity (Figure 12B) decreased by an estimated -0.93% annually (90%-CI: -1.67% , -0.19%), and grassland Shannon diversity (Figure 12C) declined by -1.89% per year

(90%-CI: -3.19%, -0.57%) annually over the monitoring period. Native shrub density (Figure 12D) did not demonstrate a change since 1984. However, a decline in native shrub cover (Figure 12E) was observed with the odds of cover decreasing by -5.23% annually (90%-CI: -7.59%, -2.81%). Native forb cover (Figure 12F) declined by a similar amount since 1984 with an estimated annual decline in the odds of -5.75% annually (90%-CI: -9.11%, -2.27%). No trend was observed in nonnative forb cover (Figure 13A, $p = 0.4571$) or native grass cover (Figure 13B, $p = 0.6150$). However, nonnative grass cover (Figure 13C) declined significantly, with the odds of cover decreasing by -9.30% (90%-CI: -13.05%, -5.38%) since 1984.

Species-level cover trends were also estimated. No significant trend was observed for the native shrub *Deinandra clementina* (Figure 13D, $p = 0.8784$) over the monitoring period, but odds of the cover proportion for the native shrub *Eriogonum giganteum* var. *compactum* (Figure 14A) increased annually by 6.98% (90%-CI: 5.29%, 8.71%). The odds of the nonnative annual grass *Hordeum murinum* cover (Figure 14B) declined by -8.85% (90%-CI: -12.35%, -5.21%) annually. *Mesembryanthemum crystallinum* (nonnative forb) cover demonstrated no statistical trend over the monitoring period (Figure 14C, $p = 0.2527$), but the odds of the native shrub *Suaeda taxifolia* cover (Figure 14D) on SB index sites declined on average by -8.05% (90%-CI: -9.54%, -6.53%) annually since 1984.

Table 12. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Barbara Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	1.7765	0.1101	-0.0153	0.0044	0.0006	0.1319	0.0414	0.0001	–
Native Shannon Diversity	1.0959	0.1508	-0.0094	0.0045	0.0384	0.3588	0.0425	0.0001	–
Grassland Shannon Diversity	1.5385	0.1543	-0.0191	0.0081	0.0191	0.0721	0.0266	0.0002	–
Native Shrub Density	-0.8859	0.4111	-0.0168	0.0322	0.6020	1.7288	0.0000	0.0108	0.3471
Native Shrub Cover	-1.6574	0.4955	-0.0537	0.0153	0.0004	4.7136	0.0528	0.0028	–
Native Forb Cover	-1.0835	0.5318	-0.0592	0.0221	0.0072	3.1749	0.9493	0.0029	0.2864
Nonnative Forb Cover	-1.4990	0.4169	-0.0147	0.0198	0.4571	0.4620	1.0778	0.0004	–
Native Grass Cover	-7.2445	1.3753	0.0258	0.0512	0.6150	14.7247	0.6824	0.0093	–
Nonnative Grass Cover	1.0397	0.6378	-0.0976	0.0257	0.0001	3.5714	1.7566	0.0012	–
<i>Deinandra clementina</i> Cover	-13.8509	2.5991	-0.0175	0.1146	0.8784	113.2085	0.0966	0.0041	–
<i>Eriogonum giganteum</i> var. <i>compactum</i> Cover	-16.5931	2.4109	0.0675	0.0097	<0.0001	125.0497	0.0595	–	–
<i>Hordeum murinum</i> Cover	-2.2888	0.6288	-0.0927	0.0238	<0.0001	4.7495	1.0022	0.0009	–
<i>Mesembryanthemum crystallinum</i> Cover	-4.0909	0.6554	0.0275	0.0240	0.2527	4.2710	1.3503	0.0010	–
<i>Suaeda taxifolia</i> Cover	-12.2859	2.0237	-0.0839	0.0100	<0.0001	103.9996	0.0919	–	0.2632

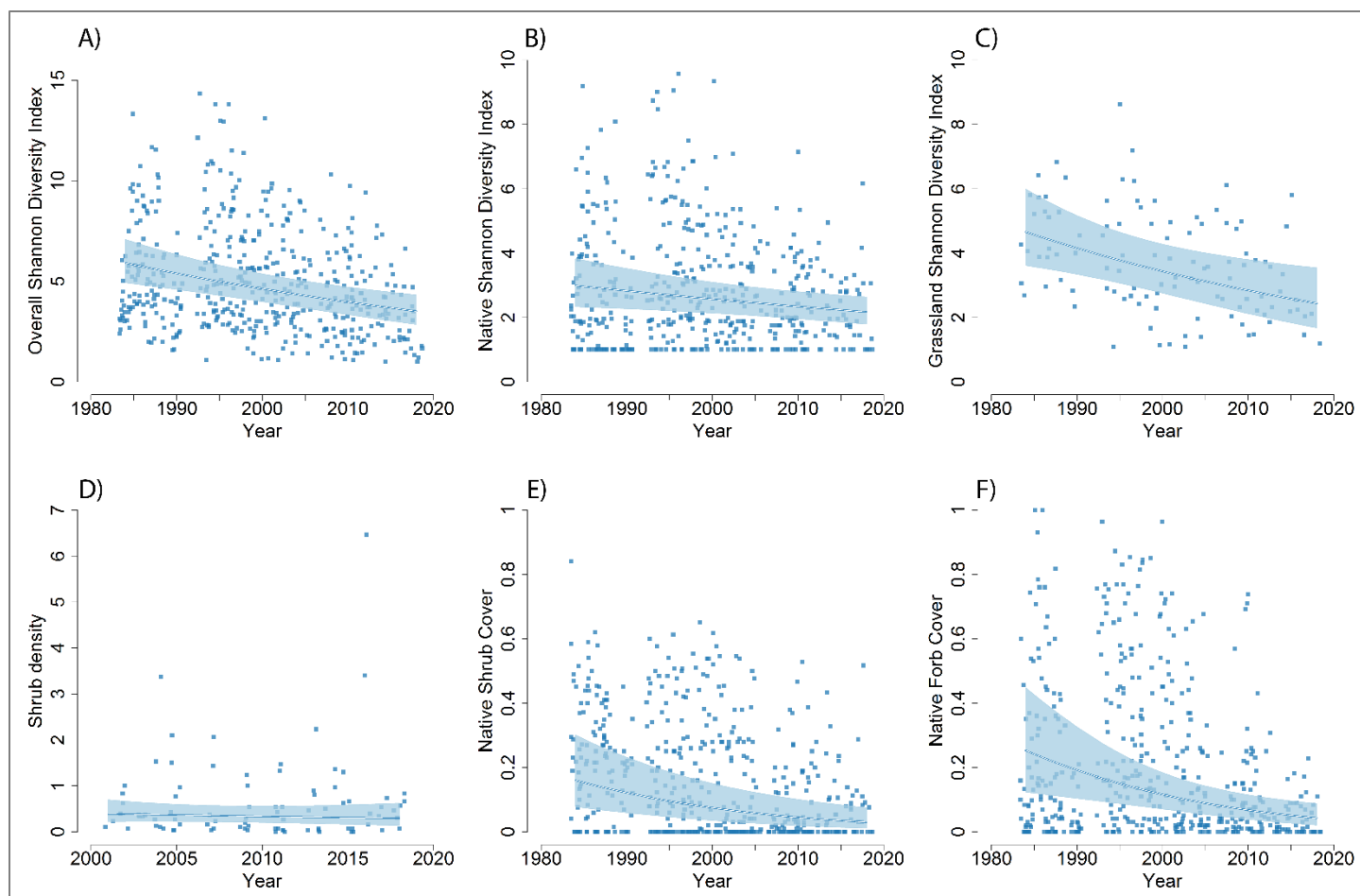


Figure 12. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (first of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p = 0.0006$). B) Native Shannon diversity index ($p = 0.0384$). C) Grassland Shannon diversity index ($p = 0.0191$). D) Native shrub density ($p = 0.6020$). E) Native shrub cover ($p = 0.0004$). F) Native forb cover ($p = 0.0072$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

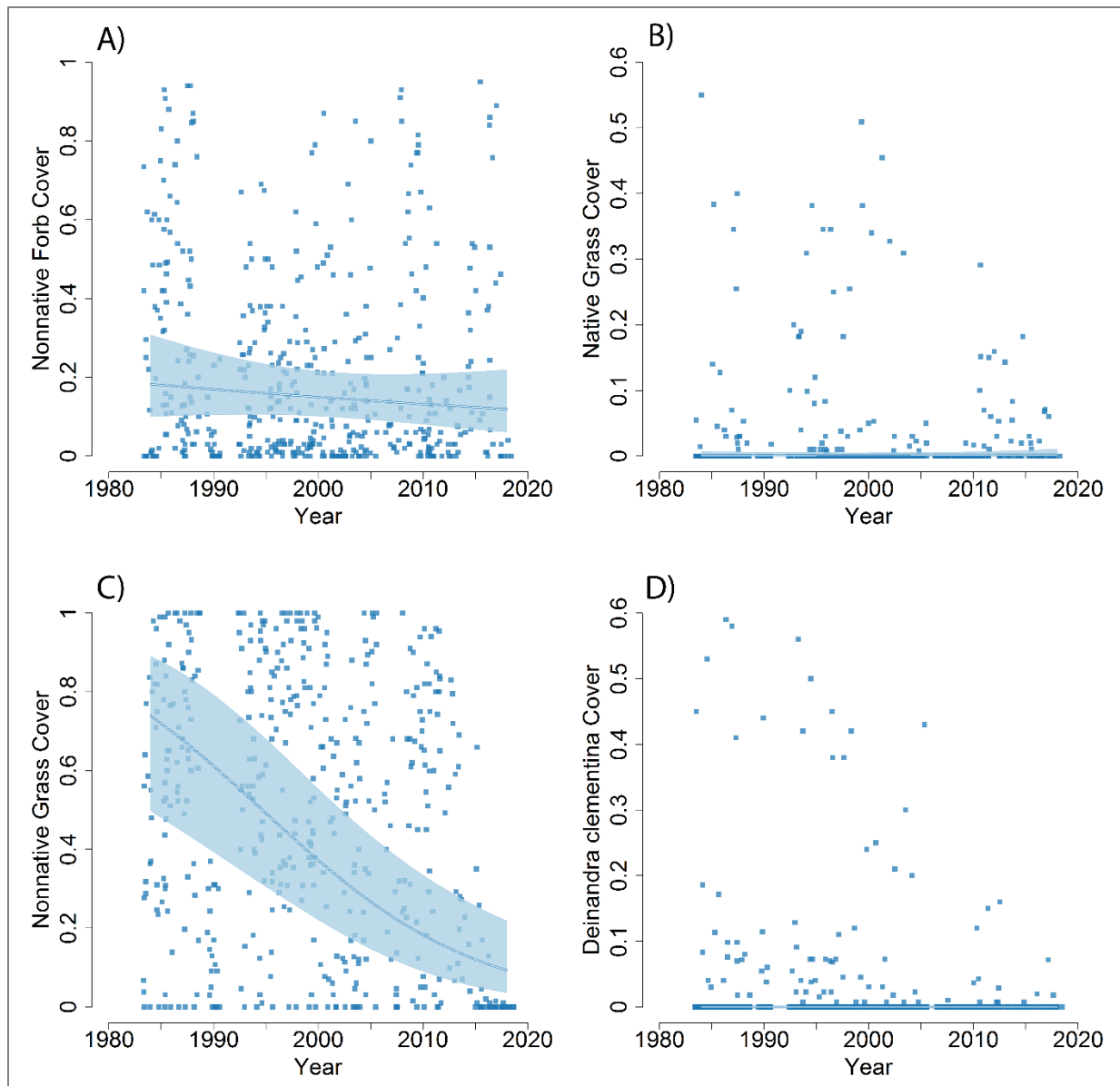


Figure 13. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (second of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Nonnative forb cover ($p = 0.4571$). B) Native grass cover ($p = 0.6150$). C) Nonnative grass cover ($p = 0.0001$). D) *Deinandra clementina* cover ($p = 0.8784$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

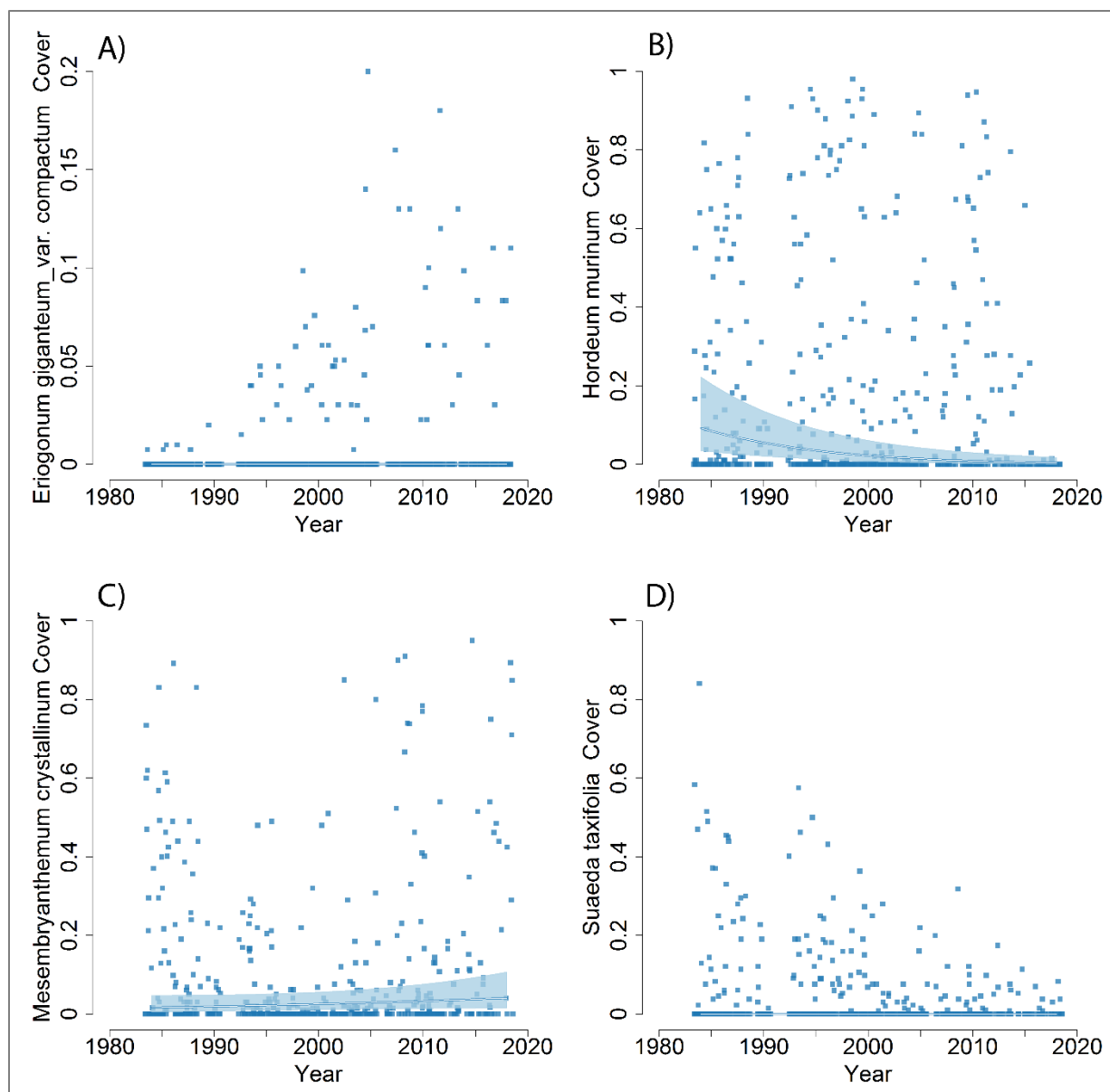


Figure 14. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Barbara Island (third of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) *Eriogonum giganteum* var. *compactum* cover ($p < 0.0001$). B) *Hordeum murinum* cover ($p < 0.0001$). C) *Mesembryanthemum crystallinum* cover ($p = 0.2527$). D) *Suaeda taxifolia* cover ($p < 0.0001$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Santa Barbara Island Probability Sites

Trends in terrestrial vegetation metrics at SB (Table 13) were estimated for data collected at probability sites. No statistical evidence of trend was observed for overall Shannon diversity (Figure 15A, $p = 0.1552$), native shrub density (Figure 15B, $p = 0.4527$), native shrub cover (Figure 15C, $p = 0.6942$), native forb cover (Figure 15D, $p = 0.6653$), or nonnative forb cover (Figure 15E, $p = 0.5096$). However, statistically decreasing trends were observed for the odds of nonnative grass cover

(Figure 15F; annual trend: -61.50% , 90%-CI: -75.17% , -40.32%) and *Hordeum murinum* cover (Figure 16A; annual trend: -47.45% , 90%-CI: -61.65% , -27.98%), and an increasing trend was observed for the odds of *Mesembryanthemum crystallinum* cover (Figure 16B; annual trend: 46.13% , 90%-CI: 5.84% , 101.75%). No significant trend was observed in *Suaeda taxifolia* cover (Figure 16C, $p = 0.1907$). Note that variance among site-level slopes was not estimable for any model.

Table 13. Trend analysis results for all CHIS vegetation indicators for probability sites on Santa Barbara Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	4.1185	2.1855	-0.0985	0.0693	0.1552	0.0781	0.0737	–	–
Native Shrub Density	1.2630	4.5809	-0.1954	0.2602	0.4527	–	0.5056	–	1.3246
Native Shrub Cover	-5.0965	1.8040	0.0217	0.0553	0.6942	2.8988	0.0000	–	–
Native Forb Cover	0.3147	9.5974	-0.1331	0.3077	0.6653	0.8094	1.0982	–	–
Nonnative Forb Cover	6.5186	12.3041	-0.2580	0.3912	0.5096	0.6119	2.3263	–	–
Nonnative Grass Cover	27.4166	8.2942	-0.9546	0.2665	0.0003	1.3390	0.8328	–	–
<i>Hordeum murinum</i> Cover	16.8127	5.7478	-0.6434	0.1916	0.0008	2.0270	0.0000	–	–
<i>Mesembryanthemum crystallinum</i> Cover	-14.3939	6.4451	0.3793	0.1961	0.0531	2.3177	0.2006	–	–
<i>Suaeda taxifolia</i> Cover	4.4668	7.7730	-0.3372	0.2577	0.1907	4.2173	0.5987	–	–

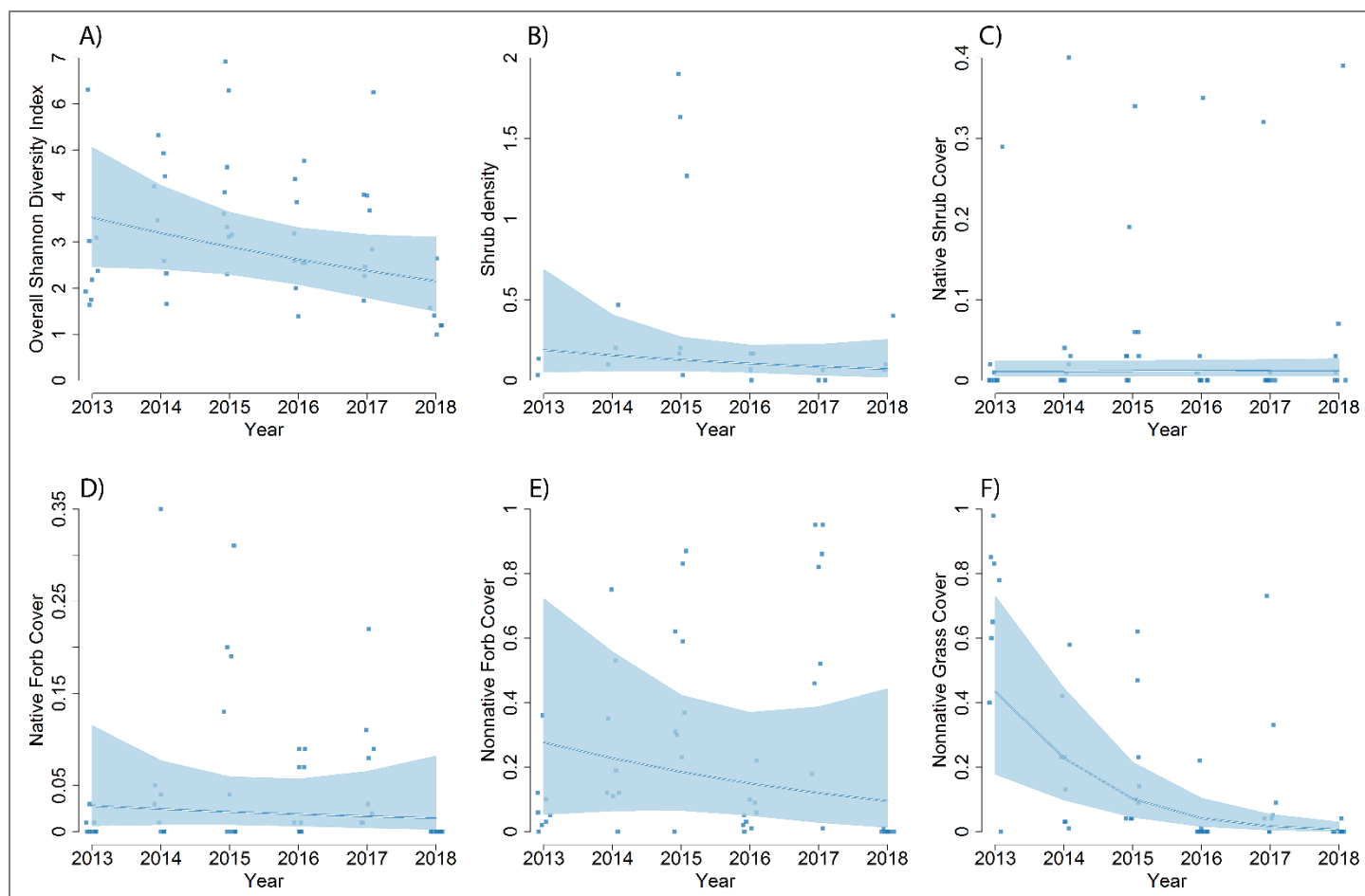


Figure 15. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Barbara Island (first of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p = 0.1552$). B) Native shrub density ($p = 0.4527$). C) Native shrub cover ($p = 0.6942$). D) Native forb cover ($p = 0.6653$). E) Nonnative forb cover ($p = 0.5096$). F) Nonnative grass cover ($p = 0.0003$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

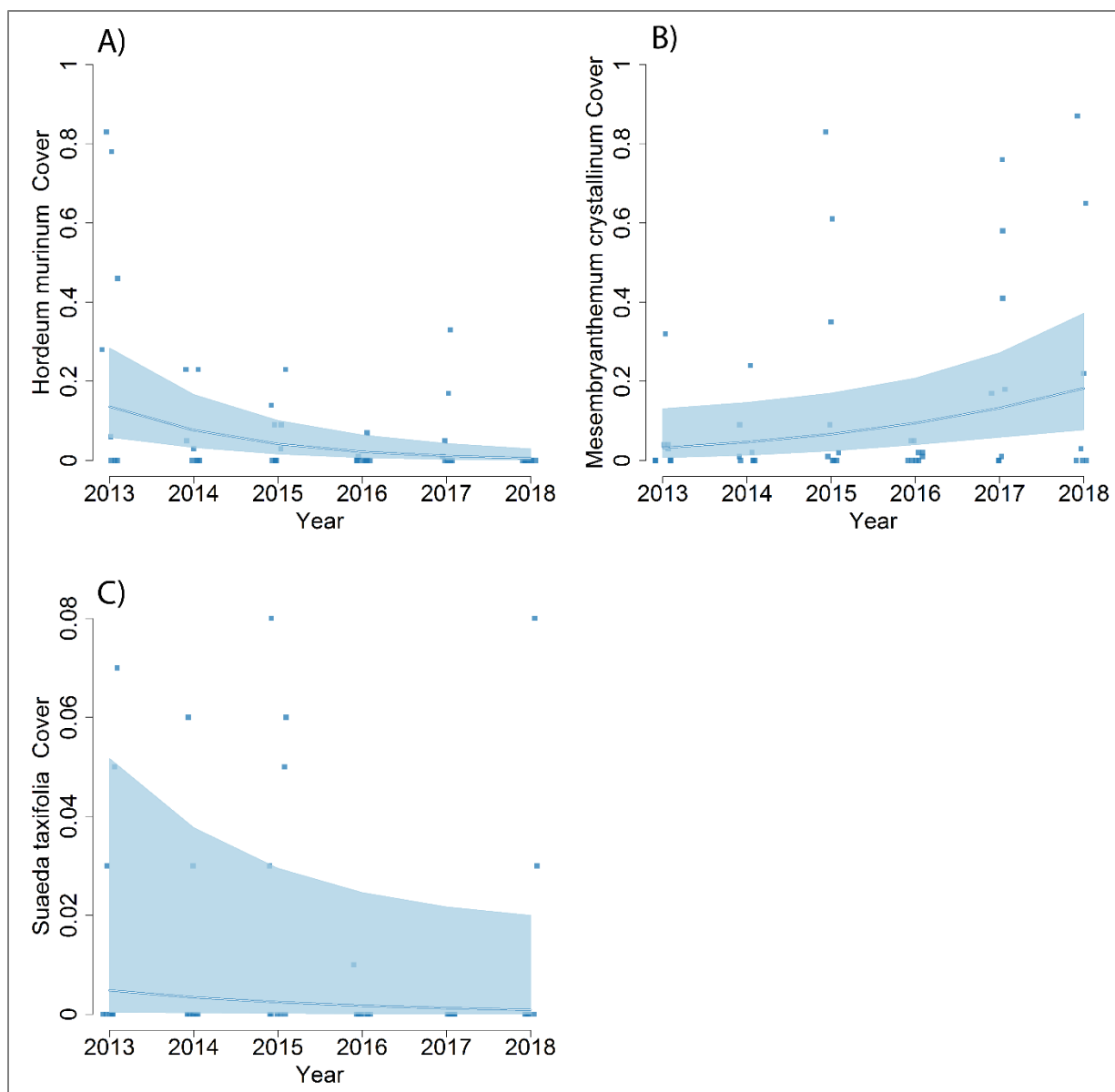


Figure 16. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Barbara Island (second of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) *Hordeum murinum* cover ($p = 0.0008$). B) *Mesembryanthemum crystallinum* cover ($p = 0.0531$). C) *Suaeda taxifolia* cover ($p = 0.1907$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Trends on Santa Cruz Island

Santa Cruz Island Index Sites

Overall Shannon diversity (Figure 17A) was estimated to have declined by -1.40% annually (90%-CI: -2.32% , -0.47%) at index sites in SC (Table 14) since monitoring began in 2000. Weak evidence of an annual 0.81% trend was observed in native Shannon diversity (Figure 17B; 90%-CI: -0.05% , 1.68%) but the p -value slightly exceeded the Type I error rate of 0.10 ($p = 0.1206$). Coastal sage

scrub Shannon diversity (Figure 17C) demonstrated no trend over the monitoring period ($p = 0.7661$). Grassland Shannon diversity (Figure 17D) declined by an estimated -2.17% (90%-CI: -4.21% , -0.10%) annually since 2000. No statistical trends were observed in riparian Shannon diversity (Figure 17E, $p = 0.7810$), oak Shannon diversity (Figure 17F, $p = 0.5054$), native tree density (Figure 18A, $p = 0.1464$), or tree recruitment density (Figure 18B, $p = 0.7410$). However, significant increasing trends were observed in native shrub density (Figure 18C; annual trend: 22.96% , 90%-CI: 12.42% , 34.48%) and native shrub recruitment density (Figure 18D; annual trend: 10.46% , 90%-CI: 2.00% , 19.62%). A decreasing trend was observed in the odds of native tree cover (Figure 18E; annual trend: -3.76% , 90%-CI: -5.08% , -2.41%) and an increasing trend was found in native shrub cover (Figure 18F; annual trend: 18.82% , 90%-CI: 10.88% , 27.34%). Native forb cover (Figure 19A) demonstrated no overall trend since 2000 ($p = 0.8628$), but a significant decreasing trend was found in the odds of nonnative forb cover (Figure 19B; annual trend: -23.02% , 90%-CI: -28.92% , -16.62%). Similarly, no trend was observed in native grass cover (Figure 19C; $p = 0.5666$), but a significant decline was found in the odds of nonnative grass cover (Figure 19D; annual trend: -10.45% , 90%-CI: -15.21% , -5.42%) in SC index sites.

No evidence of a trend in the native shrub *Baccharis pilularis* cover was observed (Figure 19E, $p = 0.5709$), but the odds of *Eriogonum* Group cover (Figure 19F) increased an average of 58.73% annually (90%-CI: 10.39% , 128.25%). No statistical trend was observed for nonnative *Foeniculum vulgare* cover (Figure 20A, $p = 0.1698$) and *Pinus muricata* (native tree) cover (Figure 20B, $p = 0.2495$). An increasing trend was observed for *Rhus integrifolia* (native shrub) cover of 53.57% (Figure 20C; 90%-CI: 28.60% , 83.40%), but no statistical change was found in the native perennial bunchgrass *Stipa* Group cover (Figure 20D, $p = 0.1643$).

Note that the large proportions of plots with zero cover for individual species result in large site variation estimates. These trend plots are more difficult to interpret because the trend lines and confidence intervals are near zero for all years. The exception is the plot for *Pinus muricata* cover (Figure 20B) which had a wide confidence interval due to the high site-to-site variance from detection at only two sites.

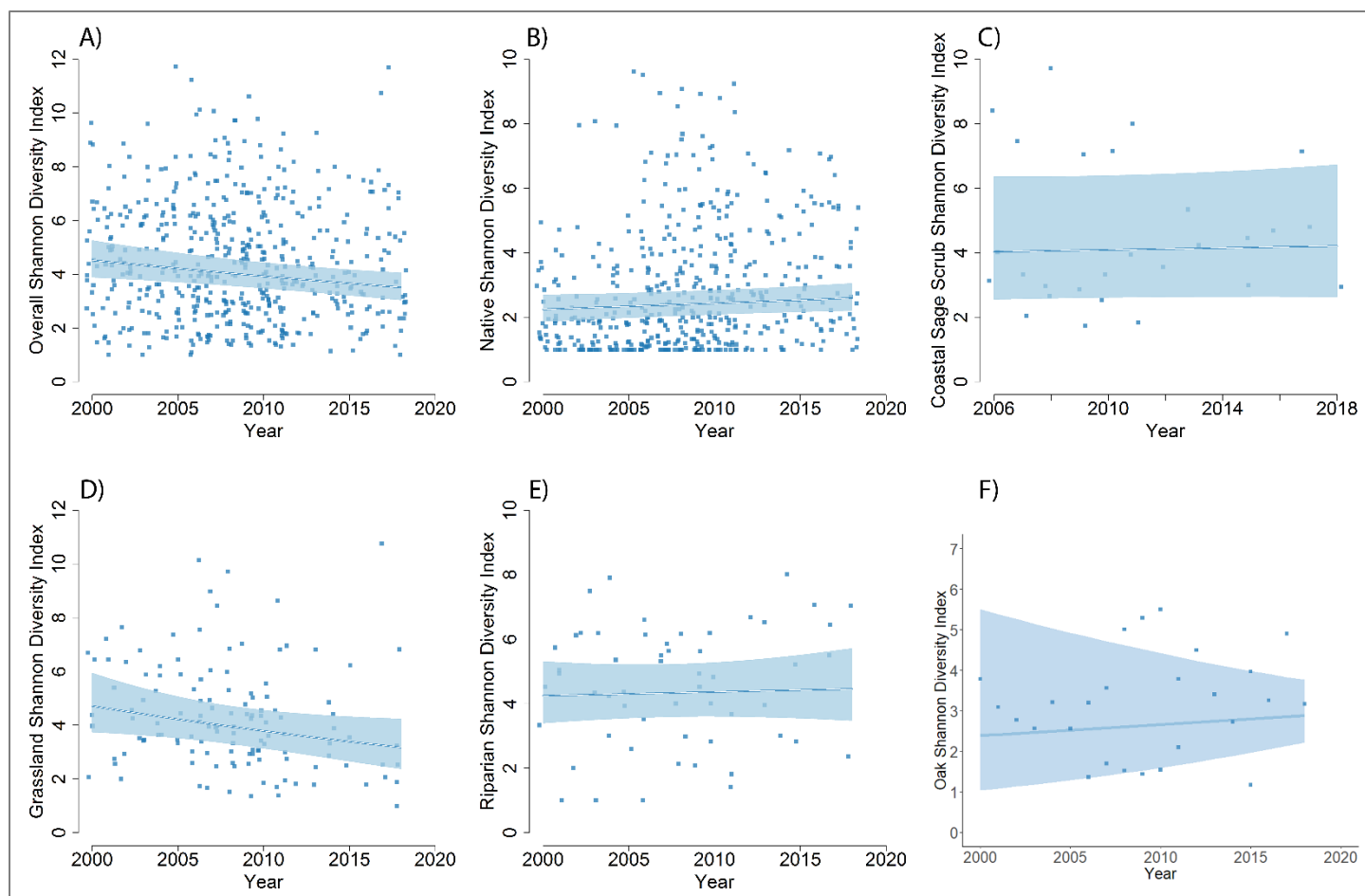


Figure 17. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (first of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p = 0.0138$). B) Native Shannon diversity index ($p = 0.1206$). C) Coastal sage scrub Shannon diversity index ($p = 0.7661$). D) Grassland Shannon diversity index ($p = 0.0852$). E) Riparian Shannon diversity index ($p = 0.7810$). F) Oak Shannon diversity index ($p = 0.5054$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Table 14. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Cruz Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	1.7343	0.1636	-0.0141	0.0057	0.0138	0.8111	0.0012	0.0009	–
Native Shannon Diversity	0.6801	0.1712	0.0081	0.0052	0.1206	0.8882	0.0026	0.0006	–
Coastal Sage Scrub Shannon Diversity	1.3166	0.4186	0.0036	0.0120	0.7661	0.2158	0.0024	–	–
Grassland Shannon Diversity	1.9024	0.3138	-0.0220	0.0128	0.0852	0.8485	0.0000	0.0014	–
Riparian Shannon Diversity	1.4034	0.2554	0.0027	0.0097	0.7810	0.0408	0.0024	–	–
Oak Shannon Diversity	0.8708	0.4070	0.0105	0.0158	0.5054	–	0.0000	–	–
Native Tree Density	-3.1048	0.2858	-0.0177	0.0122	0.1464	1.0196	0.0084	–	0.0551
Native Tree Recruitment Density	-5.1752	1.3215	0.0333	0.1009	0.7410	8.7476	1.0843	0.0431	1.1856
Native Shrub Density	-5.2413	1.0371	0.2066	0.0545	0.0001	14.0486	0.0522	0.0188	–
Native Shrub Recruitment Density	-4.3345	0.7948	0.0995	0.0484	0.0399	5.0614	0.0000	–	1.7882
Native Tree Cover	-11.0089	1.6057	-0.0383	0.0084	<0.0001	120.2740	0.0081	–	–
Native Shrub Cover	-9.3555	1.5156	0.1725	0.0421	<0.0001	51.2653	0.0231	0.0248	–
Native Forb Cover	-3.5645	0.6820	-0.0038	0.0221	0.8628	9.4273	0.0743	0.0047	–
Nonnative Forb Cover	1.4416	1.0183	-0.2616	0.0485	<0.0001	9.4407	0.2803	0.0290	0.7733
Native Grass Cover	-5.6587	1.7893	-0.0381	0.0665	0.5666	34.4506	0.2573	0.0288	0.1142
Nonnative Grass Cover	1.2308	0.9332	-0.1104	0.0332	0.0009	11.3665	0.4186	0.0070	–
<i>Baccharis pilularis</i> Cover	-15.6412	5.1536	0.1102	0.1945	0.5709	195.1955	0.1346	0.1440	–
<i>Eriogonum</i> Group Cover	-25.4428	7.0210	0.4621	0.2208	0.0364	288.8213	0.0396	0.1057	–
<i>Foeniculum vulgare</i> Cover	-13.2683	2.0118	-0.0649	0.0473	0.1698	127.3504	0.3788	–	–
<i>Pinus muricata</i> Cover	-17.8404	3.4825	0.0593	0.0515	0.2495	143.5402	0.0000	–	–
<i>Rhus integrifolia</i> Cover	-26.9121	4.0542	0.4290	0.1079	<0.0001	64.5888	0.7039	–	–
<i>Stipa</i> Group Cover	-16.6662	4.3261	0.1988	0.1429	0.1643	123.1635	0.1359	0.0423	0.0751

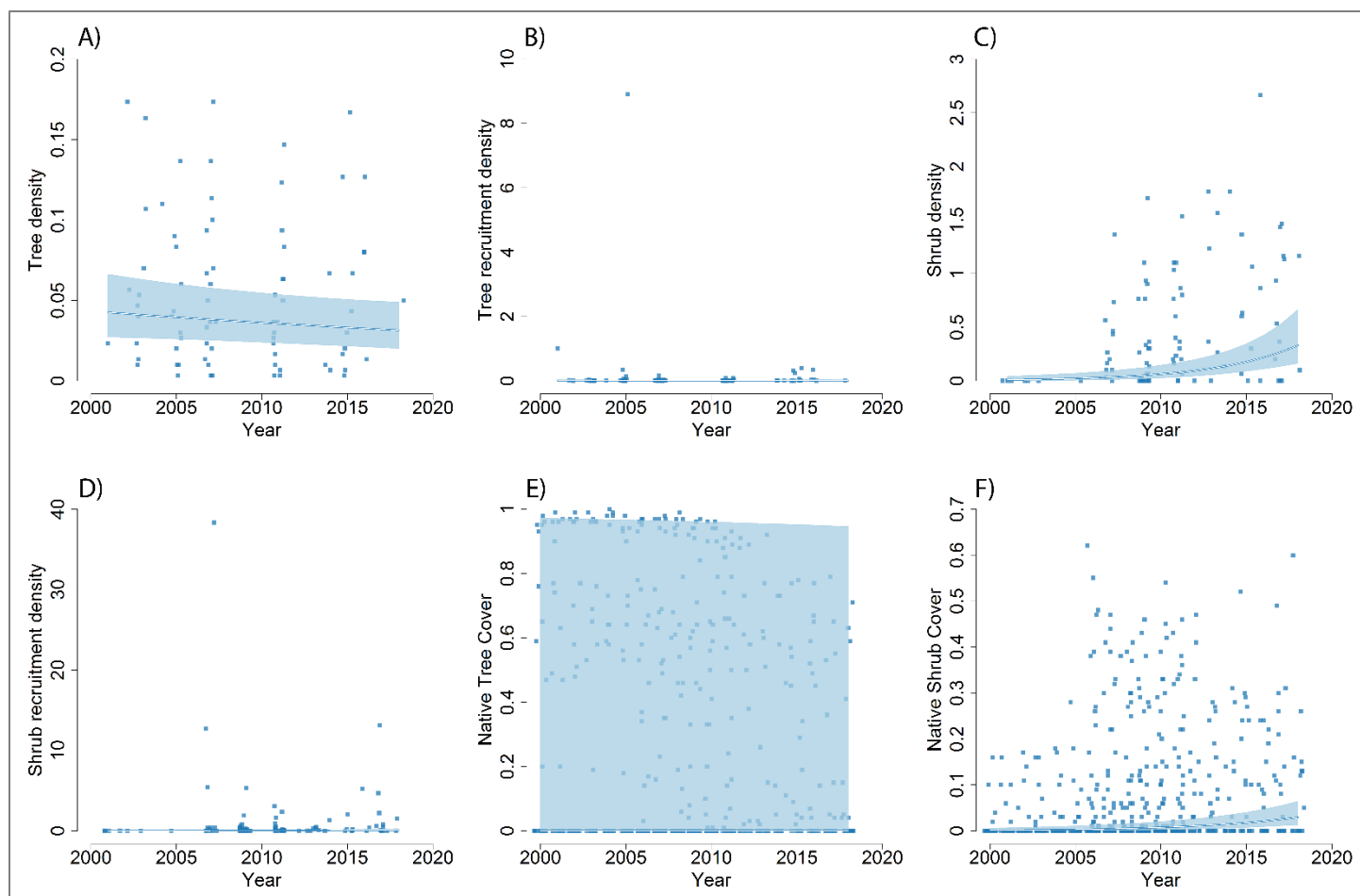


Figure 18. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (second of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native tree density ($p = 0.1464$). B) Native tree recruitment density ($p = 0.7410$). C) Native shrub density ($p = 0.0001$). D) Native shrub recruitment density ($p = 0.0399$). E) Native tree cover ($p < 0.0001$). F) Native shrub cover ($p < 0.0001$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

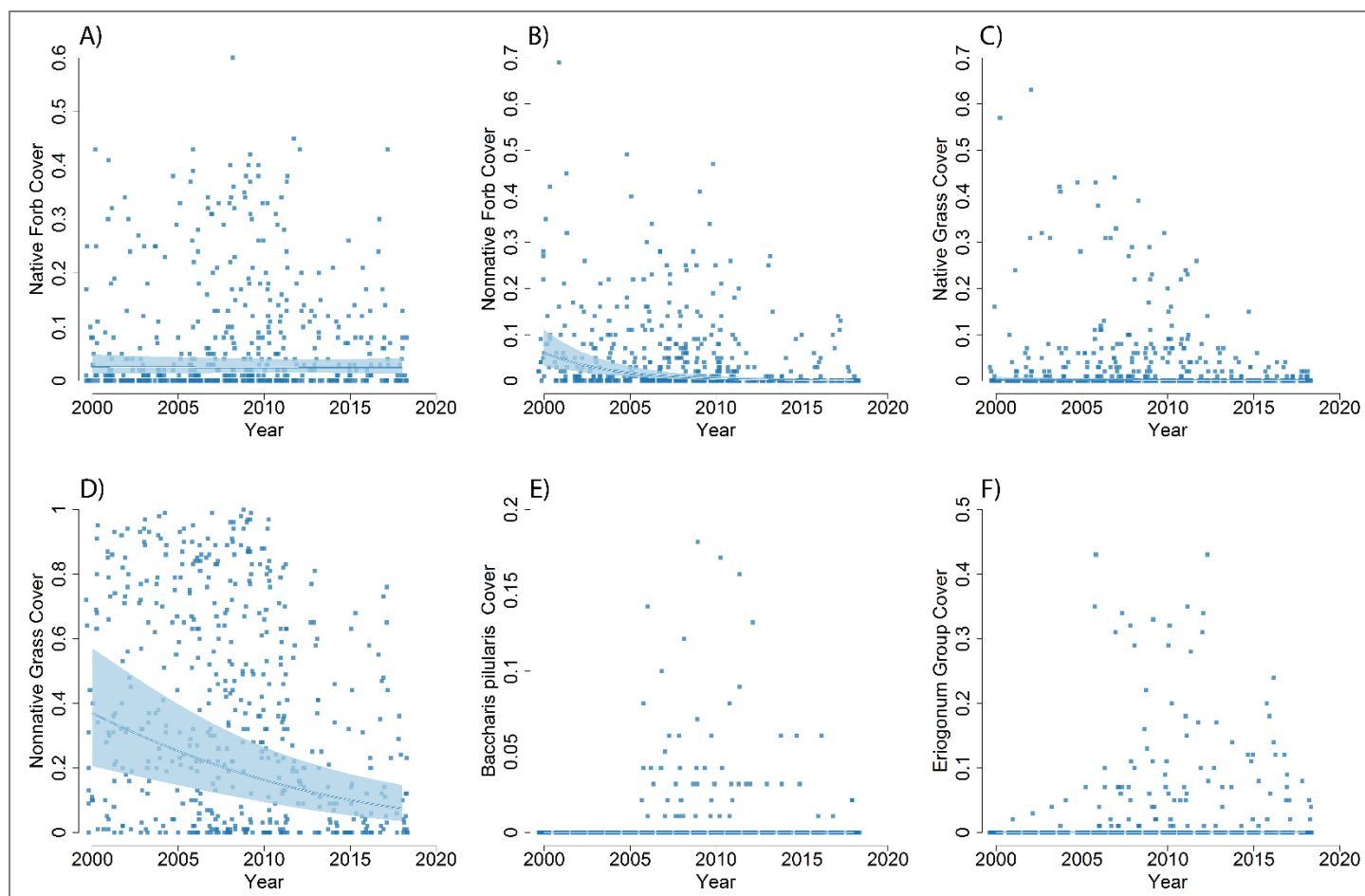


Figure 19. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (third of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native forb cover ($p = 0.8628$). B) Nonnative forb cover ($p < 0.0001$). C) Native grass cover ($p = 0.5666$). D) Nonnative grass cover ($p = 0.0009$). E) *Baccharis pilularis* cover ($p = 0.5709$). F) *Eriogonum* Group cover ($p = 0.0364$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

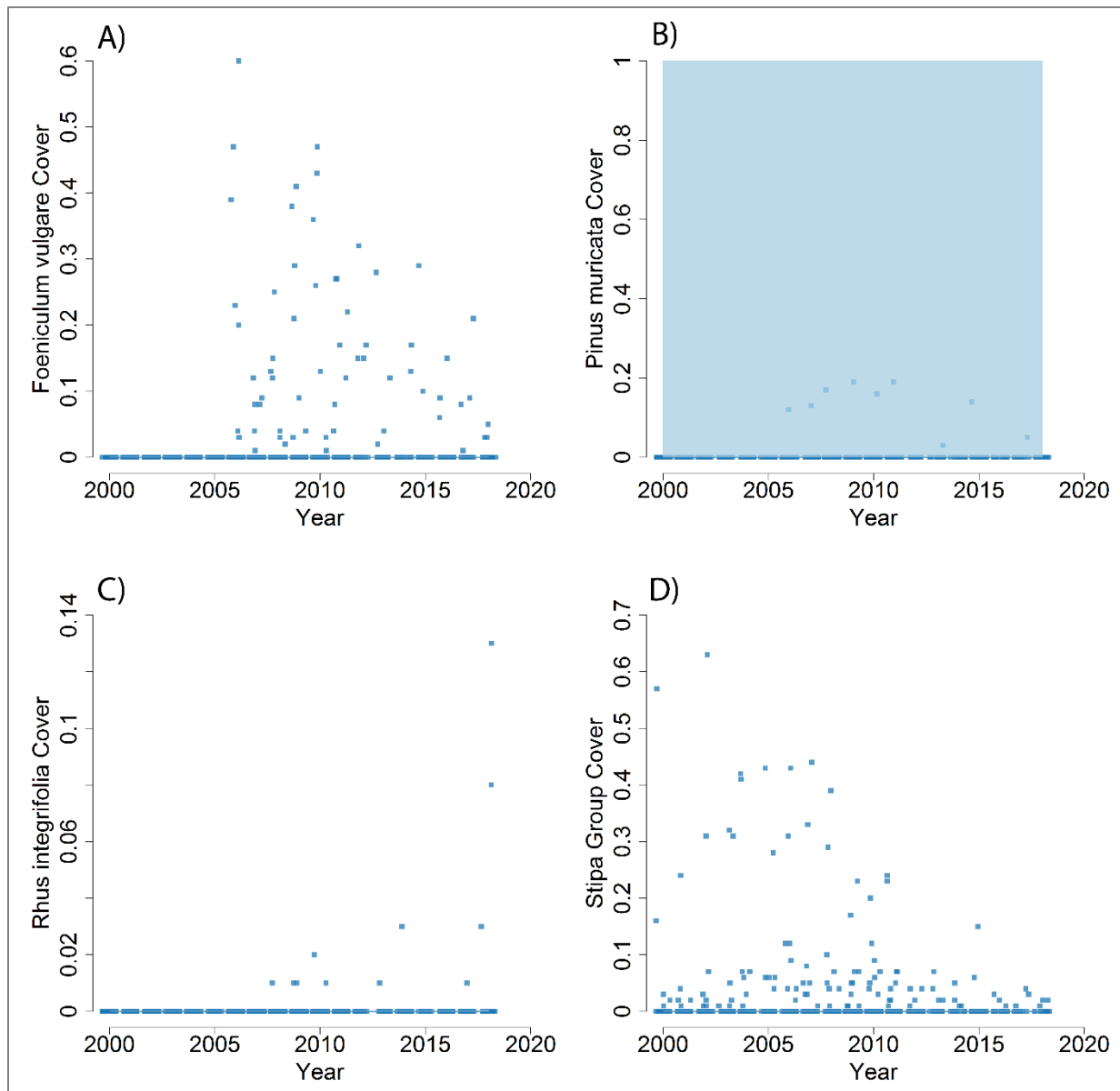


Figure 20. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Cruz Island (fourth of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) *Foeniculum vulgare* cover (p = 0.1698). B) *Pinus muricata* cover (p = 0.2495). C) *Rhus integrifolia* cover (p < 0.0001). D) *Stipa* Group cover (p = 0.1643).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Santa Cruz Island Probability Sites

For probability sites on SC (Table 15), no statistical trends since 2013 were detected in overall Shannon diversity (Figure 21A, p = 0.6454), native Shannon diversity (Figure 21B, p = 0.7479), native tree density (Figure 21C, p = 0.5460), or native tree recruitment (Figure 21D, p = 0.6594). No trend was observed in native shrub density (Figure 21E, p = 0.8499), but a significant increasing trend was found in native shrub recruitment density (Figure 21F; annual trend: 73.95%, 90%-CI: 17.70%, 157.09%). However, note that native shrub recruitment density is nearly zero for all years.

No trends were detected for native tree cover (Figure 22A, $p = 0.9849$), native shrub cover (Figure 22B, $p = 0.1654$), native forb cover (Figure 22C, $p = 0.2716$), or nonnative forb cover (Figure 22D, $p = 0.6691$). A significant decline in the odds of native grass cover (Figure 22E) was observed since 2013 (annual trend: -30.48% , 90%-CI: -37.32% , -22.89%), but nonnative grass cover (Figure 22F) appeared stable over the same time frame ($p = 0.5668$). For trends in cover of individual species, no trends were detected for *Baccharis pilularis* cover (Figure 23A, $p = 0.7479$) or *Eriogonum* Group cover (Figure 23B, $p = 0.5010$), but a significant decreasing trend was detected in the odds of *Foeniculum vulgare* cover (Figure 23C; annual trend: -24.63% , 90%-CI: -38.78% , -5.66%). *Rhus integrifolia* cover (Figure 23D) appeared stable over the monitoring period, but the odds of *Stipa* Group cover (Figure 23E) since 2013 declined an estimated -32.02% annually (90%-CI: -44.97% , -16.03%).

