USFWS, Southeast Region SET Data Analysis

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Overview

Wetland ecosystems are critical for providing important ecological functions. For example, tidal marshes and coastal wetlands help in absorbing energy of storms and preserving shorelines, improving water quality in bays and estuaries, providing nutrients to marine food webs, and supplying critical habitat for both the reproduction of a suite of ocean species and for use by an entire community of breeding and migratory birds. Wildlife species that depend on wetlands are some of the highest conservation priorities, many of which occur in coastal US Fish and Wildlife Service National Wildlife Refuges. Wetlands are increasingly influenced to some extent by anthropogenic alteration, and are threatened by accelerated rates of sea-level rise.

The goal of this project under a cooperative agreement between US Fish & Wildlife Service and the University of Delaware, is to further improve existing code that Zach Ladin developed previously for modeling, analyzing, and generating trend-estimation graphs and reports of surface elevation table (SET) data for regions and refuge managers, and for extending this functionality for incorporation within the USFWS National SET Application. Using these tools, an updated report integrating existing SET data from USFWS Northeast and Southeast Regions will be generated.

The US Fish and Wildlife Service Legacy Region 4 has implemented the Coastal Wetland Elevation Monitoring Protocol (Moorman et al. 2019, Moorman and Rankin 2020) in an ongoing effort to assess and track the condition of wetland habitats on USFWS Refuges. The development of analytical tools using data from this long-term monitoring program will help identify priority analyses for refuge-specific monitoring and management decisions. Here, we extend a recently-completed suite of analysis functionality within program R (R Core Team 2019) that was developed to analyze the surface elevation table (SET) data collected by the US Fish and Wildlife Service and other partnering institutions in Legacy Region 4. This report contains results using these tools to analyze SET data from the Legacy Region 4 USFWS refuges.

Objectives

1) Analyze SET data to determine temporal trends in the relative change in wetland surface elevation (mm) in US Fish & Wildlife Service, Southeast Region.
2) Improve analytical tools and incorporate user feedback in program R (R Core Team 2019) to facilitate current and future automated analysis of SET data.
3) Integrate functions for formatting, QA/QC'ing, analyzing, and visualizing results of SET data for use in the USFWS SET online Application (https://ecos.fws.gov/SET)

Methods

We developed data analysis tools in program R (R Core Team 2019) that enables users to analyze SET data using methods described in the SOP 8: SET and Marker Horizon Data Analysis (Lynch et al. 2015). This analysis includes data collected from USFWS refuges located in Legacy Region 4 (Table 1). Data was acquired from reports that were downloaded from: https://ecos.fws.gov/SET/Report/setusers/Export%20Pin%20Data. Standardized column headers and fields for SET data entered into the National SET Application were discussed and refined, to enable the streamlining of data processing and integration with functions included within the R code used in the present analysis.

We first visualized SET data, by computing changes in wetland elevation (mm) at each pin, and plotted these relative wetland heights against time (years). Then, by averaging among SET stations, discrete wetland monitoring sites, and National Wildlife Refuges (NWRs), produced figures showing (mean ± SE) relative changes in wetland elevation (mm/year). We converted raw SET measurements of wetland surface elevation (mm) to the rate of change in surface elevation (mm/year; hereafter delta SET) from the initial measurement at time (t0), following methods described in (Lynch et al. 2015). To calculate mean and variance estimates of delta SET at higher-levels, we averaged delta SET estimates (i.e., slopes of regression models) over the four positions, and then these were averaged to get SET station-level estimates (Lynch et al. 2015). We then computed higher-level estimation of rates (i.e., mean ± SE slope of delta SET) at the wetland site level, NWR Unit level, and at the regional scale. Additionally, we developed NWR and Site-level summaries for assessment of local-scale changes in wetland elevation change dynamics. We analyzed marker horizon data

following methods described in Lynch et al. (2015) by first averaging measured distances (mm) from the top of core samples to the marker horizon to get station-level means. We then computed mean and variance, SD, and SE among stations within a given sampling site. These estimates of accretion were plotted over time, and used in a comparison with SET-derived elevation estimates across the same corresponding time periods to estimate the degree of sub-surface subsidence/expansion effects driving overall trends in observed changes in wetland elevation (Lynch et al. 2015).

We also compared benchmark-adjusted SET elevation (m) and trend in SET elevation (m/y) to mean sea level (m) and sea-level rise trends (m/y) using data downloaded from https://api.tidesandcurrents.noaa.gov and https://tidesandcurrents.noaa.gov/sltrends/data/USStationsLinearSeaLevelTrends.csv, respectively. We then converted relative elevation measures to true surface elevation using the true elevations measured at each SET station (Moorman et al. 2019), vertical offset from SET apparatus, individaul pin lengths, and pin height measurements using the following equation from Cain and Hensel (2018):

$$\text{True Surface Elevation} = \text{SET Station Elevation} + \text{Vertical Offset} - (\text{Pin length} - \text{Pin height})$$

To compare these elevations to mean sea level elevations and trends, we divided True surface elevation by 1000 to convert from mm to m.

Results

Statement of Progress

1) We are continuing to work cooperatively, and have identified the following analysis priorities for data associated with SET data. In this case we address priorities associated specifically with wetland surface elevation table (SET) data:

2) We analyzed data collected at SET stations ($N = 58$) located within monitoring sites ($N = 22$; Fig. 1) among 18 NWRs within the USFWS Southeast Legacy Region 4 (Table 1).

3) We have developed analytical tools in program R (R Core Team 2019) to facilitate current and future analysis of SET data. Extensive R code is provided in the form of scripts (.R files) that contain functions to format data, summarize data in tabular and graphical formats, analyze data, save results (tables and figures), and produce R Markdown files (.Rmd) that can generate .doc, .html, or .pdf reports. All R code is thoroughly annotated with clear comments to help users implement analyses using program R and R Studio.

4) We compared spatial patterns in SET trends within and among sampling locations through the visualization of spatial trend estimates of delta SET rates (mm/year), by providing R code that creates maps of SET stations and displays the trend direction (positive, negative) along with the magnitude of the trend. These maps provide a nice visualization tool, that hopefully, refuge biologists can use to quickly assess patterns of wetland elevation trends at particular SET stations.

Surface Elevation Table (SET) Analysis

Table 1. List of 22 sites among 19 US Fish and Wildlife Service National Wildlife Refuge (NWR) units included in SET data analyses along with corresponding State, count of SET stations, count of unique observers, duration of years, and starting and ending years of data collection.