Table 15. Trend analysis results for all CHIS vegetation indicators for probability sites on Santa Cruz Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	0.8970	0.9546	0.0139	0.0301	0.6454	6.1461	0.0083	0.0059	–
Native Shannon Diversity	1.1008	0.5507	–0.0056	0.0174	0.7479	4.4047	0.0000	0.0044	–
Native Tree Density	–1.5637	2.4475	–0.0821	0.1360	0.5460	0.7784	0.0000	–	–
Native Tree Recruitment Density	–6.8773	7.2376	0.1752	0.3976	0.6594	–	1.2307	–	–
Native Shrub Density	–1.0819	0.7993	–0.0080	0.0424	0.8499	1.9836	0.0052	–	0.0524
Native Shrub Recruitment Density	–12.0683	4.2759	0.5536	0.2375	0.0197	3.4077	0.0000	–	3.9087
Native Tree Cover	–2.9733	3.5621	0.0021	0.1127	0.9849	–	0.0000	–	–
Native Shrub Cover	–4.2021	0.8110	0.0289	0.0209	0.1654	7.3922	0.0000	–	–
Native Forb Cover	–7.4307	3.8174	0.1323	0.1203	0.2716	80.5746	0.1495	0.0784	–
Nonnative Forb Cover	–2.8465	5.6501	–0.0766	0.1792	0.6691	1.7362	0.4506	–	–
Native Grass Cover	6.4729	1.9469	–0.3636	0.0630	<0.0001	5.0602	0.0000	–	–
Nonnative Grass Cover	1.3791	5.5719	–0.1011	0.1765	0.5668	2.5252	0.5230	–	–
<i>Baccharis pilularis</i> Cover	–13.5460	2.7233	0.0553	0.0670	0.4091	60.2681	0.0000	–	–
<i>Eriogonum</i> Group Cover	–6.2432	4.1926	0.0887	0.1318	0.5010	–	0.0000	–	1.7055
<i>Foeniculum vulgare</i> Cover	–2.9900	4.5395	–0.2827	0.1364	0.0382	51.4947	0.0000	–	–
<i>Rhus integrifolia</i> Cover	–4.5978	5.1336	0.0249	0.1620	0.8780	–	0.0000	–	–
<i>Stipa</i> Group Cover	4.3005	4.0828	–0.3860	0.1285	0.0027	17.4397	0.1762	–	–

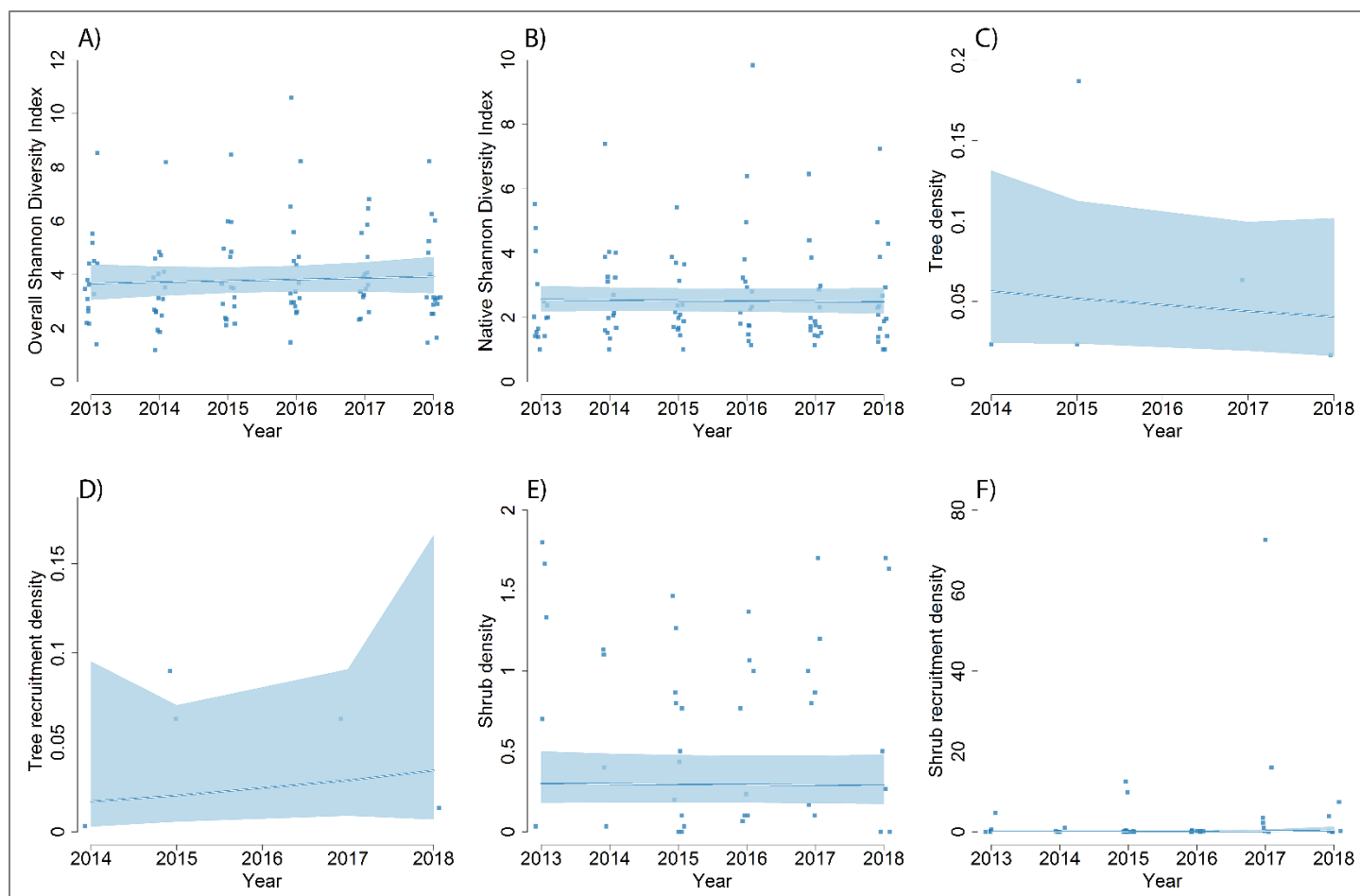


Figure 21. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (first of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p = 0.6454$). B) Native Shannon diversity index ($p = 0.7479$). C) Native tree density ($p = 0.5460$). D) Native tree recruitment density ($p = 0.6594$). E) Native shrub density ($p = 0.8499$). F) Native shrub recruitment density ($p = 0.0197$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

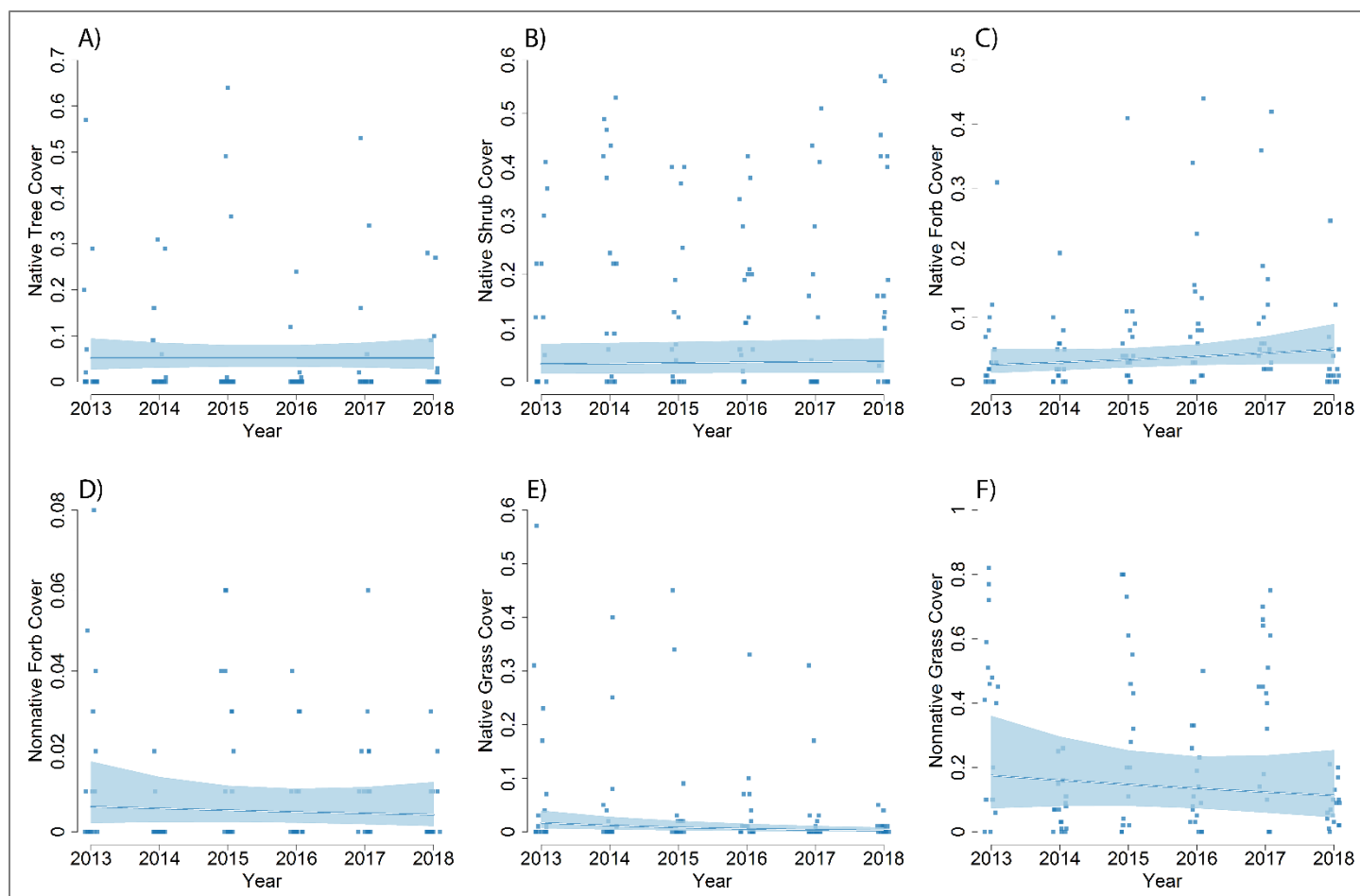


Figure 22. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (second of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native tree cover ($p = 0.9849$). B) Native shrub cover ($p = 0.1654$). C) Native forb cover ($p = 0.2716$). D) Nonnative forb cover ($p = 0.6691$). E) Native grass cover ($p < 0.0001$). F) Nonnative grass cover ($p = 0.5668$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

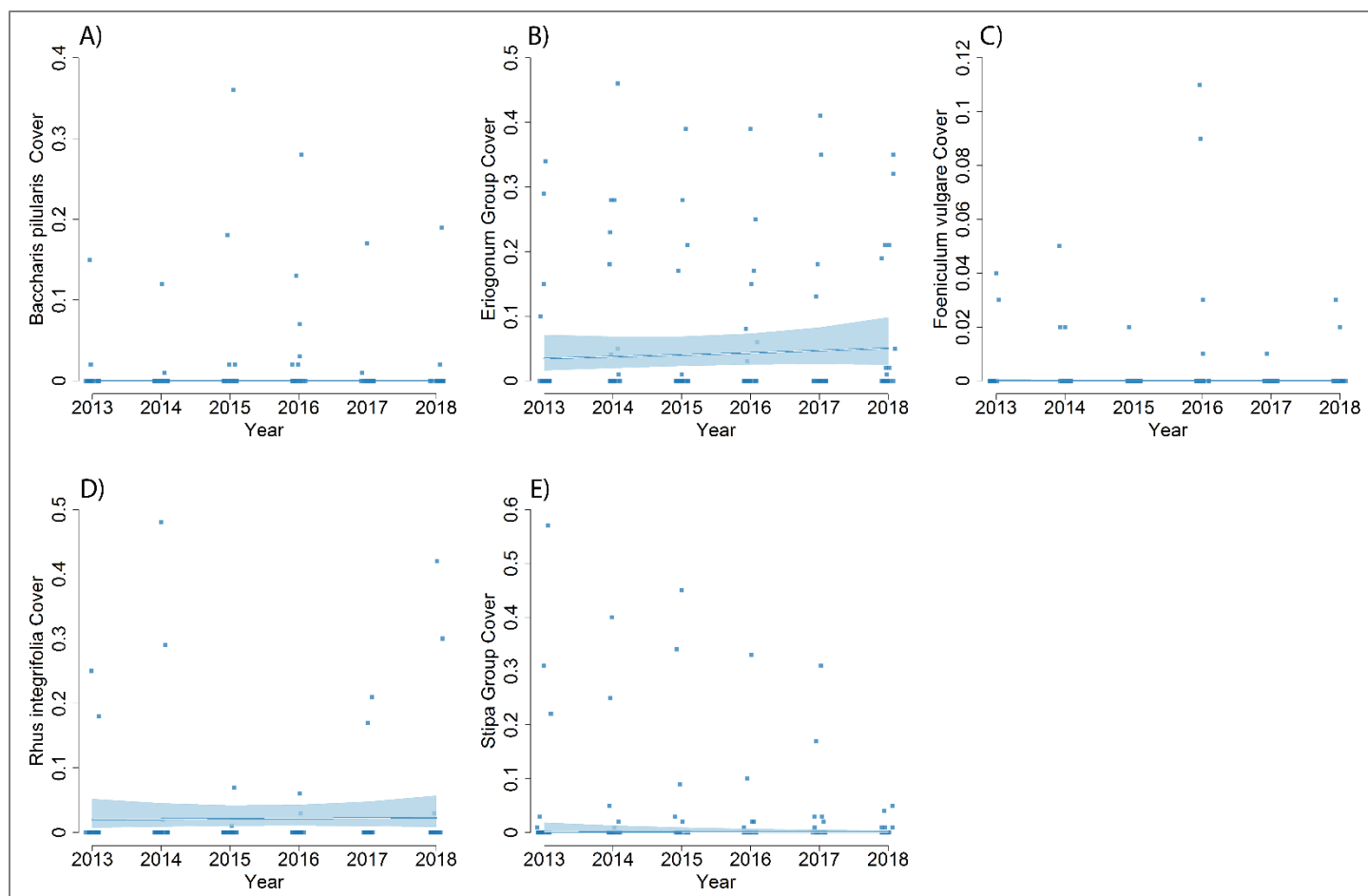


Figure 23. Trend analysis results for CHIS vegetation indicators by probability site and year across Santa Cruz Island (third of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) *Baccharis pilularis* cover ($p = 0.4091$). B) *Eriogonum* Group cover ($p = 0.5010$). C) *Foeniculum vulgare* cover ($p = 0.0382$). D) *Rhus integrifolia* cover ($p = 0.8780$). E) *Stipa* Group cover ($p = 0.0027$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Trends on San Miguel Island

San Miguel Island Index Sites

Shannon diversity at index sites on SM demonstrated negative trends for most metrics (Table 16). Overall Shannon diversity (Figure 24A) declined by an estimated -1.41% (90%-CI: -2.04% , -0.79%) per year. Native Shannon diversity appeared stable over the same time frame (Figure 24B, $p = 0.1822$). Statistically negative trends were also observed in island chaparral Shannon diversity (Figure 24C; annual trend: -2.13% , 90%-CI: -2.83% , -1.44%), coastal sage scrub Shannon diversity (Figure 24D; annual trend: -1.36% , 90%-CI: -2.28% , -0.44%), and grassland Shannon diversity (Figure 24E; annual trend: -1.16% , 90%-CI: -1.82% , -0.50%). Native shrub density (Figure 24F, $p = 0.2215$) and native shrub cover (Figure 25A, $p = 0.9296$) appeared stable over the monitoring period since 2001. However, statistically negative trends were seen in the odds of native forb cover (Figure 25B; annual trend: -5.76% , 90%-CI: -7.56% , -3.93%), nonnative forb cover (Figure 25C; annual trend: -7.77% , 90%-CI: -10.31% , -5.17%), native grass cover (Figure 25D; annual trend: -4.03% , 90%-CI: -7.63% , -0.29%), and nonnative grass cover (Figure 26A; annual trend: -8.27% , 90%-CI: -11.14% , -5.30%) at SM index sites. Cover of the native shrub *Acmispon dendroideus* var. *veatchii* did not demonstrate a trend over the monitoring period (Figure 26B, $p = 0.6164$). A negative annual trend in the odds of nonnative forb *Carpobrotus chilensis* cover (Figure 26C) of -18.43% (90%-CI: -28.79% , -6.56%) was detected, and a positive annual trend of 9.30% (90%-CI: 2.80% , 16.21%) was estimated in the odds of *Isocoma menziesii* (native shrub) cover (Figure 26D) since 2001.

Table 16. Trend analysis results for all CHIS vegetation indicators for index sites on San Miguel Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	2.0364	0.0901	-0.0142	0.0039	0.0002	0.0821	0.0207	0.0001	–
Native Shannon Diversity	1.4440	0.1190	-0.0046	0.0034	0.1822	0.2077	0.0101	0.0001	–
Island Chaparral Shannon Diversity	2.4580	0.1312	-0.0216	0.0043	<0.0001	0.0324	0.0364	–	–
Coastal Sage Scrub Shannon Diversity	1.9341	0.1655	-0.0137	0.0057	0.0151	0.0562	0.0323	–	–
Grassland Shannon Diversity	1.8146	0.0919	-0.0117	0.0041	0.0041	0.0054	0.0184	–	–
Native Shrub Density	-0.5954	0.5305	0.0371	0.0304	0.2215	1.8907	0.2080	–	0.2538
Native Shrub Cover	-1.6206	0.8573	0.0024	0.0275	0.9296	11.8359	0.1853	0.0114	0.0831
Native Forb Cover	-0.4573	0.3212	-0.0593	0.0117	<0.0001	1.2382	0.1970	0.0009	–
Nonnative Forb Cover	-0.8291	0.3405	-0.0809	0.0170	<0.0001	0.9010	0.4085	0.0017	–
Native Grass Cover	-2.4224	0.5792	-0.0411	0.0233	0.0770	4.7118	0.2372	0.0055	–
Nonnative Grass Cover	0.2020	0.4910	-0.0863	0.0194	<0.0001	2.5164	0.6425	0.0022	–
<i>Acmispon dendroideus</i> var. <i>veatchii</i> Cover	-9.5198	2.8659	-0.0748	0.1493	0.6164	15.7561	0.4530	0.0206	–
<i>Carpobrotus chilensis</i> Cover	-4.3188	1.1571	-0.2037	0.0826	0.0136	11.7942	0.4128	0.0307	0.2289
<i>Isocoma menziesii</i> Cover	-6.2477	1.4202	0.0889	0.0373	0.0170	26.0806	0.0588	0.0149	0.1247

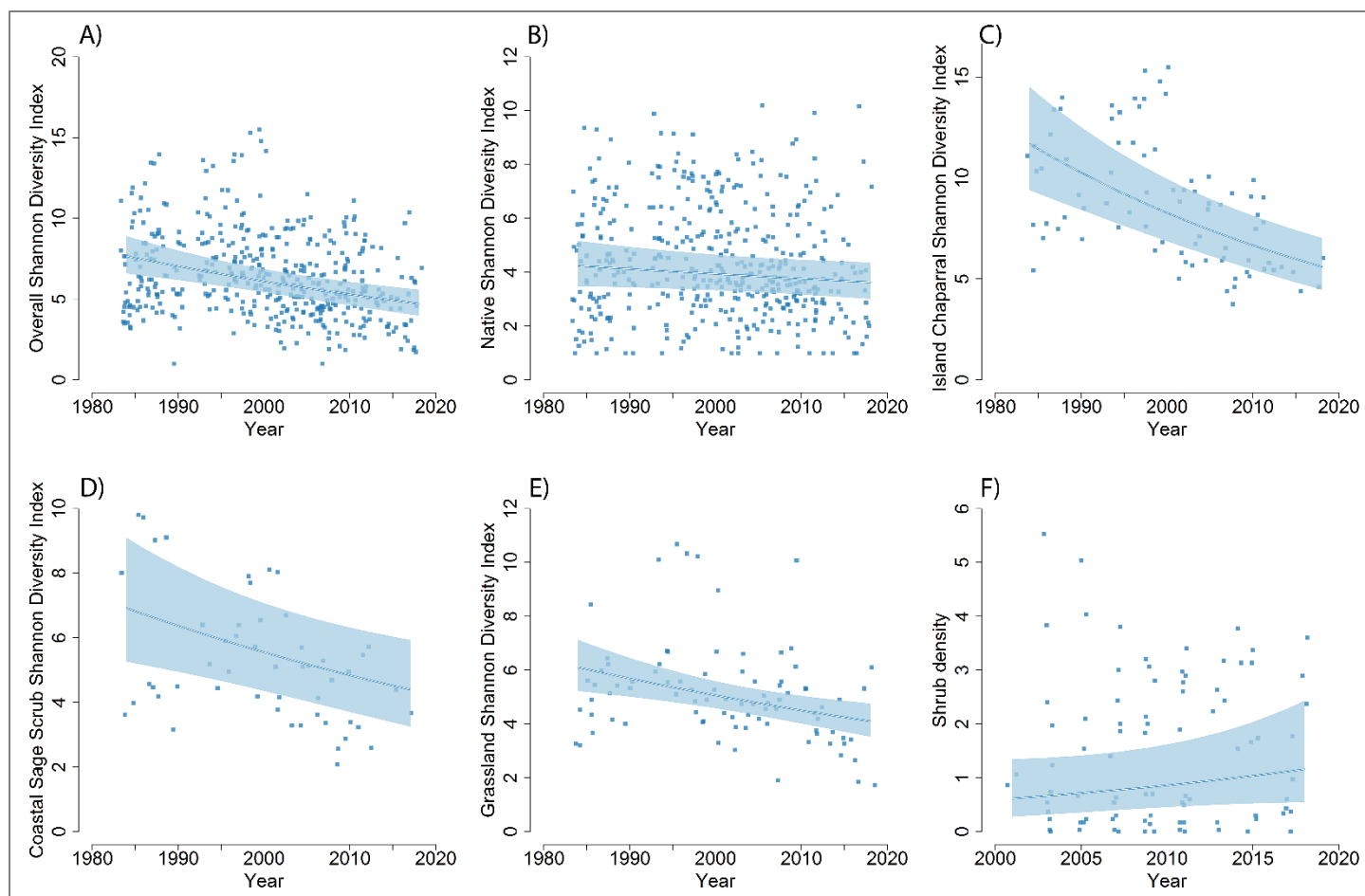


Figure 24. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (first of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p = 0.0002$). B) Native Shannon diversity index ($p = 0.1822$). C) Island chaparral Shannon diversity index ($p < 0.0001$). D) Coastal sage scrub Shannon diversity index ($p = 0.0151$). E) Grassland Shannon diversity index ($p = 0.0041$). F) Native shrub density ($p = 0.2215$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

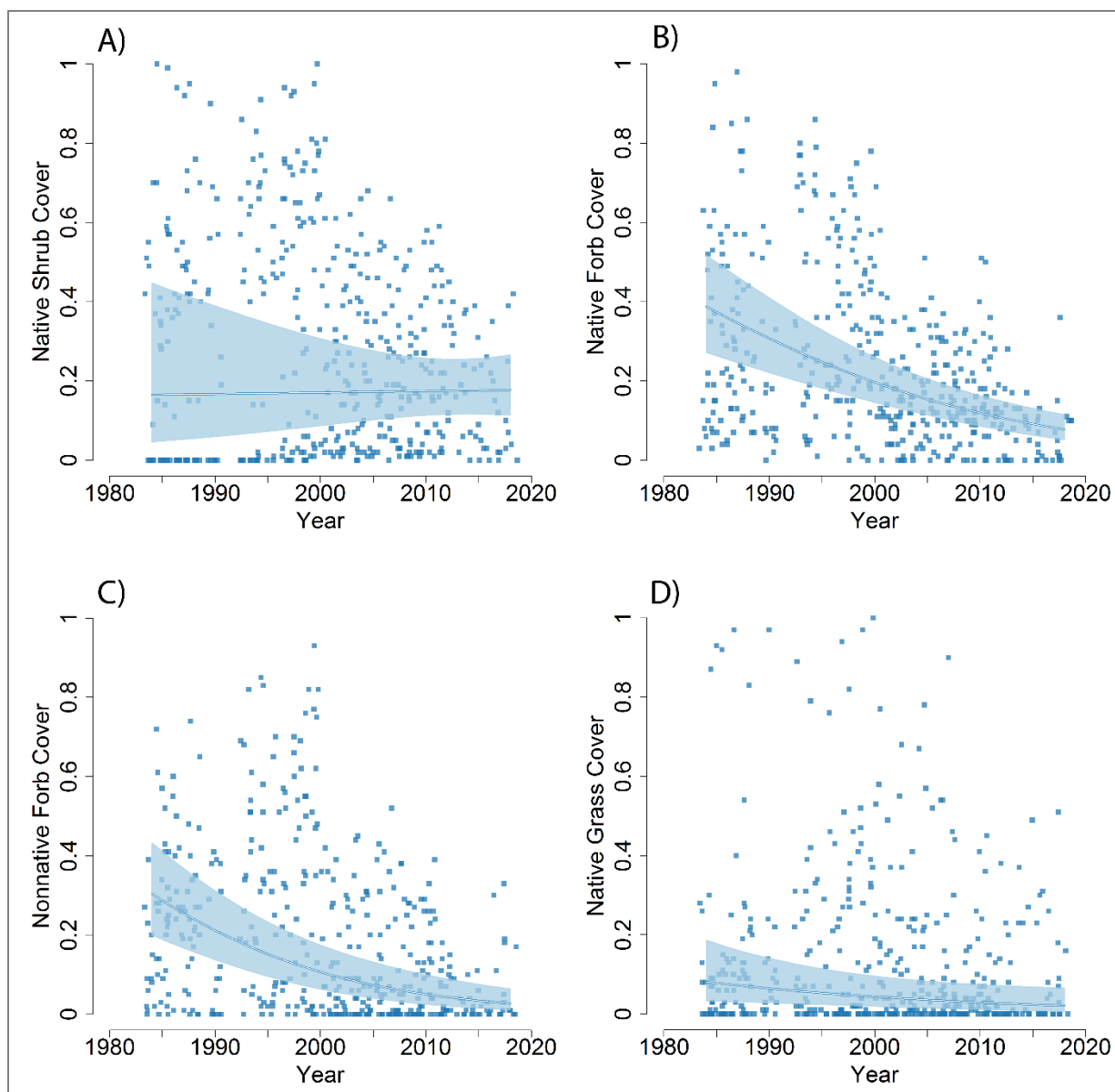


Figure 25. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (second of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native shrub cover ($p = 0.9296$). B) Native forb cover ($p < 0.0001$). C) Nonnative forb cover ($p < 0.0001$). D) Native grass cover ($p = 0.0770$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

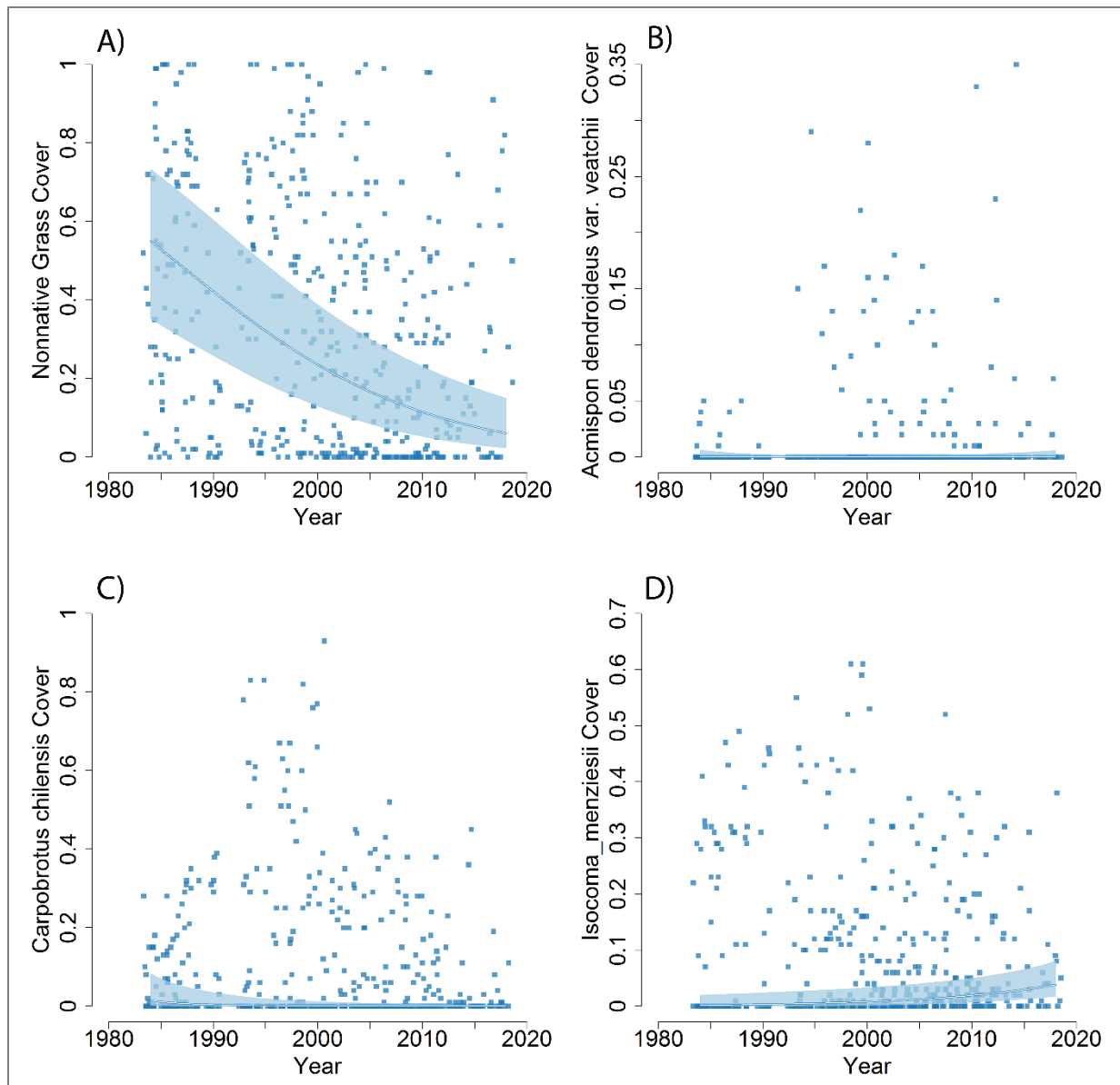


Figure 26. Trend analysis results for CHIS vegetation indicators by index site and year on San Miguel Island (third of three). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Nonnative grass cover ($p < 0.0001$). B) *Acmispon dendroideus* var. *veatchii* cover ($p = 0.6164$). C) *Carpobrotus chilensis* cover ($p = 0.0136$). D) *Isocoma menziesii* cover ($p = 0.0170$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

San Miguel Island Probability Sites

Trends in vegetation metrics at probability sites on SM (Table 17) demonstrated stable population means with the exception of two metrics. Native Shannon diversity (Figure 27A, $p = 0.4166$), native shrub density (Figure 27B, $p = 0.7075$), and native shrub cover (Figure 27C, $p = 0.8035$) all remained stable over the monitoring period since 2013. An increasing trend was detected in the odds of native forb cover (Figure 27D; annual trend: 17.24%, 90%-CI: 1.40%, 35.56%) since 2013. Other cover variables such as nonnative forb cover (Figure 27E, $p = 0.1173$), native grass cover (Figure 27F, $p =$

0.1831), nonnative grass cover (Figure 28A, $p = 0.5058$), *Acmispon dendroideus* var. *veatchii* cover (Figure 28B, $p = 0.5746$), and *Carpobrotus chilensis* cover (Figure 28C, $p = 0.9645$) did not demonstrate a statistical trend over the monitoring period. However, the p-values near the Type I error level of 0.10 for an increasing trend in nonnative forb cover and decreasing trend in native grass cover warrant attention. Finally, a decreasing trend was observed in the odds of *Isocoma menziesii* cover (Figure 28D) which was estimated as -8.64% (90%-CI: -14.84% , -1.99%) per year.

Table 17. Trend analysis results for all CHIS vegetation indicators for probability sites on San Miguel Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Native Shannon Diversity	0.6227	0.7538	0.0192	0.0236	0.4166	0.1918	0.0000	–	–
Native Shrub Density	0.7362	4.3193	–0.0918	0.2447	0.7075	2.1046	1.0259	–	0.0222
Native Shrub Cover	–3.1836	3.9729	0.0313	0.1257	0.8035	–	0.0830	–	–
Native Forb Cover	–7.3031	2.8143	0.1591	0.0883	0.0715	40.7633	0.0000	0.0396	–
Nonnative Forb Cover	–6.4354	2.1155	0.1040	0.0664	0.1173	0.7425	0.0000	–	–
Native Grass Cover	1.9440	4.8810	–0.2057	0.1545	0.1831	5.2058	0.2788	–	–
Nonnative Grass Cover	–3.4531	3.2114	0.0675	0.1014	0.5058	1.3057	0.0633	–	–
<i>Acmispon dendroideus</i> var. <i>veatchii</i> Cover	–10.5566	9.5252	0.1666	0.2968	0.5746	–	0.0000	–	–
<i>Carpobrotus chilensis</i> Cover	–2.9347	3.5563	0.0050	0.1126	0.9645	–	0.0000	–	–
<i>Isocoma menziesii</i> Cover	–1.2878	1.5399	–0.0903	0.0427	0.0345	5.4152	0.0000	–	–

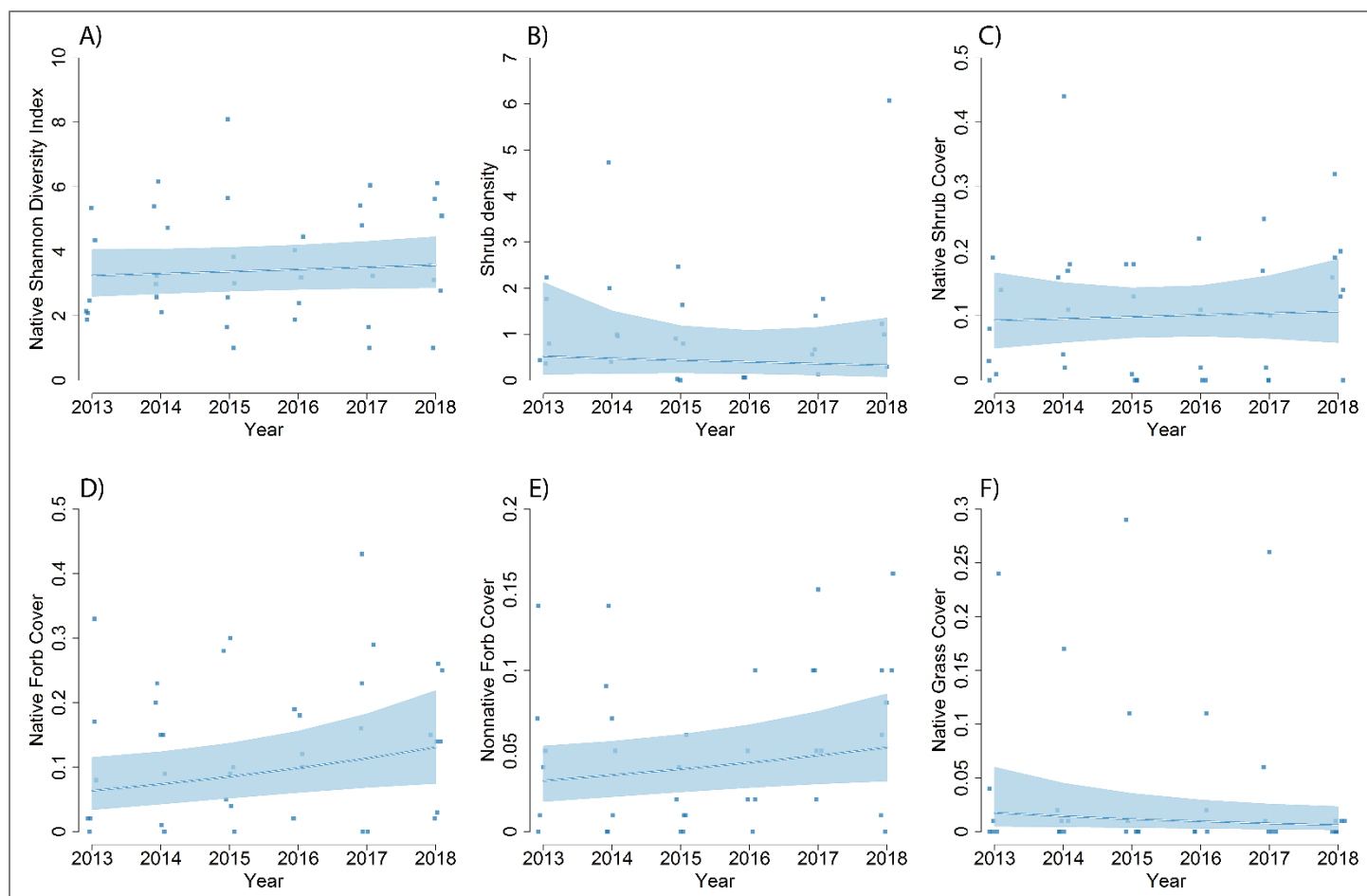


Figure 27. Trend analysis results for CHIS vegetation indicators by probability site and year across San Miguel Island (first of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native Shannon diversity index ($p = 0.4166$). B) Native shrub density ($p = 0.7075$). C) Native shrub cover ($p = 0.8035$). D) Native forb cover ($p = 0.0715$). E) Nonnative forb cover ($p = 0.1173$). F) Native grass cover ($p = 0.1831$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

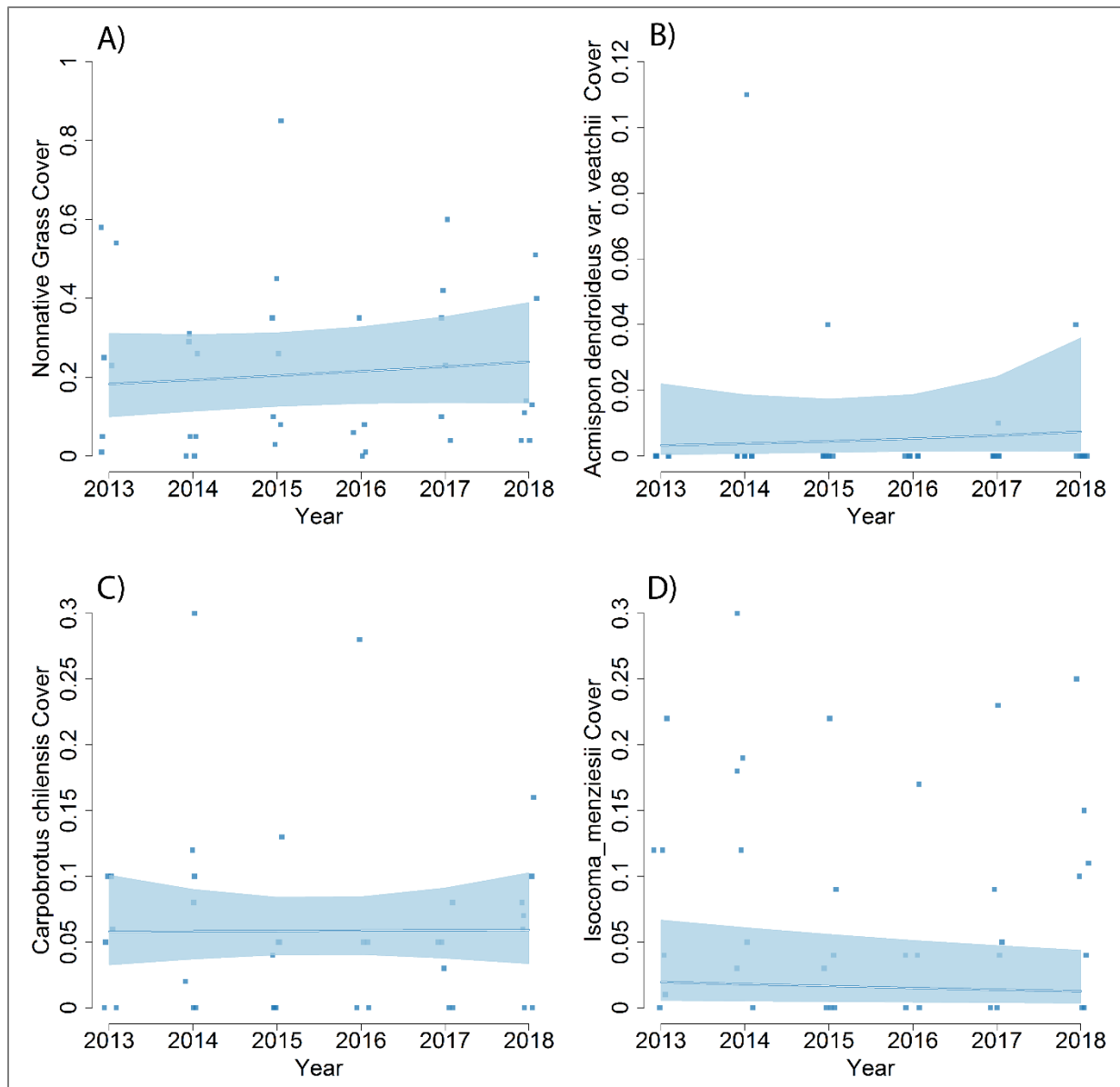


Figure 28. Trend analysis results for CHIS vegetation indicators by probability site and year across San Miguel Island (second of two). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Nonnative grass cover ($p = 0.5058$). B) *Acmispon dendroideus* var. *veatchii* cover ($p = 0.5746$). C) *Carpobrotus chilensis* cover ($p = 0.9645$). D) *Isocoma menziesii* cover ($p = 0.0345$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Trends on Santa Rosa Island

Santa Rosa Island Index Sites

Trends in SR terrestrial vegetation metrics were estimated for index sites monitored since 1998 (Table 18). Shannon diversity metrics demonstrated negative trends, although the p-values for the two-sided trend tests were not always strictly significant at the 0.10 level. Overall Shannon diversity annual trend (Figure 29A) was estimated to decrease by -1.87% (90%-CI: -2.49% , -1.24%) per year

since monitoring began in 1998. No significant trend was observed in native Shannon diversity (Figure 29B, $p = 0.1971$), but significant declines were observed in coastal sage scrub Shannon diversity (Figure 29C; annual trend: -2.69% , 90%-CI: -3.91% , -1.45%), *Baccharis* scrub Shannon diversity (Figure 29D; annual trend: -2.23% , 90%-CI: -3.14% , -1.31%), and grassland Shannon diversity (Figure 29E; annual trend: -2.13% , 90%-CI: -3.01% , -1.23%). The trend tests for riparian Shannon diversity (Figure 29F, $p = 0.1618$) and mixed woodland Shannon diversity (Figure 30A, $p = 0.7196$) were not significant at the 0.10 level. No trends were detected in native tree density (Figure 30B, $p = 0.3600$) or native tree recruitment density (Figure 30C, $p = 0.1731$). An increasing trend was estimated for native shrub density (Figure 30D; annual trend: 4.17% , 90%-CI: 1.74% , 6.66%), but no trend was detected in native shrub recruitment density (Figure 30E, $p = 0.2292$). Increasing trends were observed in the odds of native tree cover (Figure 30F; annual trend: 40.57% , 90%-CI: 13.11% , 74.69%) and native shrub cover (Figure 31A; annual trend: 3.98% , 90%-CI: 1.52% , 6.50%), but negative trends were detected in the odds of native forb cover (Figure 31B; annual trend: -5.30% , 90%-CI: -7.75% , -2.78%), nonnative forb cover (Figure 31C; annual trend: -11.38% , 90%-CI: -14.13% , -8.55%), native grass cover (Figure 31D; annual trend: -5.37% , 90%-CI: -7.84% , -2.84%), and nonnative grass cover (Figure 31E; annual trend: -9.16% , 90%-CI: -12.10% , -6.12%). The odds of observing native shrub *Arctostaphylos* Group cover (Figure 31F) at SR index sites increased 11.94% (90%-CI: 10.29% , 13.62%) annually since 1990, but the odds of *Heteromeles arbutifolia* cover (Figure 32A) declined over the same monitoring period by an estimated -1.89% (90%-CI: -2.89% , -0.89%) each year. No statistical trend was detected in native *Quercus pacifica* cover (Figure 32B, $p = 0.2806$) since 1990. The odds of observing the native riparian tree *Salix lasiolepis* cover (Figure 32C) at SR index sites increased annually by an estimated 21.63% (90%-CI: 17.88% , 25.50%) since 1990, but no change was detected in *Stipa* Group cover (Figure 32D, $p = 0.4129$) during this time.

Table 18. Trend analysis results for all CHIS vegetation indicators for index sites on Santa Rosa Island.

Outcome	Intercept	SE (Intercept)	Trend	SE (Trend)	p-value	Site Variation	Year Variation	Site- Trend Variation	Obs. Variation
Overall Shannon Diversity	1.9639	0.1028	-0.0188	0.0039	<0.0001	0.4887	0.0155	0.0004	–
Native Shannon Diversity	1.1561	0.0874	-0.0041	0.0032	0.1971	0.4267	0.0080	0.0004	–
Coastal Sage Scrub Shannon Diversity	2.3141	0.1729	-0.0272	0.0077	0.0004	0.1723	0.0421	0.0003	–
Baccharis Scrub Shannon Diversity	2.4562	0.1126	-0.0225	0.0057	<0.0001	0.0544	0.0171	0.0002	–
Grassland Shannon Diversity	2.1769	0.1138	-0.0215	0.0055	0.0001	0.1112	0.0228	0.0003	–
Riparian Shannon Diversity	1.8315	0.2459	-0.0141	0.0101	0.1618	0.3570	0.0173	0.0006	–
Mixed Woodland Shannon Diversity	1.8752	0.1124	-0.0018	0.0051	0.7196	–	0.0000	–	–
Native Tree Density	-2.9089	0.4948	-0.0430	0.0470	0.3600	0.5656	0.8182	0.0020	0.0447
Native Tree Recruitment Density	-4.2606	0.8199	0.0828	0.0607	0.1731	7.8477	0.6721	0.0145	0.9817
Native Shrub Density	-1.7986	0.2702	0.0408	0.0143	0.0044	3.2432	0.0045	0.0053	0.1115
Native Shrub Recruitment Density	-3.1482	0.3855	-0.0385	0.0320	0.2292	1.9704	0.2344	0.0072	2.0103
Native Tree Cover	-22.8651	4.0449	0.3405	0.1321	0.0100	423.5759	0.0751	0.1113	–
Native Shrub Cover	-5.0167	0.6012	0.0390	0.0145	0.0073	23.5342	0.0300	0.0087	0.0487
Native Forb Cover	-2.0768	0.3786	-0.0544	0.0159	0.0006	5.8948	0.2241	0.0086	0.7322
Nonnative Forb Cover	-1.3763	0.4412	-0.1208	0.0191	<0.0001	4.0387	0.4575	0.0045	0.4641
Native Grass Cover	-1.4997	0.4431	-0.0552	0.0160	0.0006	9.5906	0.2386	0.0073	0.4325
Nonnative Grass Cover	0.7659	0.5082	-0.0960	0.0200	<0.0001	7.0801	0.5699	0.0038	–
Arctostaphylos Group Cover	-19.2083	1.9144	0.1128	0.0090	<0.0001	164.1422	0.0000	–	–
Heteromeles arbutifolia Cover	-14.3131	1.2767	-0.0191	0.0062	0.0019	99.3815	0.0000	–	–
Quercus pacifica Cover	-15.9093	1.3733	-0.0041	0.0038	0.2806	161.1385	0.0085	–	–
Salix lasiolepis Cover	-21.4416	2.4452	0.1958	0.0190	<0.0001	203.9311	0.0000	–	–
Stipa Group Cover	-8.4869	1.8158	-0.0413	0.0504	0.4129	31.8876	0.3717	0.0087	0.0964

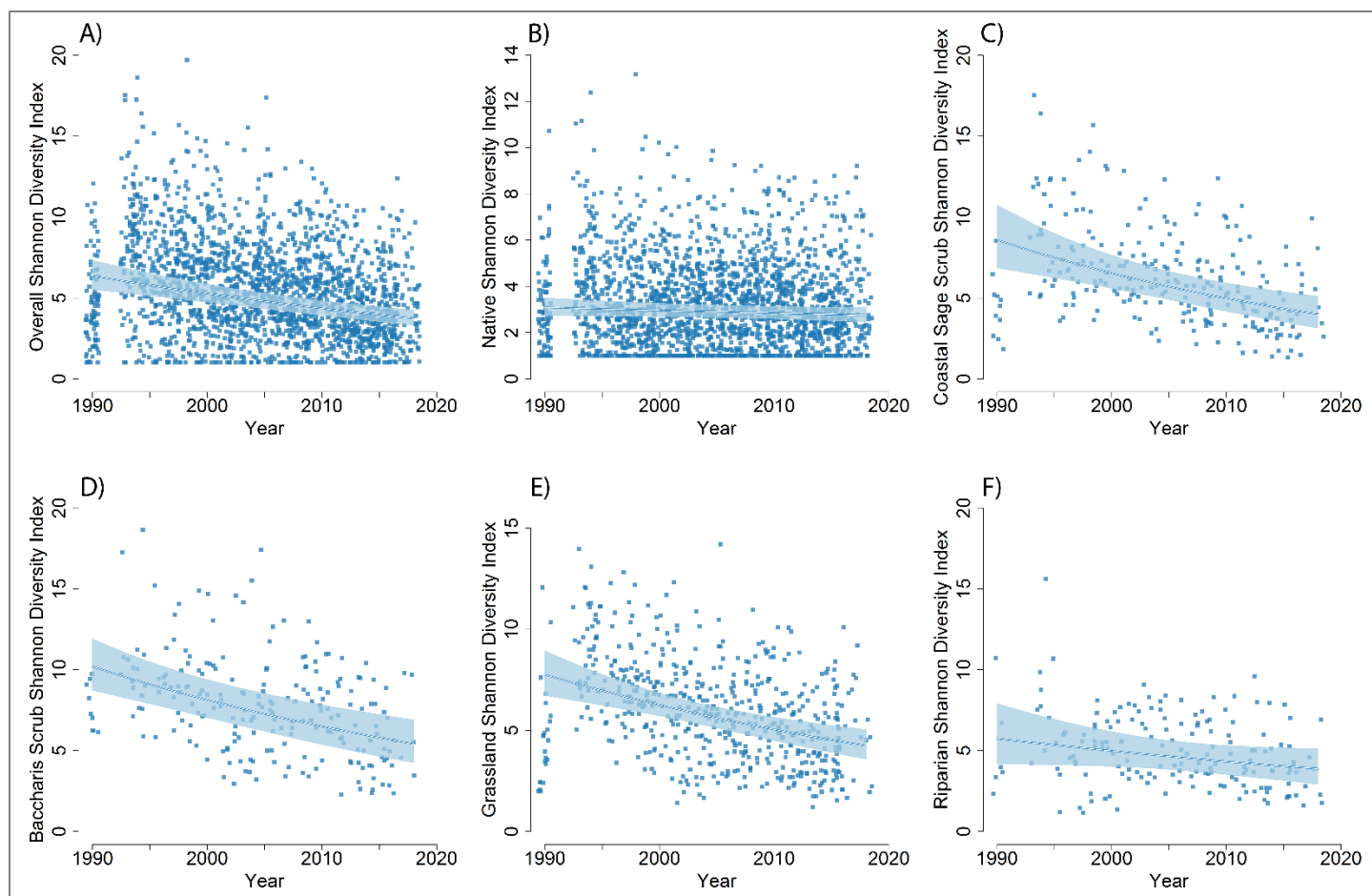


Figure 29. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (first of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Overall Shannon diversity index ($p < 0.0001$). B) Native Shannon diversity index ($p = 0.1971$). C) Coastal sage scrub Shannon diversity index ($p = 0.0004$). D) *Baccharis* scrub Shannon diversity index ($p < 0.0001$). E) Grassland Shannon diversity index ($p = 0.0001$). F) Riparian Shannon diversity index ($p = 0.1618$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

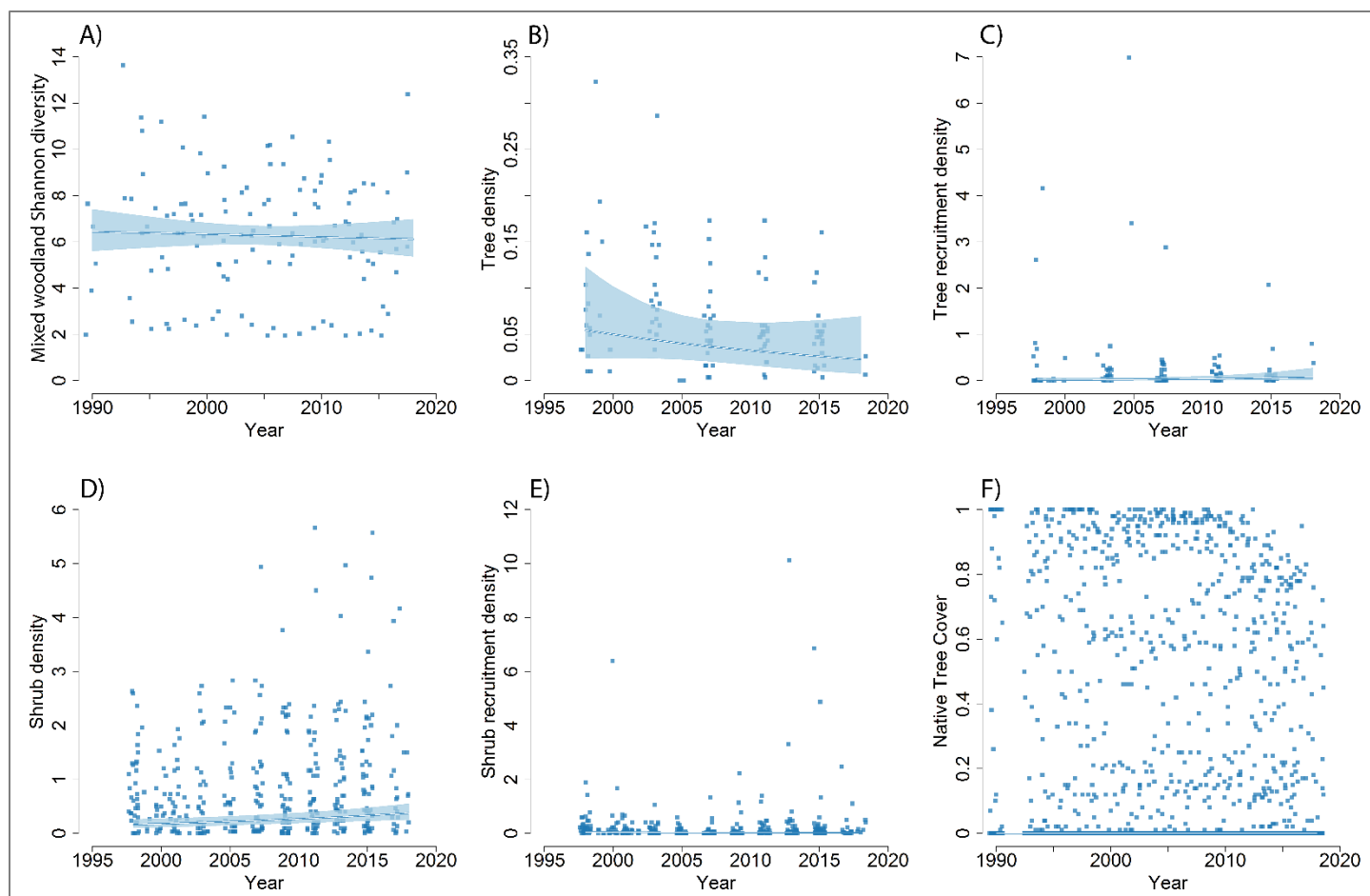


Figure 30. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (second of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Mixed woodland Shannon diversity index ($p = 0.7196$). B) Native tree density ($p = 0.3600$). C) Native tree recruitment density ($p = 0.1731$). D) Native shrub density ($p = 0.0044$). E) Native shrub recruitment density ($p = 0.2292$). F) Native tree cover ($p = 0.0100$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

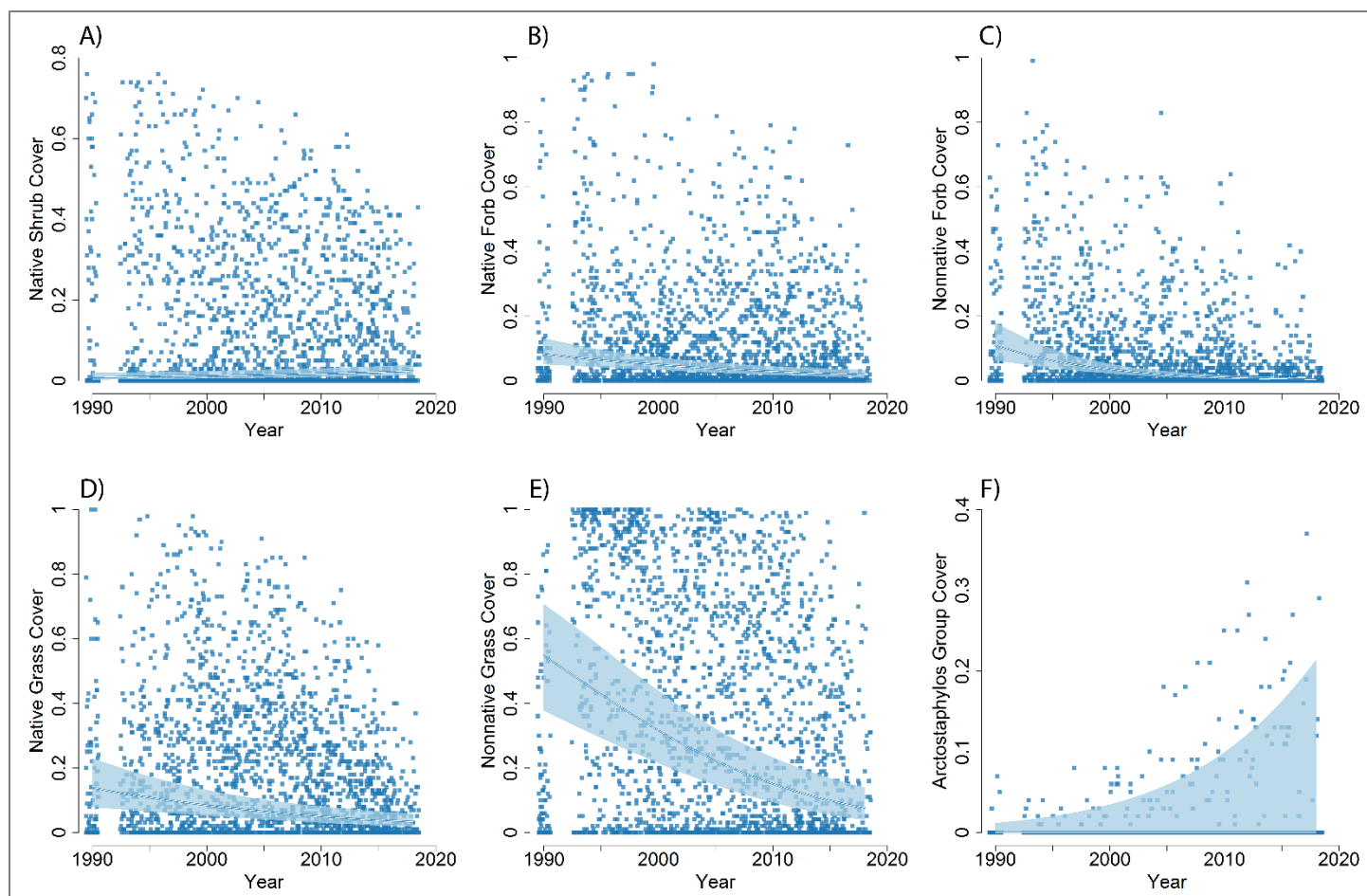


Figure 31. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (third of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) Native shrub cover ($p = 0.0073$). B) Native forb cover ($p = 0.0006$). C) Nonnative forb cover ($p < 0.0001$). D) Native grass cover ($p = 0.0006$). E) Nonnative grass cover ($p < 0.0001$). F) *Arctostaphylos* Group cover ($p < 0.0001$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

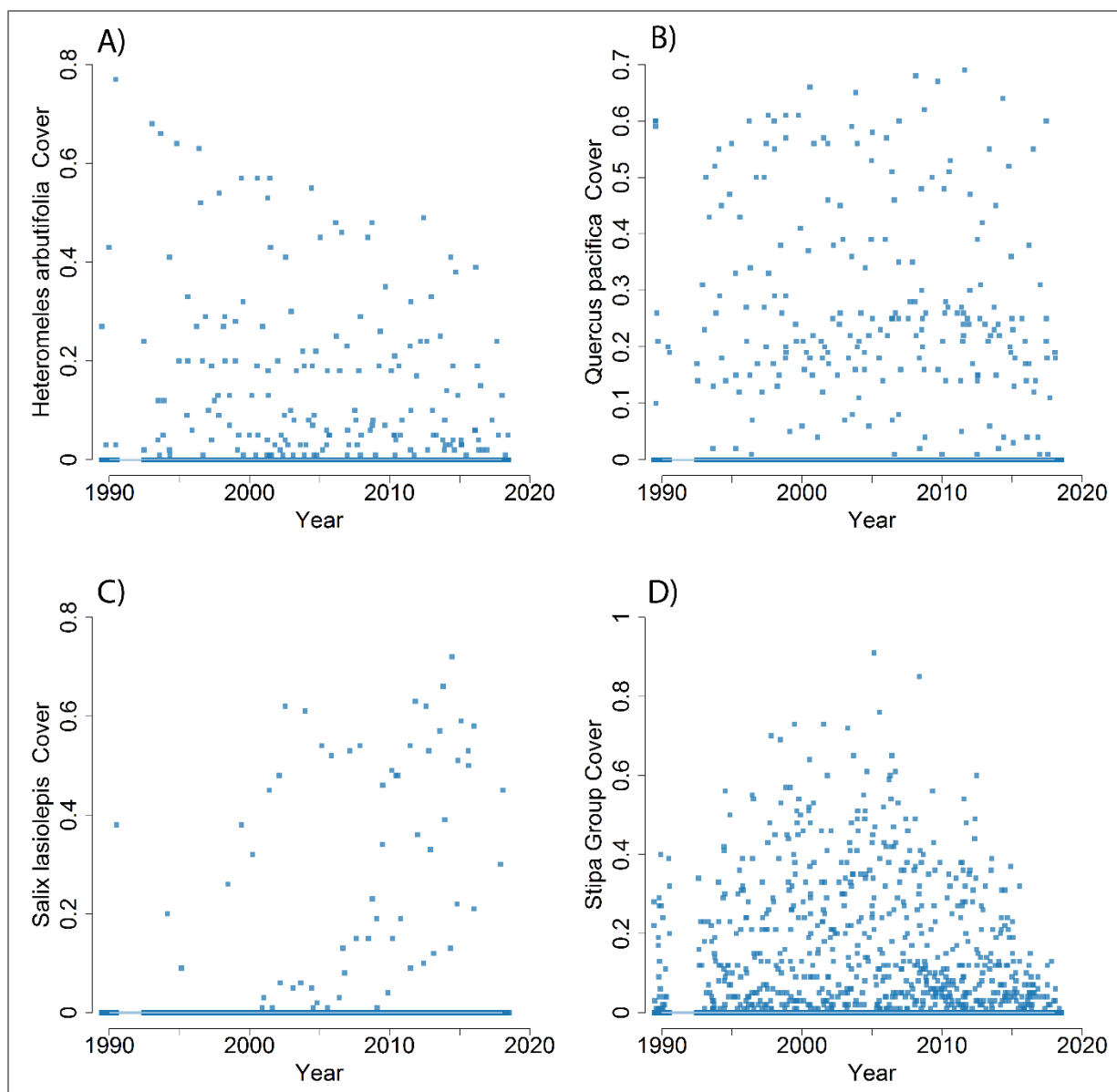


Figure 32. Trend analysis results for CHIS vegetation indicators by index site and year on Santa Rosa Island (fourth of four). In all graphs, lines represent the GLMM trend line and shaded areas represent 90%-CI bands. A) *Heteromeles arbutifolia* cover ($p = 0.0019$). B) *Quercus pacifica* cover ($p = 0.2806$). C) *Salix lasiolepis* cover ($p < 0.0001$). D) *Stipa* Group cover ($p = 0.4129$).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Probability Sites

Probability sites in SR have only been surveyed since 2017, so only two years of data were available for this data analysis. Therefore, trends at SR probability sites were not analyzed.

Covariate Modeling

A summary of the covariate modeling results is presented in this section by island, plot type, and outcome of interest. Full results are available in the [Supplemental Information](#) for this report

(Starcevich et al. 2025), including tables that contain the top ten models ranked by AICc for each island, plot type, and outcome (see Section E; in some cases these tables contain less than ten models due to duplicate models that were initially included). Other results available in the Supplemental Information (see Section F) include the regression coefficients, standard errors, p-values for two-sided hypothesis test results, and variance components estimates (e.g., Year Variation, Site Variation) for the final model. Standard errors and hypothesis test results are not provided for estimates of variance components. Descriptions of the covariates in these tables are provided in Section B of the Supplemental Information. Marginal effects plots for each covariate in the final model are shown in the remainder of this section, which begins with a description of the covariate reduction process that occurred prior to model selection.

Covariate Reduction

The large number of potential covariates was assessed to determine if correlated covariates could be reduced prior to the model selection process. Correlation among each suite of covariates (PET, AET, soil moisture, etc.) was assessed graphically and many covariates were found to have high positive correlation (Section C of the [Supplemental Information](#)).

The water balance covariates provided by Thoma consisted of four sets of the same water balance metrics but each calculated from a different PET model. The correlation between three selected outcomes of interest (overall Shannon diversity, native tree cover, and native tree density) and each of the 42 total Thoma covariates for each PET model was assessed. The PET model associated with the covariate with the largest magnitude correlation with the outcome of interest was marked as preferred. The total number of preferred covariates were summed for each PET model (Table 19). For 22 of the 42 total Thoma covariates, no PET model was preferred because the correlation with the vegetation outcome was identical for all covariates from all four PET models. Aside from those cases, the Hamon and Penman PET models were equally preferred for overall Shannon diversity, the Penman model was preferred for native tree cover, and the Hamon PET model was preferred for native tree density. Given that prediction is not of immediate interest and the Penman model is used more frequently in publication, we selected the modeled water balance covariates based on the Penman PET model for this analysis and eliminated the covariates based on the other three PET models from further consideration in the model selection exercise.

Table 19. PET model preferences for three selected vegetation outcomes.

PET Model	Overall Shannon Diversity	Native Tree Cover	Native Tree Density
Hamon	9	3	11
Oudin Daynet	2	4	3
Oudin Location	0	5	5
Penman	9	8	1
No preference	22	22	22

Water balance covariates from Mike Tercek were not available for AN, SB, and SC. Our plan was to examine their impact for SM and SR, and then retrieve these metrics if they proved to be strongly associated with CHIS vegetation indicators. Given the time required to obtain and format the large suite of covariates for this analysis, rerunning this analysis after more covariates have been assembled would have taken a prohibitive amount of time. However, the Tercek covariates could be included in the SM and SR model selection exercises to see if they are preferred over the Thoma variables. The correlation plots (see Section C of the [Supplemental Information](#)) indicate that the Tercek and Thoma variables were not highly correlated in some cases, likely due to difference in scales of water balance parameter inputs (David Thoma, NPS ecologist, personal communication).

Covariate Modeling across Islands

A subset of the full covariate modeling results across islands is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

Index Sites across Islands

The top covariate model for overall Shannon diversity at index sites across all islands included a single covariate, relative humidity for the fog year (rh_Pen_fogYr; Table 20). Other top models (within two AICc of the minimum value) contained other water deficit metrics such as monthly water deficit, actual evapotranspiration for the previous two years, water deficit for the previous year, northness, and the presence of dew during the fog year. The final model (Figure 33A) indicated that relative humidity during the fog year is positively associated ($p = 0.0001$) with overall Shannon diversity across index sites at all islands.

The final covariate model for native Shannon diversity at index sites across all islands contained effects for annual soil moisture (SOIL_Pen_an) and monthly water deficit (Def_Pen_mo; Table 20). Native Shannon diversity was negatively associated with the monthly water deficit ($p < 0.0001$, Figure 33B) but positively associated with soil moisture ($p = 0.0120$, Figure 33C).

The top model for island chaparral Shannon diversity at index sites on SC and SR included fixed effects for the slope (gradient) of the site (Slope_degrees) and the years since cattle removal (Cattle; Table 20). The regression coefficients for the final model indicated a decline in island chaparral Shannon diversity as the years since cattle removal increased ($p < 0.0001$, Figure 33D). A positive effect of the site slope on island chaparral Shannon diversity (Figure 33E) was observed, but the test provides weak evidence that the effect was significantly different from zero ($p = 0.1380$).

Table 20. Covariate models ranked by AICc for all outcomes at index sites across more than one island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and the full names of model parameters can be found in Section B. For islands, AN = Anacapa, SC = Santa Cruz, SM = San Miguel, SR = Santa Rosa. The final covariate model for each outcome is shown in bold text.

Outcome	Islands	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	All	rh_Pen_fogYr ^A	13574.50	0.00
	All	Def_Pen_mo	13575.87	1.36
	All	AET_Pen_prev2Yr+Def_Pen_prevYr	13575.96	1.46
Native Shannon Diversity	All	SOIL_Pen_an+Def_Pen_mo ^A	9574.38	0.00
	All	Def_Pen_mo	9578.65	4.26
	All	AET_Pen_an	9605.25	30.86
Island Chaparral Shannon Diversity	SC, SR	Slope_degrees+Cattle ^A	722.27	0.00
	SC, SR	Dew_Pen_fogYr+Northness+Cattle_Ind	726.22	3.96
	SC, SR	Dew_Pen_fogYr+Northness+Elevation_m+Cattle_Ind	726.96	4.70
Coastal Sage Scrub Shannon Diversity	AN, SC, SM, SR	pet_oct+AET_Pen_fogYr	1403.13	0.00
	AN, SC, SM, SR	rad_oct ^A	1404.11	0.98
	AN, SC, SM, SR	pet_oct	1407.40	4.27
Grassland Shannon Diversity	All	Def_Pen_an ^A	3963.26	0.00
	All	Def_Pen_mo	3964.52	1.26
	All	pet_allMonth+Def_Pen_mo	3965.99	2.72
Riparian Shannon Diversity	SC, SR	Northness+Cattle_Ind	834.95	0.00
	SC, SR	Northness+Pig_Ind+Cattle_Ind	835.97	1.02
	SC, SR	Northness ^A	836.29	1.34
Ironwood Shannon Diversity	SC, SR	SOIL_Pen_fogYr+Pig ^A	230.56	0.00
	SC, SR	SOIL_Pen_fogYr+Temp_Pen_fogYr	232.19	1.63

^A Final covariate model for each outcome (also in bold font).

Table 20 (continued). Covariate models ranked by AICc for all outcomes at index sites across more than one island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and the full names of model parameters can be found in Section B. For islands, AN = Anacapa, SC = Santa Cruz, SM = San Miguel, SR = Santa Rosa. The final covariate model for each outcome is shown in bold text.

Outcome	Islands	Model	AIC _c	ΔAIC _c
Ironwood Shannon Diversity (continued)	SC, SR	SOIL_Pen_fogYr+Temp_Pen_fogYr+Pig	232.53	1.97
Mixed Woodland Shannon Diversity	SC, SR	Northness+Elevation_m^A	705.12	0.00
	SC, SR	Dew_Pen_currYr+Northness+Elevation_m	705.45	0.33
	SC, SR	Dew_Pen_currYr+Northness+Elevation_m+Cattle_Ind	705.92	0.80
Native Tree Density	SC, SR	GDD_Pen_prev2Yr^A	1323.03	0.00
	SC, SR	Temp_Pen_prev2Yr	1323.19	0.16
	SC, SR	svp_Pen_prev2Yr	1323.91	0.88
Native Tree Recruitment Density	SC, SR	GDD_Pen_prevYr^A	1511.68	0.00
	SC, SR	vpd_Pen_fogYr	1514.55	2.87
	SC, SR	Pig	1514.55	2.87
Native Shrub Density	All	Slope_degrees^A	4941.49	0.00
	All	Temp_Pen_fogYr+Slope_degrees	4942.59	1.10
	All	SOIL_Pen_an+Slope_degrees	4943.04	1.55
Native Shrub Recruitment Density	SC, SR	solRad_prev2Yr^A	2382.77	0.00
	SC, SR	Dew_Pen_prev2Yr+Northness+Cattle_Ind	2389.88	7.11
	SC, SR	Dew_Pen_prev2Yr+Northness+Elevation_m+Cattle_Ind	2391.67	8.90
Native Tree Cover	SC, SR	SOIL_Pen_fogYr+Slope_degrees+Pig	6429.71	0.00
	SC, SR	SOIL_Pen_fogYr+Slope_degrees	6430.05	0.34
	SC, SR	Cattle_Ind^A	6430.74	1.03
Native Shrub Cover	All	rh_Pen_currYr+Dew_Pen_fogYr+Northness	18314.89	0.00
	All	rh_Pen_currYr+Dew_Pen_fogYr	18315.70	0.81
	All	pet_oct^A	18316.35	1.46

^A Final covariate model for each outcome (also in bold font).

Table 20 (continued). Covariate models ranked by AICc for all outcomes at index sites across more than one island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and the full names of model parameters can be found in Section B. For islands, AN = Anacapa, SC = Santa Cruz, SM = San Miguel, SR = Santa Rosa. The final covariate model for each outcome is shown in bold text.

Outcome	Islands	Model	AIC _c	ΔAIC _c
Native Forb Cover	All	SOIL_Pen_mo ^A	23020.95	0.00
	All	SOIL_Pen_mo+Slope_degrees	23021.24	0.29
	All	PET_Pen_mo+SOIL_Pen_mo	23022.90	1.95
Nonnative Forb Cover	All	AET_Pen_mo+Slope_degrees ^A	20236.82	0.00
	All	SOIL_Pen_mo+Slope_degrees	20239.60	2.78
	All	Dew_Pen_currYr+Slope_degrees	20252.95	16.13
Native Grass Cover	All	Dew_Pen_currYr+Elevation_m ^A	19381.18	0.00
	All	Dew_Pen_currYr+Dew_Pen_fogYr+Elevation_m	19383.03	1.85
	All	Dew_Pen_currYr+Dew_Pen_fogYr+Northness+Elevation_m	19383.41	2.23
Nonnative Grass Cover	All	AET_Pen_mo+Slope_degrees ^A	26155.47	0.00
	All	AET_Pen_mo+SOIL_Pen_fogYr+Slope_degrees	26156.17	0.71
	All	Temp_Pen_mo+Slope_degrees	26159.33	3.86

^A Final covariate model for each outcome (also in bold font).

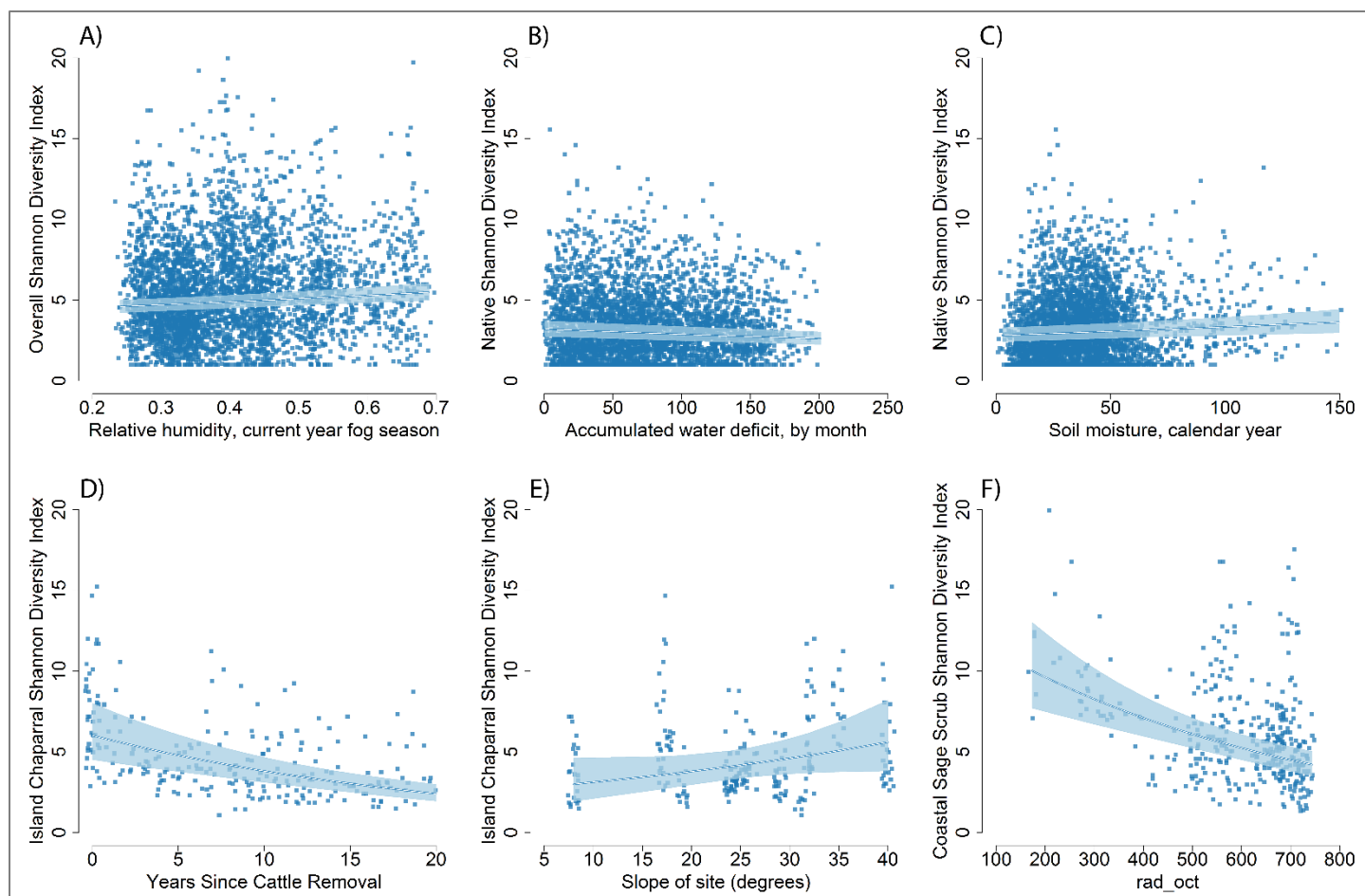


Figure 33. Marginal effects plots for final covariate models at index sites across more than one island (first of five). A) Relative humidity (percent divided by 100) during the current year fog season ($p = 0.0001$) for overall Shannon diversity index. B) Monthly accumulated water deficit (mm, $p < 0.0001$) for native Shannon diversity index. C) Annual soil moisture (mm, $p = 0.0120$) for native Shannon diversity index. D) Years since cattle removal ($p < 0.0001$) for island chaparral Shannon diversity index (Santa Cruz and Santa Rosa islands). E) Site slope (degrees, $p = 0.1380$) for island chaparral Shannon diversity index (Santa Cruz and Santa Rosa islands). F) Mean of 30-year monthly means for previous October to current survey month of total clear sky solar radiation (watts per square meter, $p < 0.0001$) for coastal sage scrub Shannon diversity index (Anacapa, Santa Cruz, San Miguel, and Santa Rosa islands).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The final model for coastal sage scrub Shannon diversity at index sites on AN, SC, SM, and SR (Table 20) contained a term for the 30-year mean solar radiation for monthly means between October and the survey month (rad_oct). Mean solar radiation was estimated to have a negative association with coastal sage scrub Shannon diversity ($p < 0.0001$, Figure 33F). The model with the lowest AICc value contained terms for the 30-year mean potential evapotranspiration (for monthly means between October and the survey month) and for the actual evapotranspiration metric (during the fog season matching the survey year), but the more parsimonious model was selected for final inference.

The top grassland Shannon diversity models for index sites across all islands (Table 20) included a fixed effect for annual water deficit (Def_Pen_an) but note that the model for monthly water deficit performed similarly relative to the AICc value, indicating that this covariate is also a useful predictor. The annual water deficit was negatively related to grassland Shannon diversity ($p = 0.0005$, Figure 34A).

The final model for riparian Shannon diversity at index sites on SC and SR contained a single term for northness (Northness), but other top models included indicators of cattle and pig removal (Table 20). The regression results indicated a positive relationship between northness and riparian Shannon diversity ($p = 0.0269$, Figure 34B). This relationship implied lower riparian Shannon diversity at sites with southern orientation and higher diversity at sites with northern orientation.

The top model for ironwood Shannon diversity at index sites on SC and SR (Table 20) included fixed effects for soil moisture during the fog year (SOIL_Pen_fogYr) and the number of years since pig removal (Pig). Temperature during the fog year also appeared in top models with AICc values within two AICc units of the minimum value. The years since pig removal had a negative relationship with ironwood Shannon diversity, but the effect was not statistically significant ($p = 0.1946$, Figure 34C). Soil moisture during the fog season was positively associated with ironwood Shannon diversity ($p < 0.0001$, Figure 34D).

Nine models for predictors of mixed woodland Shannon diversity at index sites on SC and SR fell within two AICc units of the minimum AICc value (top three models shown in Table 20). The most parsimonious model of these top models contained fixed effects for northness (Northness) and elevation (Elevation_m). Elevation demonstrated a negative association with mixed woodland Shannon diversity ($p = 0.0012$, Figure 34E). Northness was negatively associated with mixed woodland Shannon diversity, but the effect was not statistically significant ($p = 0.2441$, Figure 34F).

Top native tree density on SC and SR index sites included terms for growing-degree days, temperature, vapor pressure for the previous two years, and the site elevation (top three models shown in Table 20). The final model contained a fixed effect for growing-degree days over the previous two years (GDD_Pen_prev2Yr) which demonstrated a negative effect on native tree density at index sites on SC and SR ($p = 0.0049$, Figure 35A).

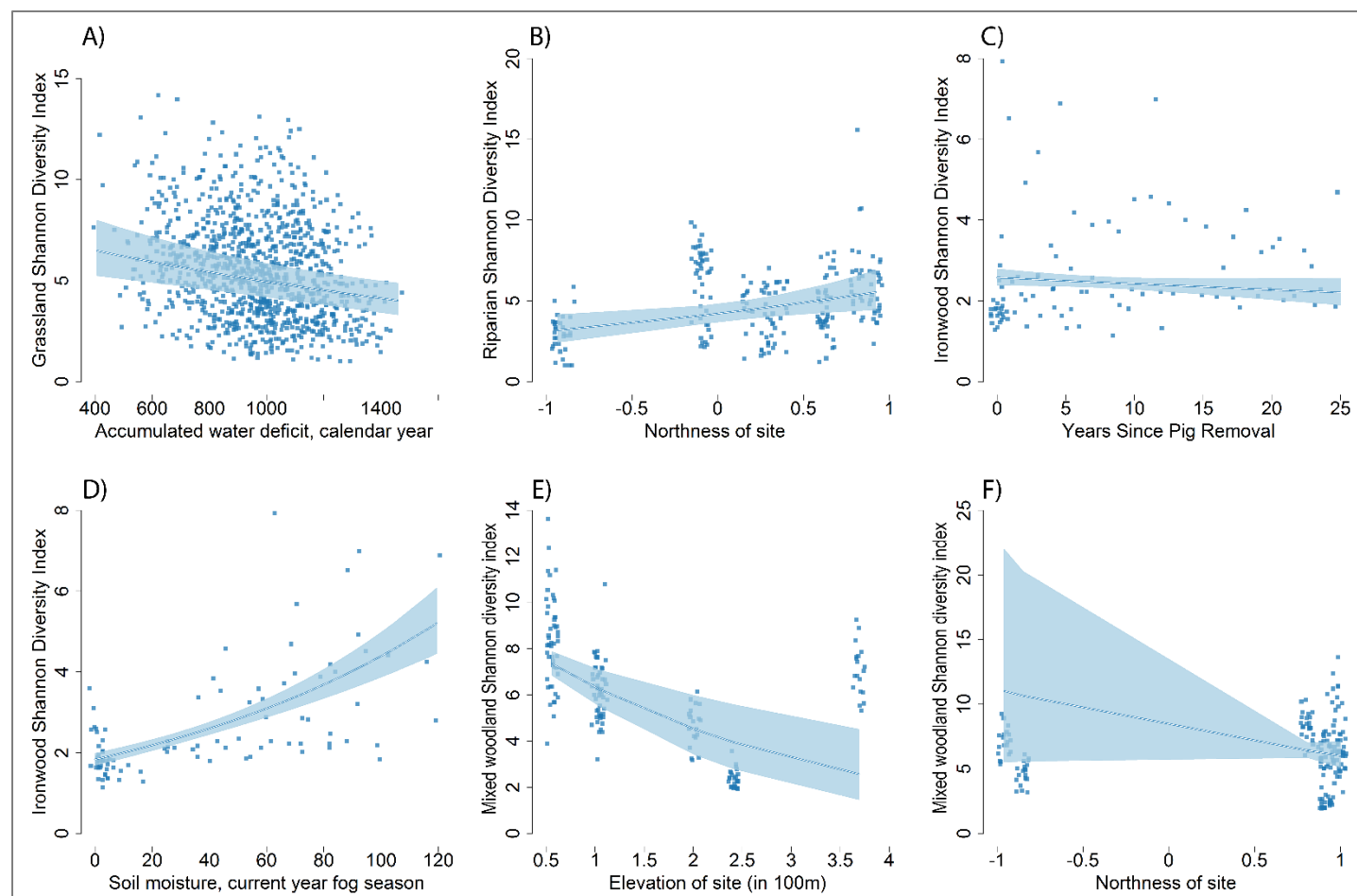


Figure 34. Marginal effects plots for final covariate models at index sites across more than one island (second of five). A) Annual accumulated water deficit (mm, $p = 0.0005$) for grassland Shannon diversity index. B) Site northness ($p = 0.0269$) for riparian Shannon diversity index. C) Years since pig removal ($p = 0.1946$) for ironwood Shannon diversity index. D) Soil moisture during the current year fog season (mm, $p < 0.0001$) for ironwood Shannon diversity index. E) Site elevation (in 100 m increments, $p = 0.0012$) for mixed woodland Shannon diversity index. F) Site northness ($p = 0.2441$) for mixed woodland Shannon diversity index. Note that graphs B through F show data from Santa Cruz and Santa Rosa islands only; for graphs B and F, northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

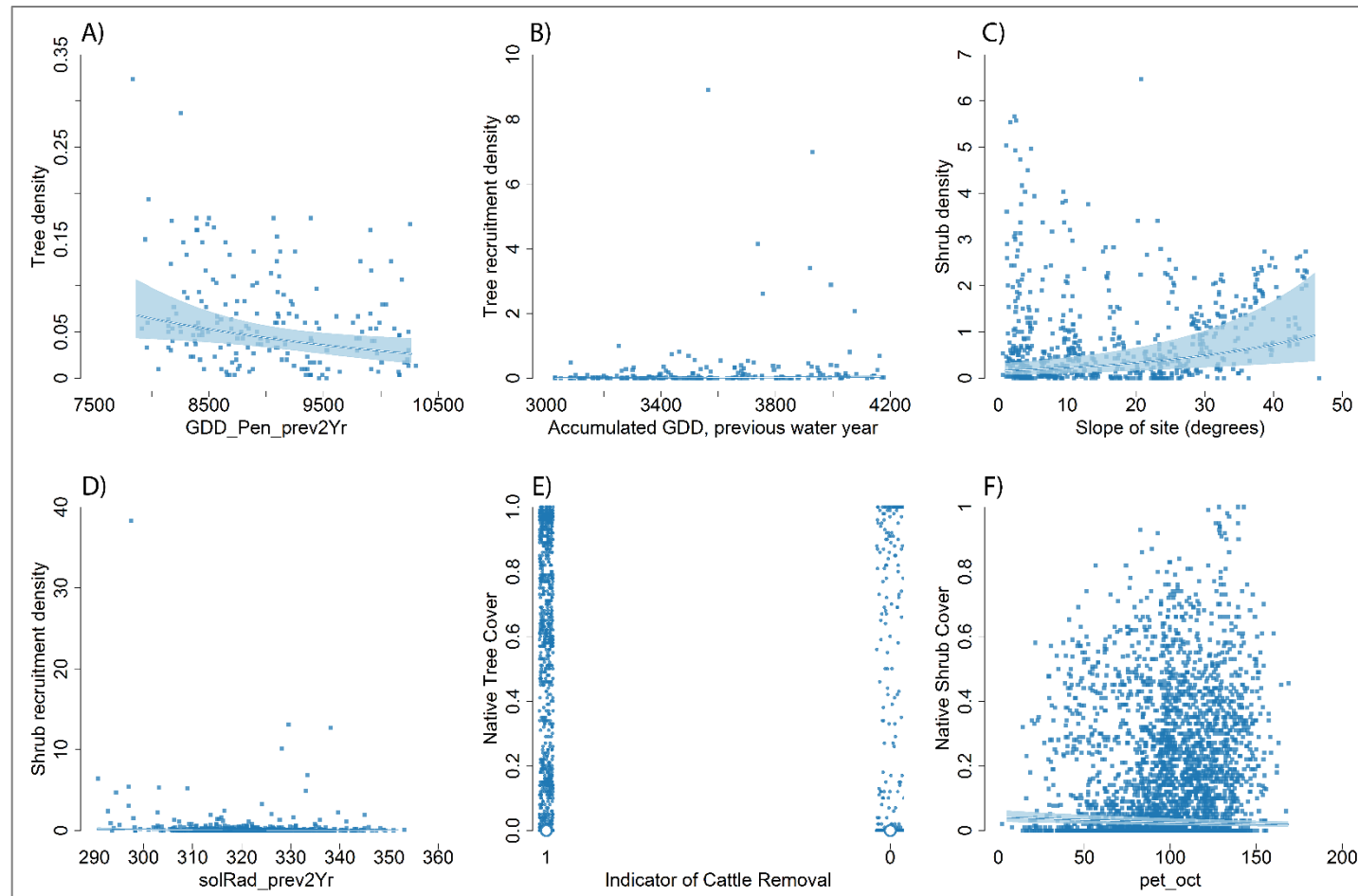


Figure 35. Marginal effects plots for final covariate models at index sites across more than one island (third of five). A) Accumulated growing-degree days (measured as cumulative degrees Celsius) for the previous two water years combined ($p = 0.0049$) for native tree density. B) Accumulated growing-degree days (measured as cumulative degrees Celsius) during the previous water year ($p = 0.0002$) for native tree recruitment density. C) Site slope (degrees, $p = 0.0008$) for native shrub density. D) Total clear sky solar radiation (watts per square meter) for the previous two water years combined ($p < 0.0001$) for native shrub recruitment density. E) Indicator of cattle removal ($p = 0.0025$) for native tree cover (coded as 1 when cattle removal has occurred and 0 prior to removal). F) Mean of 30-year monthly means for previous October to current survey month of cumulative potential evapotranspiration (mm, $p < 0.0001$) for native shrub cover at index sites across all islands. Note that graphs A, B, D, and E show data from Santa Cruz and Santa Rosa islands only.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

In contrast to the results of the native tree density covariate analysis, the final model for the native tree recruitment density analysis at SC and SR index sites (Table 20) exhibited a positive effect of growing-degree days (GDD_Pen_prevYr; $p = 0.0002$). However, tree recruitment density across SC and SR was near zero for all survey years (Figure 35B).

All of the top models for native shrub density at index sites on all islands contained a fixed effect for the site slope (top three models shown in Table 20). The final model contained only a term for the site slope (Slope_degrees) which demonstrated a positive relationship with native shrub density ($p = 0.0008$, Figure 35C).

The top model for native shrub recruitment at SC and SR index sites contained a single effect for mean solar radiation over the previous two years (solRad_prev2Yr; Table 20). The effect of this covariate was negatively associated with native shrub recruitment density ($p < 0.0001$, Figure 35D). However, note that the native shrub recruitment density was near zero for all years.

The top models for native tree cover at index sites in SC and SR included covariates for soil moisture during the fog year, the slope of the site, and the number of years since pig removal (Table 20). The final model contained a single covariate for cattle removal (Cattle_Ind). The effect of cattle removal was positively associated with native tree cover ($p = 0.0025$, Figure 35E).

Top models for native shrub cover at index sites on all islands included covariates for relative humidity in the current year, the number of days with dew during the fog year, northness, 30-year mean potential evapotranspiration from October to the current survey month, and net solar radiation (top three models shown in Table 20). The final model included only the effect for 30-year mean cumulative potential evapotranspiration from October to the current survey month (pet_oct), and the effect of this covariate was negatively associated with native shrub cover ($p < 0.0001$, Figure 35F).

All top models for native forb cover at index sites across all islands contained a term for monthly soil moisture (SOIL_Pen_mo; Table 20), which was the sole predictor in the final model. Monthly soil moisture was positively associated with native forb cover at index sites across all islands ($p < 0.0001$, Figure 36A).

The final model for nonnative forb cover at index sites across all islands contained terms for monthly modeled actual evapotranspiration (AET_Pen_mo) and the slope of the site (Slope_degrees; Table 20). Nonnative forb cover was positively associated with monthly modeled actual evapotranspiration ($p < 0.0001$, Figure 36B) and negatively associated with the slope of the site ($p < 0.0001$, Figure 36C).

The final model for native grass cover at index sites across all islands (Table 20) contained a positive effect of the number of days with dew in the current year (Dew_Pen_currYr; $p = 0.0019$, Figure 36D) and a negative effect of site elevation (Elevation_m; $p < 0.0001$, Figure 37A).

The top model for nonnative grass cover at index sites on all islands (Table 20) included predictors for monthly modeled actual evapotranspiration (AET_Pen_mo) and the slope of the site in degrees

(Slope_degrees). Nonnative grass cover was negatively associated with both the monthly actual evapotranspiration ($p = 0.0310$, Figure 37B) and the site slope ($p < 0.0001$, Figure 37C).

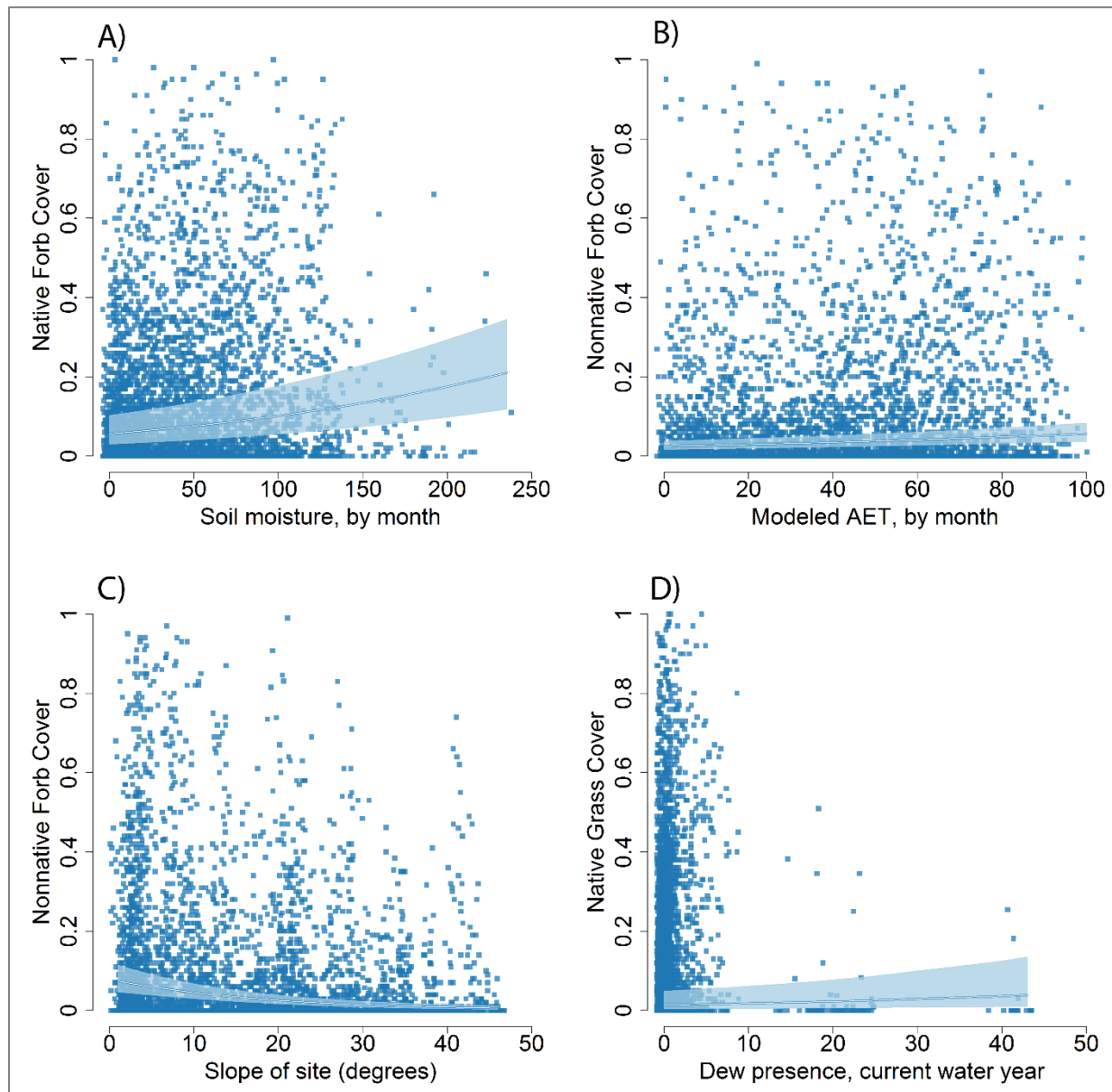


Figure 36. Marginal effects plots for final covariate models at index sites across more than one island (fourth of five). A) Monthly soil moisture (mm, $p < 0.0001$) for native forb cover. B) Monthly modeled actual evapotranspiration (mm, $p < 0.0001$) for nonnative forb cover. C) Site slope (degrees, $p < 0.0001$) for nonnative forb cover. D) Dew presence (measured as the number of days that dew was present) during the current water year ($p = 0.0019$) for native grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

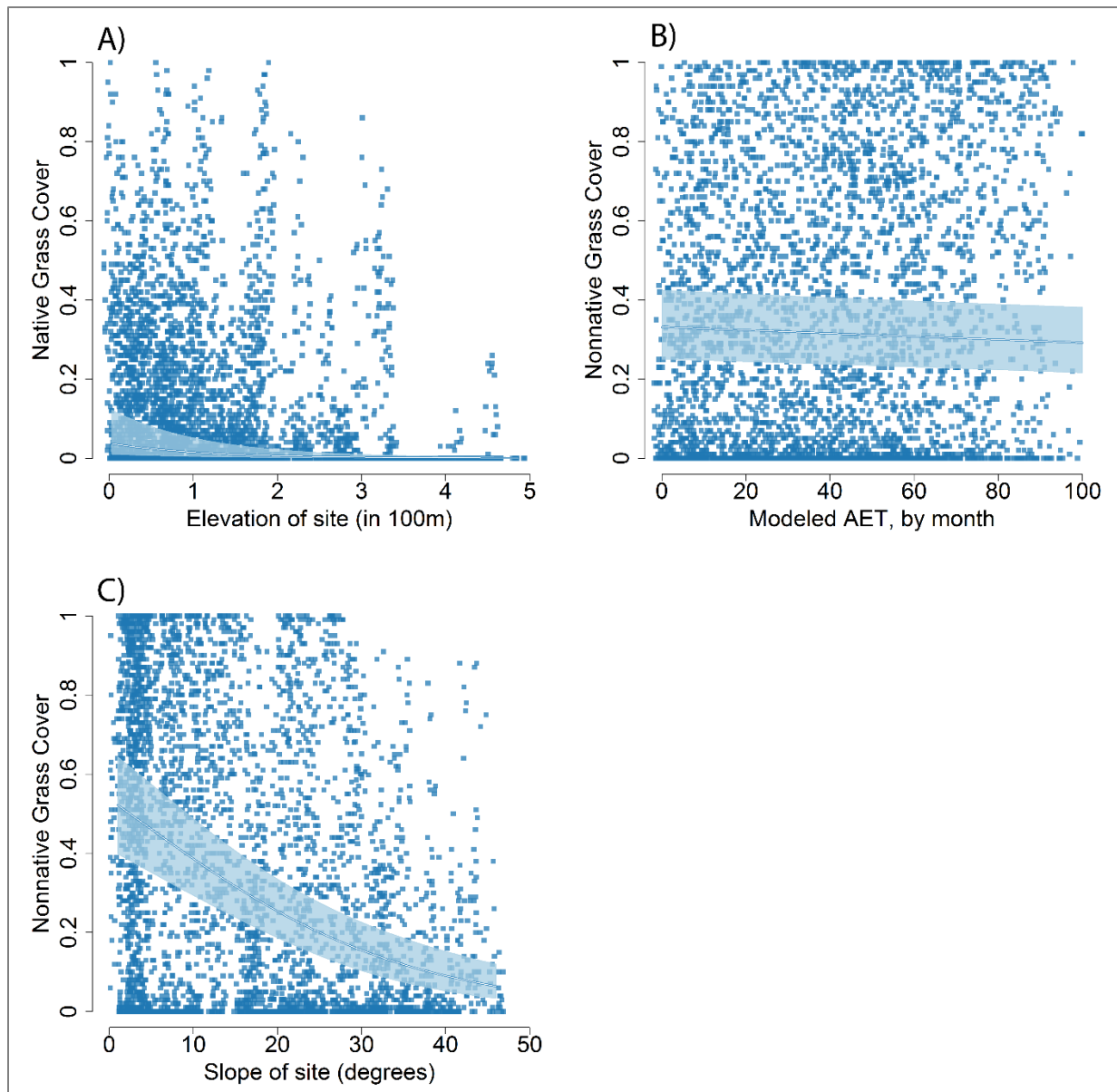


Figure 37. Marginal effects plots for final covariate models at index sites across more than one island (fifth of five). A) Site elevation (in 100 m increments, $p < 0.0001$) for native grass cover. B) Monthly modeled actual evapotranspiration (mm, $p = 0.0310$) for nonnative grass cover. C) Site slope (degrees, $p < 0.0001$) for nonnative grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Probability Sites across All Islands

The final model for native Shannon diversity at probability sites across all islands included monthly temperature (Temp_Pen_mo) and the site slope (Slope_degrees; Table 21). Native Shannon diversity increased with the site slope ($p = 0.0027$, Figure 38A). The effect of monthly temperature on native Shannon diversity was negative, but the significance test for this covariate provided weak evidence of a statistical effect ($p = 0.0997$, Figure 38B).

Table 21. Covariate models ranked by AICc for all outcomes at probability sites across all islands. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Shannon Diversity	Temp_Pen_mo+Slope_degrees^A	738.63	0.00
	SOIL_Pen_currYr+Slope_degrees	740.13	1.50
	rn_allMonth	742.30	3.67
Native Shrub Density	Temp_Pen_prev2Yr+Slope_degrees^A	1094.77	0.00
	Temp_Pen_prev2Yr	1099.30	4.53
	svp_Pen_prev2Yr	1099.59	4.82
Native Shrub Cover	Slope_degrees^A	1425.85	0.00
	Temp_Pen_prevYr+Slope_degrees	1426.69	0.85
	AET_Pen_mo+Slope_degrees	1427.44	1.60
Native Forb Cover	rh_Pen_fogYr+Northness^A	1528.28	0.00
	rh_Pen_fogYr+Dew_Pen_prevYr+Northness	1530.05	1.77
	rh_Pen_fogYr+Dew_Pen_fogYr+Northness	1530.19	1.91
Nonnative Forb Cover	SOIL_Pen_mo+Def_Pen_mo^A	1348.71	0.00
	SOIL_Pen_mo+Temp_Pen_prevYr	1355.80	7.09
	SOIL_Pen_mo+Temp_Pen_prevYr+Slope_degrees	1357.71	9.00
Native Grass Cover	Elevation_m^A	1045.66	0.00
	Dew_Pen_prev2Yr+Elevation_m	1045.70	0.04
	solRad_prevYr	1046.32	0.67
Nonnative Grass Cover	AET_Pen_currYr^A	2152.56	0.00
	AET_Pen_prev2Yr+vpd_Pen_prevYr	2153.57	1.01
	AET_Pen_currYr+Def_Pen_mo	2153.88	1.32

^A Final covariate model for each outcome (also in bold font).

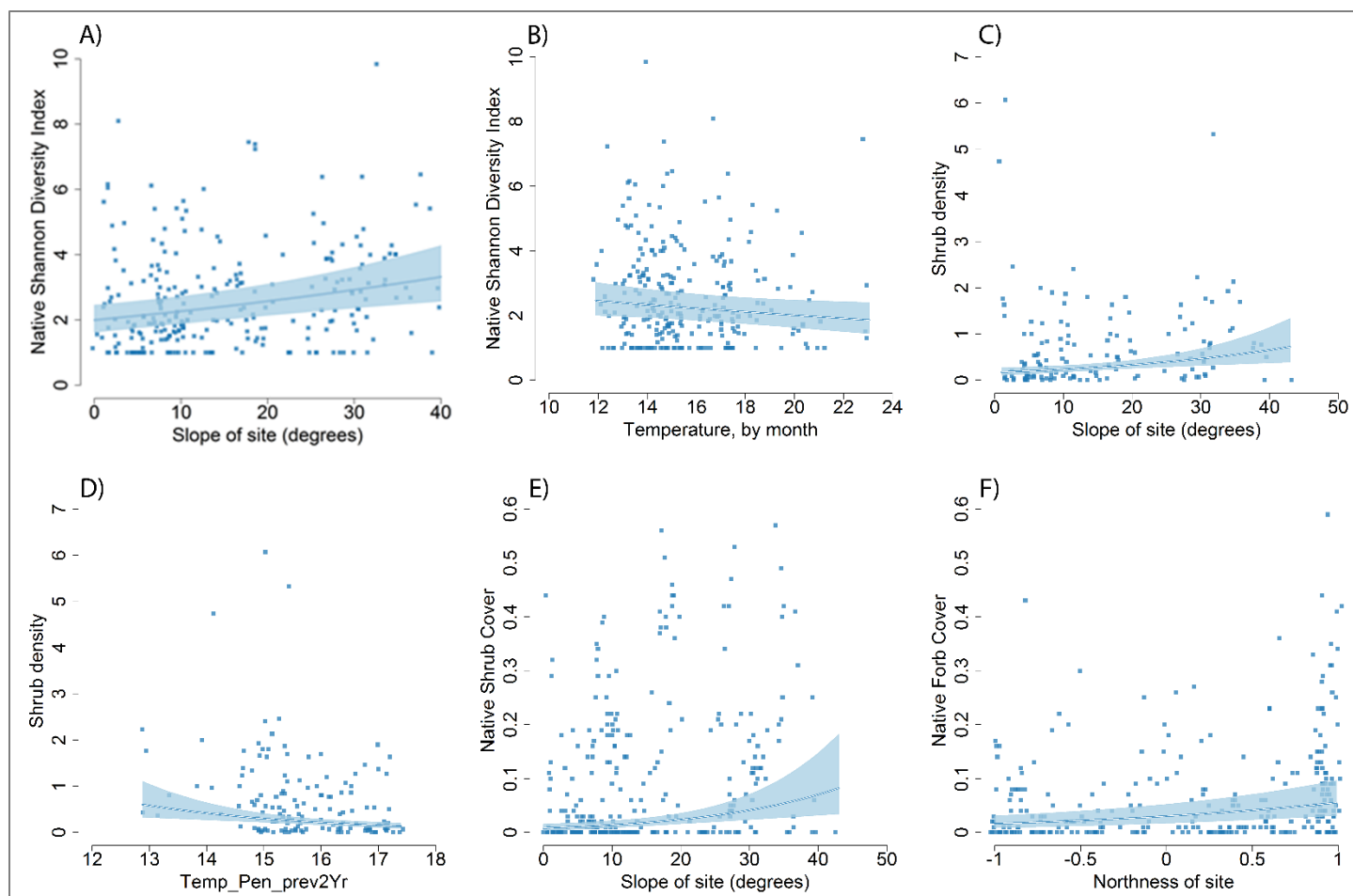


Figure 38. Marginal effects plots for final covariate models at probability sites across all islands (first of two). A) Site slope (degrees, $p = 0.0027$) for native Shannon diversity index. B) Monthly temperature (degrees Celsius, $p = 0.0997$) for native Shannon diversity index. C) Site slope (degrees, $p = 0.0092$) for native shrub density. D) Temperature (degrees Celsius) for the previous two water years combined ($p = 0.0029$) for native shrub density. E) Site slope (degrees, $p = 0.0027$) for native shrub cover. F) Site northness ($p < 0.0001$) for native forb cover (a value of 1 indicates that the site is oriented due north, while a value of -1 indicates due south orientation).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top model for native shrub density at probability sites across all islands included terms for the mean temperature for the previous two water years (Temp_Pen_prev2Yr) and for the slope of the site in degrees (Slope_degrees; Table 21). The slope of the site was positively associated with native shrub density ($p = 0.0092$, Figure 38C), but native shrub density declined with increasing mean temperature summarized over the previous two years ($p = 0.0029$, Figure 38D).

For native shrub cover at probability sites across all islands, all of the top models included site slope (Slope_degrees) as a model predictor (top three models shown in Table 21). The final model contained only the site slope which was positively associated with native shrub cover ($p = 0.0027$, Figure 38E).

The top models for native forb cover at probability sites across all islands all contained terms for site northness (Northness) and relative humidity during the current year fog season (rh_Pen_fogYr), and these covariates were the only terms in the final model (Table 21). Native forb cover was higher at sites oriented toward the north ($p < 0.0001$, Figure 38F) and increased with the relative humidity measured during the current year fog season ($p = 0.0086$, Figure 39A).

The final model for nonnative forb cover at probability sites across all islands included terms for monthly soil moisture (SOIL_Pen_mo) and monthly accumulated water deficit (Def_Pen_mo; Table 21). Positive effects on nonnative forb cover were observed for both monthly accumulated water deficit ($p = 0.0002$, Figure 39B) and monthly soil moisture ($p < 0.0001$, Figure 39C).

Top models for native grass cover at probability sites across all islands included covariates for site elevation, days with dew during the previous two water years and during the fog season, solar radiation during the previous year, and site northness (top three models shown in Table 21). The final model contained a single term for site elevation (Elevation_m) which was negatively associated with native grass cover ($p = 0.0057$, Figure 39D).

The final model for nonnative grass cover at probability sites across all islands contained a single term for modeled actual evapotranspiration during the current water year (AET_Pen_currYr; Table 21). This term was positively associated with nonnative grass cover ($p < 0.0001$, Figure 39E).