Site	State	NWR	SETs (N)	Observers (N)	Num. Years	Start Year	End Year
Mackay Island	NC	Mackay Island	3	1	7	2013	2019
Currituck	NC	Currituck	3	2	7	2013	2019
Roanoke River	NC	Roanoke River	3	1	8	2013	2020
Alligator River - Pocosin	NC	Alligator River	3	2	8	2013	2020
Pocosin Lakes	NC	Pocosin Lakes	3	5	8	2013	2020
Pea Island	NC	Pea Island	3	3	8	2013	2020
Alligator River - Salt Marsh	NC	Alligator River	3	1	8	2013	2020
Swanquarter	NC	Swanquarter	3	3	8	2013	2020
Cedar Island	NC	Cedar Island	3	2	8	2013	2020
Waccamaw	SC	Waccamaw	3	4	8	2012	2019
Cape Romain - Horsehead Key	SC	Cape Romain	3	2	9	2010	2018
Cape Romain - Racoon Key	SC	Cape Romain	2	1	7	2010	2016
ACE Basin	SC	Ernest F. Hollings Ace Basin	3	2	8	2012	2019
Pinckney Island	SC	Pinckney Island	3	2	9	2012	2020
Savannah	GA	Savannah-Pinckney	3	2	9	2012	2020
Wassaw	GA	Wassaw	3	1	8	2012	2019
Harris Neck	GA	Harris Neck	3	1	9	2012	2020
Blackbeard Island	GA	Blackbeard Island	3	2	9	2012	2020
Wolf Island	GA	Wolf Island	3	2	8	2012	2019
St. Marks	FL	St. Marks	3	3	10	2012	2021
Lower Suwanee - Salt Marsh	FL	Lower Suwannee	3	1	5	2012	2016
Lower Suwanee - Oligohaline	FL	Lower Suwannee	3	1	2	2013	2014

Figure 1. Study Area showing sites ($N = 22$) where SET benchmarks are located among 19 USFWS National Wildlife Refuges, Southeast Region.

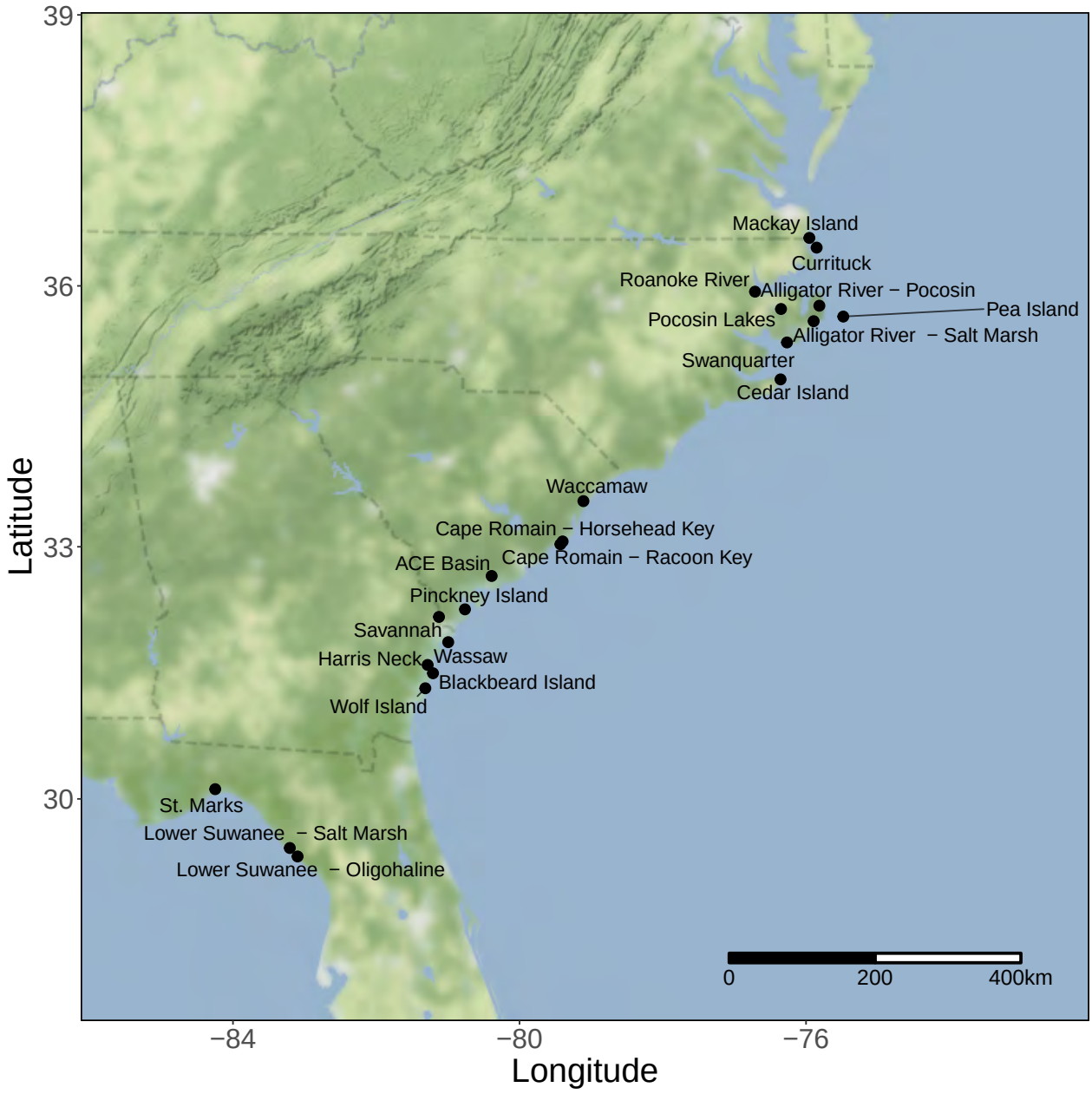


Figure 2. Plot change in elevation data relative to initial height (mm) over time for all pin-level SET data.

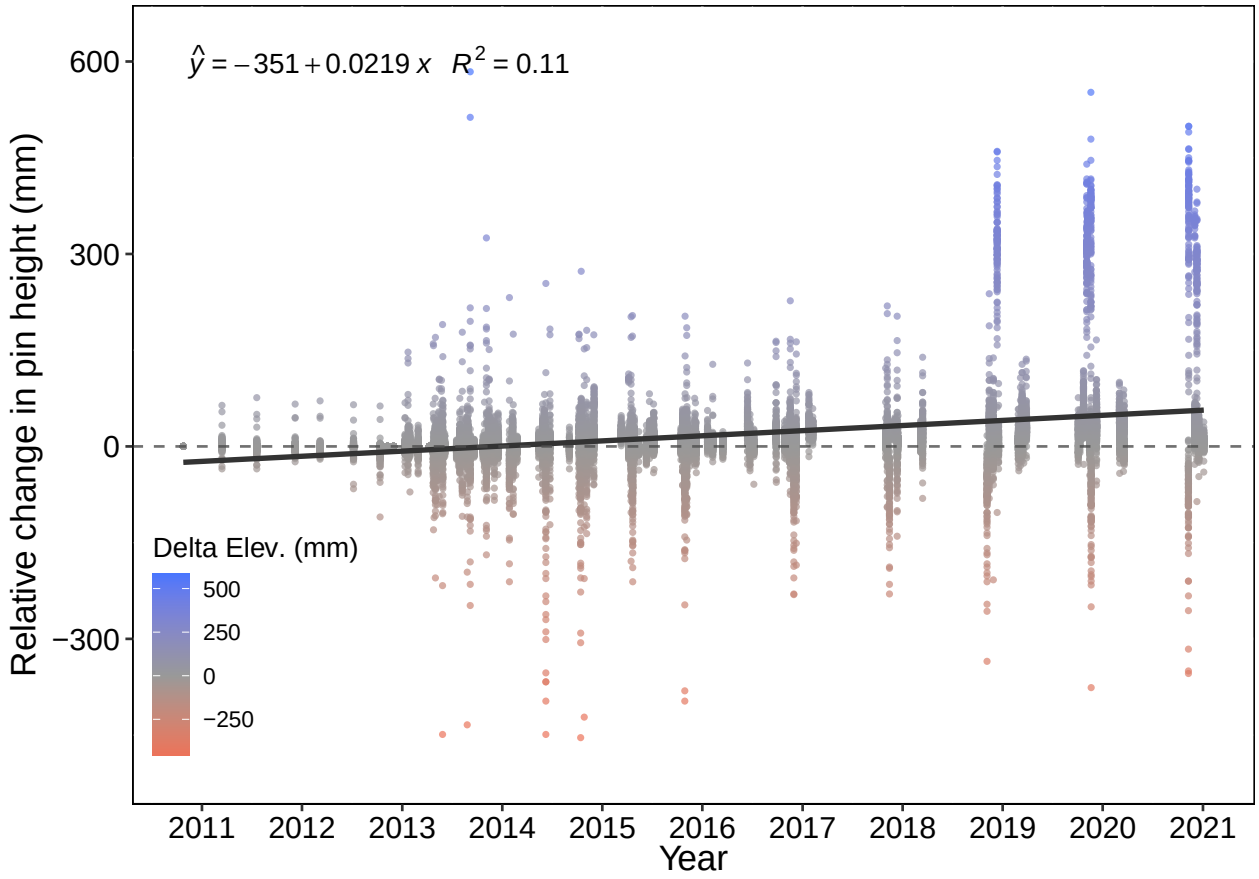


Table 2. List of SETs with fewer than 5 years of data which are omitted from analyses

NWR Refuge	Site Name	SET Station	Number of Years
Lower Suwannee	Lower Suwanee - Salt Marsh	SWE002A	4
Lower Suwannee	Lower Suwanee - Salt Marsh	SWE002B	4
Lower Suwannee	Lower Suwanee - Salt Marsh	SWE002C	4
Lower Suwannee	Lower Suwanee - Oligohaline	SWE038A	2
Lower Suwannee	Lower Suwanee - Oligohaline	SWE038B	2
Lower Suwannee	Lower Suwanee - Oligohaline	SWE038C	2

Figure 3. Plot change in elevation data relative to initial height (mm) over time with SETs with fewer than 5 years of data omitted.

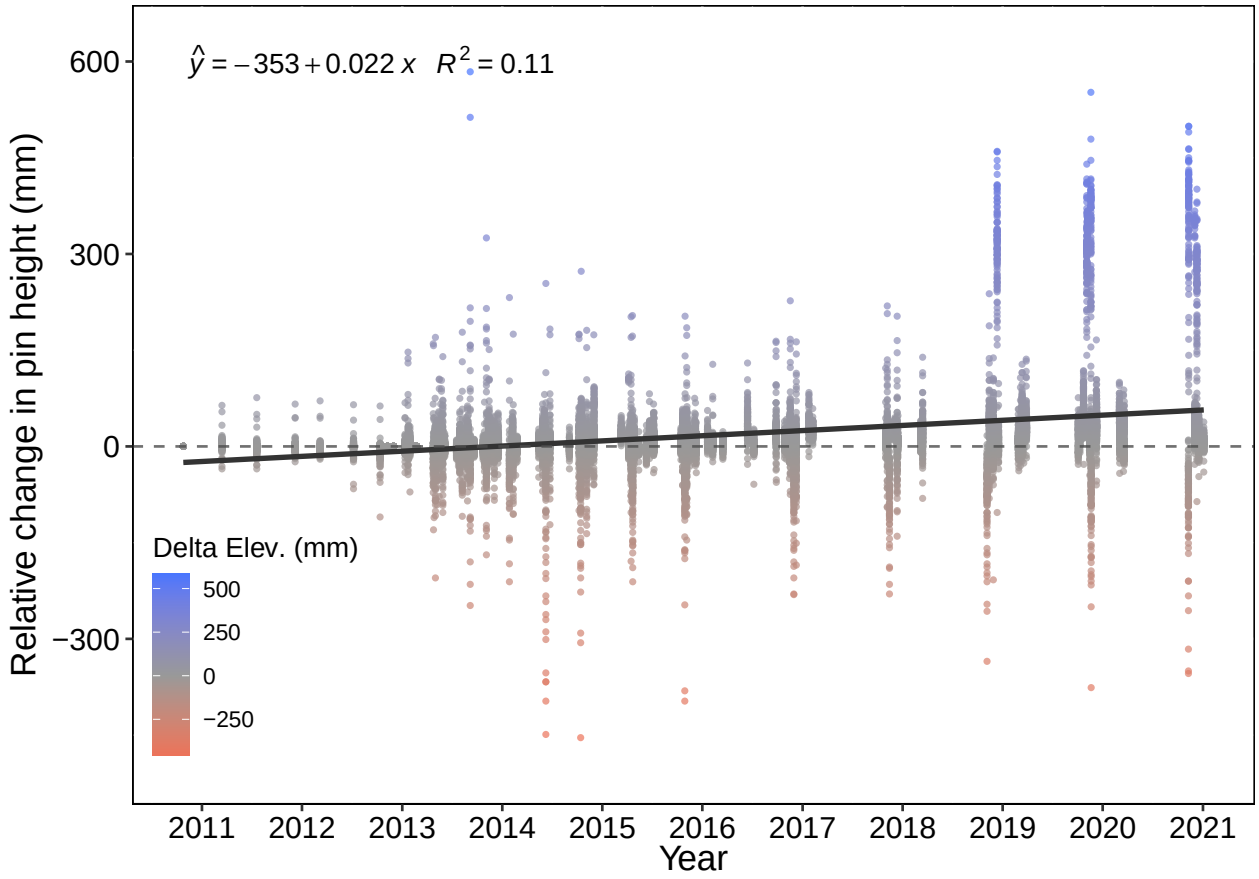


Figure 4. Station-level change in elevation data relative to initial height (mm) over time.