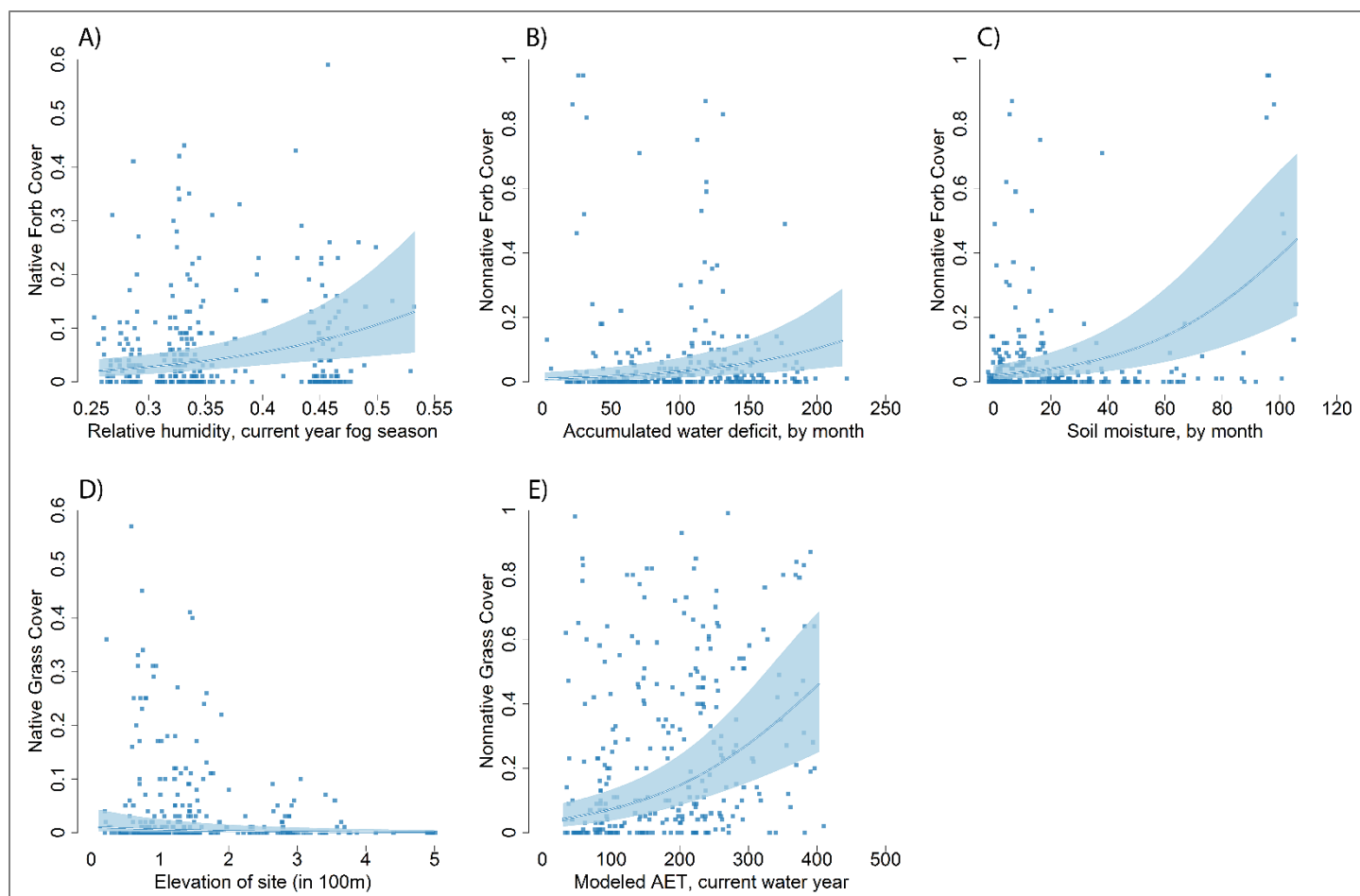


Figure 39. Marginal effects plots for final covariate models at probability sites across all islands (second of two). A) Relative humidity (percentage divided by 100) during the current year fog season ($p = 0.0086$) for native forb cover. B) Monthly accumulated water deficit (mm, $p = 0.0002$) for nonnative forb cover. C) Monthly soil moisture (mm, $p < 0.0001$) for nonnative forb cover. D) Site elevation (in 100 m increments, $p = 0.0057$) for native grass cover. E) Modeled actual evapotranspiration (AET, mm) during the current water year ($p < 0.0001$) for nonnative grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Covariate Modeling for Anacapa Island

A subset of the full covariate modeling results across Anacapa Island (AN) is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

Anacapa Island Index Sites

Top models for overall Shannon diversity at AN contained covariates related to water balance such as temperature, number of days with dew, vapor pressure, vapor pressure deficit, and growing-degree days for the previous two water years (top three models shown in Table 22). Other models included terms for site slope and monthly soil moisture. The final model contained a single fixed effect for vapor pressure over the previous two water years (svp_Pen_prev2Yr), and this effect was negatively associated with overall Shannon diversity at index sites on AN ($p < 0.0001$, Figure 40A).

The top model for native Shannon diversity at index sites on AN contained fixed effects for temperature over the past two water years (Temp_Pen_prev2Yr) and the slope at the site (Slope_degrees; Table 22). Native Shannon diversity increased as a function of site slope ($p < 0.0001$, Figure 40B) but decreased as the temperature over the previous two water years increased ($p = 0.0039$, Figure 40C).

The final model for coastal sage scrub Shannon diversity at index sites on AN included a single fixed effect for accumulated water deficit from the current water year (Def_Pen_currYr; Table 22). Water deficit was negatively associated with coastal sage scrub Shannon diversity ($p < 0.0001$, Figure 40D).

The top models for grassland Shannon diversity at index sites on AN included covariates related to water balance summarized over the previous two water years such as vapor pressure deficit, temperature, the number of days with dew, water deficit, and vapor pressure (top three models shown in Table 22). The final model contained a single fixed effect for vapor pressure deficit over the previous two water years (vpd_Pen_prev2Yr), and this effect was associated with a decline in grassland Shannon diversity ($p < 0.0001$, Figure 40E).

The final model for native shrub cover at index sites on AN contained a single fixed effect for vapor pressure deficit summarized over the previous two water years (vpd_Pen_prev2Yr; Table 22). This effect was negative, indicating that increases in water vapor deficit were associated with declines in native shrub cover ($p < 0.0001$, Figure 40F).

The top models for native forb cover at index sites on AN included monthly soil moisture and water balance variables summarized over the previous two water years including temperature, the number of days with dew, growing-degree days, and vapor pressure (top three models shown in Table 22). The final model contained a single fixed effect of the temperature for the previous two water years (Temp_Pen_prev2Yr) which was negatively associated with native forb cover ($p < 0.0001$, Figure 41A).

Table 22. Covariate models ranked by AICc for all outcomes at index sites across Anacapa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	Temp_Pen_prev2Yr+Dew_Pen_prev2Yr	1239.36	0.00
	svp_Pen_prev2Yr^A	1239.48	0.12
	vpd_Pen_prev2Yr	1239.53	0.17
Native Shannon Density	Temp_Pen_prev2Yr+Slope_degrees^A	856.60	0.00
	svp_Pen_prev2Yr	860.19	3.58
	Temp_Pen_prev2Yr	861.08	4.48
Coastal Sage Scrub Shannon Diversity	Def_Pen_currYr^A	183.99	0.00
	rh_Pen_currYr+Northness	185.60	1.60
	svp_Pen_prev2Yr	186.57	2.58
Grassland Shannon Diversity	vpd_Pen_prev2Yr^A	655.65	0.00
	Temp_Pen_prev2Yr+Dew_Pen_prev2Yr	656.19	0.54
	Def_Pen_prev2Yr	657.60	1.96
Native Shrub Cover	vpd_Pen_prev2Yr^A	1872.23	0.00
	Temp_Pen_prev2Yr+Slope_degrees	1875.38	3.15
	rh_Pen_prev2Yr+Northness	1875.92	3.69
Native Forb Cover	SOIL_Pen_mo+Temp_Pen_prev2Yr	2121.29	0.00
	Temp_Pen_prev2Yr+Dew_Pen_prev2Yr	2121.79	0.50
	Temp_Pen_prev2Yr^A	2122.97	1.68
Nonnative Forb Cover	rh_Pen_currYr+Islet	1813.99	0.00
	rh_Pen_currYr+Northness	1814.13	0.14
	rh_Pen_currYr^A	1814.73	0.74
Native Grass Cover	vpd_Pen_prev2Yr^A	1744.49	0.00
	rh_Pen_prev2Yr+Islet	1746.82	2.33

^A Final covariate model for each outcome (also in bold font).

Table 22 (continued). Covariate models ranked by AICc for all outcomes at index sites across Anacapa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Grass Cover (continued)	rh_Pen_prev2Yr	1747.84	3.34
Nonnative Grass Cover	rh_Pen_currYr+Islet	2117.33	0.00
	vpd_Pen_currYr^A	2117.38	0.04
	AET_Pen_an	2119.01	1.68

^A Final covariate model for each outcome (also in bold font).

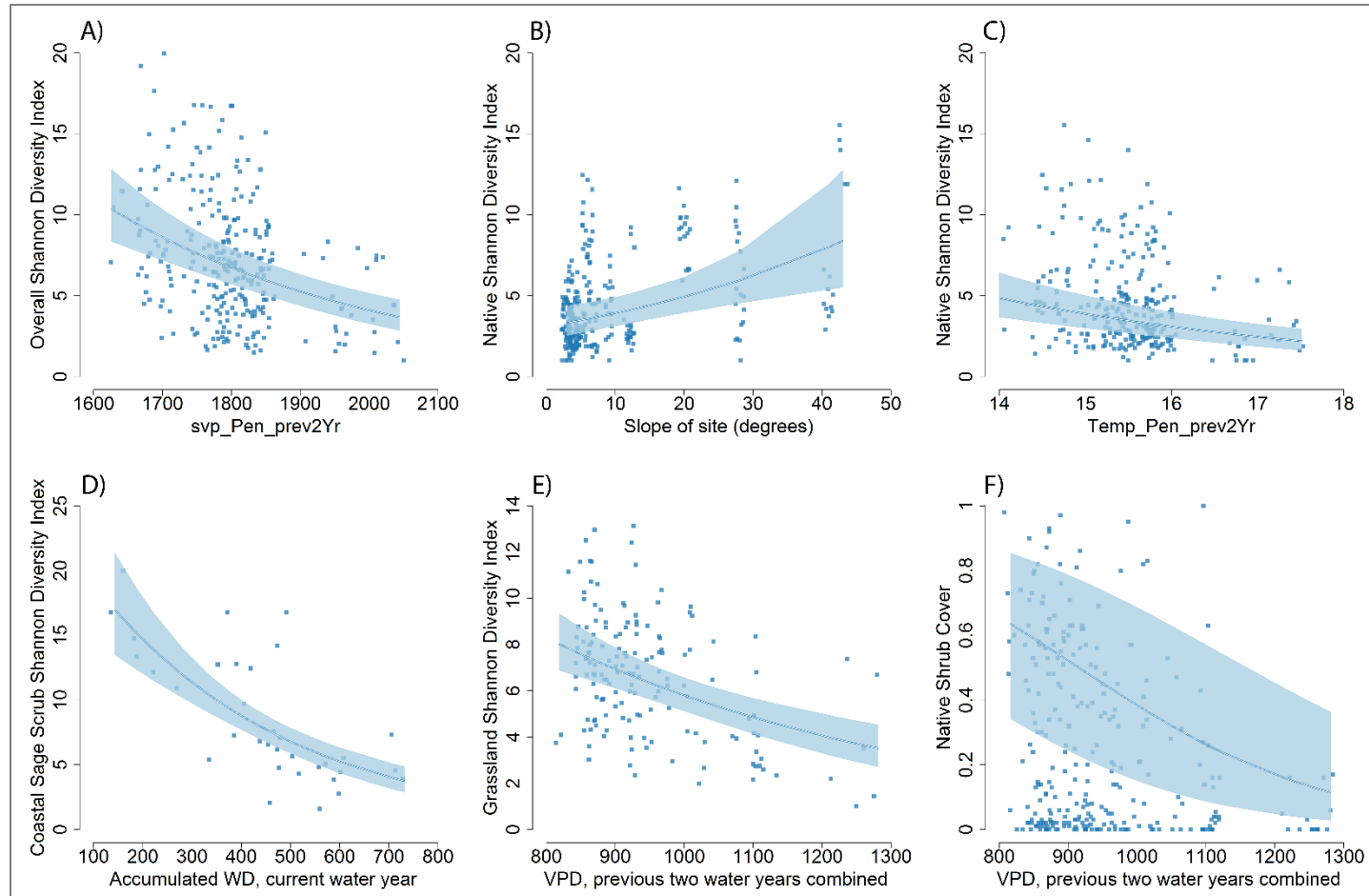


Figure 40. Marginal effects plots for final covariate models at index sites across Anacapa Island (first of two). A) Vapor pressure (svp, pascals) for the previous two water years combined ($p < 0.0001$) for overall Shannon diversity index. B) Site slope (degrees, $p = 0.0039$) for native Shannon diversity index. C) Temperature (degrees Celsius) for the previous two water years combined ($p < 0.0001$) for native Shannon diversity index. D) Accumulated water deficit (WD, mm) during the current water year ($p < 0.0001$) for coastal sage scrub Shannon diversity index. E) Vapor pressure deficit (VPD, pascals) for the previous two water years combined ($p < 0.0001$) for grassland Shannon diversity index. F) Vapor pressure deficit (VPD, pascals) for the previous two water years combined ($p < 0.0001$) for native shrub cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

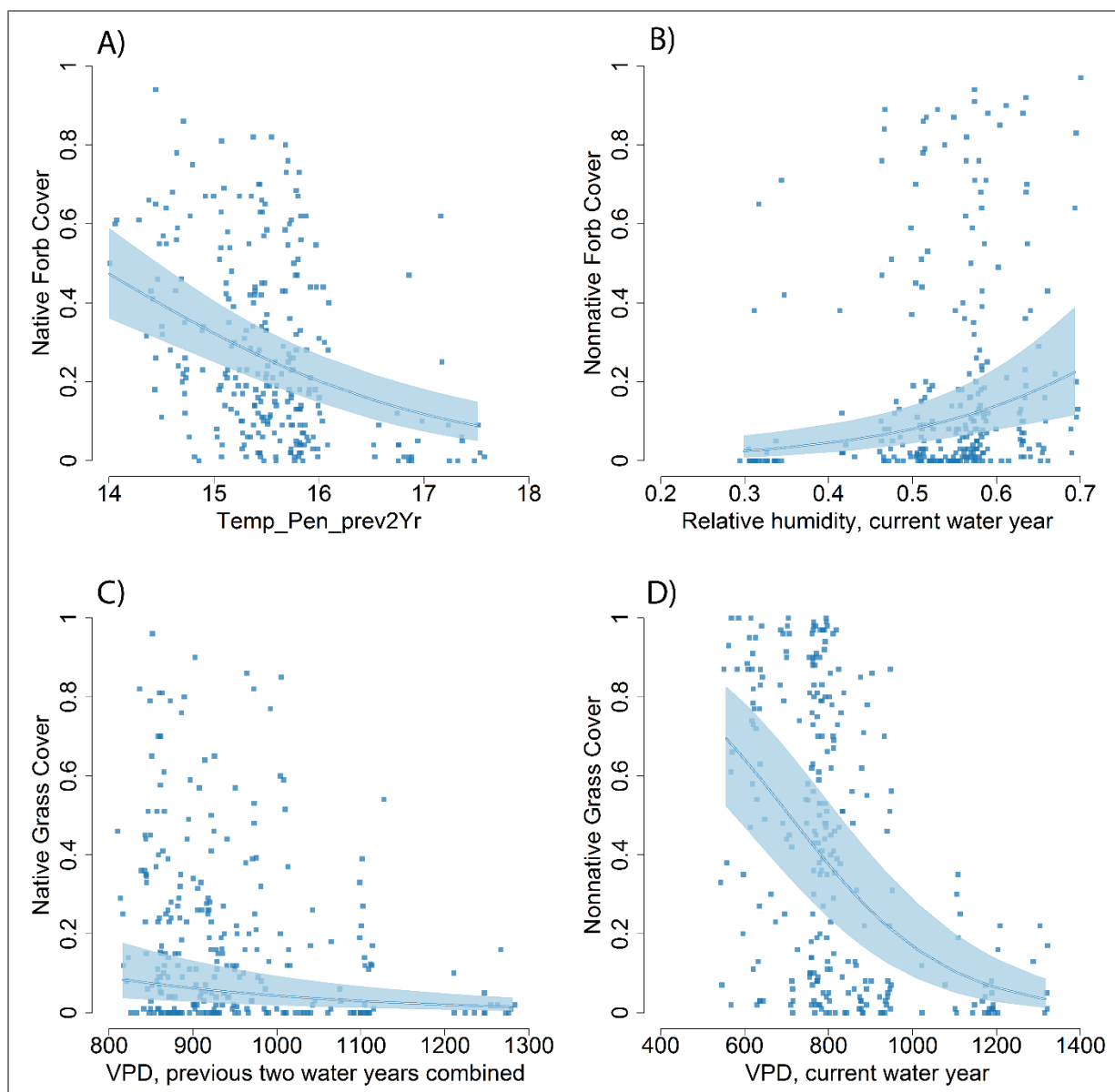


Figure 41. Marginal effects plots for final covariate models at index sites across Anacapa Island (second of two). A) Temperature (degrees Celsius) for the previous two water years combined ($p < 0.0001$) for native forb cover. B) Relative humidity (percentage divided by 100) during the current water year ($p = 0.0016$) for nonnative forb cover. C) Vapor pressure deficit (VPD, pascals) for the previous two water years combined ($p < 0.0001$) for native grass cover. D) Vapor pressure deficit (VPD, pascals) during the current water year ($p < 0.0001$) for nonnative grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for nonnative forb cover at index sites on AN contained a number of water balance covariates summarized for the current water year or calendar year, such as relative humidity, soil moisture, modeled actual evapotranspiration, and vapor pressure deficit (top three models shown in Table 22). Additionally, some of the top models contained a fixed effect for the AN islet (East, Middle, or West), the northness of the site, the slope of the site, and monthly water deficit. The final

model contained a single fixed effect for relative humidity summarized over the current water year (rh_Pen_currYr), and this effect was positively associated with nonnative forb cover ($p = 0.0016$, Figure 41B).

The final model for native grass cover at index sites on AN contained only a single fixed effect for vapor pressure deficit over the previous two water years (vpd_Pen_prev2Yr; Table 22). This effect was negatively associated with native grass cover ($p < 0.0001$), demonstrating that as vapor pressure deficit increased the native grass cover declined (Figure 41C).

The top models for nonnative grass cover at AN index sites contained covariates for islet, relative humidity and vapor pressure deficit for the current water year, and modeled actual evapotranspiration summarized over the calendar year (top three models shown in Table 22). The final model contained only a fixed effect for the current water year vapor pressure deficit (vpd_Pen_currYr). This effect was negatively associated with nonnative grass cover ($p < 0.0001$) and demonstrated decreasing nonnative grass cover as vapor pressure deficit increased (Figure 41D).

Anacapa Island Probability Sites

The final model for native Shannon diversity at probability sites on AN included terms for the islet (Islet; East, Middle, or West) and soil moisture during the current year fog season (SOIL_Pen_fogYr; Table 23). Soil moisture was negatively associated with native Shannon diversity but the effect was not statistically significant ($p = 0.3728$, Figure 42A). Native Shannon diversity was significantly higher at West islet sites as compared to East islet sites ($p < 0.0001$, Figure 42A) but was not significantly different from Middle islet sites ($p = 0.2611$, Figure 42A).

The final native shrub density model for probability sites on AN contained only a single fixed effect for the islet (Islet; Table 23). Native shrub density (Figure 42B) was significantly lower on the East islet than on the Middle islet ($p = 0.0022$) and the West islet ($p = 0.0021$).

Similar to native shrub density, the final model for native shrub cover included only a fixed effect for the islet (Islet; Table 23). Native shrub cover (Figure 42C) on the East islet was significantly lower than cover on the Middle islet ($p = 0.0118$) and on the West islet ($p = 0.0002$).

The top models for native forb cover at probability sites on AN included several water balance covariates summarized at the monthly level such as cumulative potential evapotranspiration, growing-degree days, temperature, modeled actual potential evapotranspiration, and water deficit (top three models shown in Table 23). The final model contained a single fixed effect of site elevation (Elevation_m) which was positively associated with native forb cover ($p = 0.0413$, Figure 43A).

Table 23. Covariate models ranked by AICc for all outcomes at probability sites across Anacapa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Shannon Diversity	SOIL_Pen_fogYr+Islet^A	77.21	0.00
	vpd_Pen_prev2Yr	89.01	11.80
	Def_Pen_currYr	89.28	12.06
Native Shrub Density	Islet^A	71.97	0.00
	Northness+Islet	72.65	0.68
	rh_Pen_prevYr+Islet	73.87	1.90
Native Shrub Cover	Northness+Islet	108.36	0.00
	Islet^A	109.37	1.01
	rh_Pen_fogYr+Islet	110.50	2.15
Native Forb Cover	Elevation_m^A	148.97	0.00
	PET_Pen_mo	149.04	0.06
	GDD_Pen_mo	149.24	0.27
Nonnative Forb Cover	rh_Pen_prev2Yr^A	135.27	0.00
	solRad_prev2Yr	135.42	0.15
	rh_Pen_prev2Yr+Northness	136.11	0.84
Native Grass Cover	vpd_Pen_prev2Yr^A	109.82	0.00
	solRad_fog	110.99	1.17
	AET_Pen_fogYr	111.28	1.46
Nonnative Grass Cover	Northness^A	146.50	0.00
	rh_Pen_currYr+Northness	146.55	0.04
	Northness+Islet	146.73	0.23

^A Final covariate model for each outcome (also in bold font).

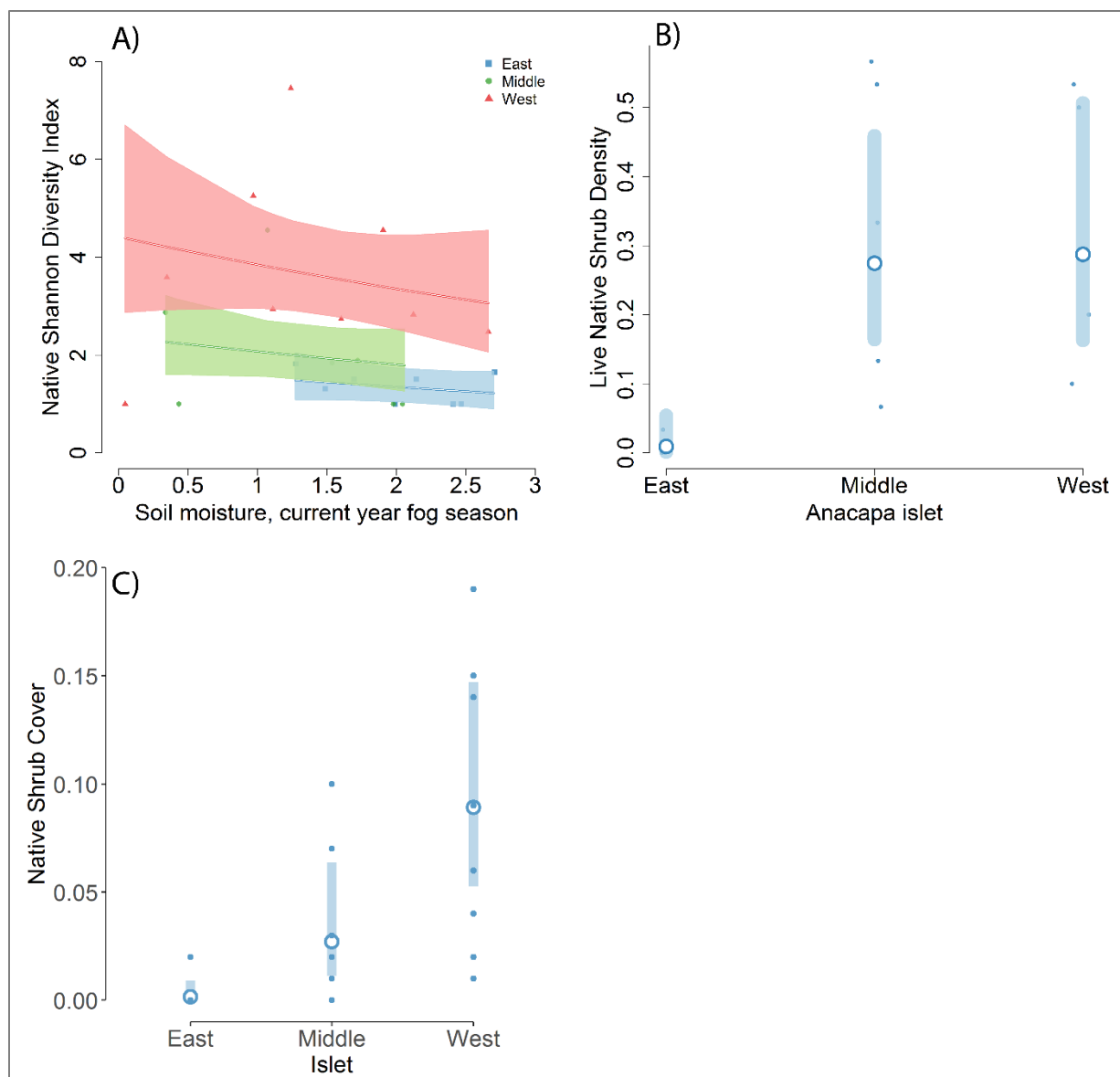


Figure 42. Marginal effects plots for final covariate models at probability sites across Anacapa Island (first of two). A) Soil moisture (mm, $p = 0.3728$) by islet during the current year fog season for native Shannon diversity index. B) Box plot by islet (Middle, $p = 0.0022$; West, $p = 0.0021$) for native shrub density. C) Box plot of islet (Middle, $p = 0.0118$; West, $p = 0.0002$) for native shrub cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

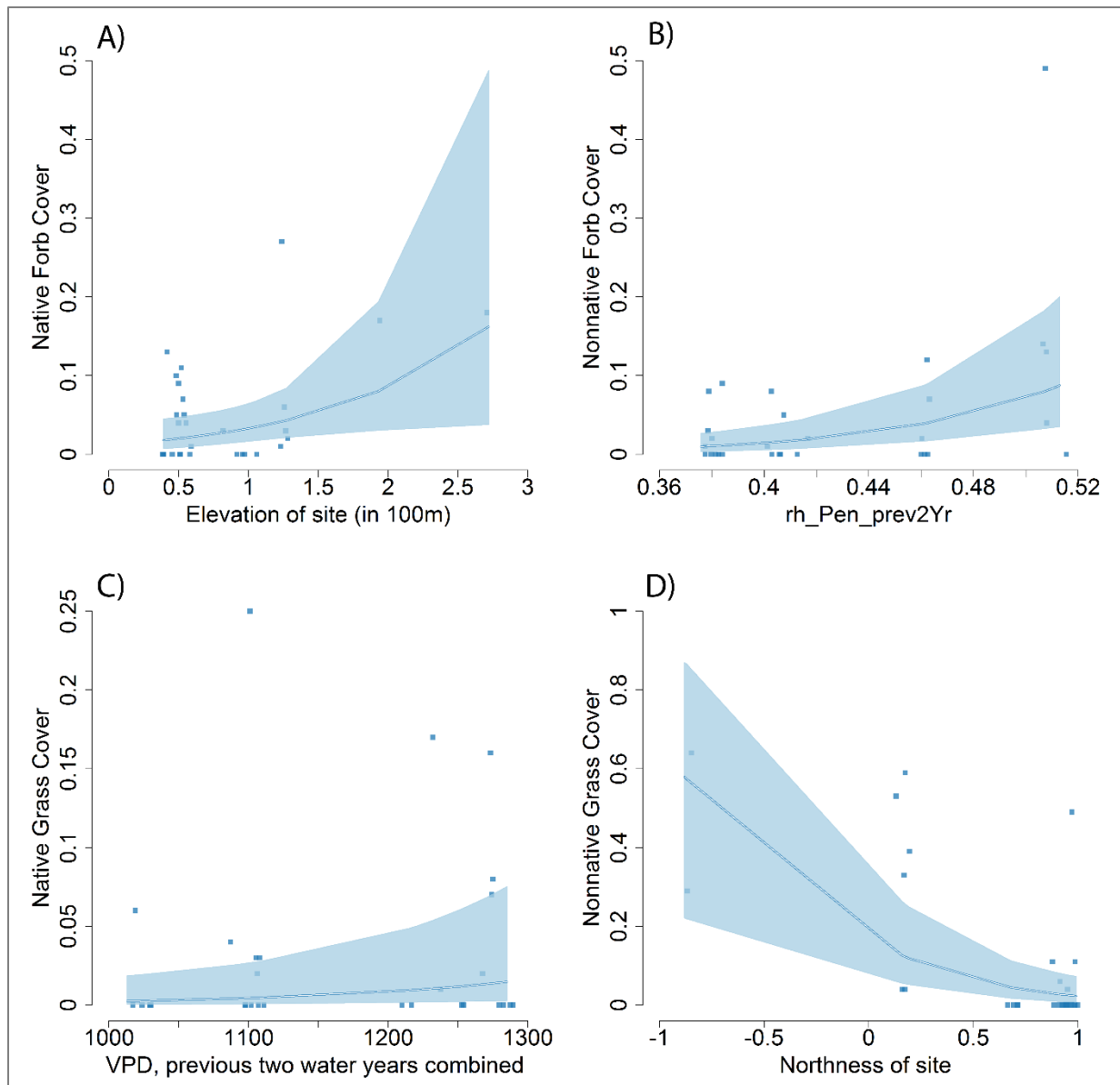


Figure 43. Marginal effects plots for final covariate models at probability sites across Anacapa Island (second of two). A) Site elevation (in 100 m increments, $p = 0.0413$) for native forb cover. B) Relative humidity (percentage divided by 100) for the previous two water years combined ($p = 0.0001$) for nonnative forb cover. C) Vapor pressure deficit (VPD, pascals) for the previous two water years combined ($p = 0.0204$) for native grass cover. D) Site northness ($p = 0.0003$) for nonnative grass cover (northness values of 1 indicate the site is oriented due north, while values of -1 indicate due south orientation).
NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Top models for nonnative forb cover at probability sites on AN included terms for relative humidity and solar radiation summarized over the previous two water years as well as a model that included site northness (Table 23). The final model included only a single term for relative humidity over the previous two water years (rh_Pen_prev2Yr) which was positively correlated with nonnative forb cover ($p = 0.0001$, Figure 43B).

The top models for native grass cover at probability sites on AN included several water balance variables such as vapor pressure deficit, solar radiation, modeled actual evapotranspiration, and water deficit (top three models shown in Table 23). The final model included a fixed effect for vapor pressure deficit summarized over the previous two water years (vpd_Pen_prev2Yr). This effect had a positive association with native grass cover ($p = 0.0204$), indicating that as the vapor pressure deficit increased, native grass cover also increased (Figure 43C).

The top models for nonnative grass cover at probability sites on AN contained fixed effects for site northness, current year relative humidity, islet, elevation, and 30-year means for solar radiation, potential evapotranspiration, and clear sky net solar radiation for all months (top three models shown in Table 23). The final model contained a single fixed effect for site northness (Northness) which was negatively associated with nonnative grass cover ($p = 0.0003$), indicating that sites oriented to the north have lower nonnative grass cover than sites with more southerly exposure (Figure 43D).

Covariate Modeling for Santa Barbara Island

A subset of the full covariate modeling results across Santa Barbara Island (SB) is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

Santa Barbara Island Index Sites

The top models for overall Shannon diversity at index sites on SB included the soil moisture summarized by calendar year, the site slope, and the number of days with dew during the current water year (Table 24). The final model contained only a single fixed effect for the modeled actual evapotranspiration for the calendar year (AET_Pen_an). This effect was estimated to be positively associated with overall Shannon diversity ($p < 0.0001$, Figure 44A).

The top model for native Shannon diversity at index sites on SB included soil moisture for the calendar year (SOIL_Pen_an) and the site slope (Slope_degrees; Table 24). Both site slope ($p = 0.0005$, Figure 44B) and soil moisture ($p < 0.0001$, Figure 44C) were positively associated with native Shannon diversity.

The top covariate model for grassland Shannon diversity at index sites on SB contained terms for the number of days with dew during the current water year (Dew_Pen_fogYr), site northness (Northness), and site elevation (Elevation_m; Table 24). However, the significance test for the number of days with dew ($p = 0.3973$, Figure 44D) was not significant at the 0.10 level. Site elevation was positively associated with grassland Shannon diversity ($p < 0.0001$, Figure 44E). Site northness ($p = 0.2222$, Figure 44F) was also not significant at the 0.10 level. An examination of correlation among covariates indicated that the correlation between northness and elevation for this data set was -0.86 , so multicollinearity may affect these results despite generating a condition number less than 5. The data set consists of only four transects for which simpler models did not converge, so the model is likely overparameterized.

Table 24. Covariate models ranked by AICc for all outcomes at index sites across Santa Barbara Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	SOIL_Pen_an+Slope_degrees	1679.22	0.00
	SOIL_Pen_an+Dew_Pen_currYr+Slope_degrees	1680.95	1.73
	AET_Pen_an^A	1681.18	1.96
Native Shannon Diversity	SOIL_Pen_an+Slope_degrees^A	1117.37	0.00
	SOIL_Pen_an+Dew_Pen_currYr+Slope_degrees	1119.37	1.99
	AET_Pen_an+AET_Pen_prevYr	1123.62	6.25
Grassland Shannon Diversity	Dew_Pen_fogYr+Northness+Elevation_m^A	329.46	0.00
	Dew_Pen_currYr+Slope_degrees	332.67	3.22
	Northness+Elevation_m	335.63	6.17
Native Shrub Density	SOIL_Pen_prev2Yr+Slope_degrees	633.72	0.00
	Slope_degrees^A	633.88	0.16
	Temp_Pen_prevYr+Slope_degrees	634.25	0.53
Native Shrub Cover	Def_Pen_mo+Dew_Pen_prevYr+Slope_degrees^A	2719.91	0.00
	Temp_Pen_mo+Dew_Pen_prevYr+Slope_degrees	2720.42	0.51
	Temp_Pen_mo+Slope_degrees	2724.41	4.49
Native Forb Cover	AET_Pen_an+Def_Pen_currYr	3197.47	0.00
	AET_Pen_an^A	3197.77	0.30
	AET_Pen_an+Def_Pen_mo	3198.71	1.24
Nonnative Forb Cover	SOIL_Pen_prevYr+Slope_degrees	3461.99	0.00
	AET_Pen_currYr^A	3462.78	0.79
	Def_Pen_mo+Slope_degrees	3463.37	1.38
Native Grass Cover	SOIL_Pen_fogYr+Slope_degrees	851.01	0.00
	Dew_Pen_prevYr+Slope_degrees	851.64	0.63

^A Final covariate model for each outcome (also in bold font).

Table 24 (continued). Covariate models ranked by AICc for all outcomes at index sites across Santa Barbara Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Grass Cover (continued)	Slope_degrees^A	852.02	1.01
Nonnative Grass Cover	AET_Pen_currYr+Def_Pen_mo^A	3502.08	0.00
	SOIL_Pen_prev2Yr+Def_Pen_mo	3505.05	2.97
	Temp_Pen_mo+Dew_Pen_currYr+Slope_degrees	3505.21	3.14
<i>Deinandra clementina</i> Cover	SOIL_Pen_prev2Yr+Slope_degrees^A	597.91	0.00
	Def_Pen_currYr	601.93	4.02
	Temp_Pen_currYr+Slope_degrees	602.09	4.18
<i>Eriogonum giganteum</i> Var. <i>compactum</i> Cover	solRad_prev2Yr^A	406.90	0.00
	Northness+Elevation_m	416.44	9.53
	AET_Pen_prev2Yr+Def_Pen_prevYr	416.71	9.81
<i>Hordeum murinum</i> Cover	AET_Pen_currYr+Def_Pen_mo^A	2219.14	0.00
	SOIL_Pen_currYr+Def_Pen_mo	2224.67	5.53
	SOIL_Pen_currYr+Def_Pen_mo+Dew_Pen_prev2Yr	2226.31	7.18
<i>Mesembryanthemum crystallinum</i> Cover	Temp_Pen_mo+Dew_Pen_prev2Yr^A	2072.46	0.00
	SOIL_Pen_fogYr+Temp_Pen_mo+Dew_Pen_prev2Yr+Slope_degrees	2072.83	0.36
	Temp_Pen_prev2Yr+Dew_Pen_prev2Yr	2073.13	0.66
<i>Suaeda taxifolia</i> Cover	SOIL_Pen_prevYr+Def_Pen_mo^A	1193.16	0.00
	AET_Pen_currYr+Def_Pen_mo	1193.61	0.46
	Def_Pen_mo	1198.24	5.08

^A Final covariate model for each outcome (also in bold font).

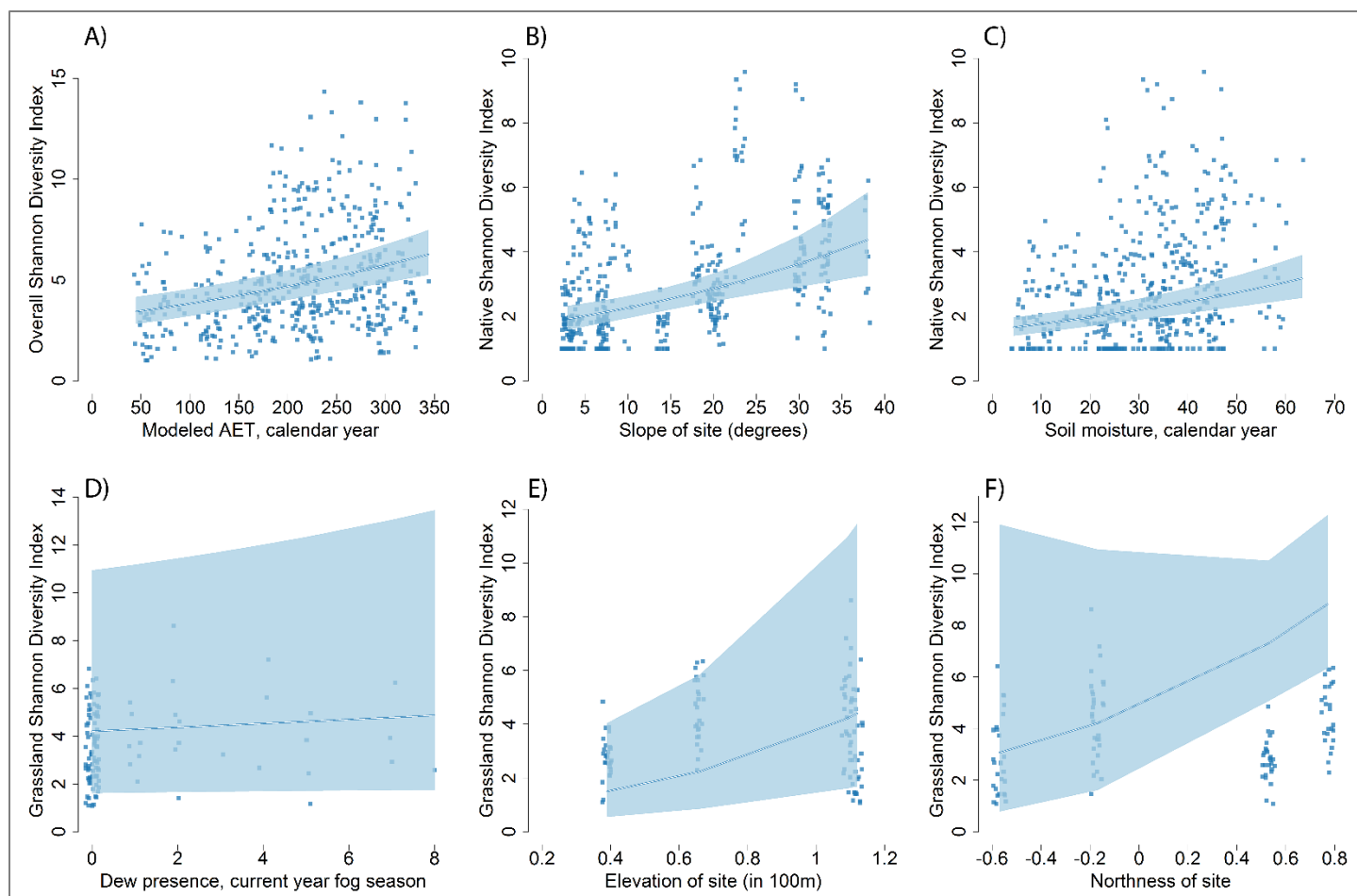


Figure 44. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (first of four). A) Annual modeled actual evapotranspiration (AET, mm; $p < 0.0001$) for overall Shannon diversity index. B) Site slope (degrees, $p = 0.0005$) for native Shannon diversity index. C) Annual soil moisture (mm, $p < 0.0001$) for native Shannon diversity index. D) Dew presence (measured as the number of days that dew was present) during the current year fog season ($p = 0.3973$) for grassland Shannon diversity index. E) Site elevation (in 100 m increments, $p < 0.0001$) for grassland Shannon diversity index. F) Site northness ($p = 0.2222$) for grassland Shannon diversity index (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top covariate models for native shrub density at index sites on SB included terms for soil moisture over the past two water years; the site slope; the temperature over the previous water year; and monthly summaries of water deficit, modeled actual evapotranspiration, and temperature (top three models shown in Table 24). The final model contained a single fixed effect for the site slope (Slope_degrees) which was positively associated with native shrub density ($p = 0.0298$, Figure 45A).

The final model for native shrub cover at index sites on SB contained terms for monthly water deficit (Def_Pen_mo), number of days with dew in the previous water year (Dew_Pen_prevYr), and the slope of the site (Slope_degrees; Table 24). However, the significance test for monthly water deficit, which was negatively associated with native shrub cover, resulted in a p-value that was larger than the Type I error level of 0.10 ($p = 0.1698$, Figure 45B). Both the number of days with dew in the previous water year ($p = 0.0039$, Figure 45C) and the site slope ($p = 0.0083$, Figure 45D) were positively associated with native shrub cover.

Top models for native forb cover at SB index sites contained covariates for modeled actual evapotranspiration and water deficit (top three models shown in Table 24). The final model contained the modeled actual evapotranspiration for the calendar year (AET_Pen_an), and this effect was positively associated with native forb cover ($p < 0.0001$, Figure 45E).

Top models for nonnative forb cover on SB index sites include terms for soil moisture, site slope, modeled actual evapotranspiration, and water deficit (top three models shown in Table 24). The final model contained only a single fixed effect for modeled actual evapotranspiration over the current water year (AET_Pen_currYr), which is positively associated with nonnative forb cover ($p < 0.0001$, Figure 45F).

Top native grass cover models on SB index sites contained the site slope, soil moisture for the current fog season, number of days with dew in the previous water year, water deficit by month, and temperature for the month or current water year level (top three models shown in Table 24). The final model contained only a fixed effect for the site slope (Slope_degrees), and this effect was positively associated with native grass cover ($p = 0.0016$, Figure 46A).

The final covariate model for nonnative grass cover at SB index sites contained a term for modeled actual evapotranspiration during the current water year (AET_Pen_currYr) and the monthly water deficit (Def_Pen_mo; Table 24). Modeled actual evapotranspiration was positively associated with nonnative grass cover ($p = 0.0001$, Figure 46B). A negative relationship between monthly water deficit and nonnative grass cover was estimated, but the two-sided test for the regression coefficient was not significant at the 0.10 level ($p = 0.6441$, Figure 46C).

The final model for *Deinandra clementina* cover at index sites on SB contained a term for soil moisture summarized over the previous two water years (SOIL_Pen_prev2Yr) and the site slope (Slope_degrees; Table 24). Both the site slope ($p = 0.0834$, Figure 46D), and the soil moisture summarized over the previous two water years ($p = 0.0033$, Figure 46E) were positively associated with *Deinandra clementina* cover.

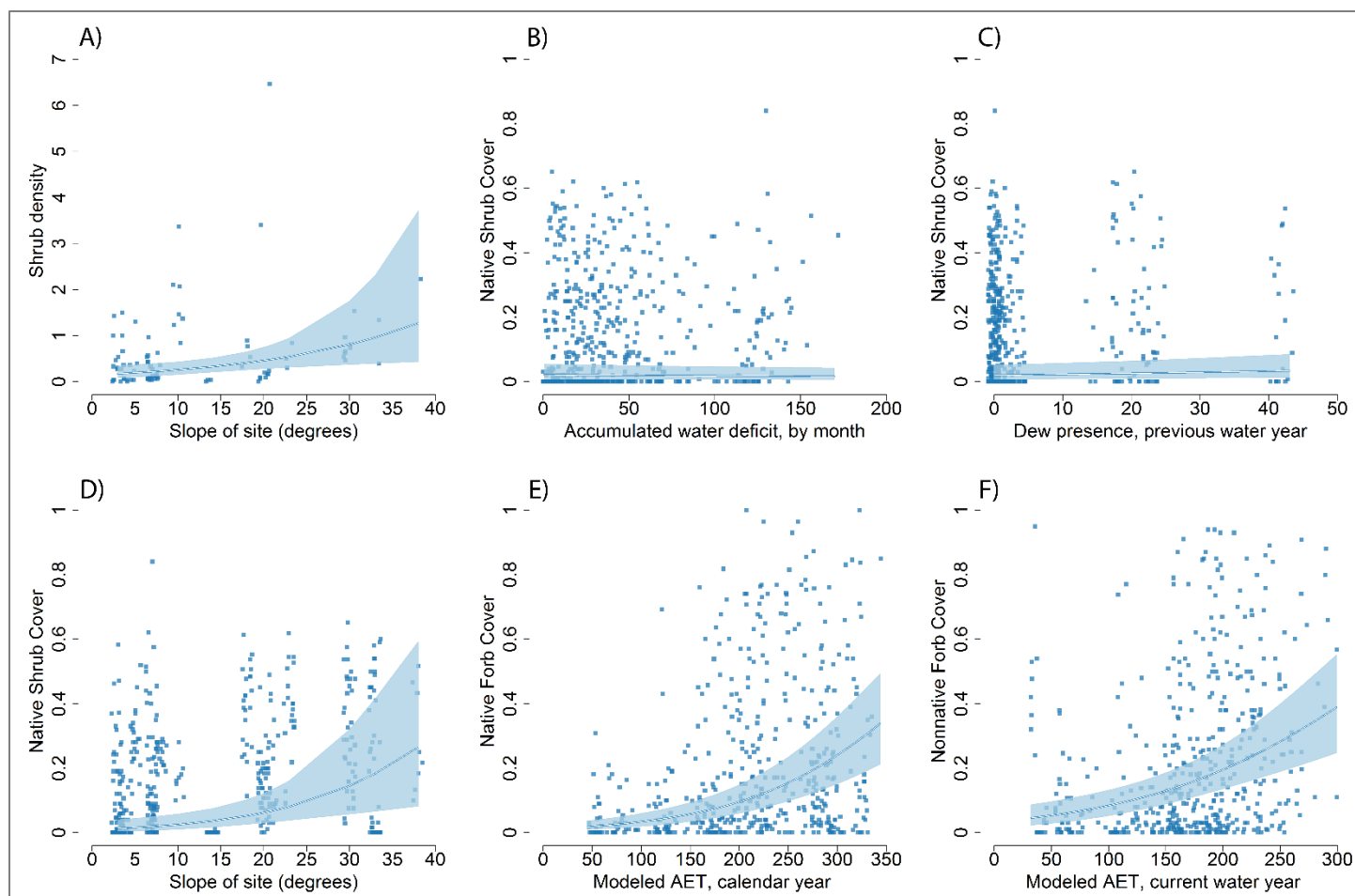


Figure 45. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (second of four). A) Site slope (degrees, $p = 0.0298$) for native shrub density. B) Monthly accumulated water deficit (mm, $p = 0.1698$) for native shrub cover. C) Dew presence (measured as the number of days that dew was present) during the previous water year ($p = 0.0039$) for native shrub cover. D) Site slope (degrees, $p = 0.0083$) for native shrub cover. E) Annual modeled actual evapotranspiration (AET, mm; $p < 0.0001$) for native forb cover. F) Modeled actual evapotranspiration (AET, mm) during the current water year ($p < 0.0001$) for nonnative forb cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

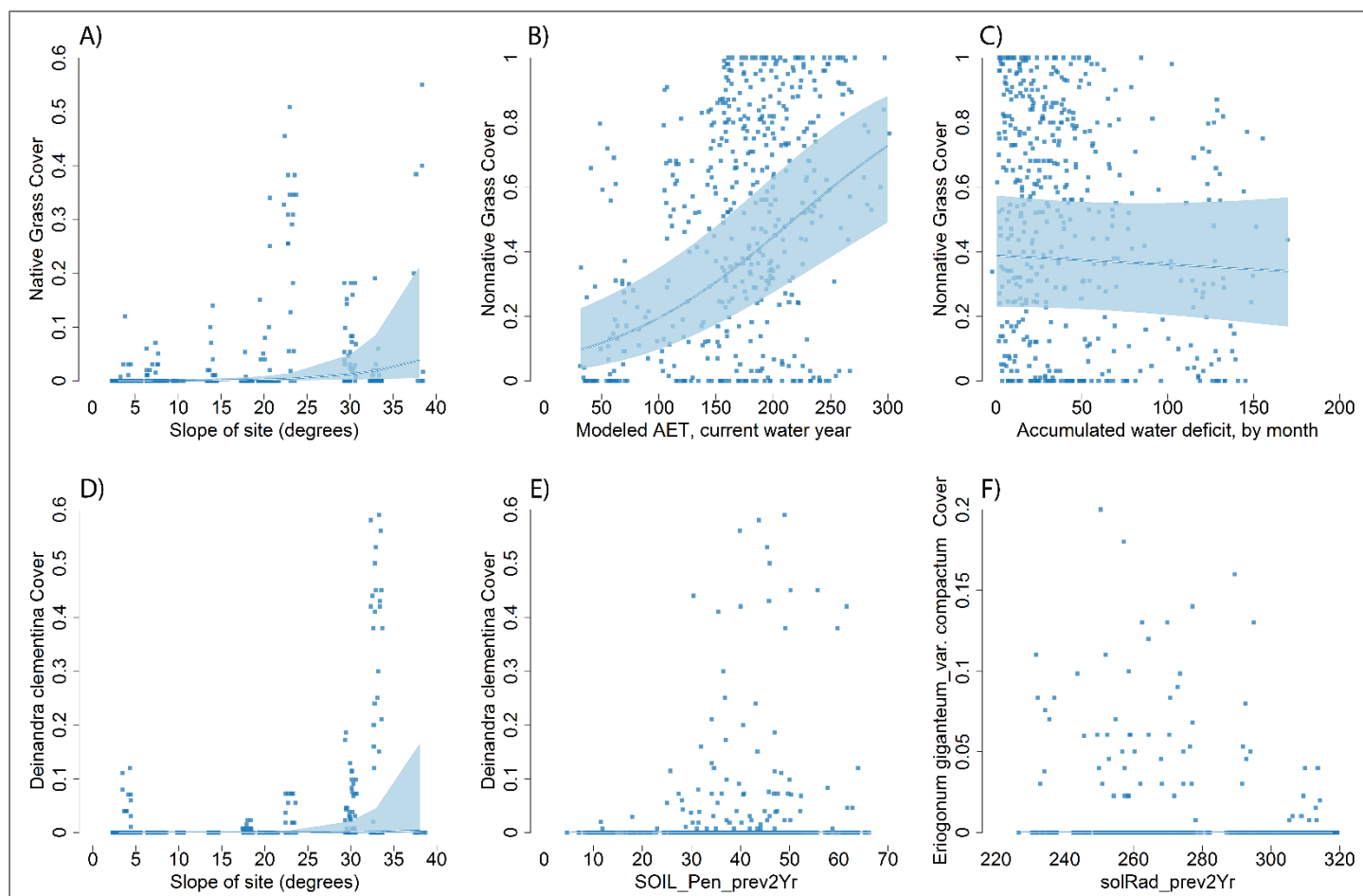


Figure 46. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (third of four). A) Site slope (degrees, $p = 0.0016$) for native grass cover. B) Modeled actual evapotranspiration (AET, mm) during the current water year ($p = 0.0001$) for nonnative grass cover. C) Monthly accumulated water deficit (mm, $p = 0.6441$) for nonnative grass cover. D) Site slope (degrees, $p = 0.0834$) for *Deinandra clementina* cover. E) Soil moisture (mm) for the previous two water years combined ($p = 0.0033$) for *Deinandra clementina* cover. F) Total clear sky solar radiation (watts per square meter) for the previous two water years combined ($p < 0.0001$) for *Eriogonum giganteum* var. *compactum* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The final model for *Eriogonum giganteum* var. *compactum* cover at index sites on SB contained a single fixed effect for solar radiation over the previous two water years (solRad_prev2Yr; Table 24). This effect was negatively associated with *Eriogonum giganteum* cover ($p < 0.0001$, Figure 46F). However, note that *Eriogonum giganteum* cover was near zero for all years.

The final model for *Hordeum murinum* cover at index sites on SB contained terms for modeled actual evapotranspiration for the current water year (AET_Pen_currYr) and monthly water deficit (Def_Pen_mo; Table 24). The effect for modeled actual evapotranspiration for the current water year was positively associated with *Hordeum murinum* cover ($p = 0.0002$, Figure 47A). The monthly water deficit was negatively associated with *Hordeum murinum* cover, but the two-sided test was not significant at the 0.10 level ($p = 0.4877$, Figure 47B).

The top models for *Mesembryanthemum crystallinum* cover at index sites on SB, defined as models with AICc values within two units of the minimum AICc value, contained terms for monthly temperature, the number of days with dew within the previous two water years, soil moisture during the current fog season, site slope, and temperature summarized over the previous two water years (top three models shown in Table 24). The final model contained terms for monthly temperature (Temp_Pen_mo) and the number of days with dew within the previous two water years (Dew_Pen_prev2Yr; Table 24). The number of days with dew within the previous two water years was negatively associated with *Mesembryanthemum crystallinum* cover ($p = 0.0014$, Figure 47C), and monthly temperature was positively associated with *Mesembryanthemum crystallinum* cover ($p < 0.0001$, Figure 47D).