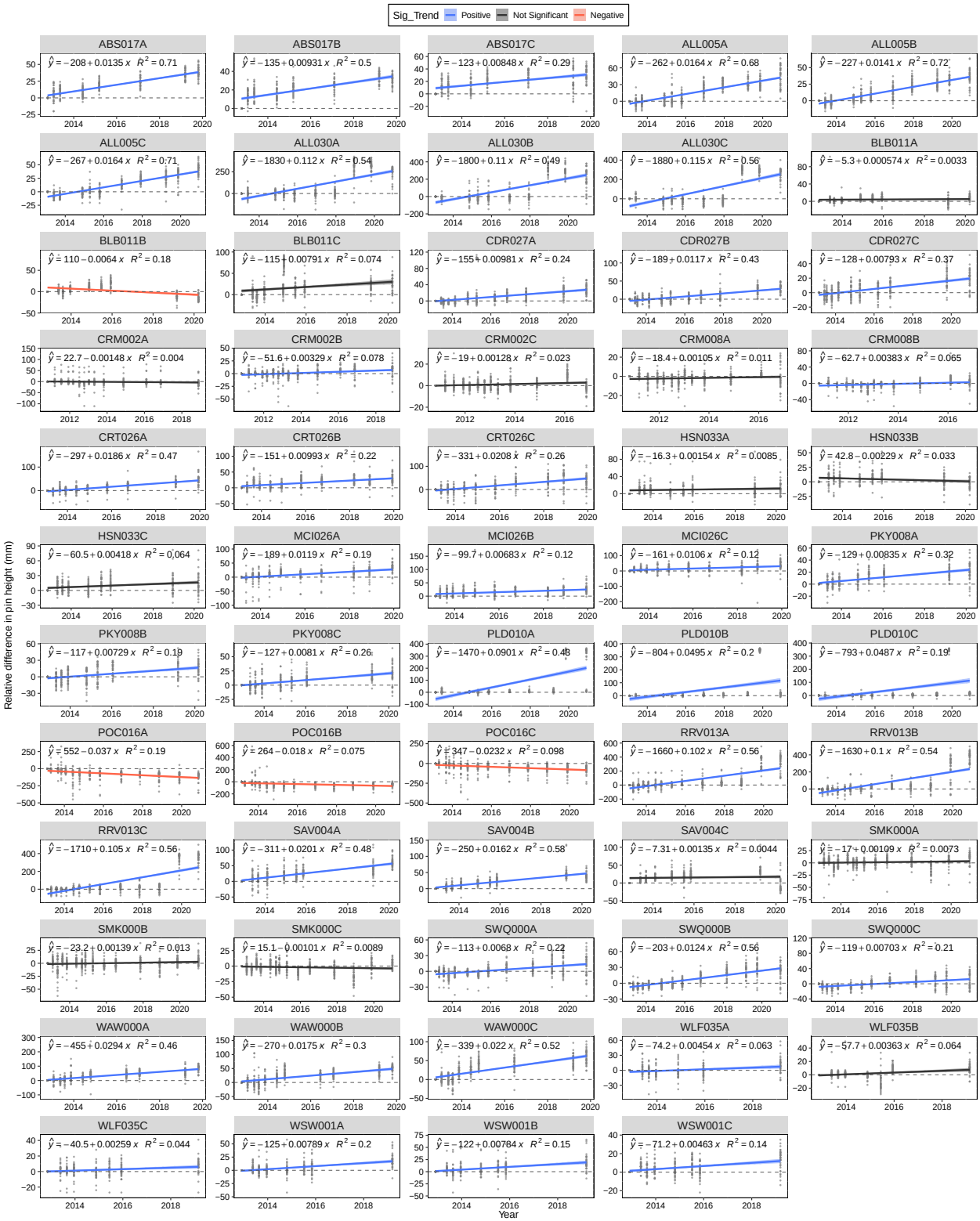


Table 3. Site-level trend estimates mean, and upper and lower 95% confidence intervals for change in wetland elevation (mm/year).

Site	NWR	State	N	Mean	SE	Lower 95% CI	Upper 95% CI
Mackay Island	Mackay Island	NC	3	3.539	0.5987	2.366	4.713
Currituck	Currituck	NC	3	6.419	1.345	3.783	9.056
Roanoke River	Roanoke River	NC	3	40.74	0.6259	39.52	41.97
Alligator River - Pocosin	Alligator River	NC	3	46.11	0.6714	44.79	47.42
Pocosin Lakes	Pocosin Lakes	NC	3	-10.2	2.182	-14.48	-5.92
Pea Island	Pea Island	NC	3	23.89	5.193	13.71	34.07
Alligator River - Salt Marsh	Alligator River	NC	3	5.993	0.2868	5.431	6.556
Swanquarter	Swanquarter	NC	3	3.349	0.697	1.983	4.715
Cedar Island	Cedar Island	NC	3	3.844	0.4181	3.025	4.664
Waccamaw	Waccamaw	SC	3	8.04	1.163	5.76	10.32
Cape Romain - Horsehead Key	Cape Romain	SC	3	0.4703	0.4933	-0.4965	1.437
Cape Romain - Racoon Key	Cape Romain	SC	2	1.033	0.5467	-0.03897	2.104
ACE Basin	Ernest F. Hollings Ace Basin	SC	3	3.908	0.5429	2.844	4.973
Pinckney Island	Pinckney Island	SC	3	2.673	0.1043	2.469	2.878
Savannah	Savannah-Pinckney	GA	3	4.248	1.949	0.4276	8.069
Wassaw	Wassaw	GA	3	2.351	0.3484	1.668	3.034
Harris Neck	Harris Neck	GA	3	0.4332	0.6814	-0.9022	1.769
Blackbeard Island	Blackbeard Island	GA	3	0.07763	1.344	-2.557	2.712
Wolf Island	Wolf Island	GA	3	1.223	0.2085	0.814	1.632
St. Marks	St. Marks	FL	3	0.274	0.2631	-0.2416	0.7896

Figure 5. Site-level trend (mean ± SE) in change in wetland elevation (mm/year).

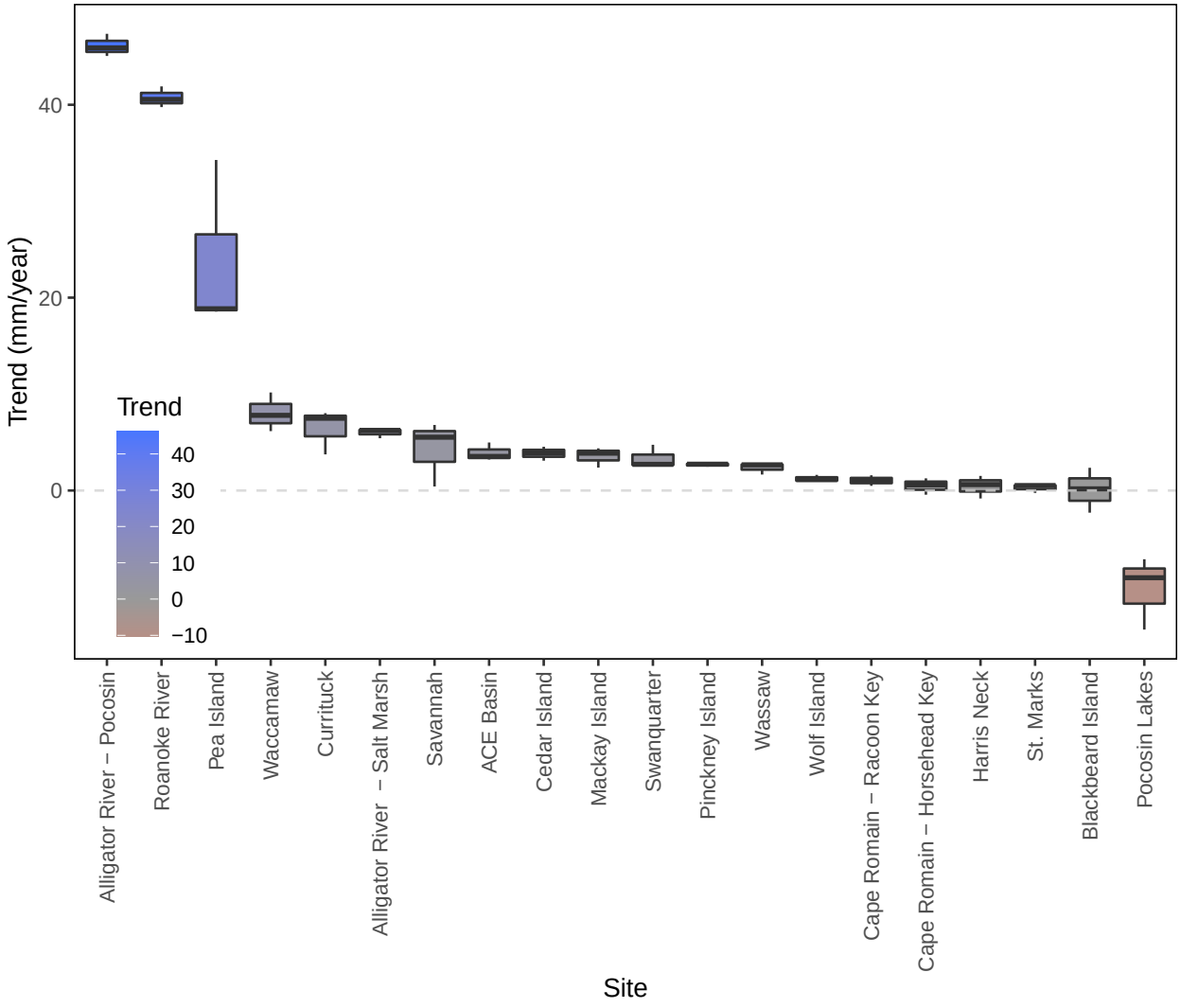


Figure 6. SET Station-level trend (mean ± SE) in change in wetland elevation (mm/year).

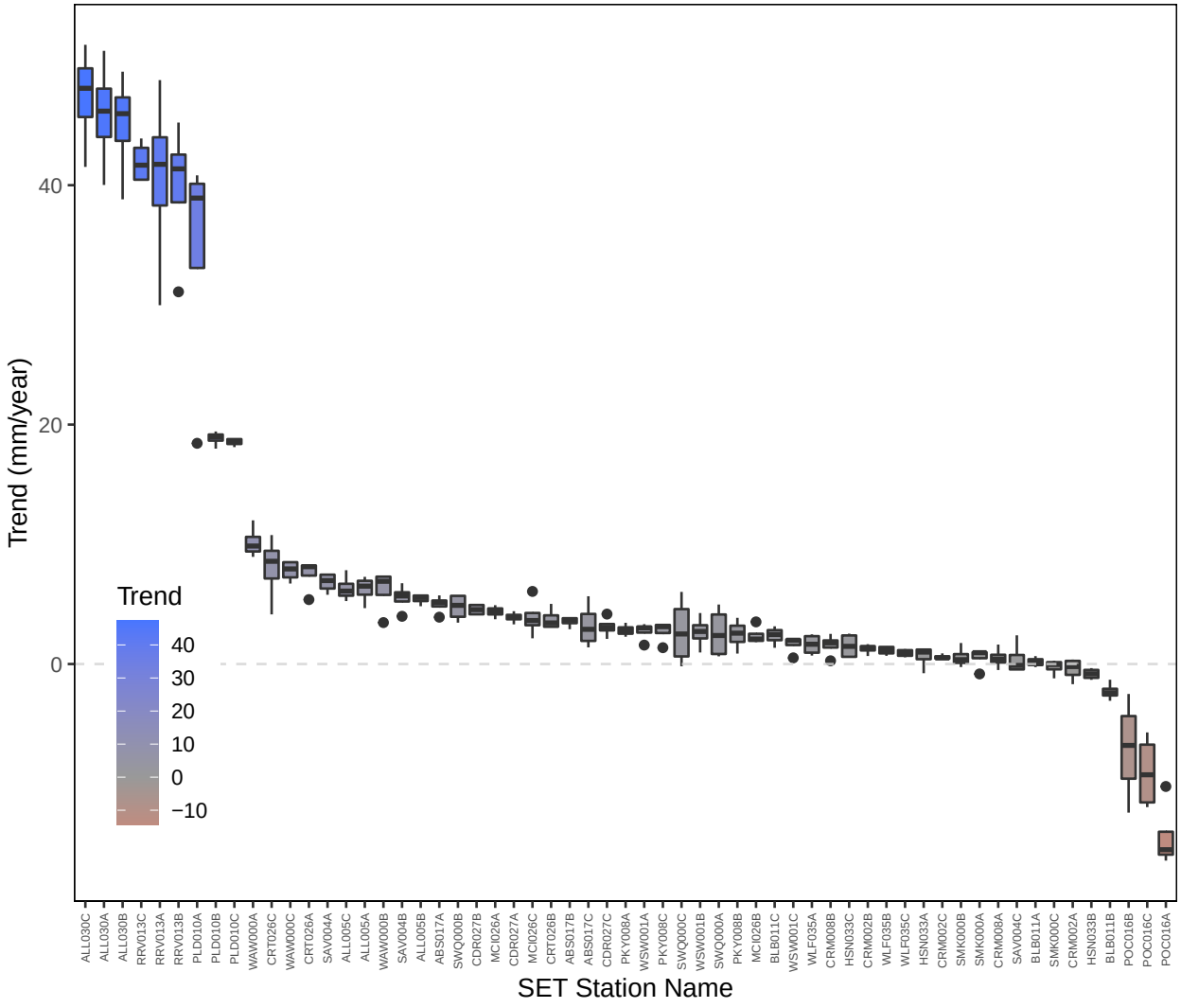
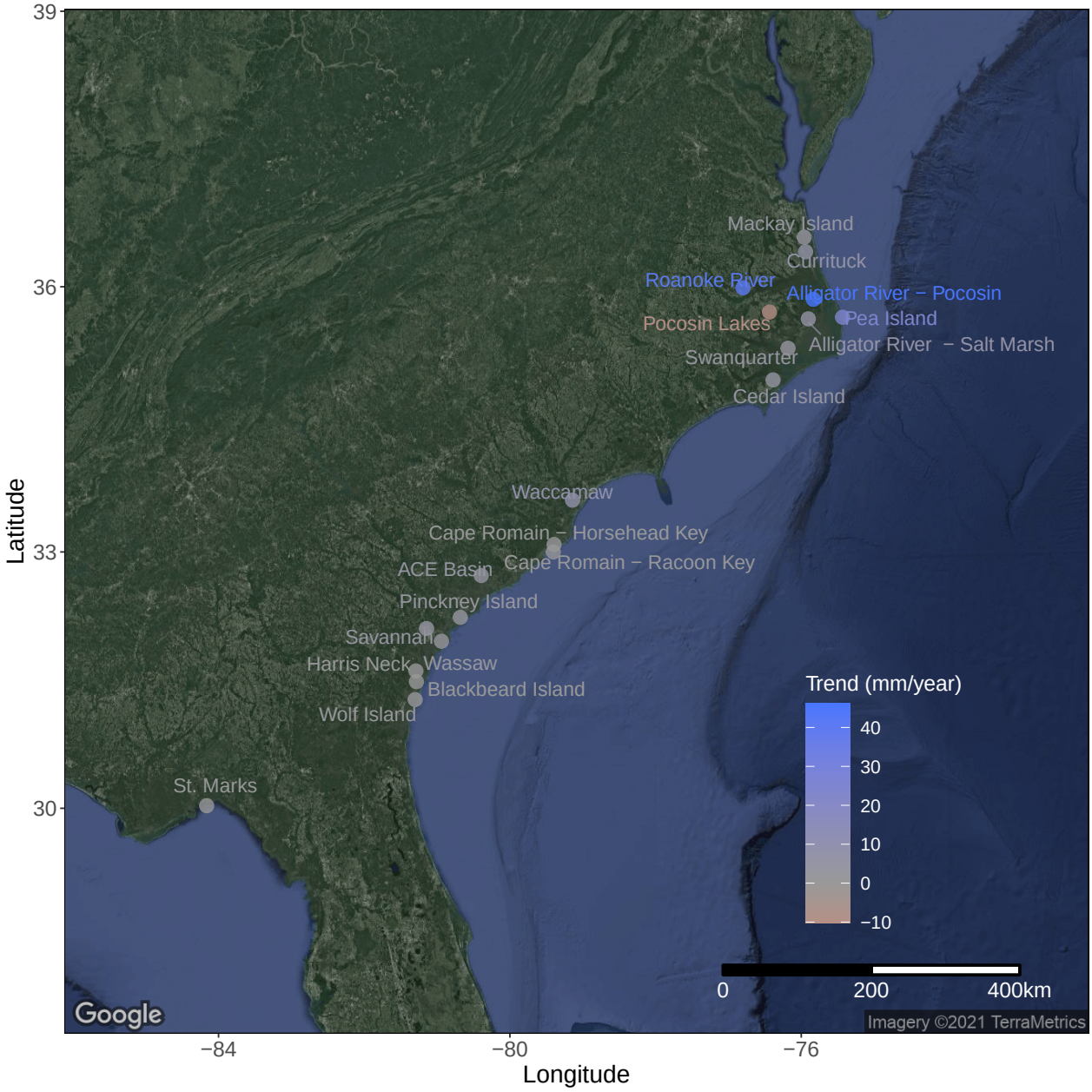