The top model for *Suaeda taxifolia* cover at index sites on SB contained terms for soil moisture over the previous water year (SOIL_Pen_prevYr) and monthly water deficit (Def_Pen_mo; Table 24). Both effects were positively associated with *Suaeda taxifolia* cover, but the test for monthly water deficit did not provide evidence of a statistical effect ($p = 0.1765$, Figure 47E). The two-sided hypothesis for soil moisture, however, was significant at the 0.10 level ($p = 0.0055$, Figure 47F).

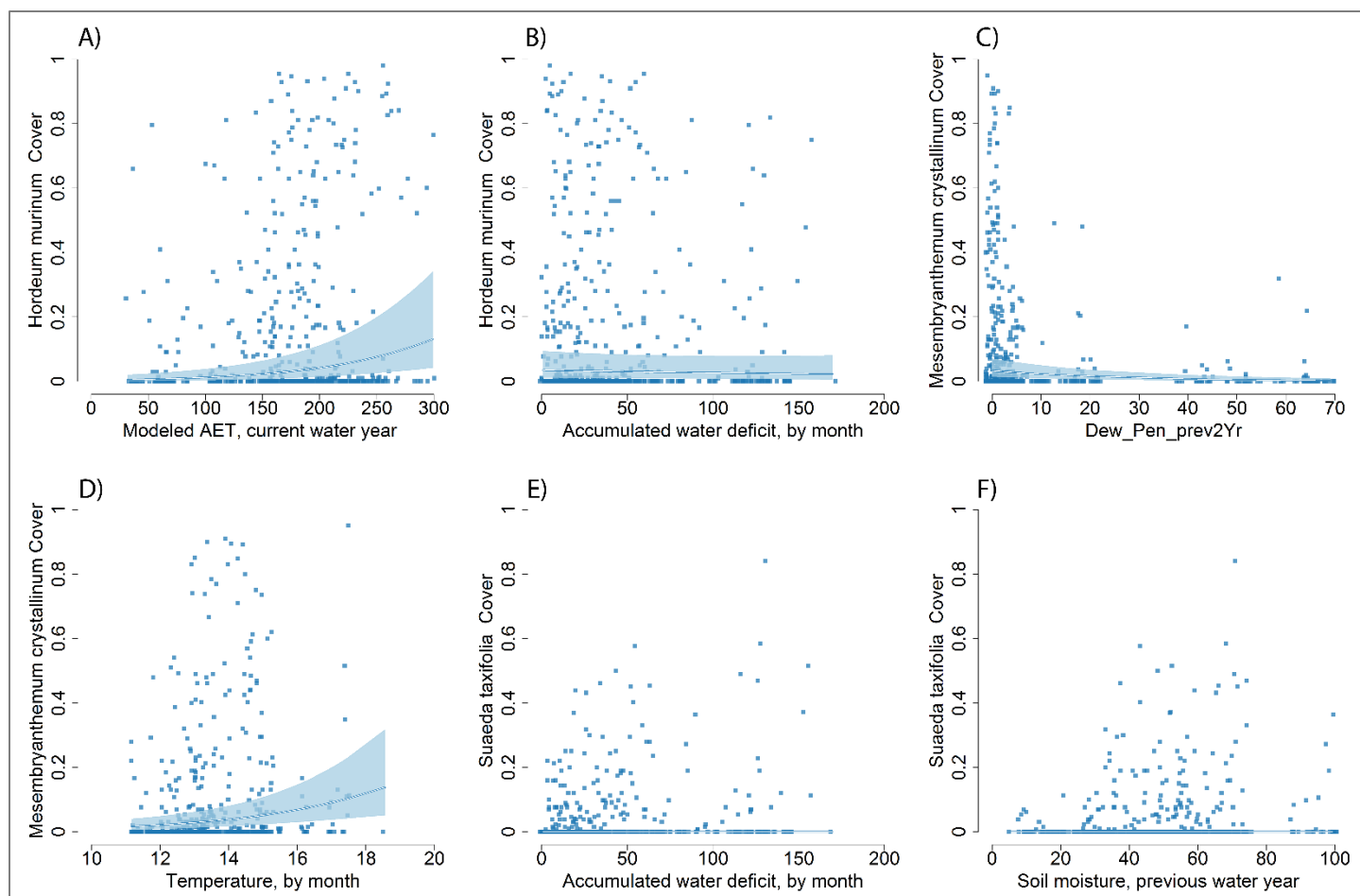


Figure 47. Marginal effects plots for final covariate models at index sites across Santa Barbara Island (fourth of four). A) Modeled actual evapotranspiration (AET, mm) during the current water year ($p = 0.0002$) for *Hordeum murinum* cover. B) Monthly accumulated water deficit (mm, $p = 0.4877$) for *Hordeum murinum* cover. C) Dew presence (measured as the number of days that dew was present) for the previous two water years combined ($p < 0.0001$) for *Mesembryanthemum crystallinum* cover. D) Monthly temperature (degrees Celsius, $p = 0.0014$) for *Mesembryanthemum crystallinum* cover. E) Monthly accumulated water deficit (mm, $p = 0.1765$) for *Suaeda taxifolia* cover. F) Soil moisture during the previous water year (mm, $p = 0.0055$) for *Suaeda taxifolia* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Santa Barbara Island Probability Sites

The final covariate model for overall Shannon diversity at probability sites on SB contained a single fixed effect for soil moisture summarized over the previous water year (SOIL_Pen_prevYr; Table 25). The effect exhibited a negative association with overall Shannon diversity ($p < 0.0001$, Figure 48A).

The top models for native shrub cover at SB probability sites contained several water balance covariates summarized across all months and averaged over the previous 30 years, including cumulative potential evapotranspiration, total clear sky solar radiation, and clear sky net solar radiation, in addition to modeled actual evapotranspiration summarized over the previous water year (top three models shown in Table 25). The final model contained a single fixed effect for the 30-year mean of cumulative potential evapotranspiration averaged across all months (pet_allMonth), and this effect was positively associated with native shrub cover ($p = 0.0201$, Figure 48B).

The top models for native forb cover at probability sites on SB contained site slope, modeled actual evapotranspiration and water deficit summarized over the current fog season, and temperature summarized by the month or the calendar year (top three and final models shown in Table 25). The final model contained a single fixed effect for water deficit summarized over the current fog season (Def_Pen_fogYr; the fifth-ranked model), and this effect had a negative association with native forb cover ($p = 0.0028$, Figure 48C).

The top covariate model for nonnative forb cover at SB probability sites contained fixed effects for soil moisture summarized over the current water year (SOIL_Pen_currYr) and monthly accumulated water deficit (Def_Pen_mo; Table 25). Both accumulated water deficit ($p = 0.0029$, Figure 48D) and soil moisture ($p < 0.0001$, Figure 48E) were positively correlated with nonnative forb cover at SB probability sites.

The top model for nonnative grass cover at probability sites on SB contained an effect for site northness (Northness) and an effect for site elevation (Elevation_m; Table 25). Both the site elevation ($p < 0.0001$, Figure 48F) and site northness ($p < 0.0001$, Figure 49A) were positively associated with nonnative grass cover at probability sites on SB.

The top covariate models for *Hordeum murinum* cover at probability sites on SB contained variables for site northness and water balance variables such as monthly cumulative potential evapotranspiration, relative humidity for the current fog season, modeled actual evapotranspiration for the previous water year, and soil moisture for the previous water year (top three models shown in Table 25). The final model contained a single fixed effect for monthly cumulative potential evapotranspiration (PET_Pen_mo) which increased with *Hordeum murinum* cover ($p = 0.0002$, Figure 49B) at SB probability sites.

The final model for *Mesembryanthemum crystallinum* cover at SB probability sites contained a single fixed effect for cumulative potential evapotranspiration measured in the current fog season (PET_Pen_fogYr; Table 25). *Mesembryanthemum crystallinum* cover increased as cumulative potential evapotranspiration increased ($p = 0.0011$, Figure 49C).

Table 25. Covariate models ranked by AICc for all outcomes at probability sites across Santa Barbara Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	SOIL_Pen_prevYr^A	144.83	0.00
	AET_Pen_fogYr+Temp_Pen_mo	151.81	6.98
	GDD_Pen_mo	152.80	7.96
Native Shrub Cover	pet_allMonth^A	183.08	0.00
	rad_allMonth	183.70	0.62
	rn_allMonth	183.70	0.62
Native Forb Cover	AET_Pen_fogYr+Temp_Pen_an+Slope_degrees	221.45	0.00
	AET_Pen_fogYr+Temp_Pen_mo	221.59	0.14
	AET_Pen_fogYr+Temp_Pen_mo+Slope_degrees	221.81	0.36
	Def_Pen_fogYr^A	222.84	1.39
Nonnative Forb Cover	AET_Pen_prevYr+SOIL_Pen_currYr+Def_Pen_mo	349.90	0.00
	SOIL_Pen_currYr+Def_Pen_mo^A	350.45	0.56
	Def_Pen_prevYr	353.10	3.21
Nonnative Grass Cover	Dew_Pen_currYr+Northness+Elevation_m	293.85	0.00
	Northness+Elevation_m^A	295.18	1.33
	Dew_Pen_currYr+Northness	305.93	12.08
<i>Hordeum Murinum</i> Cover	PET_Pen_mo^A	214.59	0.00
	rh_Pen_fogYr+Northness	216.06	1.47
	PET_Pen_mo+AET_Pen_prevYr	216.43	1.85
<i>Mesembryanthemum Crystallinum</i> Cover	PET_Pen_fogYr^A	277.59	0.00
	Slope_degrees	279.54	1.95
	SOIL_Pen_prev2Yr+Slope_degrees	280.40	2.81

^A Final covariate model for each outcome (also in bold font).

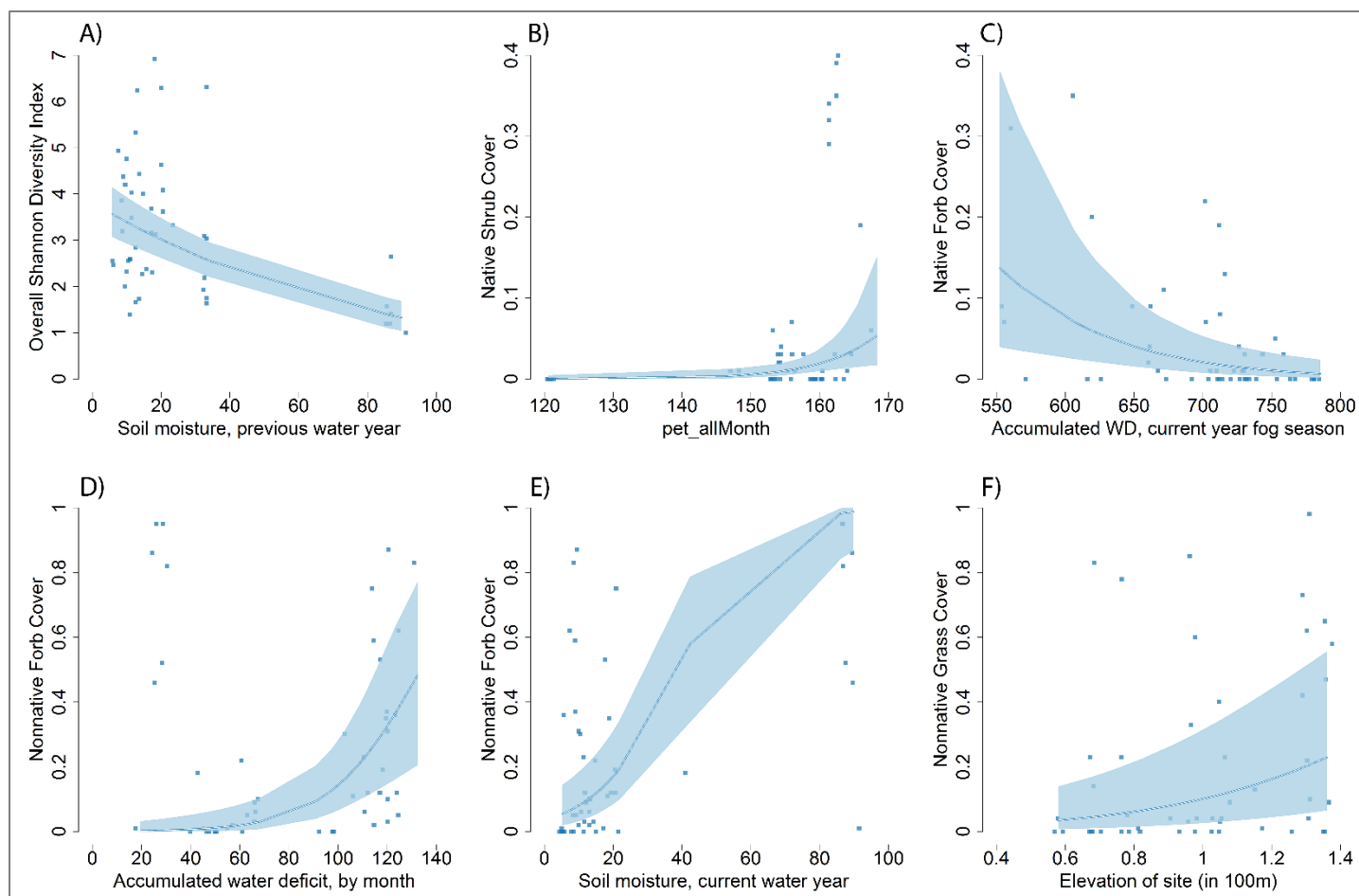


Figure 48. Marginal effects plots for final covariate models at probability sites across Santa Barbara Island (first of two). A) Soil moisture (mm) during the previous water year ($p < 0.0001$) for overall Shannon diversity index. B) Mean of 30-year monthly means for all months of cumulative potential evapotranspiration (PET, mm; $p = 0.0201$) for native shrub cover. C) Accumulated water deficit (WD, mm) during the current year fog season ($p = 0.0028$) for native forb cover. D) Monthly accumulated water deficit (mm, $p = 0.0029$) for nonnative forb cover. E) Soil moisture (mm) during the current water year ($p < 0.0001$) for nonnative forb cover. F) Site elevation (in 100 m increments, $p < 0.0001$) for nonnative grass cover. NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

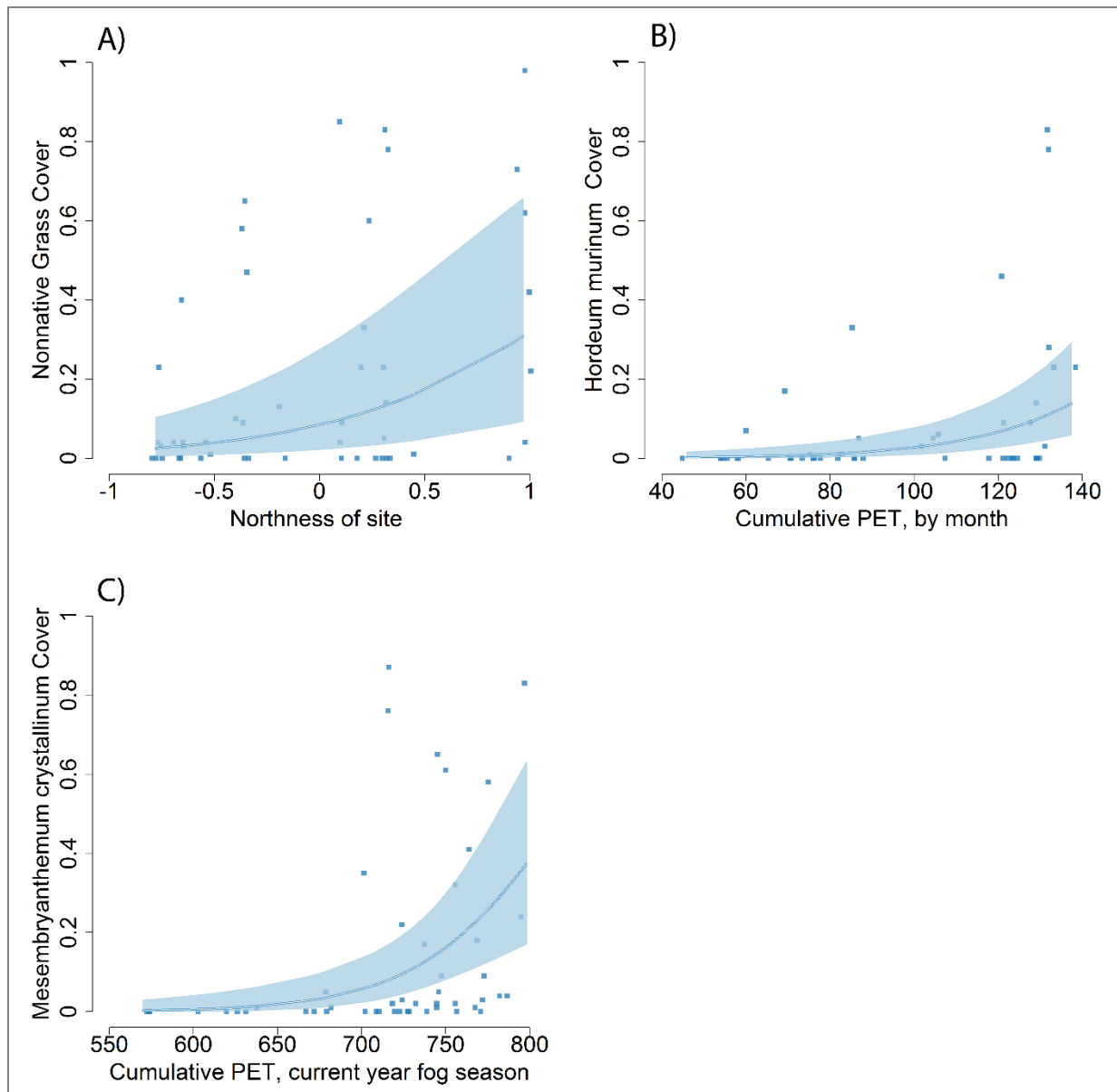


Figure 49. Marginal effects plots for final covariate models at probability sites across Santa Barbara Island (second of two). A) Site northness ($p < 0.0001$) for nonnative grass cover (values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation). B) Monthly cumulative potential evapotranspiration (PET, mm; $p = 0.0002$) for *Hordeum murinum* cover. C) Cumulative potential evapotranspiration (PET, mm) during the current year fog season ($p = 0.0011$) for *Mesembryanthemum crystallinum* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Covariate Modeling for Santa Cruz Island

A subset of the full covariate modeling results across Santa Cruz Island (SC) is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

Santa Cruz Island Index Sites

The top covariate model for overall Shannon diversity at index sites on SC consisted of fixed effects for monthly temperature (Temp_Pen_mo) and the number of years since pig removal (Pig; Table 26). Overall Shannon diversity was negatively associated with years since pig removal ($p = 0.0004$, Figure 50A) and positively associated with monthly temperature ($p < 0.0001$, Figure 50B).

The top models ranked by AICc for native Shannon diversity at SC index sites were all within two AICc units of the minimum, indicating a large suite of competing models. These models included fixed effects for the number of days with dew during the current fog season; indicators of pig and sheep removal; the number of years since sheep, cattle, or pig removal; and monthly summaries of temperature, growing-degree days, and water deficit (top three and final models shown in Table 26). The final model contained only a term for monthly temperature (Temp_Pen_mo, the fourth-ranked model) which was positively associated with native Shannon diversity at SC index sites ($p = 0.0167$, Figure 50C).

The top model for grassland Shannon diversity at SC index sites contained fixed effects for the monthly temperature (Temp_Pen_mo) and the number of years since pig removal (Pig; Table 26). Grassland Shannon diversity decreased as time passed since pig removal ($p = 0.0033$, Figure 50D) but increased as a function of monthly temperature ($p = 0.0098$, Figure 50E).

The top models for riparian Shannon diversity at SC index sites contained a range of water balance covariates, site northness, and nonnative mammal removal indicators (top three models shown in Table 26). The final model included fixed effects for relative humidity over the previous two water years (rh_Pen_prev2Yr) and site northness (Northness). Northness was positively associated with riparian Shannon diversity ($p < 0.0001$, Figure 50F). Relative humidity was negatively associated with riparian Shannon diversity, but the two-sided test of the coefficient was not significant at the 0.10 level ($p = 0.4449$, Figure 51A).

The final model for oak Shannon diversity at SC index sites contained fixed effects for monthly water deficit (Def_Pen_mo) and mean cumulative potential evapotranspiration calculated from 30-year monthly means for all months (pet_allMonth; Table 26). Both monthly water deficit ($p = 0.0246$, Figure 51B) and mean cumulative potential evapotranspiration ($p < 0.0001$, Figure 51C) were positively associated with oak Shannon diversity at SC index sites.

Top models for native tree density at SC index sites contained covariates such as site elevation, the number of years since pig removal, modeled actual evapotranspiration over the previous two water years, water deficit over the previous water year, and site northness (top three models shown in Table 26). The final model contained a single fixed effect for site elevation (Elevation_m) which was positively associated with native tree density at SC index sites ($p = 0.0016$, Figure 51D).

Table 26. Covariate models ranked by AICc for all outcomes at index sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	Temp_Pen_mo+Pig^A	1690.30	0.00
	AET_Pen_mo+Soil_water_mm_fog+Temp_Pen_mo	1692.87	2.57
	Def_Pen_mo	1693.11	2.82
Native Shannon Diversity	Dew_Pen_fogYr+Pig_Ind	1013.90	0.00
	Dew_Pen_fogYr+Northness+Pig_Ind	1013.94	0.03
	Dew_Pen_fogYr+Pig_Ind+Sheep_Ind	1014.02	0.12
	Temp_Pen_mo^A	1014.03	0.12
Grassland Shannon Diversity	Temp_Pen_mo+Pig^A	408.65	0.00
	Pig	413.14	4.50
	Temp_Pen_prev2Yr+Pig	413.16	4.51
Riparian Shannon Diversity	rh_Pen_currYr+Dew_Pen_fogYr+Northness	214.46	0.00
	rh_Pen_prev2Yr+Dew_Pen_fogYr+Northness	214.75	0.30
	rh_Pen_prev2Yr+Northness^A	215.23	0.77
Oak Shannon Diversity	pet_allMonth+Def_Pen_mo^A	57.21	0.00
	Slope_degrees+Cattle	60.59	3.38
	solRad_fog	71.01	13.80
Native Tree Density	Elevation_m^A	507.30	0.00
	Elevation_m+Pig	507.91	0.61
	AET_Pen_prev2Yr+Deficit_mm_prevYr	509.18	1.88
Tree Recruitment Density	Sheep_Ind	490.55	0.00
	Pig_Ind+Sheep_Ind	491.75	1.19
	Dew_Pen_fogYr+Sheep_Ind	492.52	1.97
	solRad_fog^A	495.35	4.80

^A Final covariate model for each outcome (also in bold font).

Table 26 (continued). Covariate models ranked by AICc for all outcomes at index sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Shrub Density	Cattle ^A	558.62	0.00
	Sheep	558.62	0.00
	AET_mm_fog+Cattle	560.06	1.44
Native Shrub Recruitment Density	Dew_Pen_fogYr+Northness+Pig_Ind	608.56	0.00
	Northness+Pig_Ind	609.32	0.75
	Dew_Pen_fogYr+Pig_Ind	609.47	0.90
	AET_mm_fog+Temp_Pen_mo ^A	610.06	1.50
Native Tree Cover	Elevation_m+Pig ^A	1783.76	0.00
	Pig	1790.95	7.18
	Temp_Pen_prev2Yr+Pig	1791.99	8.23
Native Shrub Cover	AET_Pen_fogYr+Cattle ^A	1706.29	0.00
	Cattle	1709.51	3.22
	Slope_degrees+Cattle	1710.16	3.87
Native Forb Cover	rh_Pen_currYr+Northness+Pig_Ind ^A	2273.30	0.00
	rh_Pen_currYr+Dew_Pen_fogYr+Northness+Pig_Ind	2273.99	0.69
	Northness+Pig_Ind+Sheep_Ind	2275.42	2.12
Nonnative Forb Cover	Temp_Pen_mo+Pig ^A	2146.85	0.00
	Temp_Pen_mo+Sheep	2150.30	3.45
	Temp_Pen_mo+Cattle	2150.32	3.46
Native Grass Cover	Elevation_m+Pig	1280.50	0.00
	SOIL_Pen_fogYr+Elevation_m+Pig	1281.61	1.11
	Temp_Pen_mo+Pig	1281.64	1.14
	Pig ^A	1282.31	1.81

^A Final covariate model for each outcome (also in bold font).

Table 26 (continued). Covariate models ranked by AICc for all outcomes at index sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Nonnative Grass Cover	Temp_Pen_mo+Pig^A	3579.41	0.00
	AET_Pen_an+Def_Pen_mo	3582.73	3.32
	Def_Pen_mo	3585.32	5.92
<i>Baccharis pilularis</i> Cover	Dew_Pen_currYr+Dew_Pen_prevYr^A	378.26	0.00
	Dew_Pen_currYr+Pig_Ind	379.35	1.09
	PET_mm_prev2Yr	379.35	1.09
<i>Eriogonum</i> Group Cover	Slope_degrees+Cattle^A	681.18	0.00
	Slope_degrees+Sheep	681.21	0.03
	Temp_Pen_prev2Yr+Sheep	685.64	4.47
<i>Foeniculum vulgare</i> Cover	rn_oct^A	463.23	0.00
	pet_oct	463.27	0.04
	rad_oct	463.48	0.25
<i>Pinus muricata</i> Cover	AET_mm_fog+Slope_degrees^A	81.38	0.00
	AET_mm_fog+Cattle	82.34	0.96
	AET_mm_fog+SOIL_Pen_currYr+Slope_degrees	82.90	1.53
<i>Rhus integrifolia</i> Cover	Temp_Pen_prev2Yr+Cattle	104.16	0.00
	Temp_Pen_prev2Yr+Sheep	104.16	0.00
	Temp_Pen_prev2Yr+Pig	104.71	0.56
	Cattle^A	105.25	1.09
<i>Stipa</i> Group Cover	Temp_Pen_prevYr+Pig^A	725.40	0.00
	Pig_Ind+Sheep_Ind	731.23	5.84
	Dew_Pen_fogYr+Pig_Ind+Sheep_Ind	731.50	6.10

^A Final covariate model for each outcome (also in bold font).

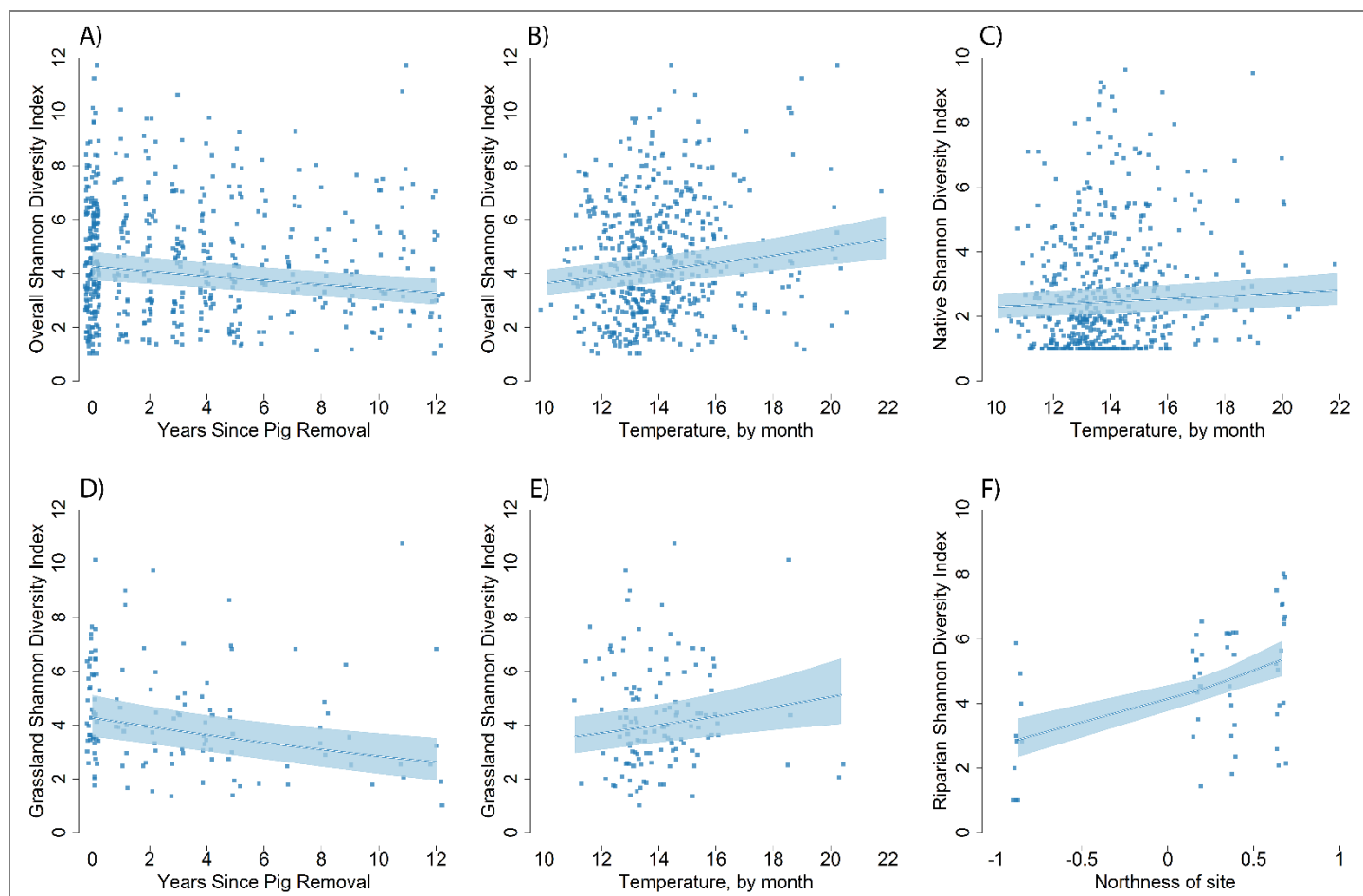


Figure 50. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (first of six). A) Years since pig removal ($p = 0.0004$) for overall Shannon diversity index. B) Monthly temperature (degrees Celsius, $p < 0.0001$) for overall Shannon diversity index. C) Monthly temperature (degrees Celsius, $p = 0.0167$) for native Shannon diversity index. D) Years since pig removal ($p = 0.0033$) for grassland Shannon diversity index. E) Monthly temperature (degrees Celsius, $p = 0.0098$) for grassland Shannon diversity index. F) Site northness ($p < 0.0001$) for riparian Shannon diversity index (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

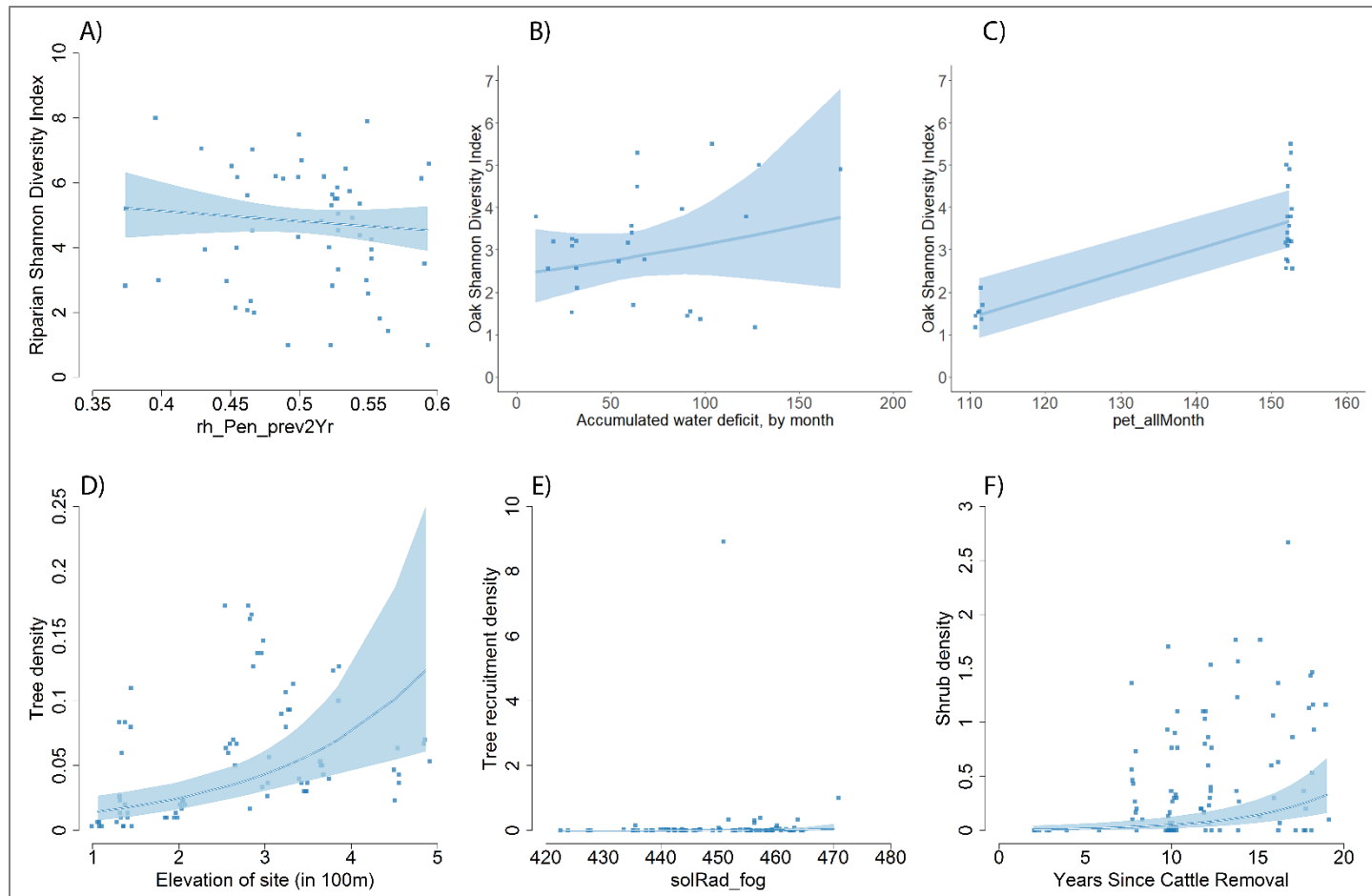


Figure 51. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (second of six). A) Relative humidity (percentage divided by 100; $p = 0.4449$) for the previous two water years combined for riparian Shannon diversity index. B) Monthly accumulated water deficit (mm, $p = 0.0246$) for oak Shannon diversity index. C) Mean of 30-year monthly means for all months of cumulative potential evapotranspiration (PET, mm; $p < 0.0001$) for oak Shannon diversity index. D) Site elevation (in 100 m increments, $p = 0.0016$) for native tree density. E) Solar radiation (watts per square meter) during the fog season ($p = 0.0113$) for native tree recruitment density. F) Years since cattle removal ($p < 0.0001$) for native shrub density.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for tree recruitment density at SC index sites included indicators for sheep and pig removal, the number of days with dew during the current fog season, and site northness (top three and final models shown in Table 26). However, note that the final model contained only the solar radiation covariate for the current fog season (solRad_fog; the eighth-ranked model). This model was selected because the indicator of sheep removal was equal to one for all index sites at SC for all years except one. Therefore, the sheep removal indicator did not obtain reasonable replication for estimating fixed effects, and the model with the lowest AICc without the sheep removal indicator was used instead. Solar radiation for the current fog season was positively associated with native tree recruitment density ($p = 0.0113$), but densities were very close to zero in almost every case (Figure 51E).

The top models for native shrub density at SC index sites consisted of the number of years since cattle or sheep removal and modeled actual evapotranspiration during the current fog season (top three models shown in Table 26). The final model included only the years since cattle removal (Cattle), but the model including a predictor for the years since sheep removal would have provided the same inference since cattle were removed two years prior to sheep on SC. The number of years since cattle removal was positively associated with native shrub density at SC index sites ($p < 0.0001$, Figure 51F).

Top models of native shrub recruitment density at SC index sites included covariates for the number of days with dew during the current fog season, site northness, the indicator of pig removal, modeled actual evapotranspiration, monthly temperature, growing-degree days summarized across the month or for the previous water year, and vapor pressure for the previous water year (top three and final models shown in Table 26). Only six sites were surveyed prior to pig removal, and only one of those was surveyed for more than one year before pig removal. Therefore, site-by-year replication for conditions prior to pig removal is insufficient to estimate the effect of pig removal. The final model (the fifth-ranked model) was the model with the lowest AICc that did not contain the indicator for pig removal. This model contained negative fixed effects for modeled actual evapotranspiration during the current year fog season (AET_mm_fog; $p = 0.1011$, Figure 52A) and a positive effect of monthly temperature (Temp_Pen_mo; $p = 0.0544$, Figure 52B). The p -values exceeding 0.05 for these significance tests provide weak evidence of statistical effects of these covariates.

The final model for native tree cover at SC index sites contained fixed effects for site elevation (Elevation_m) and the number of years since pig removal (Pig; Table 26). The site elevation effect ($p = 0.0003$, Figure 52C) was positively associated with native tree cover, and the years since pig removal effect ($p < 0.0001$, Figure 52D) was negatively associated with native tree cover. Each marginal effects plot (Figures 52C and 52D) was computed conditionally on median values of the unplotted covariate. The plots reflect that no tree cover was observed at just over half of the sites.

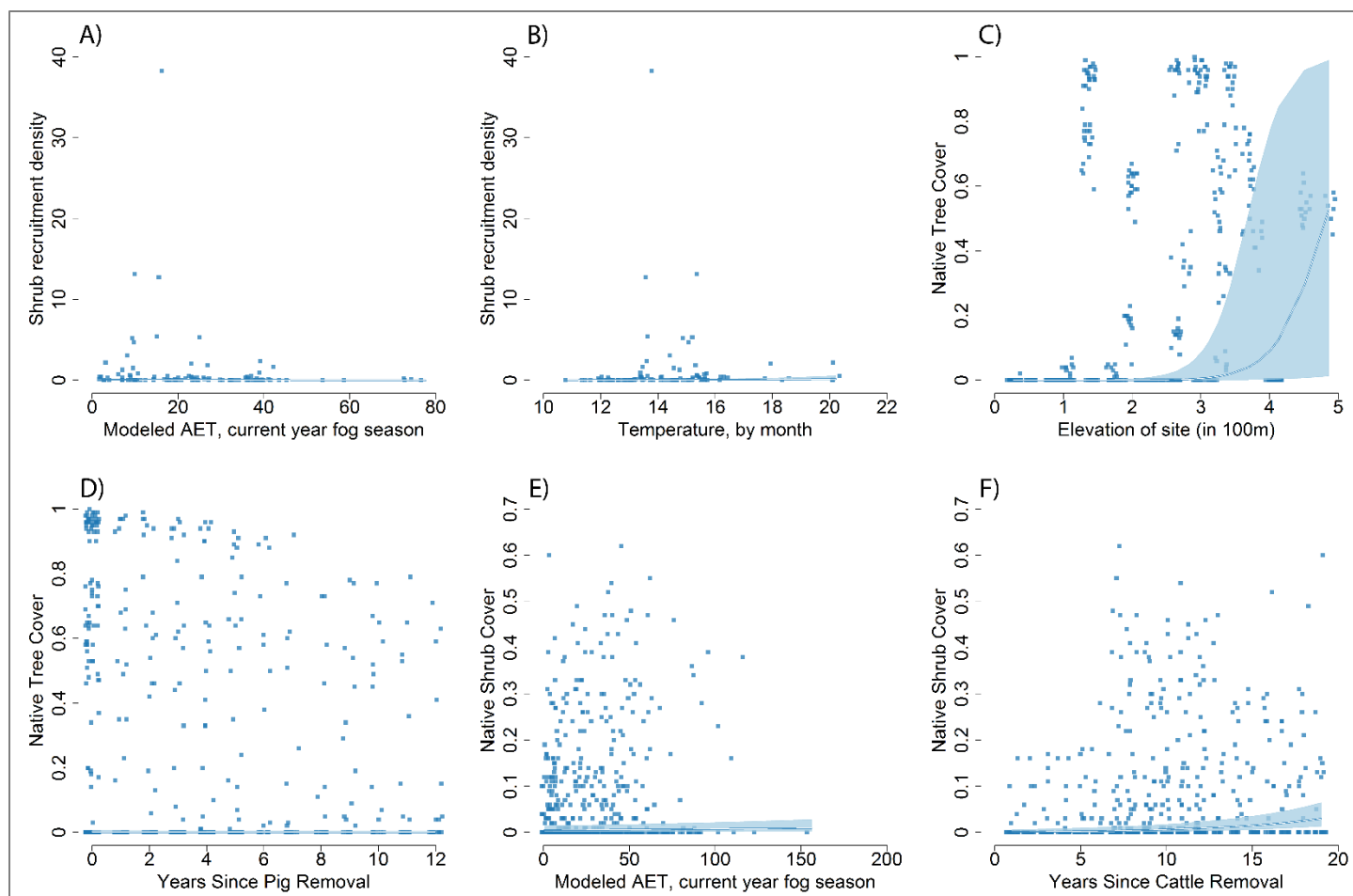


Figure 52. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (third of six). A) Modeled actual evapotranspiration (AET, mm) during the current year fog season ($p = 0.1011$) for native shrub recruitment density. B) Monthly temperature (degrees Celsius, $p = 0.0544$) for native shrub recruitment density. C) Site elevation (in 100 m increments, $p = 0.0003$) for native tree cover. D) Years since pig removal ($p < 0.0001$) for native tree cover. E) Modeled actual evapotranspiration (AET, mm) during the current fog season ($p = 0.0103$) for native shrub cover. F) Years since cattle removal ($p < 0.0001$) for native shrub cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The final covariate model for native shrub cover at SC index sites contained effects for the modeled actual evapotranspiration during the current year fog season (AET_Pen_fogYr) and the years since cattle removal (Cattle; Table 26). Both the modeled actual evapotranspiration effect ($p = 0.0103$, Figure 52E) and the years since cattle removal effect ($p < 0.0001$, Figure 52F) were positively associated with native shrub cover at SC index sites.

The final model for native forb cover at SC index sites contained relative humidity for the current water year (rh_Pen_currYr), site northness (Northness), and the indicator of pig removal (Pig_Ind; Table 26). All of the effects were positively associated with native forb cover. The pig removal indicator takes the value of zero for surveys prior to pig removal and values of one after pig removal. The positive effect of pig removal ($p = 0.0004$) is demonstrated in the marginal effects plot for site northness ($p = 0.0263$, Figure 53A) and the marginal effects plot for relative humidity ($p = 0.0105$, Figure 53B).

The final model for nonnative forb cover at SC index sites contained a term for monthly temperature (Temp_Pen_mo) and the years since pig removal (Pig; Table 26). The number of years since pig removal was negatively associated with nonnative forb cover ($p < 0.0001$, Figure 53C), and monthly temperature was positively associated with nonnative forb cover ($p = 0.0003$, Figure 53D) at SC index sites.

All of the top models for native grass cover at SC index sites contained the covariate for the number of years since pig removal (top three and final models shown in Table 26N). Additionally, top models included site elevation, soil moisture during the current fog season, and temperature summarized by month or calendar year. The final model included only the fixed effect for the number of years since pig removal (Pig; the fifth-ranked model), which was negatively associated with native grass cover at SC index sites ($p = 0.0001$, Figure 53E).

The final model for nonnative grass cover at SC index sites contained terms for monthly temperature (Temp_Pen_mo) and the number of years since pig removal (Pig; Table 26). The number of years since pig removal was negatively associated with nonnative grass cover ($p < 0.0001$, Figure 53F) and the monthly temperature was positively associated with nonnative grass cover ($p = 0.0009$, Figure 54A) at SC index sites.

The top models for *Baccharis pilularis* cover at SC index sites included covariates for the number of days with dew for the current water year and for the previous water year, the indicator of pig removal, potential evapotranspiration over the previous two water years, and relative humidity during the current fog season and for the previous water year (top three models shown in Table 26). The final model contained effects for the number of days with dew in the current water year (Dew_Pen_currYr; $p = 0.0250$, Figure 54B) and the number of days with dew in the previous water year (Dew_Pen_prevYr; $p = 0.0557$, Figure 54C), both of which were positively associated with *Baccharis pilularis* cover at SC index sites.

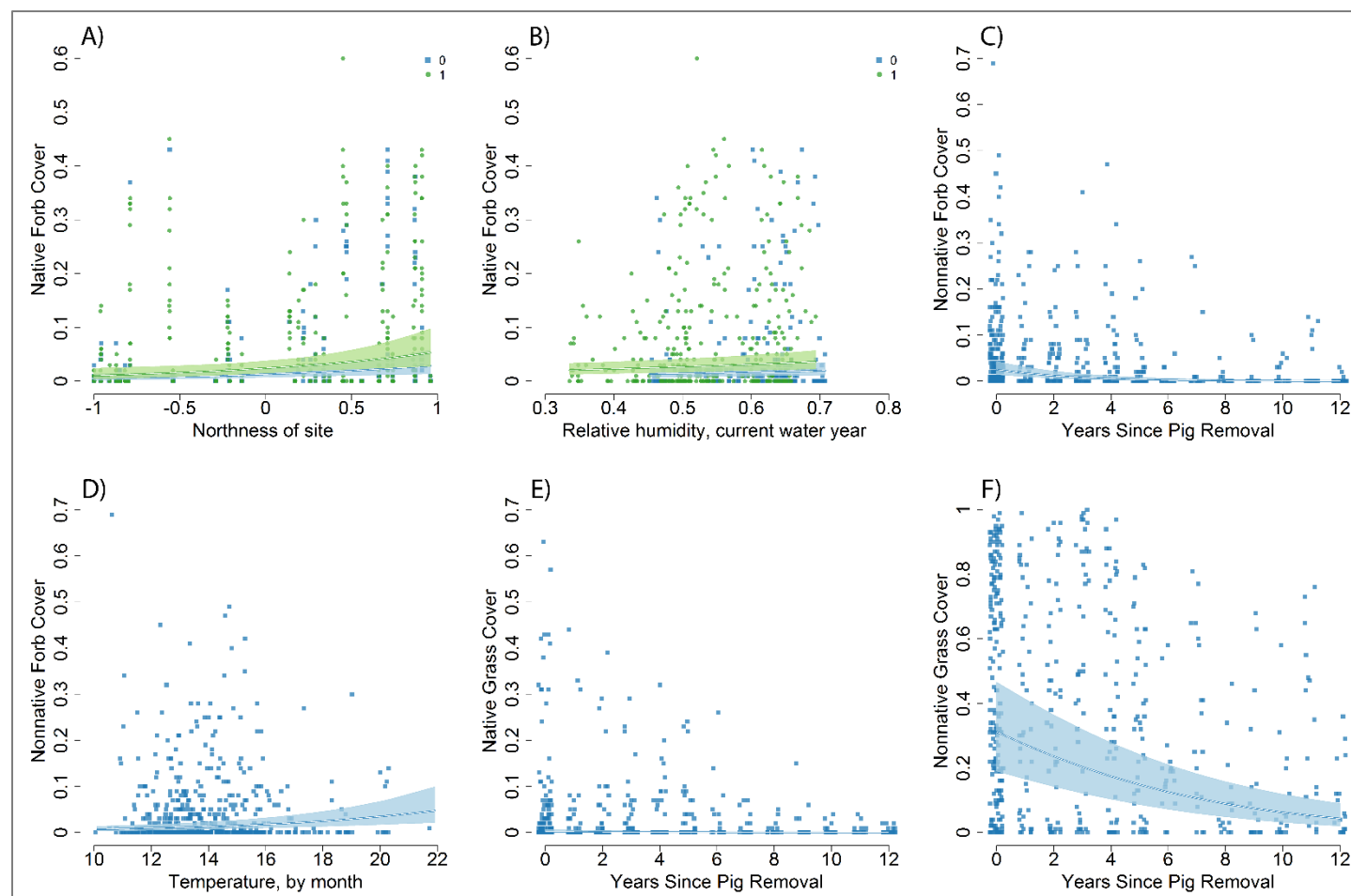


Figure 53. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (fourth of six). A) Site northness ($p = 0.0263$) for native forb cover (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation). B) Relative humidity (percentage divided by 100) during the current water year ($p = 0.0105$) for native forb cover. C) Years since pig removal ($p < 0.0001$) for nonnative forb cover. D) Monthly temperature (degrees Celsius, $p = 0.0003$) for nonnative forb cover. E) Years since pig removal ($p = 0.0001$) for native grass cover. F) Years since pig removal ($p < 0.0001$) for nonnative grass cover. Note that for graphs A and B, sites where pigs were removed are indicated by a value of 1 plotted with a green circle, while sites where pigs were not removed are indicated by a value of 0 plotted with a blue box.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

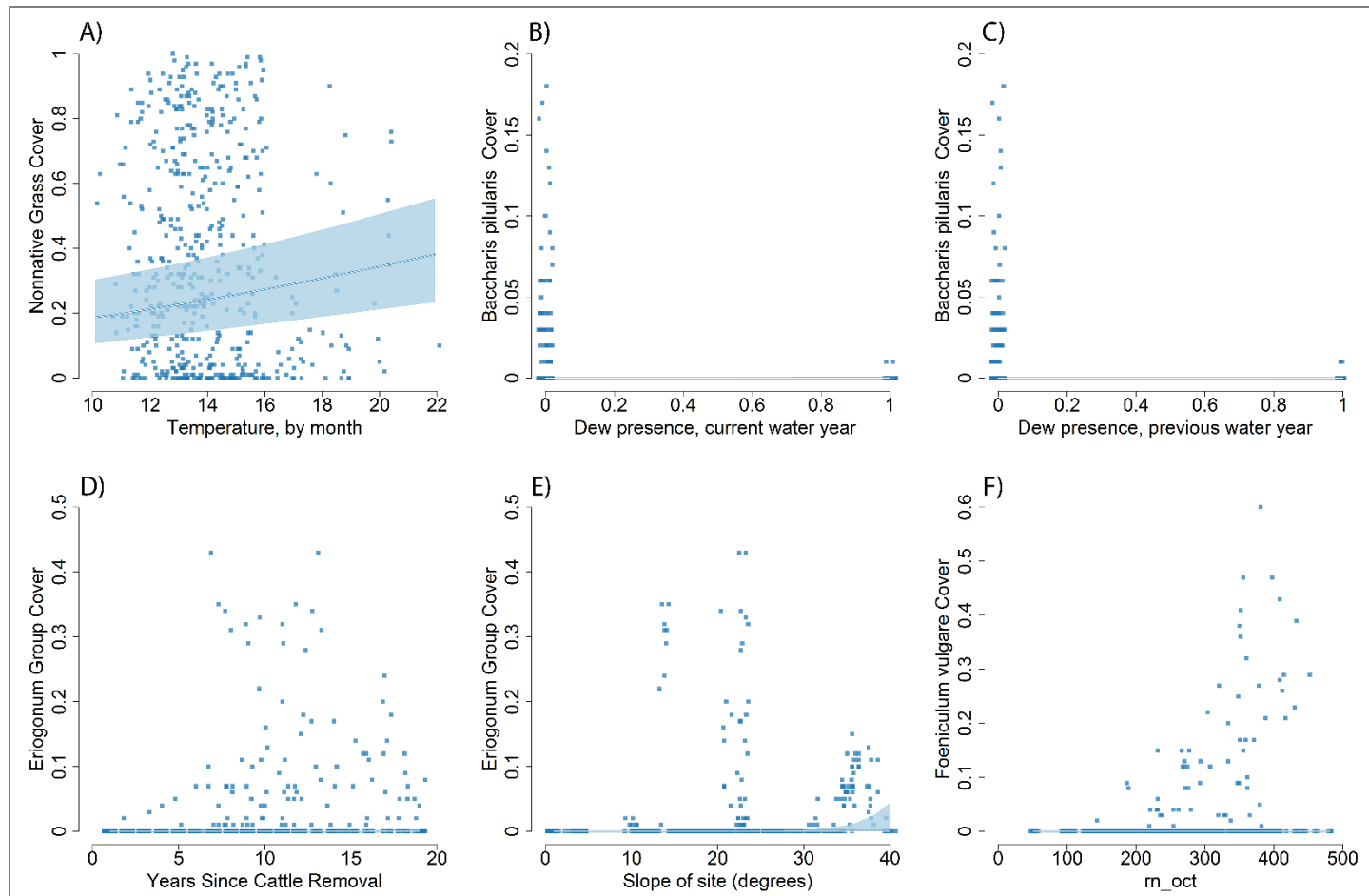


Figure 54. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (fifth of six). A) Monthly temperature (degrees Celsius, $p = 0.0009$) for nonnative grass cover. B) Dew presence (measured as the number of days that dew was present) during the current water year ($p = 0.0250$) for *Baccharis pilularis* cover. C) Dew presence (measured as the number of days that dew was present) during the previous water year ($p = 0.0557$) for *Baccharis pilularis* cover. D) Years since cattle removal ($p < 0.0001$) for *Eriogonum* Group cover. E) Site slope (degrees, $p = 0.0028$) for *Eriogonum* Group cover. F) Mean of 30-year monthly means for previous October to current survey month of clear sky net solar radiation (watts per square meter, $p < 0.0001$) for *Foeniculum vulgare* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The final model for *Eriogonum* Group cover at SC index sites contained a term for site slope (Slope_degrees) and a term for the number of years since cattle removal (Cattle; Table 26). The model that included the number of years since sheep removal was nearly equivalent. Both the number of years since cattle removal ($p < 0.0001$, Figure 54D) and the site slope ($p = 0.0028$, Figure 54E) were positively associated with *Eriogonum* Group cover at SC index sites.

The top models for *Foeniculum vulgare* cover at SC index sites included water balance covariates calculated as the mean of 30-year monthly means for the previous October to current survey month for clear sky net solar radiation, cumulative potential evapotranspiration, and total clear sky solar radiation, as well as monthly means for soil moisture and water deficit (top three models shown in Table 26). The final model consisted of the 30-year mean for clear sky net solar radiation calculated from monthly means between October and the current survey month (rn_oct). This effect was positively associated with *Foeniculum vulgare* cover at SC index sites ($p < 0.0001$, Figure 54F). Note that the prevalence of sites with zero cover results in a trend line near zero for all values of clear sky net solar radiation.