Figure 7. Regional map showing site-level trends.

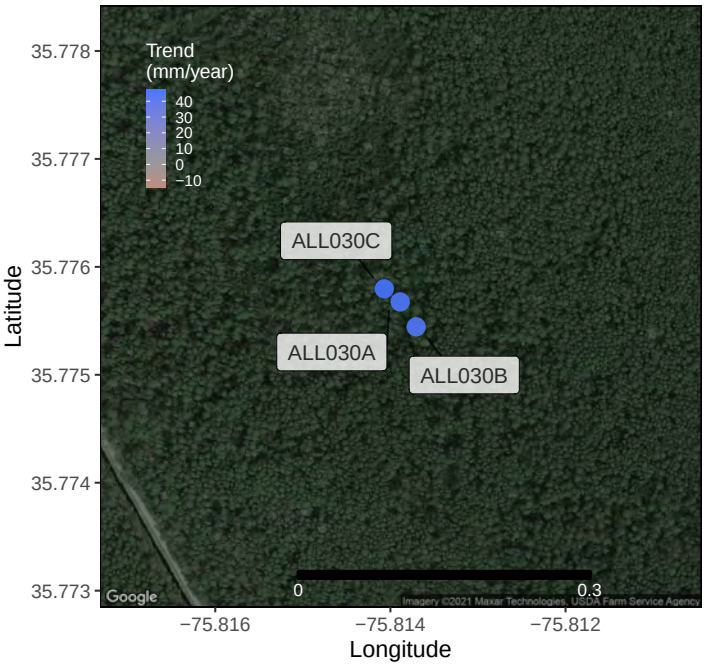


Site-level summaries showing map of SET stations with trends, and station-level trend plots.

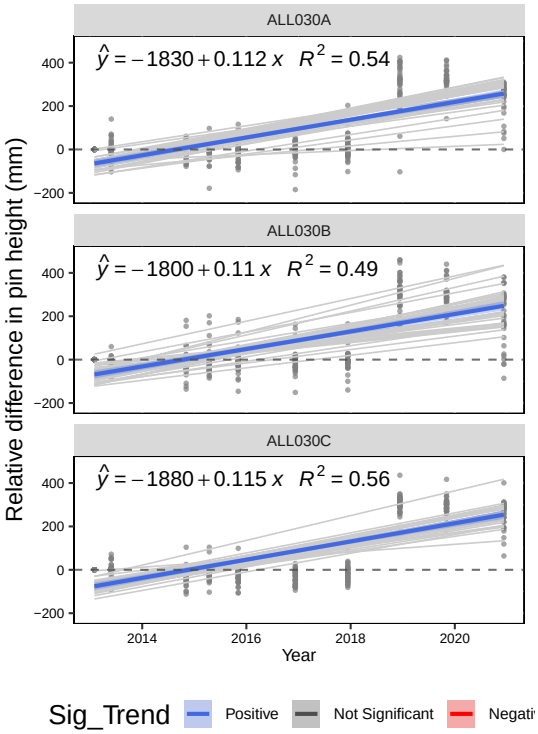
Summary of Alligator River - Pocosin

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Alligator River - Pocosin within the Alligator River NWR. The estimated trend in change in surface elevation (mean ± SE) was 46.11 ± 0.67 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

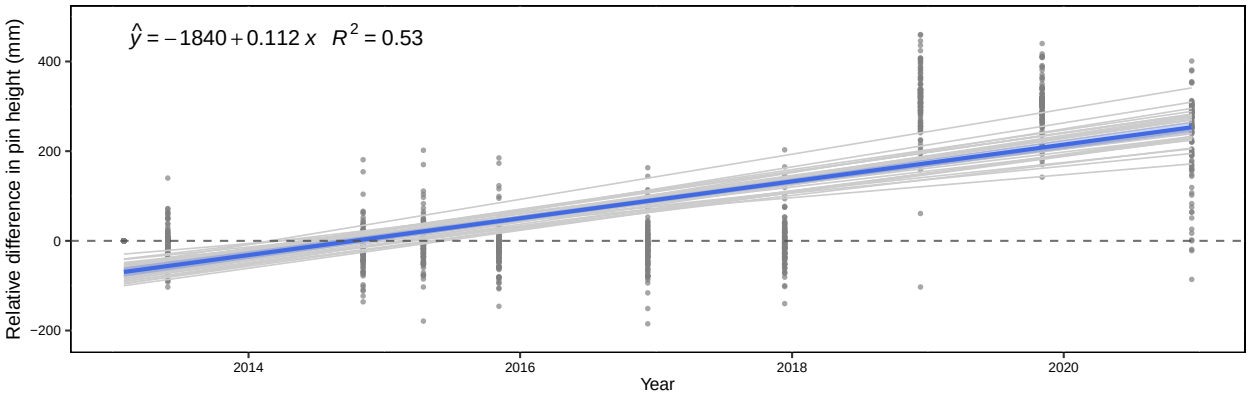
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Alligator River − Pocosin site within Alligator River NWR.

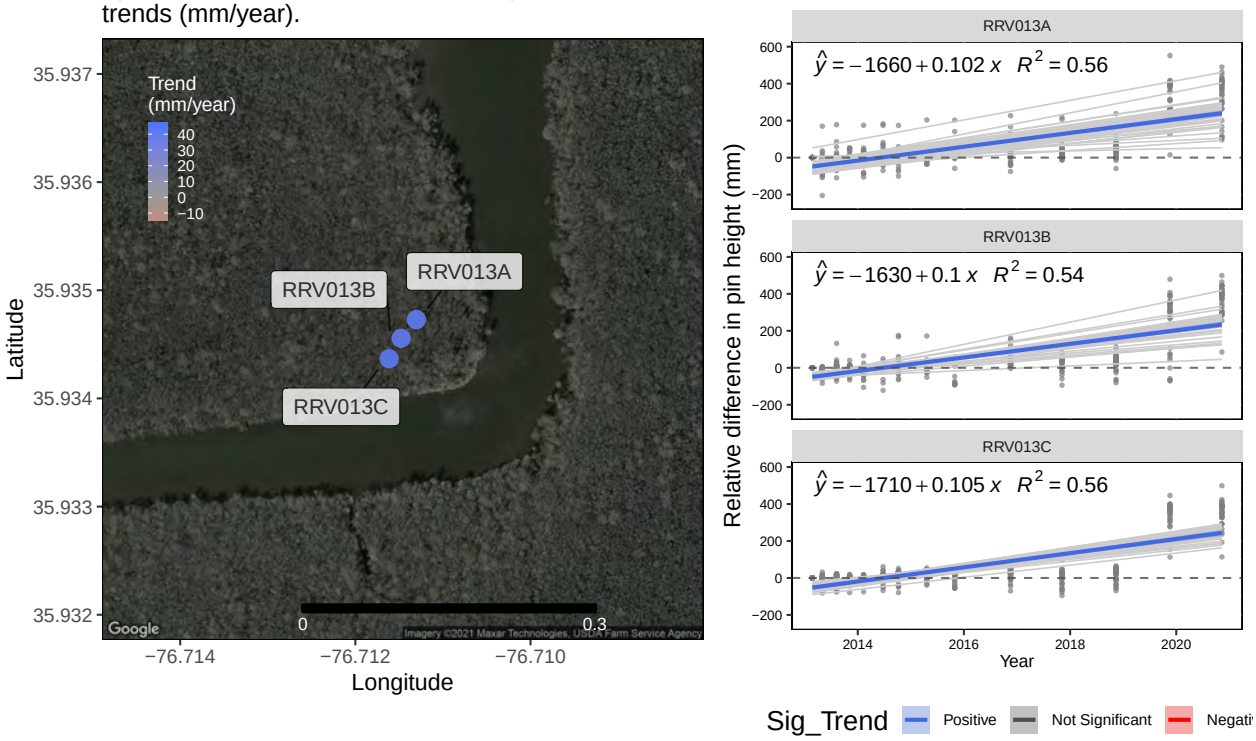


Summary of Roanoke River

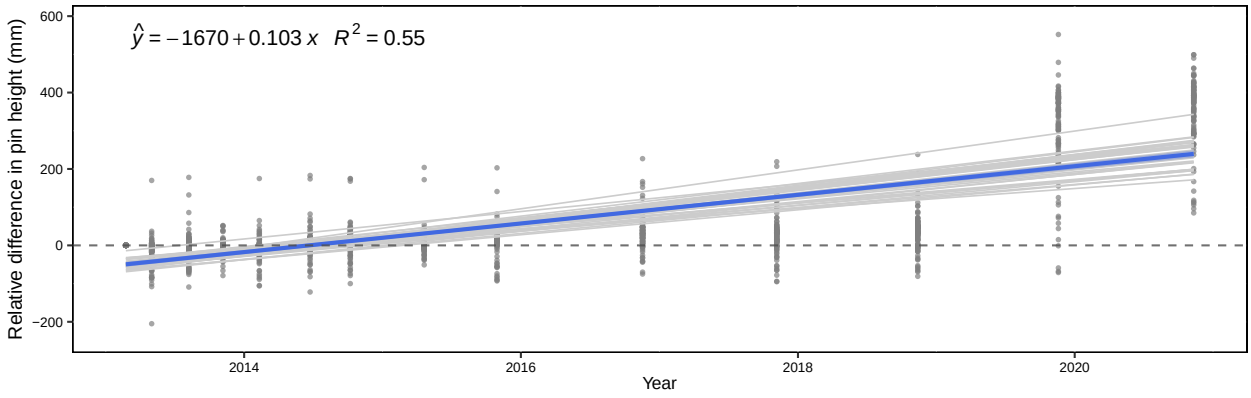
Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Roanoke River within the Roanoke River NWR. The estimated trend in change in surface elevation (mean ± SE) was 40.74 ± 0.63 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



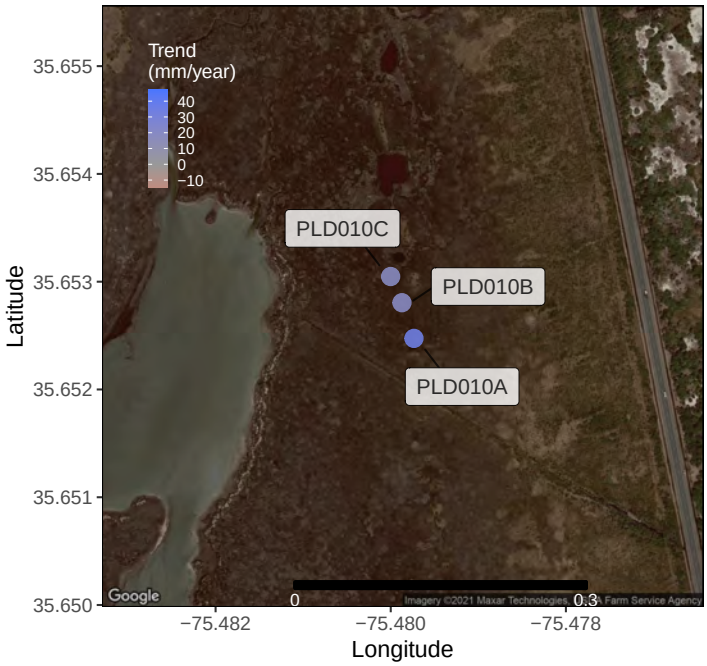
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Roanoke River site within Roanoke River NWR.



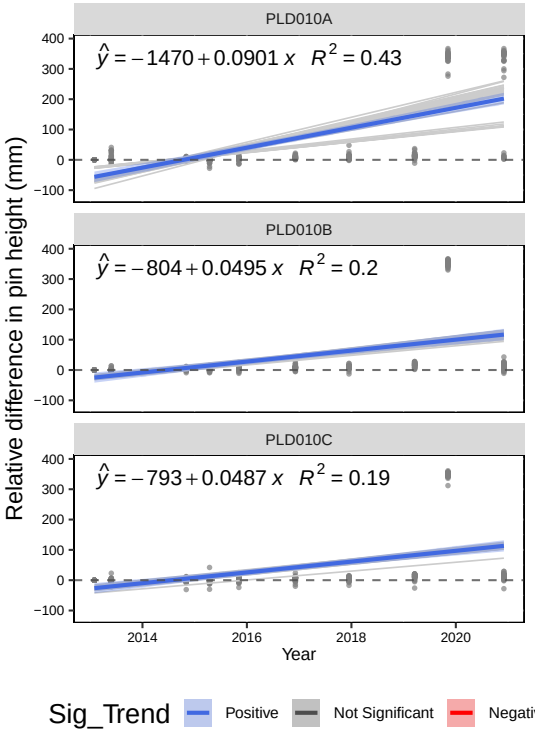
Summary of Pea Island

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Pea Island within the Pea Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 23.89 ± 5.19 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