The top models for *Pinus muricata* cover at index sites on SC all contained the modeled actual evapotranspiration covariate summarized over the current year fog season (top three models shown in Table 26). Additionally, top models included covariates for the site slope, number of years since cattle removal, and soil moisture from the current water year and previous water year. The final model included covariates for the modeled actual evapotranspiration in the current fog season (AET_mm_fog) and site slope (Slope_degrees). Both modeled actual evapotranspiration ($p = 0.0703$, Figure 55A) and site slope ($p = 0.3204$, Figure 55B) were negatively associated with *Pinus muricata* cover at SC index sites. However, the p-values indicate that the effects may not be statistically significant, and the marginal effects plots indicate that fits may be poor due to small samples of transects with non-zero cover.

Top models for *Rhus integrifolia* cover at SC index sites included the mean temperature for the previous two water years and covariates for the number of years since cattle, sheep, and pig removal (top three and final models shown in Table 26). The final model contained only a covariate for the years since cattle removal (Cattle; the fourth-ranked model) which was positively associated with *Rhus integrifolia* cover at SC index sites ($p < 0.0001$, Figure 55C). However, note that *Rhus integrifolia* cover was near zero for nearly all of the survey occasions.

The final model for *Stipa* Group cover at SC index sites contained effects for mean temperature over the previous water year (Temp_Pen_prevYr) and the number of years since pig removal (Pig; Table 26). Both the number of years since pig removal ($p < 0.0001$, Figure 55D) and the previous water year mean temperature ($p = 0.5411$, Figure 55E) were negatively associated with *Stipa* Group cover at SC index sites, but the p-value for mean temperature was not statistically significant.

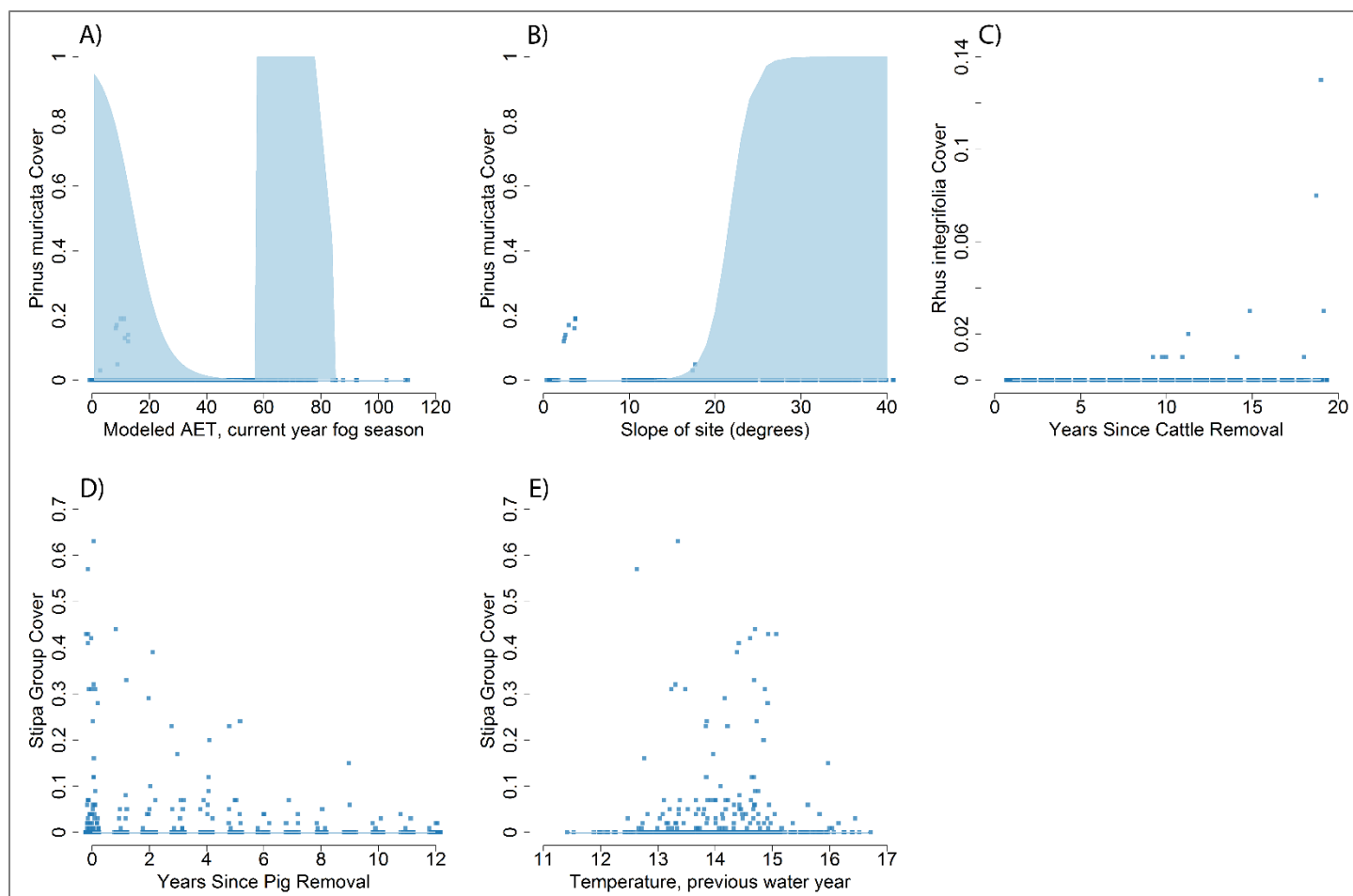


Figure 55. Marginal effects plots for final covariate models at index sites across Santa Cruz Island (sixth of six). A) Modeled actual evapotranspiration (AET, mm) during the current year fog season ($p = 0.0703$) for *Pinus muricata* cover. B) Site slope (degrees, $p = 0.3204$) for *Pinus muricata* cover. C) Years since cattle removal ($p < 0.0001$) for *Rhus integrifolia* cover. D) Years since pig removal ($p < 0.0001$) for *Stipa* Group cover. E) Temperature (degrees Celsius) during the previous water year ($p = 0.5411$) for *Stipa* Group cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Santa Cruz Island Probability Sites

The top models for overall Shannon diversity at SC probability sites contained water balance covariates including modeled actual evapotranspiration for the previous and current water years, monthly water deficit, and the 30-year mean of monthly cumulative potential evapotranspiration (top three and final models shown in Table 27). The final model contained a single covariate for monthly accumulated water deficit (Def_Pen_mo; the fourth-ranked model), and this effect was positively associated with overall Shannon diversity at SC probability sites ($p = 0.0549$, Figure 56A).

Final models for native Shannon diversity at SC probability sites included the site slope; covariates for the years since sheep and cattle removal; and water balance covariates such as modeled monthly actual evapotranspiration, mean soil moisture for the current water year and for the previous two water years, mean temperature for the survey month and for the current water year fog season, and the 30-year mean of monthly means for clear sky net solar radiation (top three models shown in Table 27). The final model contained a single fixed effect for the site slope (Slope_degrees), and this effect was positively associated with native Shannon diversity at SC probability sites ($p = 0.0091$, Figure 56B).

The top models for native tree density at SC probability sites included effects of site northness and relative humidity for the current water year fog season and for the previous two water years (Table 27). The final model consisted only of the northness covariate (Northness), and this effect was negatively associated with native tree density at SC probability sites ($p < 0.0001$, Figure 56C). However, the sample size of four sites was very small.

The final model for native shrub density at SC probability sites included terms for soil moisture during the current water year fog season (Soil_water_mm_fog) and site elevation (Elevation_m; Table 27). Site elevation was positively associated with native shrub density ($p = 0.0055$, Figure 56D), and soil moisture was negatively associated with native shrub density ($p = 0.0158$, Figure 56E). However, the one data point with high soil moisture and low shrub density may be unduly influential on the magnitude and direction of the estimated regression coefficient (Figure 56E).

The top models for native shrub recruitment density at SC probability sites contained various water balance covariates such as relative humidity, vapor pressure deficit, and accumulated water deficit for the previous two water years; modeled actual evapotranspiration for the previous water year; and monthly growing-degree days and temperature (top three models shown in Table 27). Additionally, site northness and the number of years since sheep, pigs, and cattle were removed were also included in top models. The final model contained a single term for relative humidity summarized over the previous two water years (rh_Pen_prev2Yr), and this effect was positively associated with native shrub recruitment density at SC probability sites ($p = 0.0068$, Figure 56F).

The final model for native tree cover at SC probability sites contained a single term for site elevation (Elevation_m; Table 27). Site elevation was positively associated with native tree cover at SC probability sites ($p < 0.0001$, Figure 57A).

Table 27. Covariate models ranked by AICc for all outcomes at probability sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	AET_Pen_prevYr+AET_Pen_currYr+Def_Pen_mo	352.01	0.00
	pet_allMonth+Def_Pen_mo	353.09	1.07
	AET_Pen_currYr+Def_Pen_mo	353.17	1.15
	Def_Pen_mo ^A	353.18	1.17
Native Shannon Diversity	Slope_degrees ^A	248.40	0.00
	AET_Pen_mo+Slope_degrees	248.83	0.43
	Soil_water_mm_currentYr+Slope_degrees	249.51	1.10
Native Tree Density	Northness ^A	33.15	0.00
	rh_Pen_fogYr+Northness	33.68	0.53
	rh_Pen_prev2Yr+Northness	34.56	1.40
Native Shrub Density	Soil_water_mm_fog+Elevation_m ^A	320.39	0.00
	Soil_water_mm_fog+SOIL_Pen_fogYr+Elevation_m	322.11	1.72
	AET_Pen_fogYr+Slope_degrees	323.10	2.71
Native Shrub Recruitment Density	rh_Pen_prev2Yr ^A	346.38	0.00
	AET_mm_prevYr	346.61	0.22
	GDD_Pen_mo	346.79	0.41
Native Tree Cover	Northness+Elevation_m	348.87	0.00
	Elevation_m ^A	348.93	0.06
	Temp_Pen_currYr+Slope_degrees	358.93	10.06
Native Shrub Cover	rh_Pen_prev2Yr+Northness	559.58	0.00
	Soil_water_mm_prev2Yr+Slope_degrees	560.06	0.48
	rh_Pen_currYr+Northness	560.23	0.65
	Northness ^A	560.38	0.80

^A Final covariate model for each outcome (also in bold font).

Table 27 (continued). Covariate models ranked by AICc for all outcomes at probability sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Nonnative Forb Cover	AET_Pen_mo+Soil_water_mm_prevYr	259.94	0.00
	Soil_water_mm_prevYr ^A	260.48	0.54
	AET_Pen_mo+Soil_water_mm_prevYr+Slope_degrees	261.88	1.94
Native Grass Cover	Slope_degrees+Sheep ^A	361.34	0.00
	Slope_degrees+Cattle	361.34	0.00
	SOIL_Pen_prevYr+Slope_degrees+Cattle	362.53	1.19
Nonnative Grass Cover	SOIL_Pen_currYr+Slope_degrees ^A	711.25	0.00
	SOIL_Pen_currYr+Slope_degrees+Cattle	712.26	1.01
	SOIL_Pen_currYr	714.08	2.84
<i>Baccharis pilularis</i> Cover	Northness ^A	144.65	0.00
	Northness+Elevation_m	144.82	0.17
	rh_Pen_currYr+Northness	146.39	1.74
<i>Eriogonum</i> Group Cover	Northness ^A	409.30	0.00
	rh_Pen_fogYr+Northness	410.89	1.59
	rh_Pen_prev2Yr+Northness	411.02	1.72
<i>Foeniculum vulgare</i> Cover	Sheep ^A	118.70	0.00
	Pig	118.70	0.00
	Cattle	118.70	0.00
<i>Rhus integrifolia</i> Cover	Slope_degrees ^A	189.94	0.00
	SRad_CurrentYear	189.97	0.03
	Soil_water_mm_prevYr+SOIL_Pen_prevYr+Slope_degrees	190.15	0.21
<i>Stipa</i> Group Cover	SOIL_Pen_prevYr+Slope_degrees+Cattle ^A	267.70	0.00

^A Final covariate model for each outcome (also in bold font).

Table 27 (continued). Covariate models ranked by AICc for all outcomes at probability sites across Santa Cruz Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
<i>Stipa</i> Group Cover (continued)	SOIL_Pen_prevYr+Slope_degrees	270.46	2.76
	Slope_degrees+Sheep	270.61	2.91

^A Final covariate model for each outcome (also in bold font).

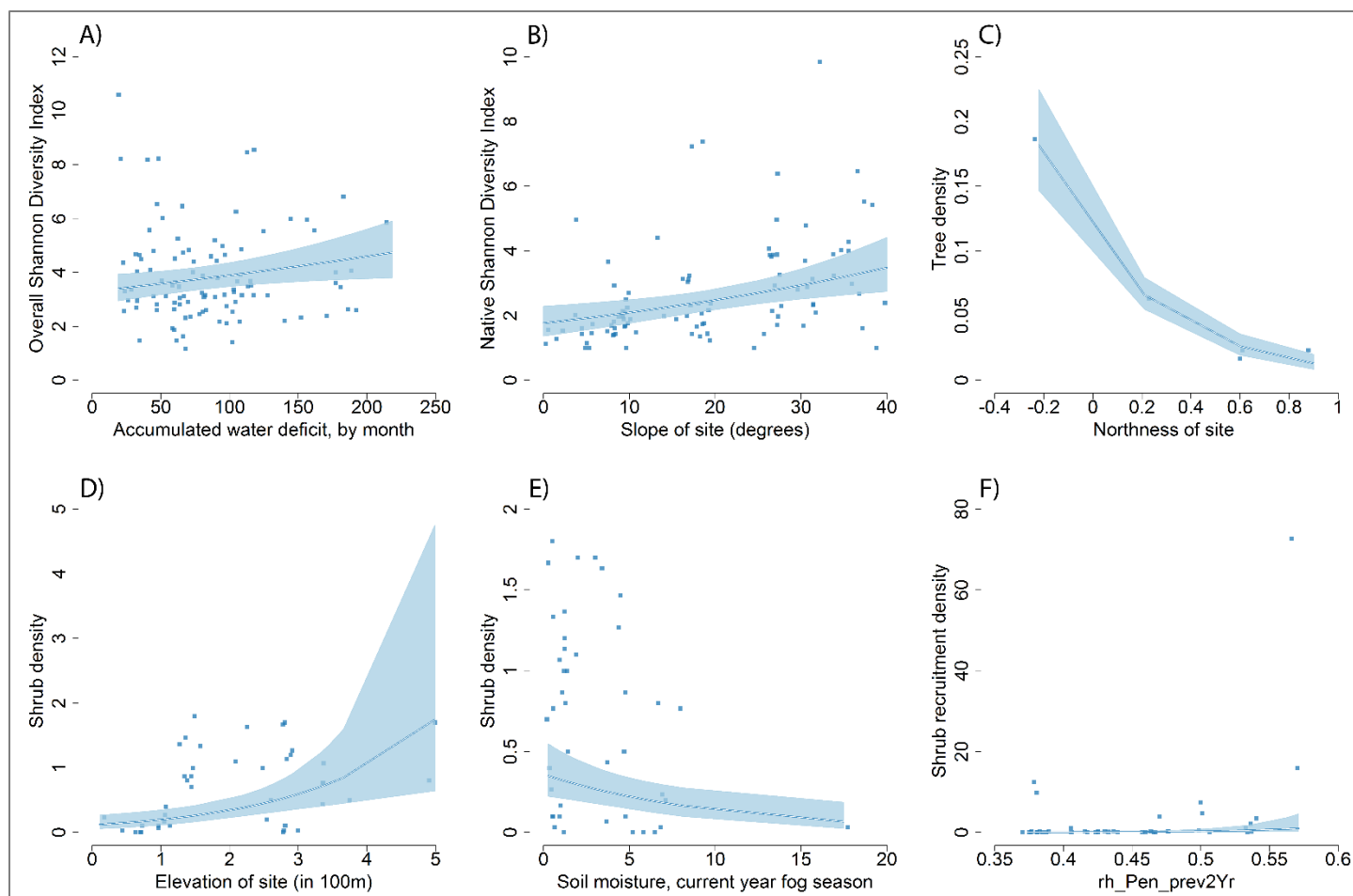


Figure 56. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (first of four). A) Monthly accumulated water deficit (mm, $p = 0.0549$) for overall Shannon diversity index. B) Site slope (degrees, $p = 0.0091$) for native Shannon diversity index. C) Site northness ($p < 0.0001$) for native tree density (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation). D) Site elevation (in 100 m increments, $p = 0.0055$) for native shrub density. E) Soil moisture (mm) during the current year fog season ($p = 0.0158$) for native shrub density. F) Relative humidity (percentage divided by 100) for the previous two water years combined ($p = 0.0068$) for native shrub recruitment density.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

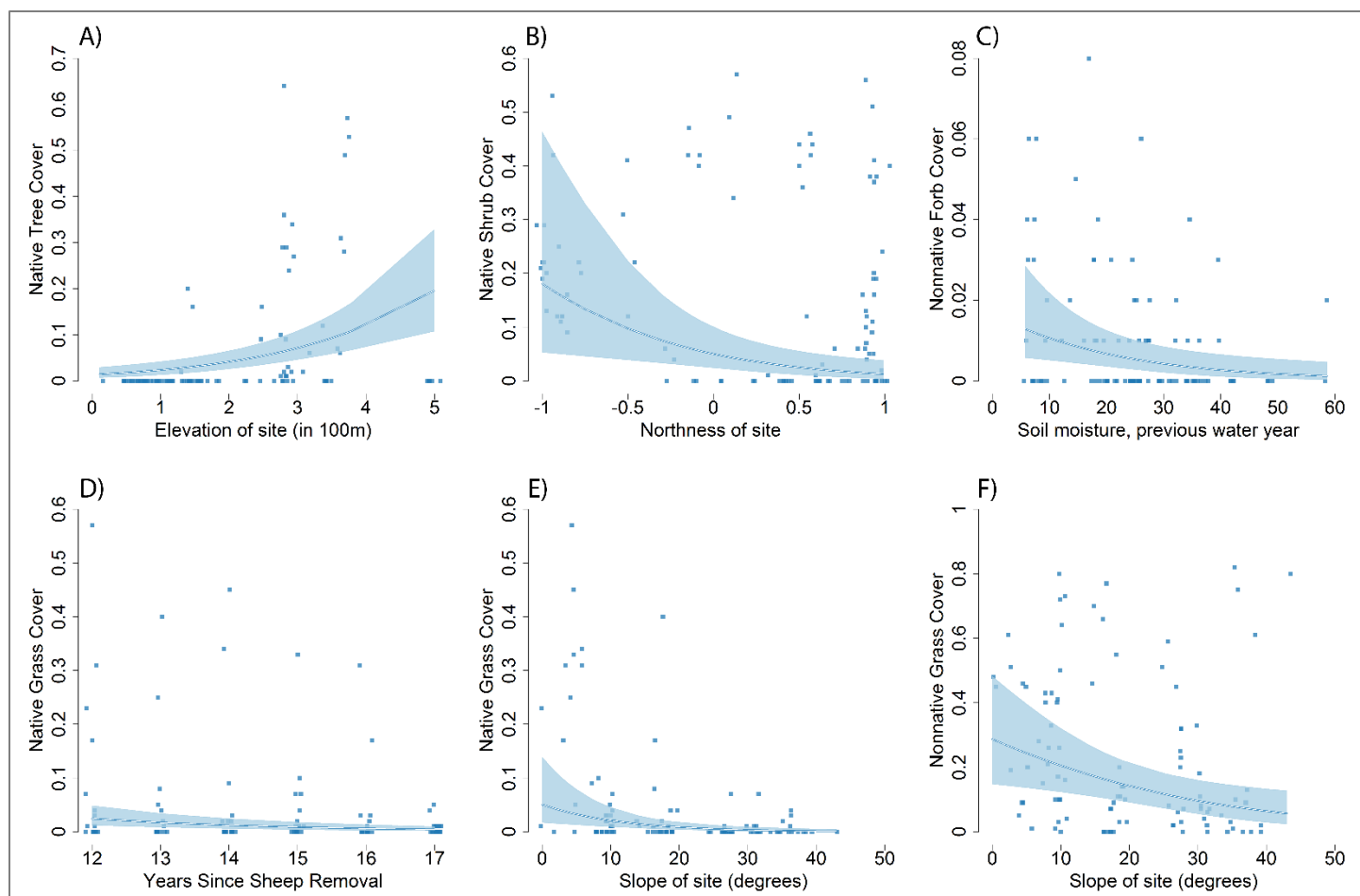


Figure 57. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (second of four). A) Site elevation (in 100 m increments, $p < 0.0001$) for native tree cover. B) Site northness ($p = 0.0163$) for native shrub cover (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation). C) Soil moisture (mm) during the previous water year ($p = 0.0249$) for nonnative forb cover. D) Years since sheep removal ($p < 0.0001$) for native grass cover. E) Site slope (degrees, $p = 0.0013$) for native grass cover. F) Site slope (degrees, $p = 0.0249$) for nonnative grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for native shrub cover at SC probability sites contained site-level covariates of northness, slope, and elevation; water balance covariates such as relative humidity and soil moisture; and nonnative mammal removal covariates indicating the number of years since cattle and sheep removal (top three and final models shown in Table 27). The final model consisted of a single effect for site northness (Northness; the fourth-ranked model), which was negatively associated with native shrub cover at SC probability sites ($p = 0.0163$, Figure 57B).

The top models for nonnative forb cover at SC probability sites contained terms for the monthly modeled actual evapotranspiration, soil moisture for the previous water year, and site slope (Table 27). The final model contained a single term for the soil moisture for the previous water year (Soil_water_mm_prevYr) which was negatively associated with nonnative forb cover at SC probability sites ($p = 0.0249$, Figure 57C).

The top models for native grass cover at SC probability sites contained terms for site slope, the number of years since sheep and cattle removal, and the soil moisture over the previous water year (top three models shown in Table 27). The final model included fixed effects for the number of years since sheep removal (Sheep; $p < 0.0001$, Figure 57D) and for site slope (Slope_degrees; $p = 0.0013$, Figure 57E) which were both negatively associated with the odds of native grass cover at a transect point.

The final model for nonnative grass cover at probability sites contained effects for soil moisture summarized over the current water year (SOIL_Pen_currYr) and the site slope (Slope_degrees; Table 27). The slope of the site was negatively associated with the odds of nonnative grass cover at a transect point ($p = 0.0249$, Figure 57F), and the soil moisture during the current water year was positively associated with the odds of nonnative grass cover ($p < 0.0001$, Figure 58A). The top models for *Baccharis pilularis* cover at SC probability sites included covariates for site northness, site elevation, and relative humidity over the current water year or the previous two water years (top three models shown in Table 27). The final model consisted of a term for site northness (Northness), which was positively associated with *Baccharis pilularis* cover at SC probability sites ($p = 0.0119$, Figure 58B). The only non-zero *Baccharis pilularis* cover measurements were observed when site northness exceeded values of 0.5.

The top models for *Eriogonum* Group cover at SC probability sites included fixed effects for site northness, relative humidity over the current fog season and the previous two water years, and the soil moisture during the current fog year (top three models shown in Table 27). The final model contained only a term for site northness (Northness), which was negatively associated with the odds of *Eriogonum* Group cover ($p < 0.0001$, Figure 58C).

The top model for *Foeniculum vulgare* cover at SC probability sites contained terms for the number of years since sheep, pig, and cattle removal and the slope of the site (top three models shown in Table 27). The final model included only the number of years since sheep removal (Sheep) and this effect was negatively associated with *Foeniculum vulgare* cover ($p = 0.0728$, Figure 58D). However, the cover values were very near zero for almost all sites and survey occasions.

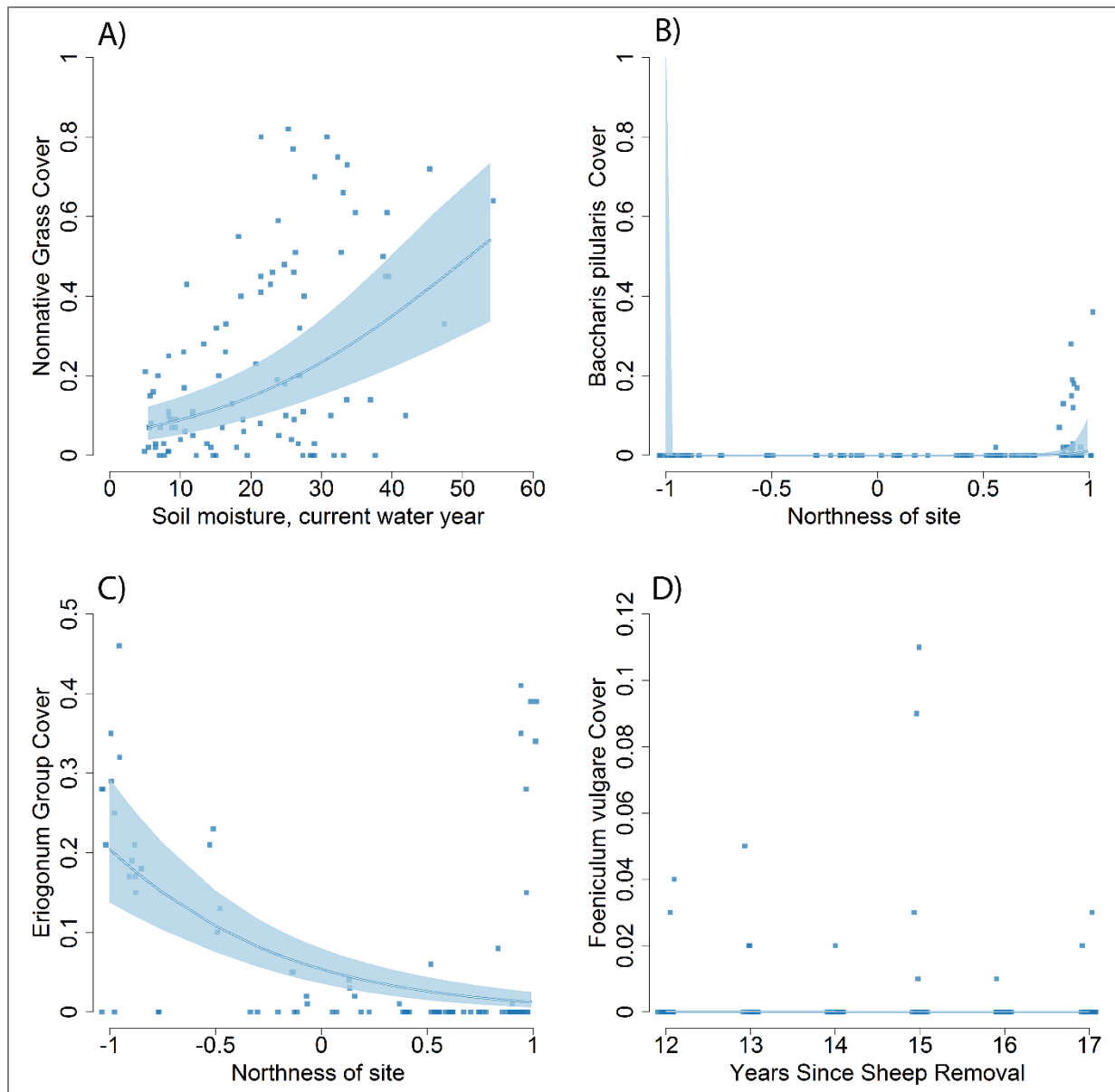


Figure 58. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (third of four). A) Soil moisture (mm) during the current water year ($p < 0.0001$) for nonnative grass cover. B) Site northness ($p = 0.0119$) for *Baccharis pilularis* cover. C) Site northness ($p < 0.0001$) for *Eriogonum* Group cover. D) Years since sheep removal ($p = 0.0728$) for *Foeniculum vulgare* cover. For graphs B and C, northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Top models for *Rhus integrifolia* cover at SC probability sites contained covariates for the site slope, solar radiation and temperature in the current water year, soil moisture in the previous water year, and modeled actual evapotranspiration and solar radiation for the current fog season (top three models shown in Table 27). The final model included only the site slope covariate (Slope_degrees), which

was positively associated with the odds of *Rhus integrifolia* cover at SC probability sites ($p = 0.0030$, Figure 59A).

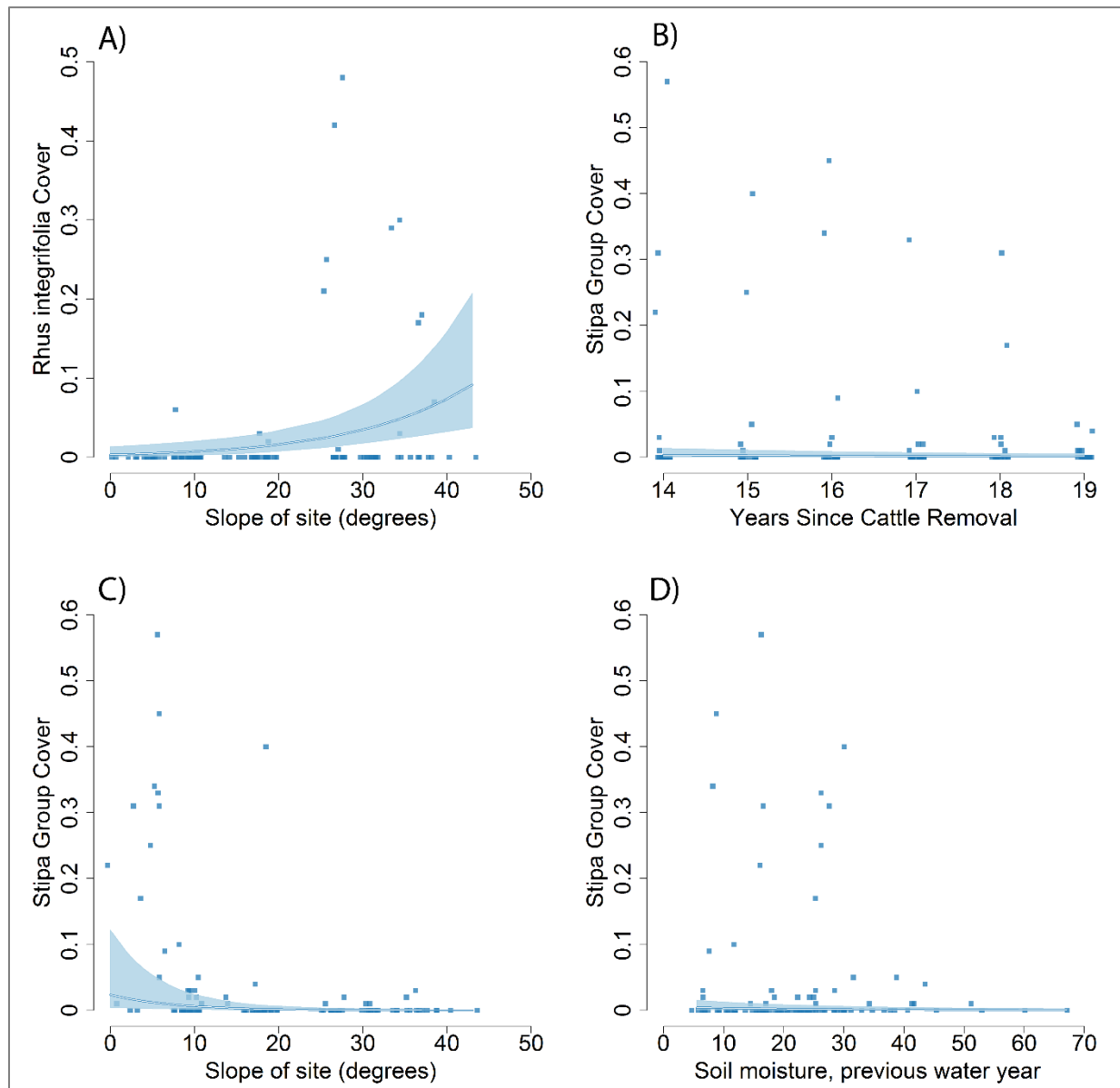


Figure 59. Marginal effects plots for final covariate models at probability sites across Santa Cruz Island (fourth of four). A) Site slope (degrees, $p = 0.0030$) for *Rhus integrifolia* cover. B) Years since cattle removal ($p = 0.0064$) for *Stipa* Group cover. C) Site slope (degrees, $p = 0.0013$) for *Stipa* Group cover. D) Soil moisture (mm) during the previous water year ($p = 0.0115$) for *Stipa* Group cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The final model for *Stipa* Group cover at SC probability sites included terms for soil moisture in the previous water year (SOIL_Pen_prevYr), the site slope (Slope_degrees), and the number of years since cattle removal (Cattle; Table 27). The effects of cattle removal over time ($p = 0.0064$, Figure

59B), site slope ($p = 0.0013$, Figure 59C), and soil moisture ($p = 0.0115$, Figure 59D) were all negatively associated with *Stipa* Group cover at SC probability sites.

Covariate Modeling for San Miguel Island

A subset of the full covariate modeling results across San Miguel Island (SM) is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

San Miguel Island Index Sites

The top models for overall Shannon diversity at SM index plots contained several covariates calculated as 30-year means of monthly means from October through the survey month for cumulative potential evapotranspiration, clear sky net solar radiation, and total clear sky solar radiation (top three models shown in Table 28). Additionally, models contained effects for modeled potential evapotranspiration by month and soil moisture for the previous water year. The final model included only the term for clear sky net solar radiation (rn_oct), and this effect was negatively associated with overall Shannon diversity at SM index plots ($p < 0.0001$, Figure 60A).

The top model for native Shannon diversity at SM index plots contained two water balance covariates (Table 28). The mean accumulated water deficit (Def_Pen_mo; $p = 0.0246$, Figure 60B) and the cumulative potential evapotranspiration calculated from 30-year monthly means for all months (pet_allMonth; $p = 0.0001$, Figure 60C) were both negatively associated with native Shannon diversity at SM index plots.

Top models for island chaparral Shannon diversity at SM index sites contained several covariates calculated as 30-year means of monthly means ranging from October through the survey month for total clear sky solar radiation, cumulative potential evapotranspiration, and clear sky net solar radiation (Table 28). The final model for inference included the 30-year mean for total clear sky solar radiation (rad_oct), which was negatively associated with island chaparral Shannon diversity at SM index sites ($p < 0.0001$, Figure 60D).

Coastal sage scrub Shannon diversity at SM index sites was predicted in the top models by water balance covariates and site-level metrics (top three models shown in Table 28). Water balance metrics included the number of days with dew in the current water year or in the current fog year, and the relative humidity in the previous two water years. Site-level covariates included site northness and elevation. In the final model, elevation (Elevation_m) was negatively associated with coastal sage scrub Shannon diversity ($p = 0.0001$, Figure 60E) and site northness (Northness) was positively associated with coastal sage scrub Shannon diversity ($p < 0.0001$, Figure 60F).

Table 28. Covariate models ranked by AICc for all outcomes at index sites across San Miguel Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	pet_oct+AET_Pen_mo	1665.55	0.00
	rn_oct ^A	1666.34	0.78
	pet_oct	1666.38	0.82
Native Shannon Diversity	pet_allMonth+Def_Pen_mo ^A	1272.85	0.00
	Def_Pen_mo	1275.27	2.41
	GDD_Pen_mo	1276.18	3.33
Island Chaparral Shannon Diversity	rad_oct ^A	340.82	0.00
	pet_oct	341.12	0.29
	rn_oct	341.51	0.69
Coastal Sage Scrub Shannon Diversity	Dew_Pen_currYr+Northness+Elevation_m	182.60	0.00
	Northness+Elevation_m ^A	182.96	0.36
	rh_Pen_prev2Yr+Northness	183.95	1.35
Grassland Shannon Diversity	rn_oct ^A	321.79	0.00
	rad_oct	323.17	1.38
	Def_Pen_mo	323.45	1.67
Native Shrub Density	SOIL_Pen_currYr ^A	760.87	0.00
	AET_Pen_currYr	760.95	0.08
	AET_Pen_currYr+Def_Pen_currYr	761.61	0.74
Native Shrub Cover	PET_mm_prevYr ^A	2835.20	0.00
	vpd_Pen_prev2Yr	2836.24	1.04
	GDD_Pen_prev2Yr	2836.58	1.38
Native Forb Cover	pet_oct+AET_Pen_mo	3161.25	0.00
	pet_oct ^A	3162.67	1.42

^A Final covariate model for each outcome (also in bold font).

Table 28 (continued). Covariate models ranked by AICc for all outcomes at index sites across San Miguel Island. Note that only the top three models for each outcome are presented in this table (plus the final model, if not included in the top three models); the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Forb Cover (continued)	Def_Pen_mo	3162.67	1.42
Nonnative Forb Cover	AET_Pen_mo+Soil_water_mm_prevYr^A	2870.16	0.00
	Soil_water_mm_prevYr+Def_Pen_mo	2872.80	2.64
	AET_Pen_mo	2873.28	3.12
Native Grass Cover	Dew_Pen_currYr^A	2356.32	0.00
	vpd_Pen_fogYr	2357.08	0.76
	GDD_Pen_currYr	2357.12	0.80
Nonnative Grass Cover	Soil_water_mm_prevYr+SOIL_Pen_prev2Yr	3093.58	0.00
	AET_Pen_mo+Soil_water_mm_prevYr+SOIL_Pen_prev2Yr	3094.28	0.70
	Soil_water_mm_prevYr+Def_Pen_mo	3094.53	0.95
	Soil_water_mm_prevYr^A	3095.17	1.58
<i>Acmispon dendroideus</i> Var. <i>veatchii</i> Cover	Temp_Pen_prev2Yr+Dew_Pen_prev2Yr^A	533.52	0.00
	PET_Pen_prevYr	536.58	3.06
	svp_Pen_prev2Yr	537.91	4.39
<i>Carpobrotus chilensis</i> Cover	vpd_Pen_fogYr^A	1618.69	0.00
	GDD_Pen_an	1620.17	1.49
	Temp_Pen_an	1620.17	1.49
<i>Isocoma menziesii</i> Cover	solRad_prev2Yr^A	1814.28	0.00
	solRad_fog	1814.33	0.06
	vpd_Pen_fogYr	1817.22	2.95

^A Final covariate model for each outcome (also in bold font).

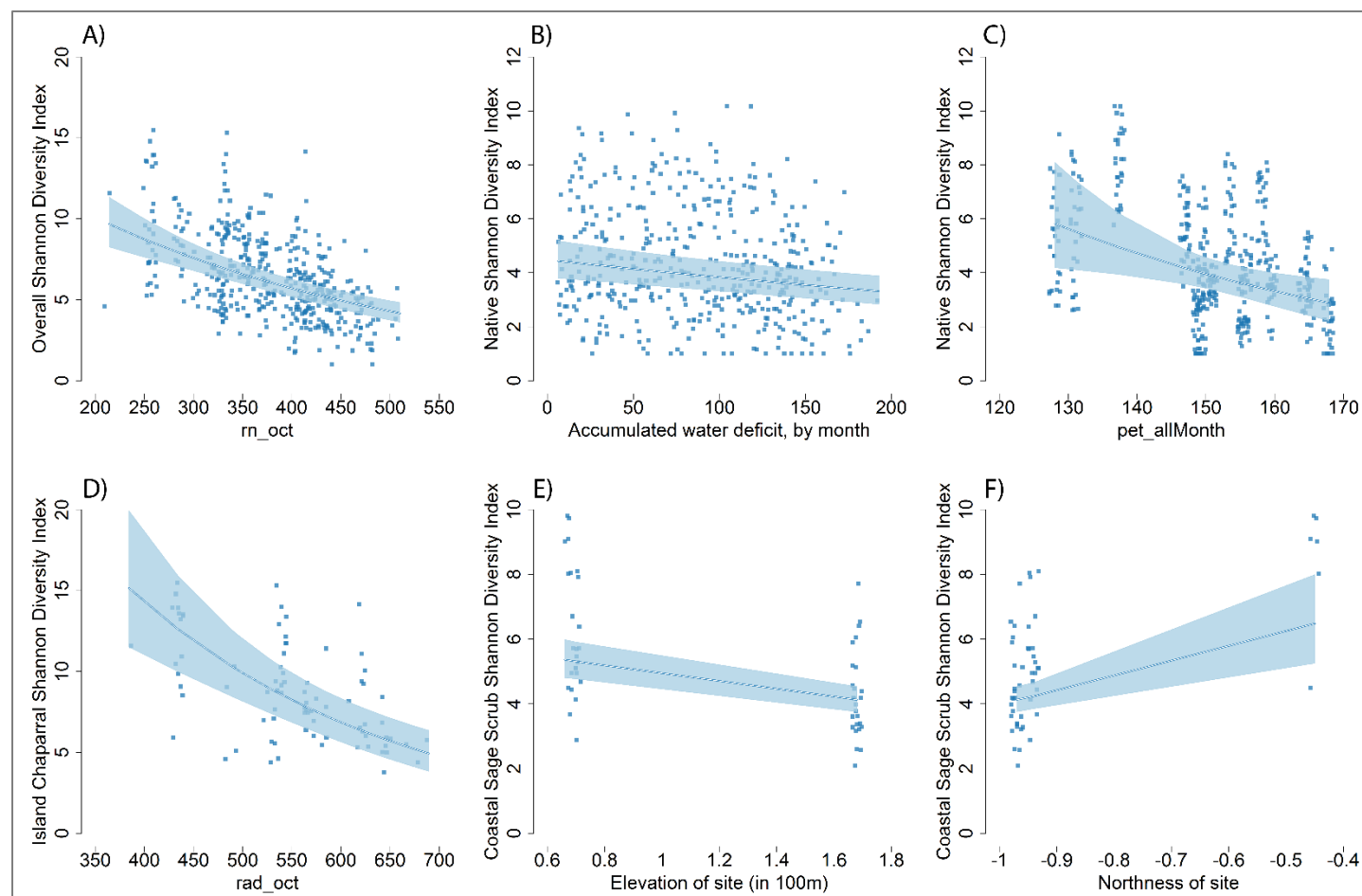


Figure 60. Marginal effects plots for final covariate models at index sites across San Miguel Island (first of three). A) Mean of 30-year monthly means for previous October to current survey month of clear sky net solar radiation (watts per square meter, $p < 0.0001$) for overall Shannon diversity index. B) Monthly accumulated water deficit (PET, mm; $p = 0.0001$) for native Shannon diversity index. C) Mean of 30-year monthly means for all months of cumulative potential evapotranspiration (PET, mm; $p = 0.0246$) for native Shannon diversity index. D) Mean of 30-year monthly means for previous October to current survey month of total clear sky solar radiation (watts per square meter, $p < 0.0001$) for island chaparral Shannon diversity index. E) Site elevation (in 100 m increments, $p = 0.0001$) for coastal sage scrub Shannon diversity index. F) Site northness ($p < 0.0001$) for coastal sage scrub Shannon diversity index (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation).

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Water balance covariates comprised the set of predictors for top models of grassland Shannon diversity at SM index sites (top three models shown in Table 28). These models included covariates for clear sky net solar radiation and total clear sky solar radiation, calculated as means of 30-year monthly means from the previous October to the current survey month, and monthly accumulated water deficit and modeled actual evapotranspiration. The final model for inference incorporated only the 30-year clear sky net solar radiation mean (rn_oct), which was negatively associated with grassland Shannon diversity at SM index sites ($p < 0.0001$, Figure 61A).

Top models for native shrub density at SM index sites contained several water balance covariates including soil moisture, modeled actual evapotranspiration, and accumulated water deficit summarized over the current water year and soil moisture computed over the current year fog season (top three models shown in Table 28). The final model consisted of only the current year soil moisture effect (SOIL_Pen_currYr), which was estimated as negatively associated with native shrub density at SM index sites ($p = 0.0172$, Figure 61B).

The top models for native shrub cover at SM index sites contained covariates for cumulative potential evapotranspiration in the previous water year and vapor pressure deficit and growing-degree days in the previous two water years (top three models shown in Table 28). The final model included only the term for cumulative potential evapotranspiration in the previous water year (PET_mm_prevYr), and this effect was negatively associated with native shrub cover at SM index sites ($p < 0.0001$, Figure 61C).

Top models for native forb cover at SM index sites included water balance covariates such as cumulative potential evapotranspiration and clear sky net solar radiation summarized as the 30-year monthly means from the previous October to the current survey month, monthly modeled actual evapotranspiration and accumulated water deficit, and soil moisture summarized over the previous two water years (top three models shown in Table 28). The 30-year mean cumulative potential evapotranspiration covariate was used in the final model for inference (pet_oct), and this effect was negatively associated with native forb cover at SM index sites ($p < 0.0001$, Figure 61D).

The final covariate model for nonnative forb cover at SM index sites included terms for the monthly modeled actual evapotranspiration (AET_Pen_mo) and the soil moisture summarized over the previous water year (Soil_water_mm_prevYr; Table 28). Modeled actual evapotranspiration was positively associated with nonnative forb cover ($p < 0.0001$, Figure 61E), and soil moisture was negatively associated with nonnative forb cover at SM index sites ($p = 0.0205$, Figure 61F).

The top models for native grass cover at SM index sites consisted of water balance metrics, such as number of days with dew, growing-degree days, and cumulative potential evapotranspiration summarized over the current water year; vapor pressure deficit for the current fog season; relative humidity for the previous year; and growing-degree days for the current month (top three models shown in Table 28). The final model included only the number of days with dew during the current water year (Dew_Pen_currYr) which increased with native grass cover ($p = 0.0038$, Figure 62A).

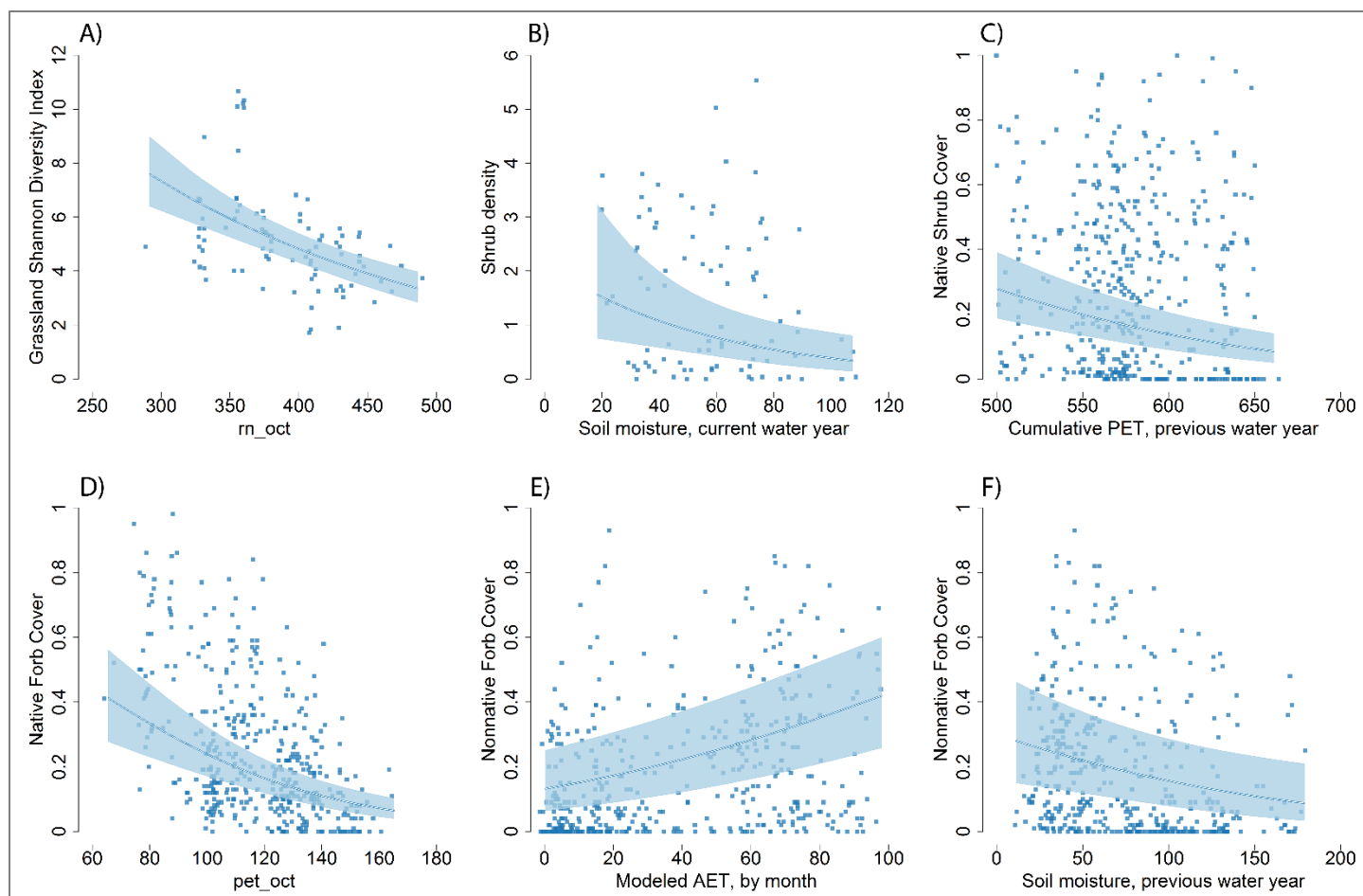


Figure 61. Marginal effects plots for final covariate models at index sites across San Miguel Island (second of three). A) Mean of 30-year monthly means for previous October to current survey month of clear sky net solar radiation (watts per square meter, $p < 0.0001$) for grassland Shannon diversity index. B) Soil moisture (mm) during the current water year ($p = 0.0172$) for native shrub density. C) Cumulative potential evapotranspiration (PET, mm) during the previous water year ($p < 0.0001$) for native shrub cover. D) Mean of 30-year monthly means for previous October to current survey month of cumulative potential evapotranspiration (PET, mm; $p < 0.0001$) for native forb cover. E) Monthly modeled actual evapotranspiration (AET, mm; $p < 0.0001$) for nonnative forb cover. F) Soil moisture (mm) during the previous water year ($p = 0.0205$) for nonnative forb cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

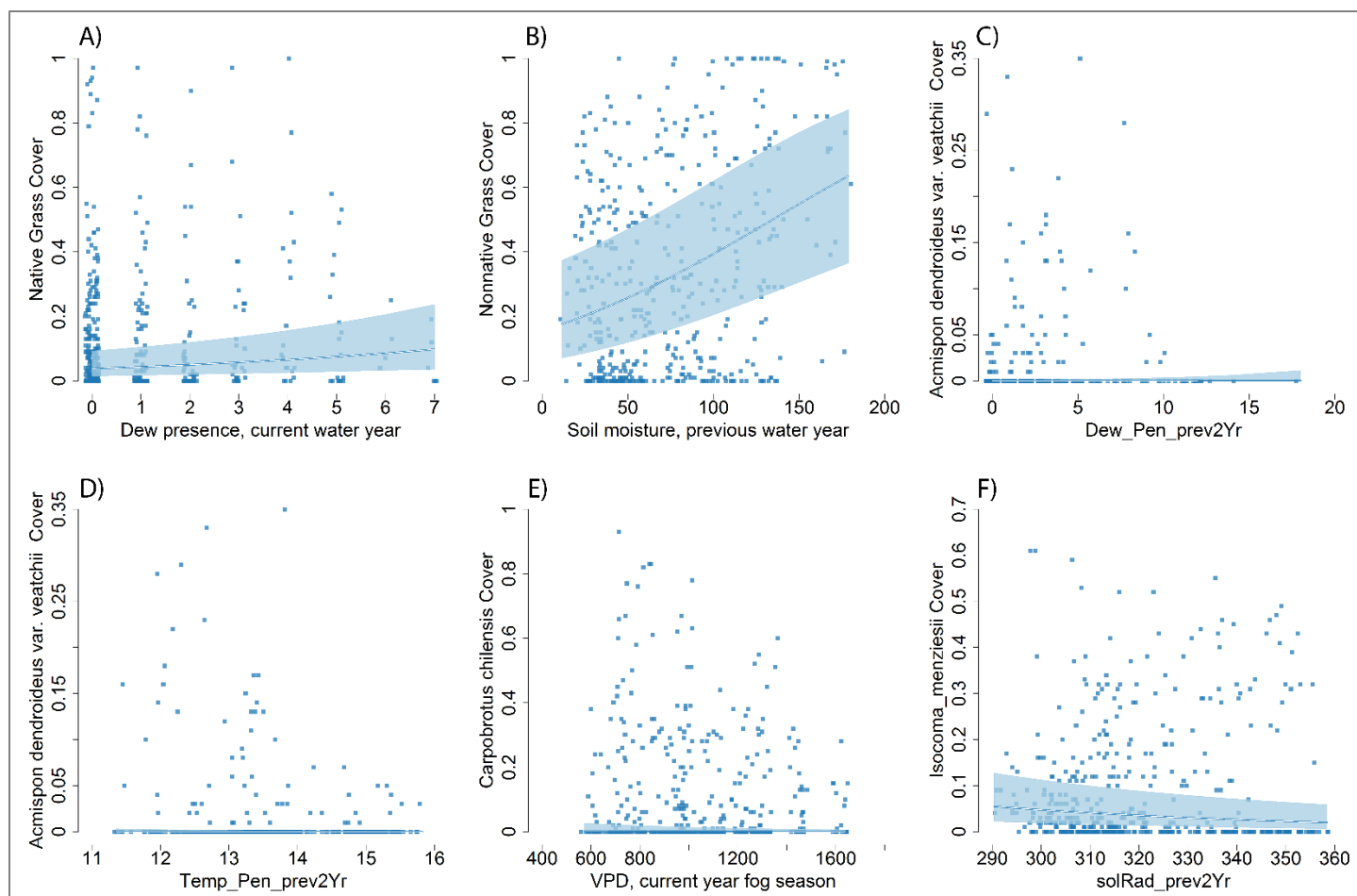


Figure 62. Marginal effects plots for final covariate models at index sites across San Miguel Island (third of three). A) Dew presence (measured as the number of days that dew was present) during the current water year ($p = 0.0038$) for native grass cover. B) Soil moisture (mm) during the previous water year ($p = 0.0012$) for nonnative grass cover. C) Dew presence (measured as the number of days that dew was present) for the previous two water years combined ($p = 0.0035$) for *Acmispon dendroideus* var. *veatchii* cover. D) Temperature (degrees Celsius) for the previous two water years combined ($p = 0.0006$) for *Acmispon dendroideus* var. *veatchii* cover. E) Vapor pressure deficit (VPD, pascals) during the current year fog season ($p = 0.0013$) for *Carpobrotus chilensis* cover. F) Total clear sky solar radiation (watts per square meter) for the previous two water years combined ($p = 0.0043$) for *Isocoma menziesii* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for nonnative grass cover at SM index sites contained terms for soil moisture in the previous year and previous two water years, and monthly modeled actual evapotranspiration and water deficit (top three and final models shown in Table 28). The final model included only the effect for soil moisture in the previous year (Soil_water_mm_prevYr; the fourth-ranked model), and this was estimated to be positively associated with the odds of nonnative grass cover at SM index sites ($p = 0.0012$, Figure 62B).

The top model for *Acmispon dendroideus* var. *veatchii* cover at SM index sites contained terms for the temperature (Temp_Pen_prev2Yr) and the number of days with dew during the previous two water years (Dew_Pen_prev2Yr; Table 28). The number of days with dew during the previous two water years was positively associated ($p = 0.0035$, Figure 62C), and temperature was negatively associated ($p = 0.0006$, Figure 62D), with the odds of *Acmispon dendroideus* var. *veatchii* cover at SM index sites.

The top models for *Carpobrotus chilensis* cover at SM index sites included water balance covariates such as vapor pressure deficit and soil moisture for the current fog season and growing-degree days and temperature summarized by the calendar year (top three models shown in Table 28). The final model contained only a term for vapor pressure deficit during the current fog season (vpd_Pen_fogYr), which was negatively associated with *Carpobrotus chilensis* cover at SM index sites ($p = 0.0013$, Figure 62E).

The top models for *Isocoma menziesii* cover at SM index sites included solar radiation summarized either over the previous two water years or the current fog season (Table 28). The final model incorporated the solar radiation summarized over the previous two water years (solRad_prev2Yr), and this effect was negatively associated with *Isocoma menziesii* cover at SM index sites ($p = 0.0043$, Figure 62F).

San Miguel Island Probability Sites

The top models for native Shannon diversity of SM probability sites contained site-level characteristics such as site northness and elevation (top three models shown in Table 29). Water balance covariates in top models included 30-year monthly means for all months for clear sky net solar radiation and cumulative potential evapotranspiration, temperature and cumulative potential evapotranspiration during the current fog season, monthly temperature and accumulated water deficit, modeled actual evapotranspiration for the previous water year, and vapor pressure deficit for the previous two water years. The final model contained a term for site northness (Northness), which was positively associated with native Shannon diversity at SM probability sites ($p = 0.1310$, Figure 63A). However, the p-value for the significance test exceeded the Type I error rate of 0.10, indicating that the effect may not be statistically different from zero.

The final model for native shrub density at SM probability sites included a single term for accumulated water deficit summarized over the current year fog season (Deficit_mm_fog; Table 29). This effect was positively associated with native shrub density at SM probability sites ($p = 0.0004$, Figure 63B).

Table 29. Covariate models ranked by AICc for all outcomes at probability sites across San Miguel Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Shannon Diversity	Northness^A	130.14	0.00
	Elevation_m	130.26	0.12
	rn_allMonth	130.26	0.12
Native Shrub Density	Deficit_mm_fog^A	238.34	0.00
	PET_Pen_prevYr	242.74	4.40
	vpd_Pen_prevYr	242.82	4.48
Native Shrub Cover	Soil_water_mm_prevYr+SOIL_Pen_currYr	251.47	0.00
	PET_Pen_currYr^A	252.04	0.58
	Northness	253.62	2.16
Native Forb Cover	SRad_CurrentYear^A	261.12	0.00
	AET_Pen_mo+Temp_Pen_fogYr+Slope_degrees	263.02	1.90
	AET_Pen_mo+Temp_Pen_fogYr	263.35	2.23
Nonnative Forb Cover	rh_Pen_prev2Yr^A	199.30	0.00
	rh_Pen_prev2Yr+Northness	200.93	1.62
	rh_Pen_prev2Yr+Dew_Pen_fogYr	201.01	1.71
Nonnative Grass Cover	SOIL_Pen_prev2Yr^A	297.74	0.00
	SOIL_Pen_prev2Yr+Slope_degrees	299.31	1.57
	Soil_water_mm_currentYr	300.92	3.18
<i>Acmispon dendroideus</i> Var. <i>Veatchii</i> Cover	Elevation_m^A	48.69	0.00
	Dew_Pen_fogYr+Elevation_m	50.08	1.39
	Northness+Elevation_m	50.67	1.98
<i>Carpobrotus chilensis</i> Cover	SOIL_Pen_currYr^A	215.25	0.00
	Soil_water_mm_currentYr	215.33	0.08

^A Final covariate model for each outcome (also in bold font).

Table 29 (continued). Covariate models ranked by AICc for all outcomes at probability sites across San Miguel Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
<i>Carpobrotus chilensis</i> Cover (continued)	AET_Pen_fogYr+Slope_degrees	216.38	1.13
<i>Isocoma menziesii</i> Cover	solRad_prev2Yr^A	207.19	0.00
	rh_Pen_fogYr+Northness	207.62	0.44
	rh_Pen_fogYr	207.69	0.50

^A Final covariate model for each outcome (also in bold font).

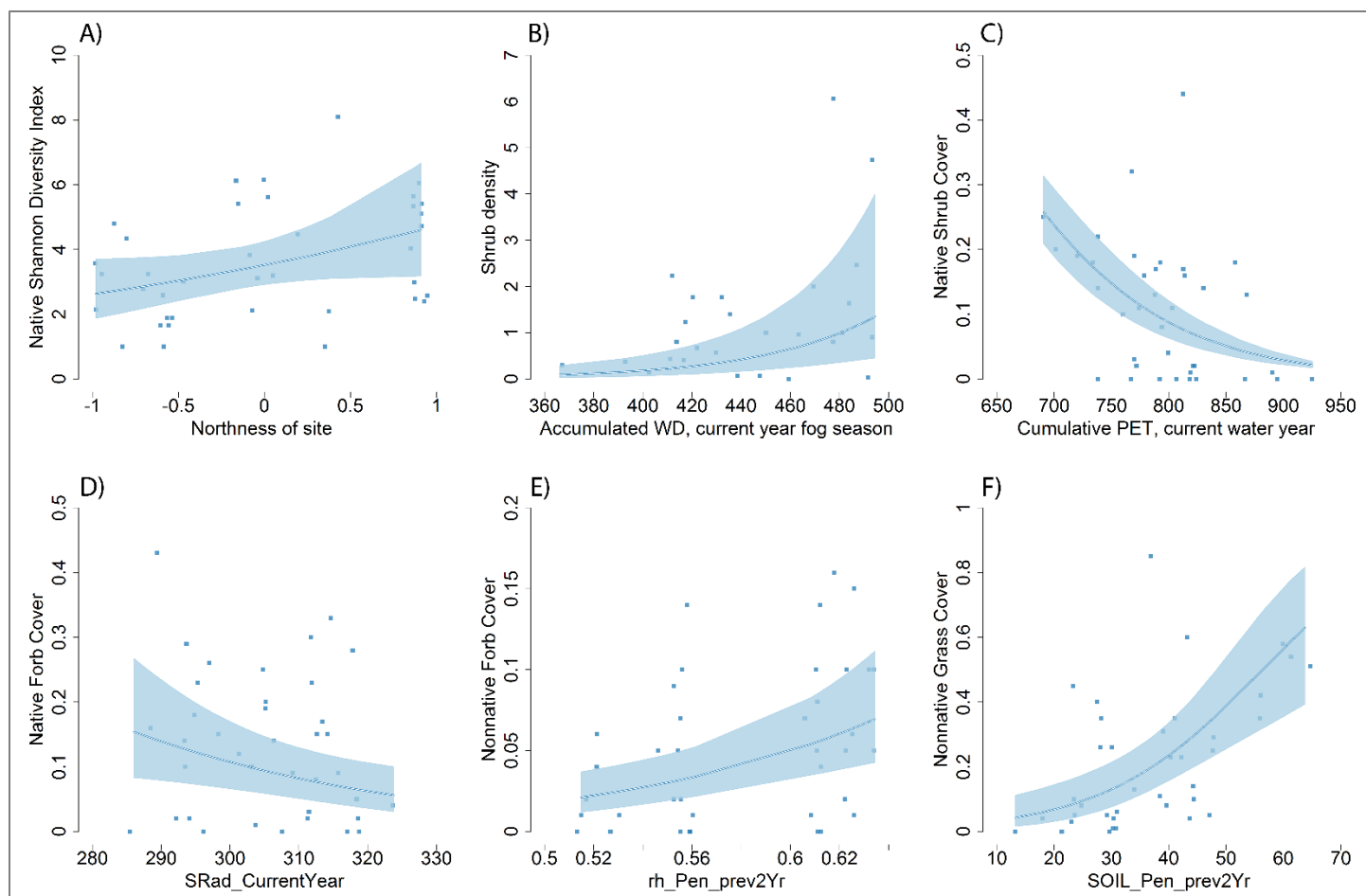


Figure 63. Marginal effects plots for final covariate models at probability sites across San Miguel Island (first of two). A) Site northness ($p = 0.1310$) for native Shannon diversity index (northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation). B) Accumulated water deficit (WD, mm) during the current year fog season ($p = 0.0004$) for native shrub density. C) Cumulative potential evapotranspiration (PET, mm) during the current water year ($p = 0.0026$) for native shrub cover. D) Total clear sky solar radiation (watts per square meter) during the current water year ($p = 0.0263$) for native forb cover. E) Relative humidity (percentage divided by 100) for the previous two water years combined ($p = 0.0013$) for nonnative forb cover. F) Soil moisture (mm) for the previous two water years combined ($p = 0.0004$) for nonnative grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for native shrub cover at SM probability sites included water balance covariates such as soil moisture during the previous water year and soil moisture and cumulative potential evapotranspiration during the current water year (top three models shown in Table 29). The final model contained only the fixed effect for cumulative potential evapotranspiration during the current water year (PET_Pen_currYr), and this effect was negatively associated with native shrub cover at SM probability sites ($p = 0.0026$, Figure 63C).

The top models for native forb cover at SM probability sites included covariates for total clear sky solar radiation for the current water year, monthly modeled actual evapotranspiration, temperature during the fog season, and site slope (Table 29). The final model contained a single fixed effect for total clear sky solar radiation for the current water year (SRad_CurrentYear), which was negatively associated with native forb cover at SM probability sites ($p = 0.0263$, Figure 63D).

All of the top models for nonnative forb cover at SM probability sites contained a term for relative humidity summarized over the previous two water years (rh_Pen_prev2Yr), and this covariate was the only term in the final model (Table 29). The effect of relative humidity was positively associated with nonnative forb cover at SM probability sites ($p = 0.0013$, Figure 63E).

The final covariate model for nonnative grass cover at SM probability sites included a covariate for soil moisture summarized over the previous two water years (SOIL_Pen_prev2Yr; Table 29). The soil moisture covariate was positively associated with the odds of nonnative grass cover at SM probability sites ($p = 0.0004$, Figure 63F).

The top covariate models for *Acmispon dendroideus* var. *veatchii* cover at SM probability sites included terms for site elevation, site northness, and the number of days with dew during the current fog season (Table 29). The final model contained only a term for elevation (Elevation_m), and this effect was positively associated with *Acmispon dendroideus* var. *veatchii* cover at SM probability sites ($p = 0.0545$, Figure 64A). One site at 190 m elevation is highly influential in the estimate of an increasing relationship with *Acmispon dendroideus* var. *veatchii* cover.

Top models for *Carpobrotus chilensis* cover at SM probability sites included covariates for soil moisture during the current water year, modeled actual evapotranspiration during the current fog season, and the site slope (Table 29). The final model contained the soil moisture for the current water year (SOIL_Pen_currYr), and this variable was negatively associated with *Carpobrotus chilensis* cover at SM probability sites ($p = 0.0222$, Figure 64B).

The top models for *Isocoma menziesii* cover at SM probability sites consisted of total clear sky solar radiation for the previous two water years, site northness, relative humidity for the current fog year and for the previous two water years, accumulated water deficit by the current fog year and by month, soil moisture for the current water year or the current fog season, and modeled actual evapotranspiration for the current fog season (top three models shown in Table 29). The final model contained a single term for total clear sky solar radiation over the previous two water years (solRad_prev2Yr), and this effect was positively associated with *Isocoma menziesii* cover at SM probability sites ($p = 0.0310$, Figure 64C).

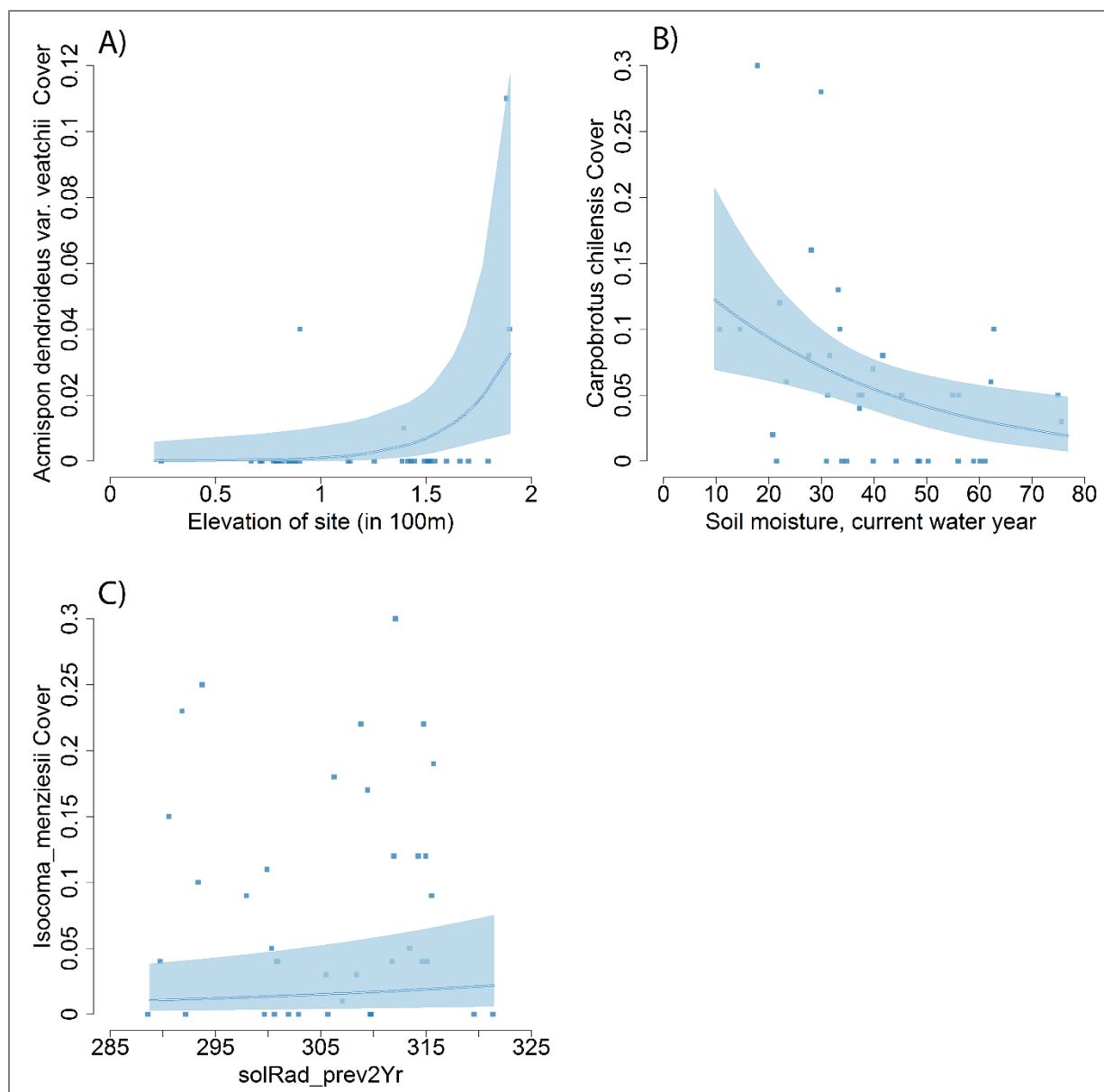


Figure 64. Marginal effects plots for final covariate models at probability sites across San Miguel Island (second of two). A) Site elevation (in 100 m increments, $p = 0.0545$) for *Acmispon dendroideus* var. *veatchii* cover. B) Soil moisture (mm) during the current water year ($p = 0.0222$) for *Carpobrotus chilensis* cover. C) Total clear sky solar radiation (watts per square meter) during the previous two water years combined ($p = 0.0310$) for *Isocoma menziesii* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Covariate Modeling for Santa Rosa Island

A subset of the full covariate modeling results across Santa Rosa Island (SR) is presented in this section. More detailed AICc analysis results for each outcome can be found in Section E of the [Supplemental Information](#), while GLMM estimates for the final covariate model for each outcome can be found in Section F.

Santa Rosa Island Index Sites

Top models for overall Shannon diversity at SR index plots contained site-specific characteristics such as site elevation and slope (top three models shown in Table 30). Several nonnative mammal removal covariates, such as the indicator of elk or cattle removal and the number of years since cattle, pigs, and deer were removed, were also included in the top models. The final model consisted of the number of years since cattle removal (Cattle; $p < 0.0001$, Figure 65A) and site slope (Slope_degrees; $p = 0.0061$, Figure 65B), both of which were negatively associated with overall Shannon diversity at SR index plots.

The final model for native Shannon diversity at SR index sites contained soil moisture for the previous water year (Soil_water_mm_prevYr) and accumulated water deficit for the month (Def_Pen_mo; Table 30). Both monthly accumulated water deficit ($p < 0.0001$, Figure 65C) and soil moisture for the previous water year ($p < 0.0001$, Figure 65D) were negatively associated with native Shannon diversity at SR index sites.

The top models for coastal sage scrub Shannon diversity at SR index sites contained water balance covariates such as soil moisture for the current fog season and relative humidity over the previous two water years, site slope, and nonnative mammal removal variables such as the years since cattle and pig removal and indicators of cattle and elk removal (top three models shown in Table 30). The final model included three predictors of coastal sage scrub Shannon diversity at SR index sites. The number of years since cattle removal (Cattle) was negatively associated with coastal sage scrub Shannon diversity ($p < 0.0001$, Figure 65E), and the site slope (Slope_degrees; $p = 0.0124$, Figure 65F) and fog season soil moisture (SOIL_Pen_fogYr; $p = 0.0205$, Figure 66A) were positively associated with coastal sage scrub Shannon diversity at SR index sites.

Top models for *Baccharis* scrub Shannon diversity at SR index sites included site northness; water balance covariates such as relative humidity and the number of days with dew for the current fog season; and indicators of mammal removal for cattle, elk, and deer (top three models shown in Table 30). The final covariate model included indicators of cattle (Cattle_Ind; $p = 0.0074$, Figure 66B) and elk (Elk_Ind; $p < 0.0001$, Figure 66C) removal; both indicators were negatively associated with *Baccharis* scrub Shannon diversity at SR index sites.

The final model for grassland Shannon diversity at SR index sites included covariates for site northness (Northness) and indicators for cattle (Cattle_Ind) and elk (Elk_Ind) removal (Table 30). Northness was positively associated with grassland Shannon diversity ($p = 0.0014$, Figures 66D and 66E). The effects of cattle removal ($p = 0.0043$, Figure 66D) and elk removal ($p = 0.0005$, Figure 66E) were both negatively associated with grassland Shannon diversity at SR index sites. The marginal effects plots demonstrate this negative association because the trend line for grassland Shannon diversity plotted against the range of northness values when nonnative mammal removal is not used (plotted in blue and taking a value of 0) exceed the values for grassland Shannon diversity with nonnative mammal removal (plotted in red and taking a value of 1).

Table 30. Covariate models ranked by AICc for all outcomes at index sites across Santa Rosa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Overall Shannon Diversity	Elevation_m+Cattle_Ind+Elk_Ind	7130.93	0.00
	Slope_degrees+Cattle ^A	7132.70	1.77
	Slope_degrees+Pig	7132.79	1.86
Native Shannon Diversity	Soil_water_mm_prevYr+Def_Pen_mo ^A	5112.93	0.00
	Soil_water_mm_prevYr+SOIL_Pen_mo+Def_Pen_mo	5114.92	1.99
	rn_oct	5123.36	10.43
Coastal Sage Scrub Shannon Diversity	SOIL_Pen_fogYr+Slope_degrees+Cattle ^A	949.70	0.00
	rh_Pen_prev2Yr+Northness+Cattle_Ind+Elk_Ind	950.65	0.95
	rh_Pen_prev2Yr+Dew_Pen_fogYr+Cattle_Ind+Elk_Ind	951.40	1.71
<i>Baccharis</i> Scrub Shannon Diversity	rh_Pen_fogYr+Northness+Cattle_Ind+Elk_Ind	837.37	0.00
	Cattle_Ind+Elk_Ind ^A	838.01	0.64
	Northness+Cattle_Ind+Elk_Ind	838.26	0.89
Grassland Shannon Diversity	Northness+Pig_Ind+Cattle_Ind+Elk_Ind	2182.00	0.00
	Northness+Cattle_Ind+Elk_Ind ^A	2183.53	1.53
	rh_Pen_fogYr+Northness+Cattle_Ind+Elk_Ind	2184.89	2.89
Riparian Shannon Diversity	Temp_Pen_prevYr+Slope_degrees ^A	597.03	0.00
	Temp_Pen_mo+Slope_degrees	598.48	1.44
	Slope_degrees+Pig	598.96	1.93
Mixed Woodland Shannon Diversity	Elevation_m+Elk ^A	392.78	0.00
	Dew_Pen_fogYr+Elevation_m+Deer	392.93	0.15
	Dew_Pen_currYr+Elevation_m+Pig_Ind	394.22	1.44
Native Tree Density	AET_mm_fog+Def_Pen_mo	783.44	0.00
	AET_mm_fog ^A	783.61	0.17

^A Final covariate model for each outcome (also in bold font).

Table 30 (continued). Covariate models ranked by AICc for all outcomes at index sites across Santa Rosa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Tree Density (continued)	AET_mm_fog+Soil_water_mm_fog+Def_Pen_mo	784.84	1.39
Native Tree Recruitment Density	AET_mm_fog ^A	1014.18	0.00
	AET_mm_prev2Yr	1014.86	0.68
	AET_mm_fog+SOIL_Pen_currYr	1014.98	0.79
Native Shrub Density	Slope_degrees+Pig ^A	2762.72	0.00
	Slope_degrees+Cattle	2762.72	0.00
	Slope_degrees	2766.51	3.79
Native Shrub Recruitment Density	Def_Pen_fogYr ^A	1771.79	0.00
	Dew_Pen_prev2Yr+Northness+Elk+Cattle_Ind	1773.46	1.68
	Dew_Pen_prev2Yr+Elk+Cattle_Ind	1774.34	2.56
Native Tree Cover	rn_allMonth ^A	4701.33	0.00
	rad_allMonth	4702.68	1.34
	Northness+Elk	4709.67	8.33
Native Shrub Cover	Northness+Deer+Cattle_Ind+Elk_Ind	8752.10	0.00
	Dew_Pen_fogYr+Deer+Cattle_Ind+Elk_Ind	8753.34	1.24
	Deer+Cattle_Ind+Elk_Ind ^A	8753.40	1.30
Native Forb Cover	Temp_Pen_mo+Pig ^A	11866.67	0.00
	Temp_Pen_mo+Slope_degrees	11867.15	0.48
	Temp_Pen_mo+Cattle	11869.25	2.58
Nonnative Forb Cover	AET_Pen_mo+Slope_degrees+Pig ^A	9532.04	0.00
	Slope_degrees+Pig	9542.41	10.37
	Slope_degrees+Cattle	9545.55	13.51
Native Grass Cover	rn_oct ^A	12954.97	0.00

^A Final covariate model for each outcome (also in bold font).

Table 30 (continued). Covariate models ranked by AICc for all outcomes at index sites across Santa Rosa Island. Note that only the top three models for each outcome are presented in this table; the results of the full analysis are presented in Section E of the [Supplemental Information](#), and full names of model parameters can be found in Section B. The final covariate model for each outcome is shown in bold text.

Outcome	Model	AIC _c	ΔAIC _c
Native Grass Cover (continued)	rad_oct	12960.66	5.69
	Elevation_m+Elk+Cattle_Ind	12962.65	7.68
Nonnative Grass Cover	rh_Pen_prev2Yr+Northness+Cattle_Ind+Elk_Ind^A	13406.90	0.00
	rh_Pen_prev2Yr+Dew_Pen_fogYr+Cattle_Ind+Elk_Ind	13407.91	1.01
	Temp_Pen_prev2Yr+Slope_degrees	13412.26	5.35
<i>Arctostaphylos</i> Group Cover	Temp_Pen_an+Pig^A	835.23	0.00
	Slope_degrees+Cattle	836.60	1.38
	Cattle	838.32	3.10
<i>Heteromeles Arbutifolia</i> Cover	Cattle^A	1368.02	0.00
	Slope_degrees+Cattle	1368.51	0.49
	Temp_Pen_an+Cattle	1369.26	1.24
<i>Quercus Pacifica</i> Cover	rh_Pen_prevYr+Elk^A	1646.70	0.00
	rh_Pen_prevYr+Deer_Ind	1647.84	1.14
	rh_Pen_prevYr+Deer	1647.99	1.29
<i>Stipa</i> Group Cover	Dew_Pen_prev2Yr+Northness+Elk+Cattle_Ind	5013.61	0.00
	pet_allMonth+Soil_water_mm_prevYr^A	5015.54	1.93
	rh_Pen_prevYr+Northness+Elk	5016.12	2.51

^A Final covariate model for each outcome (also in bold font).

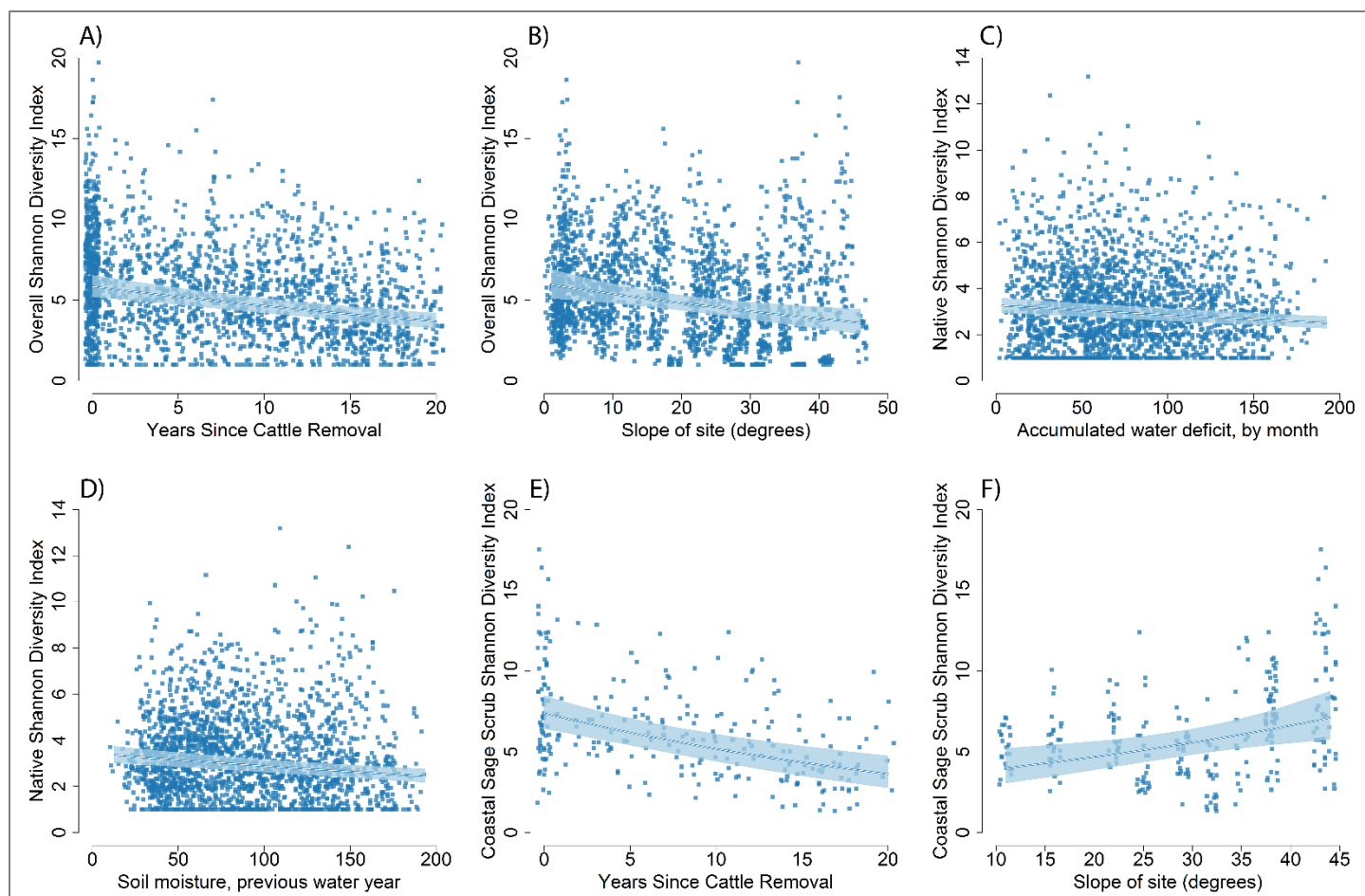


Figure 65. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (first of eight). A) Years since cattle removal ($p < 0.0001$) for overall Shannon diversity index. B) Site slope (degrees, $p = 0.0061$) for overall Shannon diversity index. C) Monthly accumulated water deficit (mm, $p < 0.0001$) for native Shannon diversity index. D) Soil moisture (mm) during the previous water year ($p < 0.0001$) for native Shannon diversity index. E) Years since cattle removal ($p < 0.0001$) for coastal sage scrub Shannon diversity index. F) Site slope (degrees, $p = 0.0124$) for coastal sage scrub Shannon diversity index.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

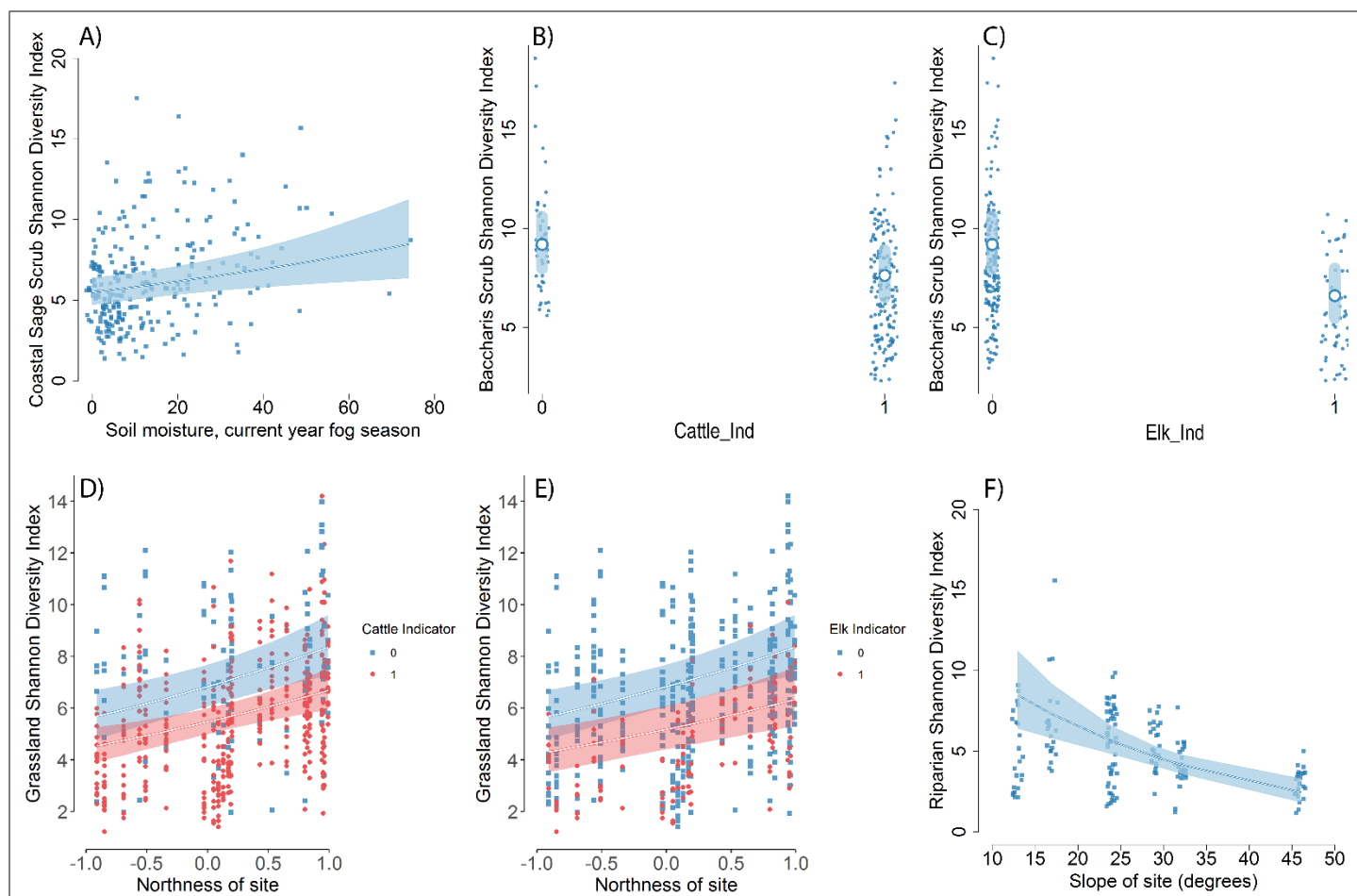


Figure 66. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (second of eight). A) Soil moisture (mm) during the current year fog season ($p = 0.0205$) for coastal sage scrub Shannon diversity index. B) Indicator of cattle removal ($p = 0.0074$) for *Baccharis* scrub Shannon diversity index. C) Indicator of elk removal ($p < 0.0001$) for *Baccharis* scrub Shannon diversity index. D) Northness ($p = 0.0014$) for levels of the indicator of cattle removal ($p = 0.0043$) for grassland Shannon diversity index. E) Northness ($p = 0.0014$) for levels of the indicator of elk removal (0.0005) for grassland Shannon diversity index. F) Site slope (degrees, $p < 0.0001$) for riparian Shannon diversity index. For graphs B through E, indicators are coded as 1 when animal removal has occurred and 0 prior to removal. For graphs D and E, northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for riparian Shannon diversity at SR index sites included terms for site slope, temperature summarized by previous water year or current month, and years since pig or cattle removal (top three models shown in Table 30). The final model contained effects of site slope (Slope_degrees; $p < 0.0001$, Figure 66F) and temperature over the previous water year (Temp_Pen_prevYr; $p = 0.0331$, Figure 67A), both of which were negatively associated with riparian Shannon diversity at SR index sites.

Top models for mixed woodland Shannon diversity at SR index sites included effects for site elevation, the indicator of pig removal, the number of years since elk or deer removal, and the number of days with dew during the fog season or the current water year (top three models shown in Table 30). The final model contained effects of site elevation (Elevation_m; $p < 0.0001$, Figure 67B) which was negatively associated with mixed woodland Shannon diversity at SR index sites. The effect of the number of years since elk removal (Elk) was not statistically significant at the 0.10 level ($p = 0.6220$, Figure 67C).

The top models for native tree density at SR index sites included covariates for modeled actual evapotranspiration during the current fog season, monthly accumulated water deficit, and soil moisture during the current fog season and previous two water years (Table 30). The final model contained a single term for modeled actual evapotranspiration during the current fog season (AET_mm_fog), which was negatively associated with native tree density at SR index sites ($p < 0.0001$, Figure 67D).

The top models for native tree recruitment density at SR index sites were comprised of water balance covariates including modeled actual evapotranspiration over the fog season and for the previous two water years, soil moisture for the current water year, monthly accumulated water deficit, the 30-year mean of cumulative potential evapotranspiration means for the survey month, and growing-degree days for the previous two water years (top three models shown in Table 30). The final model included only the effect for modeled actual evapotranspiration over the fog season (AET_mm_fog), which was positively associated with native tree recruitment density at SR index sites ($p = 0.0209$, Figure 67E).

The top models for native shrub density at SR index sites included terms for the site slope and the number of years since pig or cattle removal (Table 30). Since pig and cattle removal occurred two years apart, the two models are equivalent. The final model for inference contained terms for the number of years since pig removal (Pig; $p = 0.0114$, Figure 67F) and the site slope (Slope_degrees; $p = 0.0044$, Figure 68A), both of which were positively associated with native shrub density at SR index sites.

The final model for native shrub recruitment density at SR index sites contained a single term for accumulated water deficit for the current fog season (Def_Pen_fogYr; Table 30). This effect was negatively associated with native shrub recruitment density at SR index sites ($p = 0.0007$, Figure 68B).

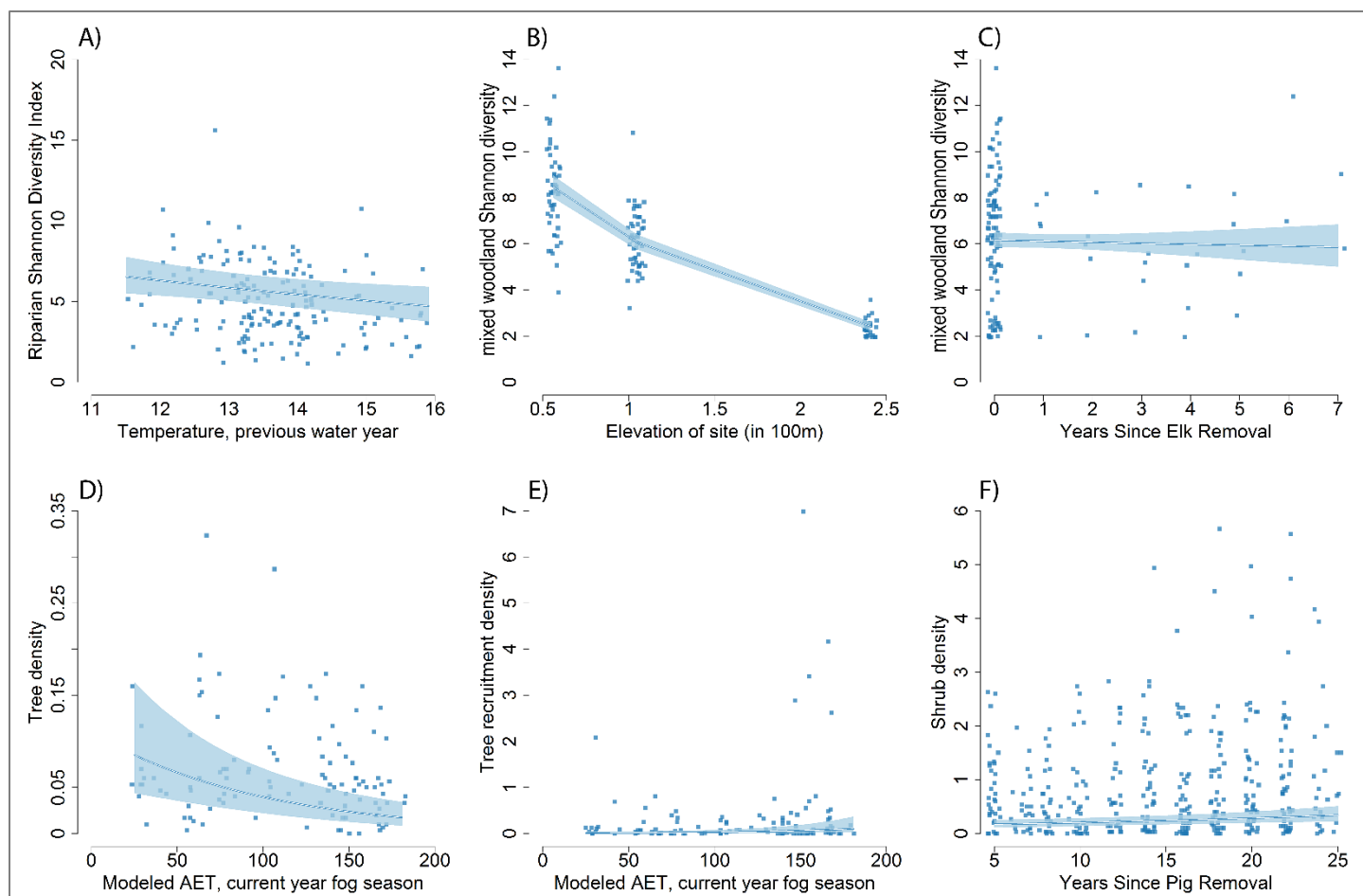


Figure 67. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (third of eight). A) Temperature (degrees Celsius) during the previous water year ($p = 0.0331$) for riparian Shannon diversity index. B) Site elevation (in 100 m increments, $p < 0.0001$) for mixed woodland Shannon diversity index. C) Years since elk removal ($p = 0.6220$) for mixed woodland Shannon diversity index. D) Modeled actual evapotranspiration (AET, mm) during the current year fog season ($p < 0.0001$) for native tree density. E) Modeled actual evapotranspiration (AET, mm) during the current year fog season ($p = 0.0209$) for native tree recruitment density. F) Years since pig removal ($p = 0.0114$) for native shrub density.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

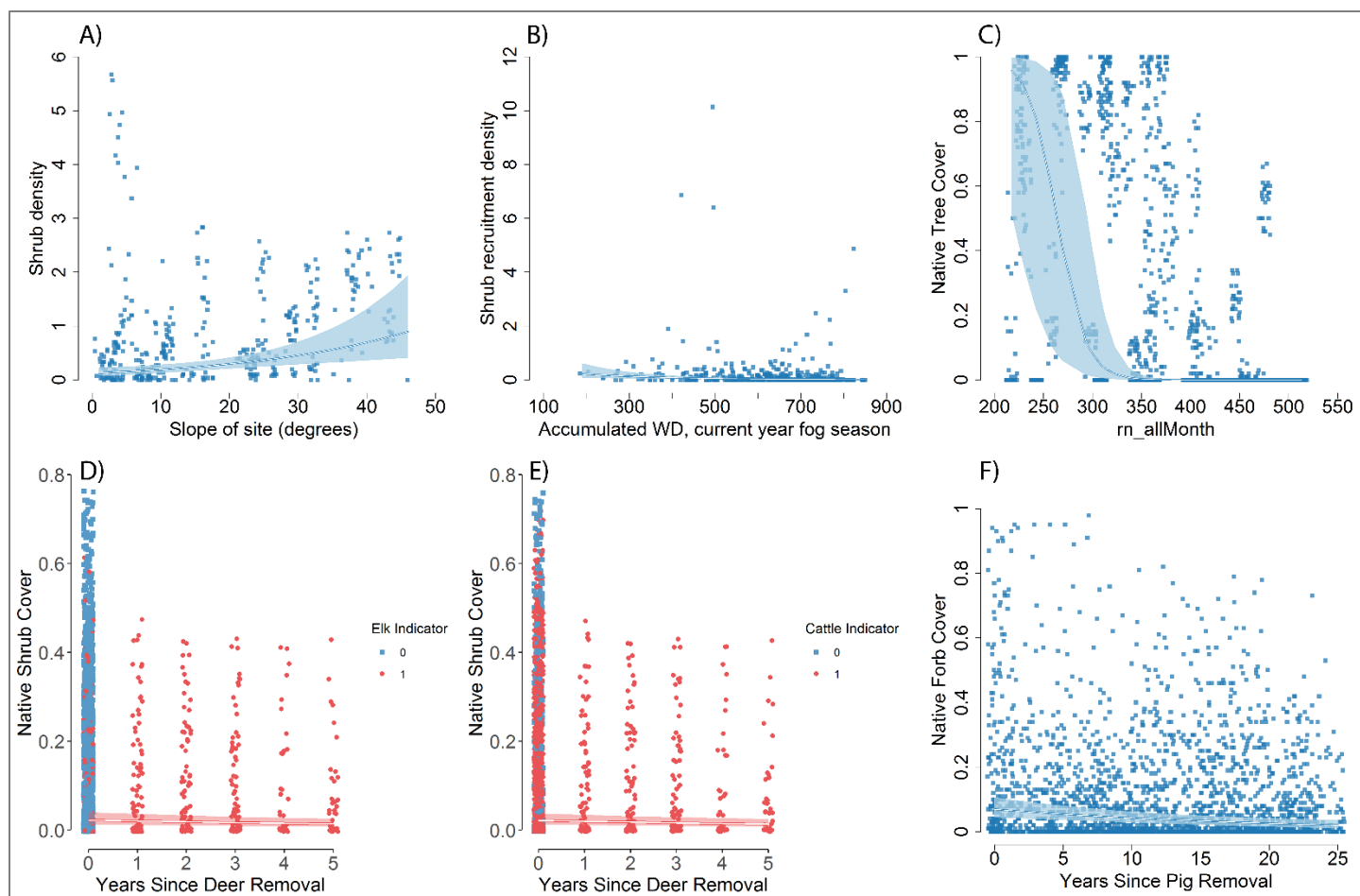


Figure 68. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (fourth of eight). A) Site slope (degrees, $p = 0.0044$) for native shrub density. B) Accumulated water deficit (WD; mm) during the current year fog season ($p = 0.0007$) for native shrub recruitment density. C) Mean of 30-year monthly means for all months of clear sky net solar radiation (watts per square meter, $p < 0.0001$) for native tree cover. D) Years since deer removal ($p = 0.0117$) for levels of the elk removal indicator ($p = 0.0157$) for native shrub cover. E) Years since deer removal ($p = 0.0117$) for levels of the cattle removal indicator ($p = 0.0222$) for native shrub cover. F) Years since pig removal ($p = 0.0016$) for native forb cover. For graphs D and E, indicators are coded as 1 when animal removal has occurred and 0 prior to removal.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The two top models for native tree cover at SR index sites contained 30-year means of monthly means from all months for clear sky net solar radiation and total clear sky solar radiation (Table 30). The top model for inference included the 30-year mean for monthly clear sky net solar radiation (rn_allMonth), which was negatively associated with native tree cover at SR index sites ($p < 0.0001$, Figure 68C).

Top models for native shrub cover at SR index sites included covariates for site northness, the number of years since deer removal, indicators of cattle or elk removal, and the number of days with dew during the current fog year (Table 30). The final model contained a term for the number of years since deer removal (Deer), which began in 2014, that was negatively associated with native shrub cover ($p = 0.0117$, Figures 68D and 68E). The indicator of elk removal since 2012 (Elk_Ind; $p = 0.0157$, Figure 68D) and the indicator of cattle removal since 1990 (Cattle_Ind; $p = 0.0222$, Figure 68E) were also contained in the final model, and were both positively associated with the odds of native shrub cover at SR index sites.

The top models for native forb cover at SR index sites included terms for monthly temperature, the number of years since pig removal, and the site slope (Table 30). The final model contained effects of the years since pig removal (Pig; $p = 0.0016$, Figure 68F) and the monthly temperature (Temp_Pen_mo; $p < 0.0001$, Figure 69A), both of which were negatively associated with native forb cover at SR index sites.

The final model for nonnative forb cover at SR index sites included the effects of monthly modeled actual evapotranspiration (AET_Pen_mo), the site slope (Slope_degrees), and the number of years since pig removal (Pig; Table 30). The effect of monthly modeled actual evapotranspiration was positively associated with nonnative forb cover at SR index sites ($p = 0.0003$, Figure 69B). Both the number of years since pig removal ($p < 0.0001$, Figure 69C) and site slope ($p = 0.0001$, Figure 69D) were negatively associated with nonnative forb cover at SR index sites.

The top model for native grass cover at SR index sites included a single term for the 30-year monthly means of clear sky net solar radiation from the previous October to current survey month (rn_oct; Table 30). The effect of clear sky net solar radiation was positively associated with native grass cover at SR index sites ($p < 0.0001$, Figure 69E).

The final model for nonnative grass cover at SR index sites included terms of relative humidity over the previous two water years (rh_Pen_prev2Yr), site northness (Northness), and indicators of cattle (Cattle_Ind) and elk (Elk_Ind) removal (Table 30). The effect of northness was negatively associated with nonnative grass cover, although the effect was not statistically significant ($p = 0.2133$, Figures 70A and 70B). The effect of relative humidity over the previous two water years was positively associated with nonnative grass cover ($p < 0.0001$, Figures 70C and 70D). The odds of nonnative grass cover decreased with cattle removal ($p < 0.0001$, Figures 70A and 70C), and a similar negative effect of elk removal was observed ($p < 0.0001$, Figures 70B and 70D).

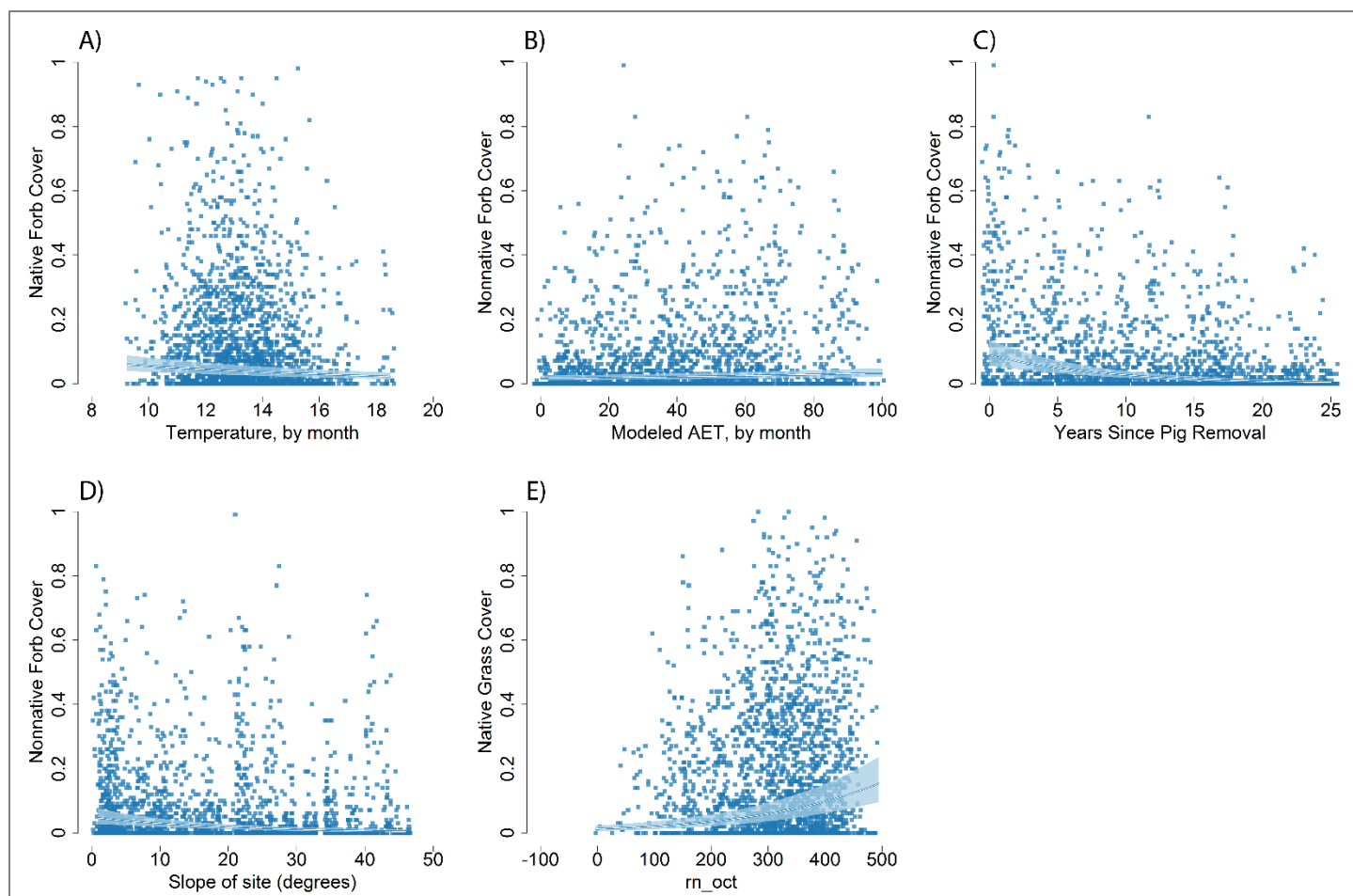


Figure 69. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (fifth of eight). A) Monthly temperature (degrees Celsius, $p < 0.0001$) for native forb cover. B) Monthly modeled actual evapotranspiration (AET, mm; $p = 0.0003$) for nonnative forb cover. C) Years since pig removal ($p < 0.0001$) for nonnative forb cover. D) Site slope (degrees, $p = 0.0001$) for nonnative forb cover. E) Mean of 30-year monthly means for previous October to current survey month of clear sky net solar radiation (watts per square meter, $p < 0.0001$) for native grass cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

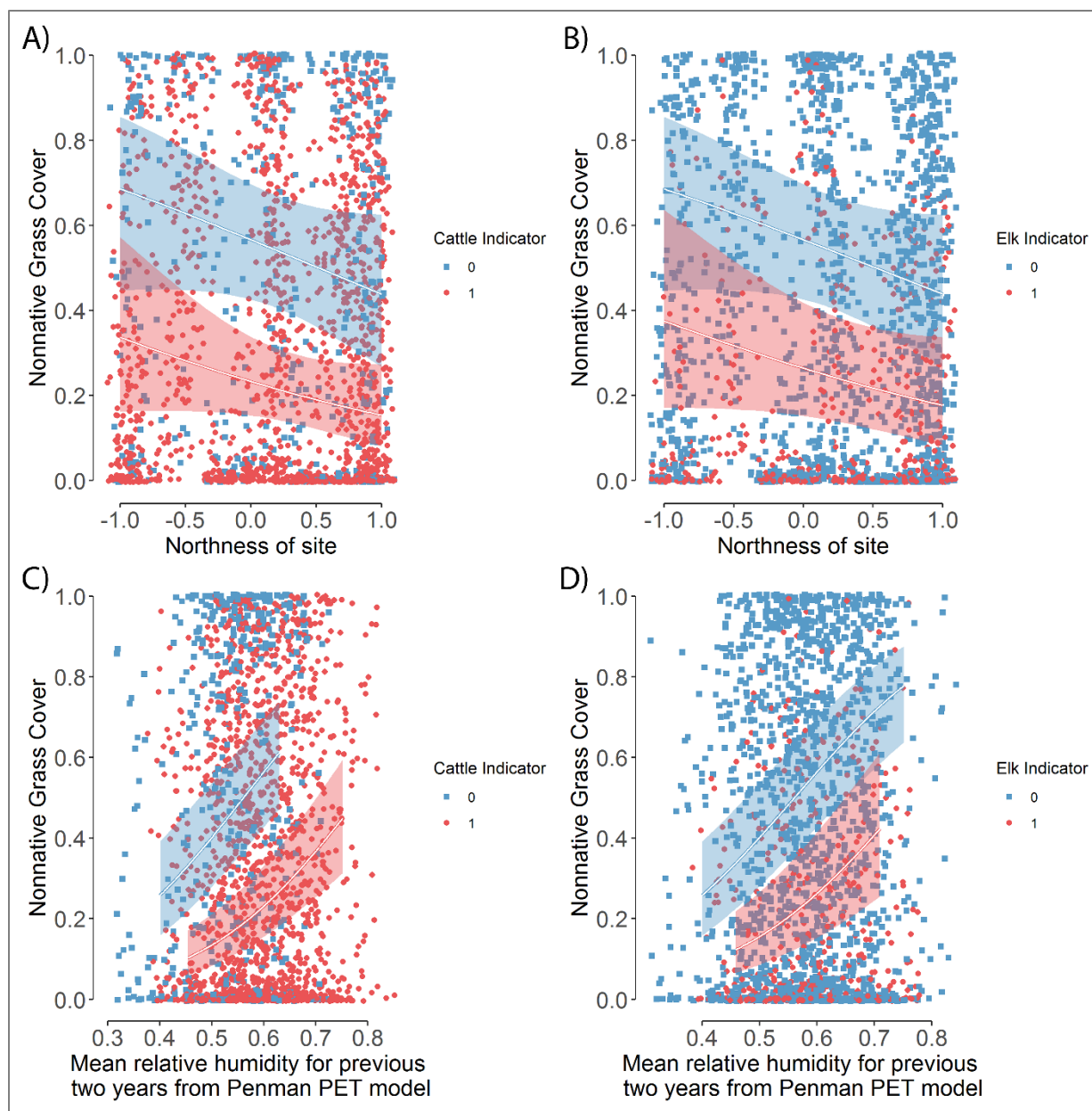


Figure 70. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (sixth of eight). A) Site northness ($p = 0.2133$) for levels of the cattle removal indicator ($p < 0.0001$) for nonnative grass cover. B) Site northness ($p = 0.2133$) for levels of the elk removal indicator ($p < 0.0001$) for nonnative grass cover. C) Relative humidity for the previous two water years combined ($p < 0.0001$) for levels of the cattle removal indicator ($p < 0.0001$) for nonnative grass cover. D) Relative humidity for the previous two water years combined ($p < 0.0001$) for levels of the elk removal indicator ($p < 0.0001$) for nonnative grass cover. For all graphs, indicators are coded as 1 when animal removal has occurred and 0 prior to removal. For graphs A and B, northness values of 1 indicate that the site is oriented due north, while values of -1 indicate due south orientation. For graphs C and D, relative humidity is expressed as the percentage divided by 100.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for *Arctostaphylos* Group cover at SR index sites included terms for temperature summarized over the calendar year, the number of years since pig or cattle removal, and the site slope (top three models shown in Table 30). The final model included the number of years since pig removal (Pig; $p < 0.0001$, Figure 71A) and the effect of annual temperature (Temp_Pen_an; $p = 0.1917$, Figure 71B), however, the latter effect was not statistically significant at the 0.10 level.

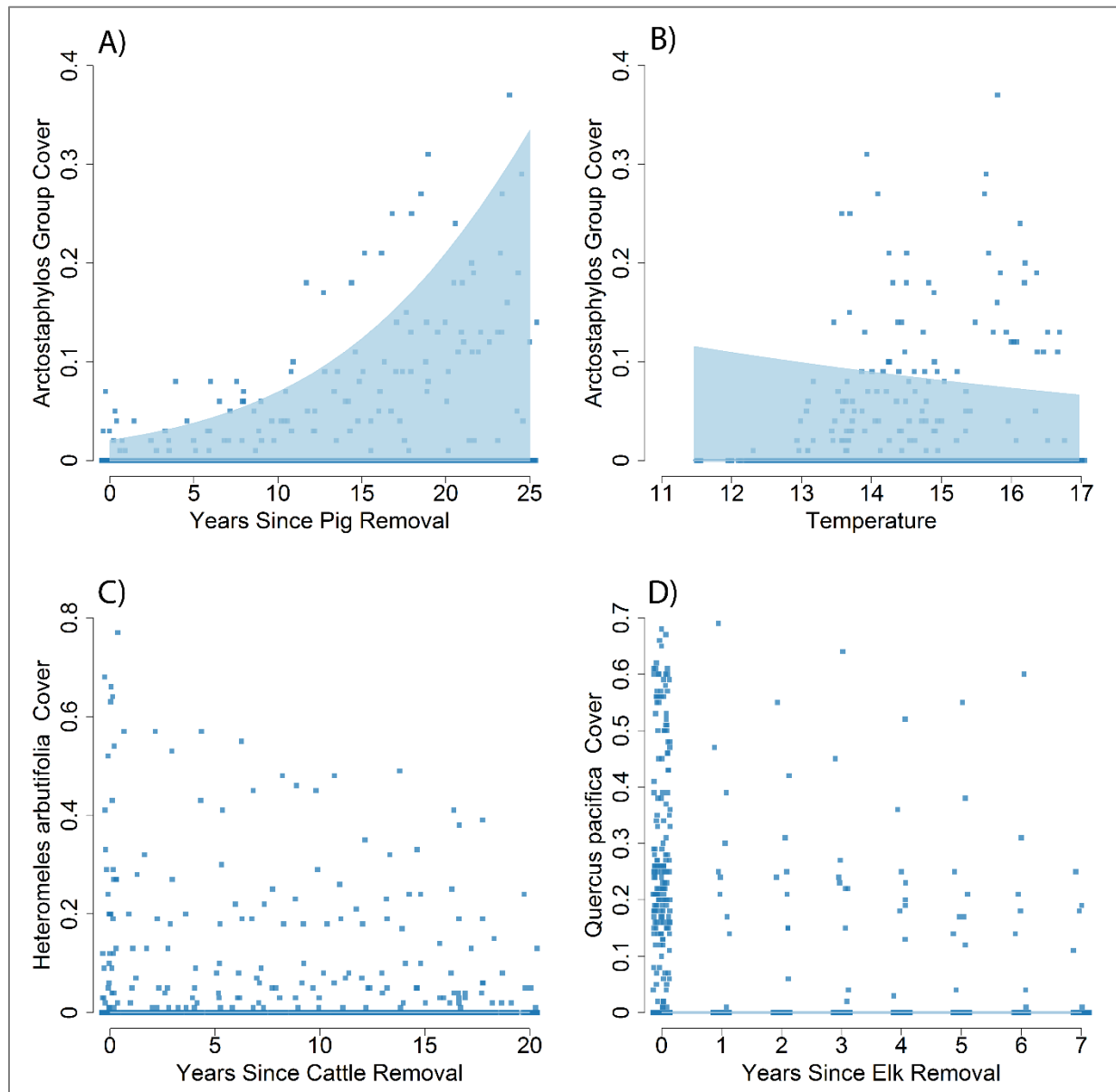


Figure 71. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (seventh of eight). A) Years since pig removal ($p < 0.0001$) for *Arctostaphylos* Group cover. B) Temperature (degrees Celsius, $p = 0.1917$) for *Arctostaphylos* Group cover. C) Years since cattle removal ($p = 0.0006$) for *Heteromeles arbutifolia* cover. D) Years since elk removal ($p = 0.0050$) for *Quercus pacifica* cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

The top models for native shrub *Heteromeles arbutifolia* cover at SR index sites included the number of years since cattle or pig removal, the site slope, and the temperature summarized over the calendar year or month (top three models shown in Table 30). The final model contained a single fixed effect for the number of years since cattle removal (Cattle), and this covariate was negatively associated with *Heteromeles arbutifolia* cover at SR index sites ($p = 0.0006$, Figure 71C). No *Heteromeles arbutifolia* cover was detected in any year for nearly half of the index sites on SR, so this species is patchily distributed, which contributes to the large site-to-site variation.

The top models for *Quercus pacifica* cover at SR index sites included terms for relative humidity over the previous water year, the number of years since elk or deer removal, and the indicator of deer removal (Table 30). The final model contained the effects of the number of years since elk removal (Elk; $p = 0.0050$, Figure 71D), which was negatively associated with *Quercus pacifica* cover, and the relative humidity over the previous water year (rh_Pen_prevYr; $p = 0.0156$, Figure 72A), which was positively associated with *Quercus pacifica* cover at SR index sites.

The top models for *Stipa* Group cover at SR index sites included covariates for the number of days with dew during the previous two water years, site northness, the number of years since elk removal, the indicator of cattle removal, the 30-year mean of monthly cumulative potential evapotranspiration for all months, and the soil moisture for the previous water year (top three models shown in Table 30). The final model contained the 30-year mean of monthly cumulative potential evapotranspiration (pet_allMonth; $p < 0.0001$, Figure 72B) and the soil moisture for the previous water year (Soil_water_mm_prevYr; $p = 0.0132$, Figure 72C), both of which were positively associated with *Stipa* Group cover at SR index sites.

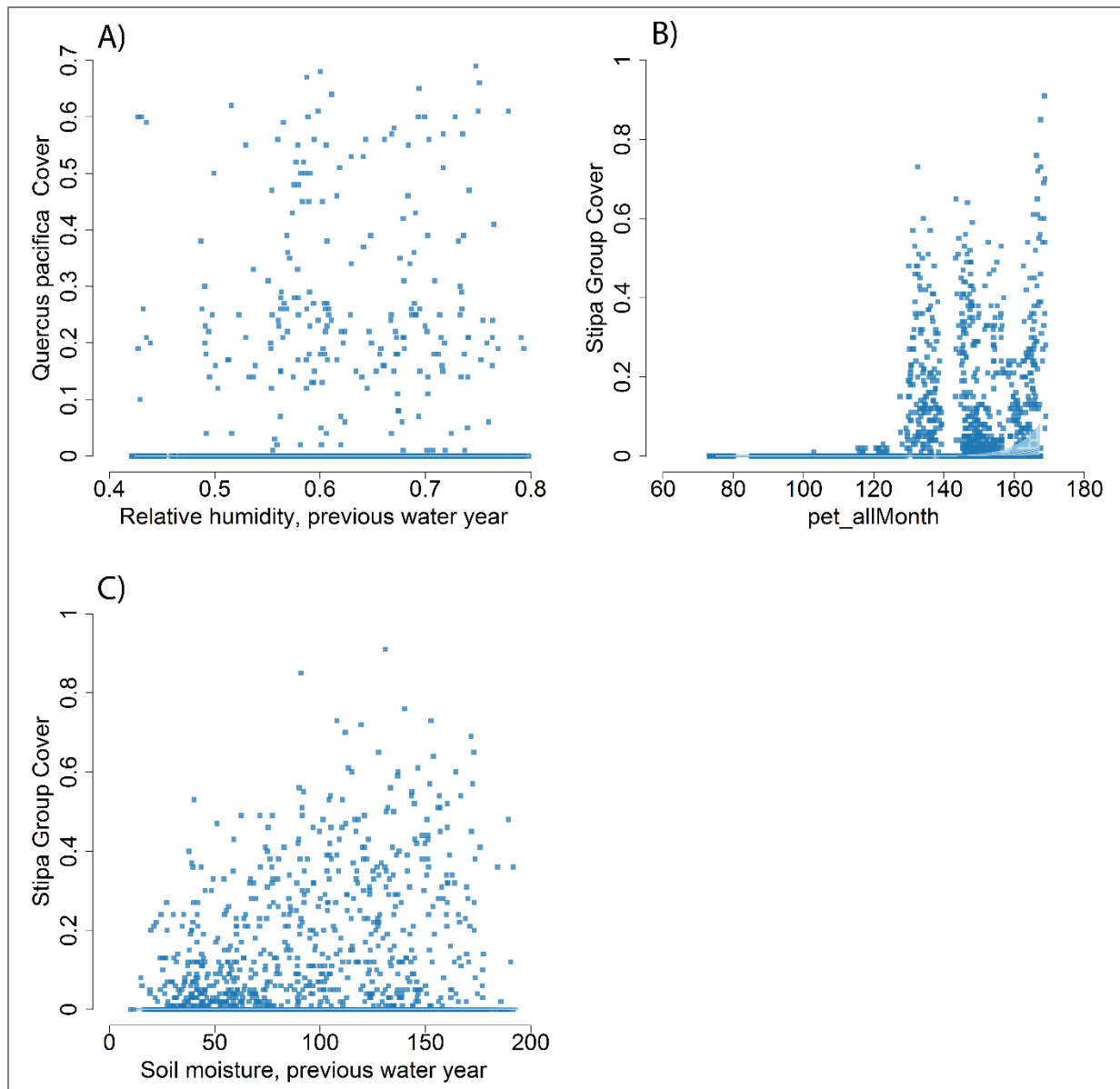


Figure 72. Marginal effects plots for final covariate models at index sites across Santa Rosa Island (eighth of eight). A) Relative humidity (percentage divided by 100) during the previous water year ($p = 0.0156$) for *Quercus pacifica* cover. B) Mean of 30-year monthly means for all months of cumulative potential evapotranspiration (PET, mm; $p < 0.0001$) for *Stipa* Group cover. C) Soil moisture (mm) during the previous water year ($p = 0.0132$) for *Stipa* Group cover.

NPS / WESTERN ECOSYSTEMS TECHNOLOGY, INC.

Santa Rosa Island Probability Sites

Because only two years of probability site data (2017 and 2018) were available for analysis, covariate modeling was not conducted for probability sites from SR.

Discussion and Conclusions

Generalized linear mixed models were applied to data collected from five islands with two different sampling designs to assess trends in time and relationships with covariates for metrics of CHIS terrestrial vegetation. In general, model results appeared reasonable based on graphical comparisons with observed data. In some cases, large proportions of zeros in the data pulled regression lines and confidence intervals toward zero. Datasets from communities with small sample sizes or patchy distributions resulted in models with large site-to-site variation estimates and wide confidence intervals on marginal effects plots.

When comparing trends between index sites and probabilistic sites, the difference in the monitoring periods must be considered. Index site surveys began in 1984 for AN, SB, and SM; in 1990 for SR; and in 2000 for SC. The probabilistic surveys began in 2013 for all islands except SR, which began in 2017. Therefore, the trends for each plot type and among subsets of islands within a plot type represent different monitoring periods. The differing scopes of inference must also be considered when interpreting results. Index sites were selected as representative of specific vegetation communities, and therefore can be seen as subjective, limiting their statistical inference to the community level. However, probabilistic sites were randomly selected from the larger population of interest representing all vegetation communities of interest with the intent of allowing statistical inference island-wide.

Trends in CHIS Terrestrial Vegetation Metrics

Shannon Diversity

Overall Shannon diversity at index sites demonstrated negative trends for all islands. However, none of the trends in overall Shannon diversity at probability sites were significantly different from zero. These two results together could indicate that changes in diversity occurred before 2013, trends were specific to selected transects, or the probabilistic survey monitoring period was too brief for trend detection (or all three). The standard errors of trend estimates from probabilistic sites were an order of magnitude larger than those obtained for trend estimates from index sites. The relatively brief monitoring period for probabilistic surveys may account for the reduced power to detect trends as opposed to the longer-term index site data set with smaller standard errors. On the other hand, changes in terrestrial vegetation due to nonnative mammal removal may have occurred prior to the adoption of the probabilistic survey design, and the lack of trend could simply describe more stable cover, density, and diversity of the vegetation. The rate of change after nonnative mammal removal may have been initially high and then moved toward stabilization by 2013, since most of the removals (except on SR) happened at least a decade earlier.

Decreasing trends in Shannon diversity were observed in index plots overall across all islands as well as within each individual island. For index sites within communities, declining trends were observed in Shannon diversity for island chaparral (SC, SR, and SM), coastal sage scrub (SM, SR, East AN), grassland (all islands), and ironwood (SC, SR) communities. These decreasing trends in overall Shannon diversity likely reflect an overall decline observed in herbaceous species. Cover trends are

negative in both native and nonnative herbs and grasses overall and on each island, but nonnatives declined at twice the magnitude, or more, than natives. In almost every case removal of nonnative mammals covaried negatively with the Shannon diversity, perhaps because the presence of grazers had increased habitat structural heterogeneity leading to higher species richness, especially among the ruderal plants. Promotion of species coexistence is known to occur when grazing produces vacant sites available for other species (Pulungan et al. 2019). We speculate that the lack of significant trends in mixed woodland and riparian Shannon diversity (SC, SR) may be due to their understory dominance by species that were less favorable to grazers. It is also possible that in the native shrub-dominated communities of SR and SC, where shrub cover increased, removing the animals could have released the shrubs to expand and in turn shade understory species.

Density

For measures of density, weak evidence of a declining trend was observed for native tree density at index sites across SC and SR, but otherwise trends in native tree density and native tree recruitment density were not detected for any islands or plot types. The weakness and paucity of trends in tree density could be due to the low statistical power provided by the small number of transects for which the tree protocol was implemented. In comparison, the shrub protocol was implemented for many more transects. Increasing trends in native shrub density were detected at index sites on SC and SR and across all islands, a result that may be driven by reduced grazing pressure, as suggested by the positive covariate relationships between native shrub density and removal of cattle and pigs. This notion is supported by the increasing trends in native shrub recruitment density detected at SC for both index and probability sites and is consistent with the overall increase of woody overstory area observed after eradication or substantial reduction (90%) of nonnative grazers from SC or SR (Beltran et al. 2014; Thomson et al. 2022). Weak evidence of a decreasing trend at the Middle islet of AN was observed, consistent with the speculation that increased activity of California Brown Pelicans (*Pelecanus occidentalis*) and Western Gulls (*Larus occidentalis*) may be impacting islet soils and plant chemistry, as previously documented for seabirds on other islands (Mulder et al. 2011). In addition, Brown Pelicans harvest a variety of plant material, including forbs, grasses, and woody stems, to construct large podium-like nests (USFWS 1983). Increasing frequency and severity of drought over southern California, and their interactions with seabird activity, may also play a role. A quantitative evaluation of the potential influence of seabirds and drought on native vegetation would inform this issue. No significant trends in native shrub density were detected from probabilistic surveys, likely due to the relatively short timeframe over which these data were collected, but the direction of all trend coefficients was negative.

Cover

The occurrence of many plots with no native tree cover resulted in estimates near zero across years in index plots, and probability plot trends were non-significant on SC (the only island where tree cover was measured in probability plots). Nonetheless, an increasing trend in the odds of native tree cover was observed in index plots on SR whereas a declining trend was detected on SC. These opposing trends could be related to differences in climate, and therefore the impact of drought between the two islands. That is, the westward increase in precipitation and incidence of fog among the northern Channel Islands may, for trees, translate into less severe droughts and stronger recovery thereafter. It

is also possible that the large increase in willow (*Salix lasiolepis*) on SR influenced this contrasting result—riparian areas are not sampled by index plots on SC.

Declining trends in the odds of shrub cover on index sites were observed for SB and all three AN islets, but increasing trends were detected for SC, SR, and all islands combined. The lack of significant increase in shrub cover on SM might be because the grazing animals were removed decades earlier there than on SC and SR (stocking numbers were severely reduced in the 1940s and 1950s, and most animals were gone by the 1960s; McEachern et al. 2016). The greatest measurable response of woody growth to removal of grazers may have been over by the time monitoring started on SM. These trends mirror the observations for shrub density and are likely attributable to the same phenomena – reduced grazing pressure that promotes woody plant recovery (Beltran et al. 2014; Thomson et al. 2022) on the large islands, whereas recovery may be inhibited by abundant seabird activity (Mulder et al. 2011) and drought on the smaller “seabird” islands.

Nearly two-thirds (19 of 32) of the results for forb and grass cover at index sites exhibited significant declines, including native and nonnative species and all islands. Moreover, none of these 32 results indicated an increase in herbaceous cover. However, nonnative herbaceous cover decreased at about twice the annual rate as native herbaceous cover. We suspect that some of this broad decline may be explained by the concurrently expanding shrub density and cover observed at SC and SR that presumably outcompetes herbaceous vegetation, along with the decrease in internal stand heterogeneity with animal removal mentioned earlier. However, the lack of evidence of shrub expansion at AN, SB, and SM suggests that additional drivers related to water balance and soil moisture, as well as time since animal removal, are important for these islands. As mentioned above for shrubs, the decline in herbaceous cover at AN and SB may also be a symptom of increased activity of seabirds as well as frequency and severity of drought at these relatively small and dry islands. Probabilistic sites showed large increases in native herbaceous cover on SM and in nonnative cover on AN. Otherwise, the scarcity and inconsistency of trends in shrub, herbaceous plant and grass cover may reflect the relatively short timeframe over which these data were collected, and therefore the low statistical power at probabilistic compared to index sites.

Species-Specific Trends

Twenty individual species were evaluated for trends, chosen because they are native dominants in some communities and have the potential to drive community trends as they change, or because they are known to be invasive and have the potential to displace native species if they increase. Ten of these are shrubs or sub-shrubs, including *Deinandra clementina*, *Suaeda taxifolia* and *Eriogonum giganteum* ssp. *compactum* on SB; *Acmispon dendroideus* var. *veatchii* and *Isocoma menziesii* on SM; *Rhus integrifolia* and *Arctostaphylos confertiflora/crustacea* on SR; and *Eriogonum arborescens/grande*, *Baccharis pilularis*, and *R. integrifolia* on SC.

Cover trends varied across these species among index and probabilistic plots. By far the largest increases were seen on SC in *E. arborescens/grande*, and *R. integrifolia*, both with greater than 50 percent change, but change was not significant in *B. pilularis*. *Arctostaphylos confertiflora/crustacea* increased by about 12 percent on SR, *I. menziesii* by 9 percent on SM, and *E. giganteum* ssp.

compactum by 7 percent on SB. Except for the *Arctostaphylos*, these are generally early successional species shown in other Channel Island studies to have increased since grazing release (e.g., Beltran et al. 2014; Christian 2007; Corry 2006; Yelenik and Levine 2010). Control-exclosure studies of *A. confertiflora* (1998–2017) on SR indicated rapid increase in canopy areas inside fenced areas that were protected from deer and elk browsing (NPS, Dirk Rodriguez, unpublished data), substantiating the trend seen in the transect data. The only shrub exhibiting decline was *S. taxifolia* on SB, a trend also seen in vegetation mapping and attributed to nesting activity of gulls (Dirk Rodriguez, retired NPS botanist, personal communication). Interestingly, while *I. menziesii* increased on SM index plots, it exhibited a nearly equal decline in probability plots. Trends were not significant in *D. clementina* on SB and *A. dendroideus* var. *veatchii* on SM.

Three evergreen trees, or large shrubs, were evaluated for trends: *Heteromeles arbutifolia* and *Quercus pacifica* on SR, and *Pinus muricata* on SC. A slight decline in cover was seen in *H. arbutifolia*, while no trend was detected in the other two species. On SC, for these trees and others in general, the large proportions of plots with zero cover for individual species resulted in large site variation estimates. Therefore, trends are more difficult to interpret because the trend lines and confidence intervals are near zero for all years. The exception is the plot for *Pinus muricata* cover which had a wide confidence interval due to the high site-to-site variance from detection at only two sites. The riparian deciduous willow, *Salix lasiolepis*, increased dramatically in SR index plots over the sampling period, a trend also documented in repeated SR canyon surveys completed in 1996 versus 2012 (Thomson et al. 2022).

Tree density modeled on SR and SC showed no change in adults or seedlings/saplings with the exception of a slight decrease in adult tree density in the pooled SC and SR index plots. Island botanists have observed that tree and shrub cover appear to be increasing (Dirk Rodriguez, retired NPS botanist, and Ken Niessen, USFWS Senior Fish and Wildlife Biologist, personal communication; K. McEachern and C.B. Williams, personal observation), but that this appears largely attributable to canopy expansion rather than recruitment of new tree seedlings into the populations. Native shrub density increased overall in island index plots but was not significant on the individual islands SB, SM, and AN, or on the individual islets East and West AN. Shrubs declined by about 20 percent on Middle AN, an observation also made by seabird biologists in recent years and attributed to an increase in Brown Pelican abundance (David Mazurkiewicz, NPS wildlife biologist, personal communication). Native shrub density increased in index plot counts on SR, but there was no detectable increase in seedlings. However, increased density was shown in both adult and seedling/sapling shrubs on SC, paralleling the large increases in cover of *E. arborescens/grande* and *R. integrifolia* also seen there.

Native bunch grasses in the genus *Stipa*, including *S. pulchra*, *S. lepida*, *S. cernua*, and *S. diegoensis*, were evaluated as a group on SR and SC because early in the sampling period the flowering culms were grazed nearly to the ground, and it was difficult to identify them to the species level. Despite the reduction in grazing pressure, they did not show significant changes in index plot cover on either SR or SC. However, they did exhibit a steep decline in the probabilistic plots on SC for reasons that are unclear without looking in more detail at those plots.

Three nonnative invasive species demonstrated dramatic declines in cover at either index or probabilistic plots. The annual grass *Hordeum murinum* declined by about 47 percent in probabilistic plots and 8 percent in index plots on SB. The herbaceous perennials *Foeniculum vulgare* (SC) and *Carpobrotus chilensis* (SB) declined by about 25 and 18 percent, respectively. Recent CHIS observations during vegetation mapping fieldwork (Dirk Rodriguez, retired NPS botanist, personal communication) show that these species dominate some communities on those islands, and so their declines may have cascading effects on species composition going forward in time if these trends continue. Conversely, the herbaceous annual *Mesembryanthemum crystallinum* increased by about 46 percent in probabilistic plots on SB but showed no significant trend in the index plot analyses. This semi-succulent plant has been shown to have the capacity to alter soil chemistry on SB (Corry 2006; D'Antonio et al. 1992), excluding other species. Its increase on SB has been attributed to the actions of gulls (Dirk Rodriguez, retired NPS botanist, personal communication) and increasing drought, resulting in the recent evaluation of declining natural resource conditions in an all-island study by Davidson et al. (2019).

Covariate Relationships

Site-specific, water balance, and nonnative mammal removal covariates were examined to assess relationships with CHIS terrestrial vegetation metrics for Shannon diversity, density, and cover.

Shannon Diversity

Overall Shannon diversity metrics by island and plot type were most frequently modeled with water balance covariates over a range of time scales. The exception was overall Shannon diversity at SR index sites, which was more strongly negatively associated with site slope and years since cattle removal than with water metrics. For index sites at all islands grouped together, diversity increased with fog (relative humidity during the fog year) and with accumulated growing degree days during the previous water year. Generally, water balance covariates demonstrated negative effects of water deficit and increasing temperature, and positive effects of soil moisture, on native Shannon diversity.

The life histories of the plants dominating island communities are related to the associated water balance covariates. For example, native plant diversity increased with annual soil water accumulation while grassland diversity decreased with annual water deficit, reflecting the life histories of the plants dominating these groups. A majority of the native grasses are perennials that derive water from deep in the soil profile where it accumulates over time. Conversely, nonnative grasslands are dominated mostly by disturbance-friendly annuals with shallow roots that track annual fluctuations in water near the surface during their short lifespans.

Site characteristics (site slope, northness, and elevation) also were positively associated with Shannon diversity across all plot types. Additionally, for index sites, water balance covariates summarized at the monthly level were included in several of the native Shannon diversity models, while site characteristics were most commonly used in final models of probability sites. Generally, slope steepness was significantly and positively associated with diversity among native lifeforms, including coastal sage scrub communities; northness with grassland, coastal sage scrub and riparian area diversity; and elevation with mixed woodland diversity.

On some islands both water balance and site covariates were important for some outcomes, indicating a nuanced relationship between, for instance, site factors and water balance. For example, SR riparian Shannon diversity was negatively associated with temperature from the previous water year and with site slope but positively associated with northness, while only northness was positively associated with riparian diversity on SC. Coastal sage scrub Shannon diversity was negatively associated with water balance metrics over all islands, but it was also positively associated with site northness on SM and site slope on SR. Ironwood Shannon diversity on SC and SR was positively associated with soil moisture, and mixed woodland Shannon diversity on SC and SR was negatively associated with site elevation. This indicates that in some island locations site variables acting at local scales may moderate the effects of drought.

Effects of nonnative mammal removal were analyzed for SR and SC only. On these islands animal removal was negatively associated with overall Shannon diversity. At the community level, animal removal (pig, cattle, elk) was negatively associated with diversity outcomes in grassland, coastal sage scrub, *Baccharis* scrub, and ironwood. These effects likely result from the loss of ruderal species that thrive on disturbance, canopy openness, and low litter cover. Conversely, diversity in chaparral on SC and SR combined was higher when pigs were absent than when present, reflecting recovery from the extreme damage done to understory vegetation in that community. Models also indicated significant effects of both water balance and nonnative mammal removal in some instances. For example, water balance metrics and site characteristics were included in models for grassland diversity on most islands, but nonnative mammal removal and site characteristics were preferred for the SR model. Overall, these water balance covariates suggests that water limitation impedes vegetation diversity.

Density

Native tree density was found to be a function of site characteristics on SC and negatively related to modeled actual evapotranspiration during the current fog season for SR. The top model across both islands included a single negative effect of growing-degree days over the previous two water years. Tree recruitment density varied with water balance covariates summarized over the current fog season and previous year, with positive effects of growing-degree days, solar radiation, and modeled actual evapotranspiration and a negative effect of water deficit.

Native shrub density models contained positive effects for site characteristics such as site slope, elevation and nonnative mammal removal for all islands except SM, where animal removal was not modeled and water balance metrics were more important. Negative effects were observed at index sites on individual islands for water balance metrics of increased evapotranspiration and growing-degree days, along with deficits in vapor pressure and soil moisture. However, native shrub density at some probability sites was positively associated with cumulative potential evapotranspiration and water deficit, indicating a possible influence of site selection on water availability. Water balance covariates summarized over the previous two water years were selected for final native shrub density models at AN and SB, but current water year and current fog year covariates were preferred in models for SC and SM. Reasons for this contrast in the number of years remain unclear, but may be related to the differences in terrain complexity between the smaller and larger islands: perhaps

topographic shading plays a beneficial role in soil water retention on the larger islands, while opportunities for such shading are lacking on the smaller islands. Native shrub density models at SR included positive effects of site slope and the number of years since pig removal. Recent observations (K. McEachern, personal observation) show coastal scrub spreading from refugia on steep canyon slopes that were inaccessible to grazing animals, also indicating beneficial effects of animal removal. The top model for native shrub recruitment contained a single effect for mean solar radiation over the previous two years: the effect of this covariate was negatively associated with native shrub recruitment density. However, note that the native shrub recruitment density was near zero for all years.

Cover

Woody plant cover varied with metrics of nonnative mammal removal, site characteristics, and water balance across all islands. Native tree cover at index sites was positively associated with years since cattle removal at both SC and SR and with site elevation for both plot types on SC. As time since pig removal increased, native tree cover decreased at SC index sites. Reasons for this counter-intuitive pattern are unclear but could be related to die-back in the *Pinus muricata* experienced during the extended drought spanned by the samples there. For SR index sites, the 30-year mean of monthly clear sky net solar radiation was the sole predictor of native tree cover and the effect was negative, likely another drought related outcome.

Water balance covariates were included in all native shrub cover top models for index sites except for SR. At SR, only nonnative mammal removal covariates were included in top models, with positive effects of years since cattle and elk removal and a negative effect of deer removal. Deer removal was complete on SR in 2014, at the beginning of a prolonged drought, so perhaps this counter-intuitive effect of the reduction in deer browse on shrub cover was confounded by both the lack of sufficient post-removal data for trend detection and the drought. Individual native shrub species on SR responded variously to nonnative mammal removal: the *Arctostaphylos* Group varied positively with pig removal, whereas *Heteromeles arbutifolia* and *Quercus pacifica* were negatively associated with cattle and elk removal. Analyses of responses over a longer post-removal time period when individual species dominated SR shrub cover might help resolve this complex response to nonnative mammal removal. For probability sites, native shrub cover models contained site-level covariates for AN and SC and cumulative potential evapotranspiration for SB and SM.

Water balance covariates also were included in the top models for native forb cover for index sites at all islands, with a positive effect of soil moisture by month on native forb cover across all islands. Northness was positively related to cover on SC; more northerly sites are typically moister, also reflecting the importance of moisture for native forbs. Probabilistic sites also included northness as a significant covariate with native forb cover overall, along with a suite of other water balance metrics. Nonnative mammal removal predictors were mixed: pig removal was a significant predictor of native forb cover at SC and SR index sites, but the effect was positive at SC and negative at SR. Vapor pressure deficit was the sole predictor of native forb cover on AN for both plot types, but the effect was negative for index sites and positive for probability sites.

Overall models of native grass cover included negative effects of site elevation for both plot types, and slope degrees were significant on SC index and probabilistic sites as well. Site slope was also a significant predictor for both plot types of native grass cover on SB (positive effect) and SC (negative effect), while models for SM and SR incorporated only water balance covariates. In general, the native perennial grasslands of SR, SC and SM tend to be found on lower elevation slopes characterized by gently sloping alluvial fans on the larger islands and marine terraces on all islands. These locations tend to have deeper soils with greater water-holding capacity favored by the deeply rooted native perennial bunch grasses than upslope locations. Historical land use likely affects the opposite slope steepness pattern seen on SB. There, the native vegetation was plowed and the nonnative annual grass *Avena* spp. was planted on the terraces and lower elevation slopes, essentially eliminating the native grasses there. *Avena* still occupies the lower elevation plowed sites, while the salt-tolerant annual *Hordeum murinum* dominates the nearshore terraces.

For nonnative forb cover, all models across islands and plot types contained terms for water balance covariates. For index sites, modeled actual evapotranspiration was positively associated with nonnative forb cover for SB, SM, and SR as well as across-island inference. Soil moisture, accumulated water deficit, and relative humidity were included as predictors in models of nonnative forb cover at probability sites. However, the directions of these effects were variable across islands. Both soil moisture and accumulated water deficit had positive effects on nonnative forb cover over all islands and on SB, a seemingly contradictory pattern. Soil moisture for the previous water year was negatively associated with nonnative forb cover at SC probability sites. Relative humidity was positively associated with nonnative forb cover on AN and SM. The number of years since pig removal was included in final models for SC and SR index plots and this effect was negatively associated with nonnative forb cover. Predictors other than slope degrees related to specific site characteristics were not significant in any models of nonnative forb cover.

Top models of nonnative grass cover for index sites consisted of water balance metrics for all islands, mammal removal for SC and SR, and site northness for SR. Relationships of nonnative grass cover with water balance metrics were variable across sites, perhaps reflecting the complex ways in which water relations are influenced by such variables as island topography, exposure to prevailing winds, site slope and elevation, and soil type. For example, modeled actual evapotranspiration and slope degrees were negatively associated with nonnative grass cover at index sites, but positively associated with cover at probabilistic sites. Site northness, slope, and elevation were included as predictors of nonnative grass cover for probability sites on AN, SB, and SC, but northness was negatively associated with nonnative grass cover at AN and positively associated at SB. Positive effects of soil moisture were estimated for nonnative grass cover on SC and SM. Nonnative grass cover declined at index sites with pig absence on SC and with years since cattle and elk removal on SR.

For cover metrics of individual species, water balance covariates were included in the top models for all species with the exceptions of cover for *Arctostaphylos* Group (SR), *Eriogonum* Group (both plot types at SC), *Acmispon dendroideus* var. *veatchii* (probability sites at SM), *Baccharis pilularis* (probability sites at SC), *Foeniculum vulgare* (probability sites at SC), *Heteromeles arbutifolia*

(index sites at SR), *Quercus pacifica* (index sites at SR), *Salix lasiolepis* (index sites at SR), and *Stipa* Group (index sites at SC). For these species, site-level covariates and numbers of years since nonnative mammal removal were among the top models. These results show that water relationships are among the most important correlates of growth for individual species, yet they each respond uniquely to the interacting effects of water availability, site and herbivory.

Conclusions

Our exploratory analysis of the CHIS vegetation monitoring dataset spanning 1984–2018 revealed many trends and covariates. Data were grouped by life form and nativity across all five islands and within individual islands, as well as by community and by species in some cases. Metrics related to water balance, individual site characteristics, and animal removal were explored in covariate models. For the 162 models tested, 77 trends and 209 covariate models were statistically significant.

Index sites were selected in the original program design to represent individual plant communities. They have benefited from a longer span of data acquisition that provides more statistical leverage than the shorter-term probabilistic sites that were selected more recently by random techniques. Therefore, comparing the results of separate trend models aided interpretation. Removal of grazers is likely to have caused an overall decline in Shannon diversity via reduced habitat heterogeneity and reduction of nonnative species richness. Nonnative species richness could also be further reduced by increased cover of native shrubs on some islands. In addition, water balance covariates demonstrated negative effects of water deficit and increasing temperature, and positive effects of soil moisture, on native plant diversity. The overall high variability we observed in the responses of diversity to water balance and site factors indicate that nuanced relationships among these variables at local scales may moderate the effects of drought. Increasing shrub density and cover at SC and SR is probably a result of reduced grazing pressure combined with a relatively favorable water balance, whereas decreasing shrub density and cover on AN and SB may be affected by unfavorable water balance (e.g., drought) and abundant seabird activity. This activity also may be responsible for a concomitant decrease in herbaceous cover at these small islands. Decreasing herbaceous cover at SC and SR is likely a reflection of reduced grazing pressure via expansion of woody plants that can outcompete the herbaceous layers. Cover of woody vegetation consistently and positively covaried with the long-ago removal of cattle and elk, whereas the responses to the more recent removals of other introduced grazers may have been additionally influenced by drought and do not yet show consistent effects.

Many of the covariates investigated in this analysis are highly correlated. Therefore, models identified as the “final” model could be substituted by equally valid models that incorporate other highly correlated covariates. When selecting covariates for future analysis, data sources that provide the covariates included in the final models or similar highly correlated covariates should be considered. Model fits may be improved by an exploration of interaction terms, which were not investigated in this modeling exercise. Also, modeling index and probability sites jointly for the time period beginning in 2013 may provide additional information on differences between the two datasets. However, since the index sites provide inference for the selected plant communities individually, while probabilistic samples can be extrapolated more broadly island wide, care should be taken in combining inference for both index and probability surveys. Continued and consistent long-term monitoring of the vegetation at CHIS using the current study design could help further resolve the relative influences of nonnative animal removal, site factors, and water balance on the park’s vegetation.

Literature Cited

- Akaike, H. 1998. Information theory and an extension of the maximum likelihood principle. Pages 199–213 *in* Selected papers of Hirotugu Akaike. Springer, New York, New York.
- Belsley, D.A., E. Kuh, and R.E. Welsch. 1980. Regression diagnostics: Identifying influential data and sources of collinearity. John Wiley & Sons, Hoboken, New Jersey.
- Beltran, R.S., N. Kreidler, D.H. Van Vuren, S.A. Morrison, E.S. Zavaleta, K. Newton, B.R. Tershy, and D.A. Croll. 2014. Passive recovery of vegetation after herbivore eradication on Santa Cruz Island, California. *Restoration Ecology* 22:790–797. <https://doi.org/10.1111/rec.12144>
- Bolker, B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens, and J.S.S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution* 24(3): 127–135. <https://doi.org/10.1016/j.tree.2008.10.008>
- Bonham, C. 2013. Measurements for terrestrial vegetation, second edition. John Wiley & Sons Ltd., Chichester, UK.
- Brooks, M.E., K. Kristensen, K.J. van Benthem, A. Magnusson, C.W. Berg, A. Nielsen, H.J. Skaug, M. Maechler, and B.M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R Journal* 9(2): 378–400. <https://doi.org/10.32614/RJ-2017-066>
- Cavanaugh, J.E. 1997. Unifying the derivations of the Akaike and corrected Akaike information criteria. *Statistics & Probability Letters* 31(2): 201–208. [https://doi.org/10.1016/S0167-7152\(96\)00128-9](https://doi.org/10.1016/S0167-7152(96)00128-9)
- Christian, J.A. 2007. Native shrub response after reduction of browse by introduced ungulates on Santa Rosa Island, California. Thesis. University of Wisconsin-Madison, Madison, Wisconsin.
- Clark, R.A., W.L. Halvorson, A. Sado, and K.C. Danielson. 1990. Plant communities of Santa Rosa Island, Channel Islands National Park. Technical Report No. 42. Cooperative Park Studies Unit, University of California-Davis, Davis, California.
- Corry, P.M. 2006. Vegetation dynamics following grazing cessation on the Channel Islands, California. Dissertation. University of North Carolina at Chapel Hill, Chapel Hill, North Carolina.
- D’Antonio, C., W.L. Halvorson, and D.B. Fenn. 1992. Restoration of denuded areas and iceplant areas of Santa Barbara Island, Channel Islands National Park. Technical Report NPS/WRUC/NRTR-92/46. Cooperative National Park Resources Study Unit, Davis, California.

- Davidson, A.D., A.K. McEachern, T.J. Coonan, W.T. Bean, and A.J. Armstrong. 2019. Channel Islands National Park: Natural Resource Condition Assessment. Natural Resource Technical Report NPS/CHIS/NRTR—2019/1899. National Park Service, Fort Collins, Colorado.
<https://irma.nps.gov/DataStore/Reference/Profile/2259718>
- Dormann, C.F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J.R. Garcia Marquéz, B. Gruber, B. Lafourcade, et al. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36(1): 27–46. <https://doi.org/10.1111/j.1600-0587.2012.07348.x>
- Douglass, D.H., B.D. Clader, J.R. Christy, P.J. Michaels, and D.A. Belsley. 2003. Test for harmful collinearity among predictor variables used in modeling global temperature. *Climate Research* 24(1): 15–18.
- Dow, T. 2008. Vegetation Change Following Removal of Livestock Disturbance from Santa Rosa Island, Channel Islands National Park. Dissertation. Northern Arizona University, Flagstaff, Arizona.
- Erlandson, J.M., T.C. Rick, T.J. Braje, M. Casperson, B. Culleton, B. Fulfrost, T. Garcia, D.A. Guthrie, N. Jew, et al. 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California’s Channel Islands. *Science* 331(6021): 1181–1185.
<https://doi.org/10.1126/science.1201477>
- Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US National Parks. *Environmental Monitoring and Assessment* 151: 161–174.
<https://doi.org/10.1007/s10661-008-0257-y>
- Fisher, R.A., A.S. Corbet, and C.B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology* 12: 42–58. <https://doi.org/10.2307/1411>
- Flint, L.E., and A.L. Flint. 2012. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. *Ecological Processes* 1: 2. <https://doi.org/10.1186/2192-1709-1-2>
- Halvorson, W.L., S.D. Veirs, Jr., R.A. Clark, and D.D. Borgias. 1988. Terrestrial vegetation monitoring handbook. National Park Service Unpublished Report, Ventura, California.
- Handley, T., D. Rodriguez, J. Yee, and K. McEachern. 2013. Exploring long-term trends in vegetation of Santa Barbara and Santa Rosa Islands, Channel Islands National Park. U.S. Geological Survey/National Park Service Unpublished Report.

- Hartig, F. 2021. DHARMA: residual diagnostics for hierarchical (multi-level/mixed) regression models. CRAN (The Comprehensive R Archive Network). <https://cran.r-project.org/web/packages/DHARMA/vignettes/DHARMA.html>
- Hartig, F., and L. Lohse. 2020. Package ‘DHARMA’. Residual diagnostics for hierarchical (multi-level/mixed) regression models. CRAN (The Comprehensive R Archive Network). <https://cran.r-project.org/web/packages/DHARMA/DHARMA.pdf>
- Johnson, J.R., T.W. Stafford Jr, H.O. Ajie, and D.P. Morris. 2002. Arlington Springs revisited. Pages 541–545 in D.R. Browne, K.L. Mitchell, and H.W. Chaney, editors. Proceedings of the Fifth California Islands symposium, volume 5. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Johnson, L., and D. Rodriguez. 2001. Terrestrial vegetation monitoring, Channel Islands National Park, 1996–2000 report. Technical Report 01-06. National Park Service, Channel Islands National Park, Ventura, California. <https://irma.nps.gov/DataStore/Reference/Profile/2204821>
- Krebs, C. 1989. Ecological methodology. Harper Collins Publishers, New York, New York.
- Lee, Y., and J.A. Nelder. 2000. Two ways of modelling overdispersion in non-normal data. Journal of the Royal Statistical Society: Series C (Applied Statistics) 49(4): 591–598. <https://doi.org/10.1111/1467-9876.00214>
- MacArthur, R.H. 1965. Patterns of species diversity. Biological Reviews 40(4): 510–533. <https://doi.org/10.1111/j.1469-185X.1965.tb00815.x>
- McAfee, S.A. 2013. Methodological differences in projected potential evapotranspiration. Climatic Change 120(4): 915–930. <https://doi.org/10.1007/s10584-013-0864-7>
- McEachern, K. 2000. Tree and shrub community monitoring protocol for Channel Islands National Park, California. Open File Report 00-74. U.S. Geological Survey, Sacramento, California.
- McEachern, K. 2001. Vegetation Monitoring Program Review for Channel Islands National Park. U.S. Geological Survey, Sacramento, California.
- McEachern, K., T. Atwater, P.W. Collins, K. Faulkner, and D.V. Richards. 2016. Managed island ecosystems. Pages 755–778 in H. Mooney and E. Zavaleta, editors. Ecosystems of California. University of California Press, Berkeley, California.
- Mitchell, J., L. Starcevich, C. Murray, and J. Studyvin. 2024. rNPSVegCHIS: Terrestrial Vegetation Monitoring Analyses for the Mediterranean Coast Network - Channel Islands National Park. R package version 5.0.0. https://lar-git.west-inc.com/national_park_service/terrestrialvegetation-chis

- Mulder, C., H. Jones, K. Kameda, C. Palmborg, S. Schmidt, J. Ellis, J.L. Orrock, D.A. Wait, D. Wardle, et al. 2011. Impacts of seabirds on plant and soil properties. Pages 135–176 in Mulder C.P., W.B. Anderson, D.R. Towns and P.J. Bellingham, editors. *Seabird islands: Ecology, invasion, and restoration*. Oxford University Press, Oxford, UK.
- Oksanen, J., G.L. Simpson, F.G. Blanchet, and 31 others. 2020. *vegan: Community ecology package*. R package version 2.5-7. CRAN (The Comprehensive R Archive Network). <https://CRAN.R-project.org/package=vegan>
- Oudin, L., L. Moulin, H. Bendjouidi, and P. Ribstein. 2010. Estimating potential evapotranspiration without continuous daily data: possible errors and impact on water balance simulations. *Hydrological Sciences Journal–Journal des Sciences Hydrologiques* 55(2): 209–222. <https://doi.org/10.1080/02626660903546118>
- Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society of London*, A193: 120–146.
- Piepho, H.-P., and J.O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. *Journal of Agricultural, Biological, and Environmental Statistics* 7(3): 350–360. <https://doi.org/10.1198/108571102366>
- Priestley, C.H.B., and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review* 100(2): 81–82. [https://doi.org/10.1175/1520-0493\(1972\)100<0081:OTAOSH>2.3.CO;2](https://doi.org/10.1175/1520-0493(1972)100<0081:OTAOSH>2.3.CO;2)
- Prudhomme, C., and J. Williamson. 2013. Derivation of RCM-driven potential evapotranspiration for hydrological climate change impact analysis in Great Britain: A comparison of methods and associated uncertainty in future projections. *Hydrology and Earth System Sciences* 17(4): 1365–1377. <https://doi.org/10.5194/hess-17-1365-2013>
- Pulungan, M.A., S. Suzuki, M.K.A. Gavina, J.M. Tubay, H.I. Momoka Nii, G. Ichinose, T. Okabe, A. Ishida, M. Shiyomi, et al. 2019. Grazing enhances species diversity in grassland communities. *Scientific Reports* 9: 11201. <https://doi.org/10.1038/s41598-019-47635-1>
- Reynolds, J.H. 2012. An overview of statistical considerations. Pages 23–53 in R.A. Gitzen, J.J. Millspaugh, A.B. Cooper, and D.S. Licht, editors. *Design and analysis of long-term ecological monitoring studies*. Cambridge University Press, Cambridge, UK.
- Skellam, J.G. 1948. A probability distribution derived from the binomial distribution by regarding the probability of success as variable between the sets of trials. *Journal of the Royal Statistical Society, Series B (Methodological)* 10: 257–261.

- Starcevich, L.A., C. Murray, L.F.S. Lee, C.B. Williams, and K. McEachern. 2025. Supplemental Information for the Science Report Publication “Analysis of Trends in Terrestrial Vegetation at Mediterranean Coast Network Parks: Channel Islands National Park.” Mediterranean Coast Network, Ventura, California. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2314792>
- Stevens, D.L., and A.R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics* 14: 594–610. <https://doi.org/10.1002/env.606>
- Stevens, D.L., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99(465): 262–278. <https://doi.org/10.1198/016214504000000250>
- Tercek, M., D. Thoma, J. Gross, and K. Sherrill. 2018. User guide for gridded water balance model dataset – version 2. Accessed from <http://www.yellowstoneecology.com> on 14 August 2021.
- Thoma, D.P., M.T. Tercek, E.W. Schweiger, S.M. Munson, J.E. Gross, and S.T. Olliff. 2020. Water balance as an indicator of natural resource condition: Case studies from Great Sand Dunes National Park and Preserve. *Global Ecology and Conservation* 24: e01300. <https://doi.org/10.1016/j.gecco.2020.e01300>
- Thoma, D.P., S.M. Munson, K.M. Irvine, D.L. Witwicki, and E.L. Bunting. 2016. Semi-arid vegetation response to antecedent climate and water balance windows. *Applied Vegetation Science* 19(3): 413–429. <https://doi.org/10.1111/avsc.12232>
- Thomson, D.M., A.K. McEachern, E.L. Schultz, K. Niessen, D. Wilken, K. Chess, L.F. Cole, R.Y. Oliver, J.D. Phillips, and A. Tucker. 2022. Diverse native island flora shows rapid initial passive recovery after exotic herbivore removal on Santa Rosa Island, California. *Biological Invasions* 24: 1635–1649. <https://doi.org/10.1007/s10530-022-02735-4>
- Thornton, P.E., M.M. Thornton, B.W. Mayer, Y. Wei, R. Devarakonda, R.S. Vose, and R.B. Cook. 2016. Daymet: Daily surface weather data on a 1-km grid for North America, version 3. ORNL DAAC, Oak Ridge, Tennessee. <http://dx.doi.org/10.3334/ORNLDAAC/1328>
- Tiszler, J., D. Rodriguez, K. Lombardo, T. Sagar, L. Aguilar, L. Lee, T. Handley, A.K. McEachern, L. Starcevich, et al. 2016. Terrestrial vegetation monitoring protocol for the Mediterranean Coast Network—Cabrillo National Monument, Channel Islands National Park, and Santa Monica Mountains National Recreation Area: Narrative, Version 1.0. Natural Resource Report NPS/MEDN/NRR—2016/1296. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2233219>

- Tweedie, M.C.K. 1984. An index which distinguishes between some important exponential families. Pages 579–604 in J.K. Ghosh and J. Roy, editors. *Statistics: Applications and new directions. Proceedings of the Indian Statistical Institute Golden Jubilee International Conference*. Indian Statistical Institute, Calcutta, India.
- Urquhart, N.S., and T.M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4: 404–414.
- U.S. Fish and Wildlife Service (USFWS). 1983. The California brown pelican recovery plan. Prepared by F. Gress and D.W. Anderson. U.S. Fish and Wildlife Service, Portland, Oregon.
- Wasserstein, R.L., A.L. Schirm, and N.A. Lazar. 2019. Moving to a world beyond “ $p < 0.05$ ”. *The American Statistician* 73: 1–19. <https://doi.org/10.1080/00031305.2019.1583913>
- Weiland, F.S., L.P.H. Van Beek, A.H. Weerts, and M.F.P. Bierkens. 2012. Extracting information from an ensemble of GCMs to reliably assess future global runoff change. *Journal of Hydrology* 412: 66–75. <https://doi.org/10.1016/j.jhydrol.2011.03.047>
- Witwicki, D.L., S.M. Munson, and D.P. Thoma. 2016. Effects of climate and water balance across grasslands of varying C3 and C4 grass cover. *Ecosphere* 7(11): e01577. <https://doi.org/10.1002/ecs2.1577>
- Yelenik, S.G., and J.M. Levine. 2010. Native shrub reestablishment in exotic annual grasslands: Do ecosystem processes recover? *Ecological Applications* 20(3): 716–727. <https://doi.org/10.1890/08-2365.1>
- Zuur, A.F., E.N. Ieno, N. Walker, A.A. Saveliev, and G.M. Smith. 2009. *Mixed effects models and extensions in ecology with R* (volume 574). Springer, New York, New York.

National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2025/358
<https://doi.org/10.36967/2315831>

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525