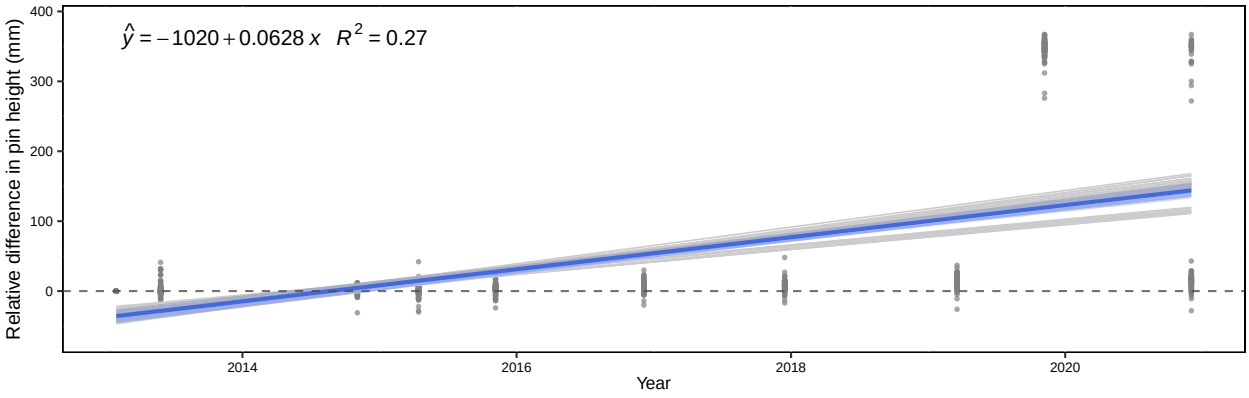
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



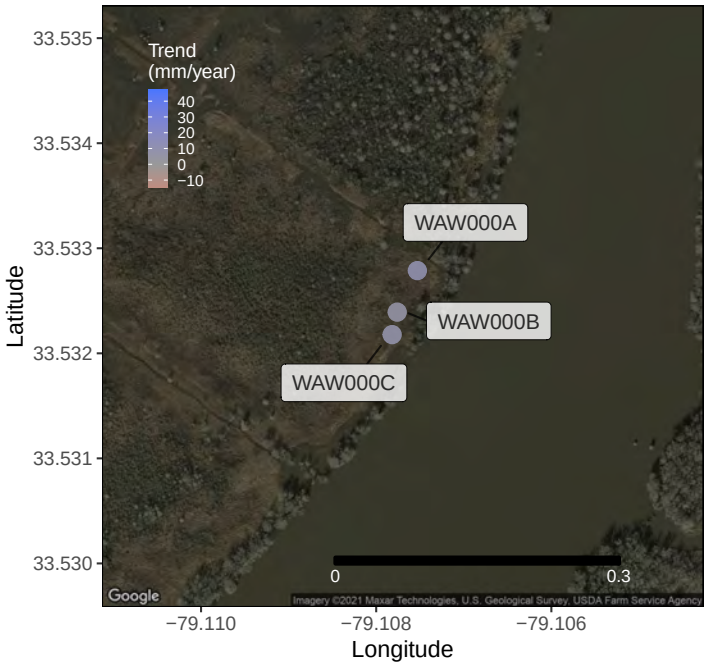
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Pea Island site within Pea Island NWR.



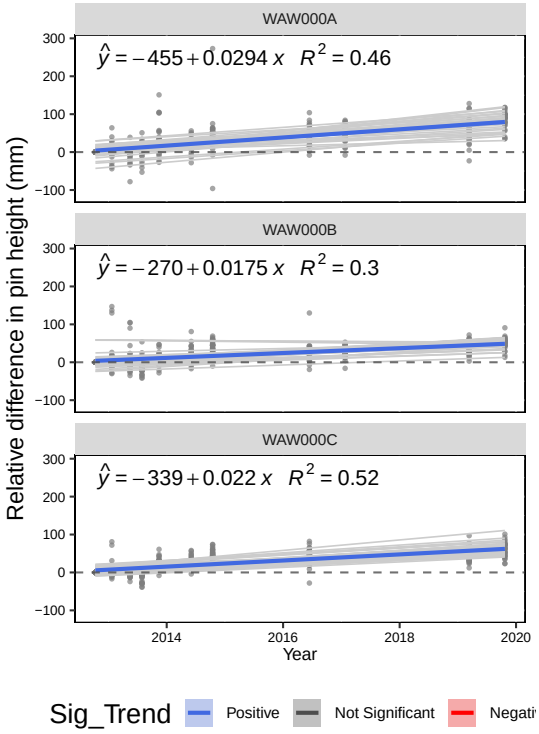
Summary of Waccamaw

Surface elevation table (SET) data were collected between 2012-2019 at A) 3 SET stations at Waccamaw within the Waccamaw NWR. The estimated trend in change in surface elevation (mean ± SE) was 8.04 ± 1.16 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

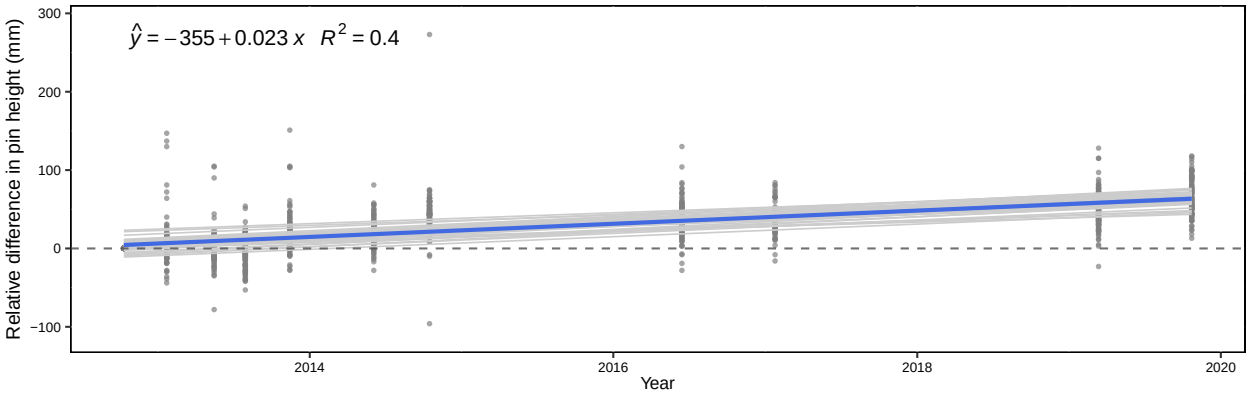
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



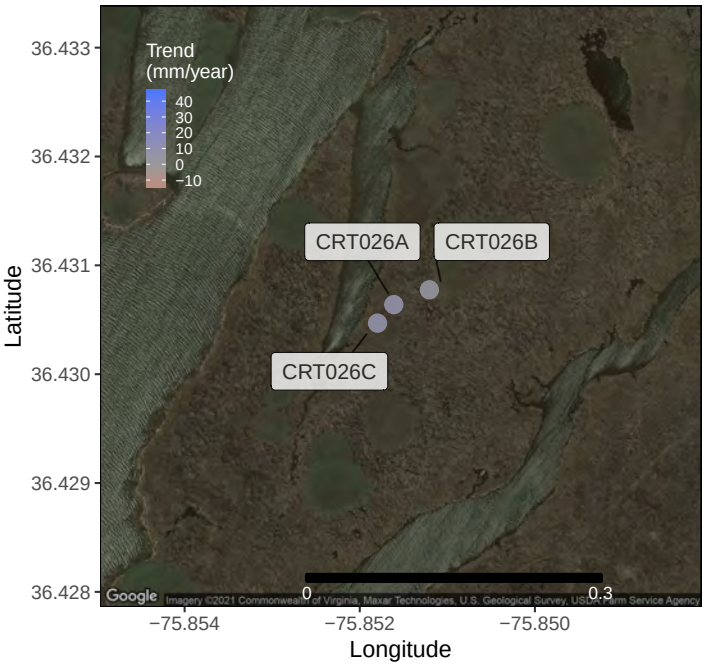
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Waccamaw site within Waccamaw NWR.



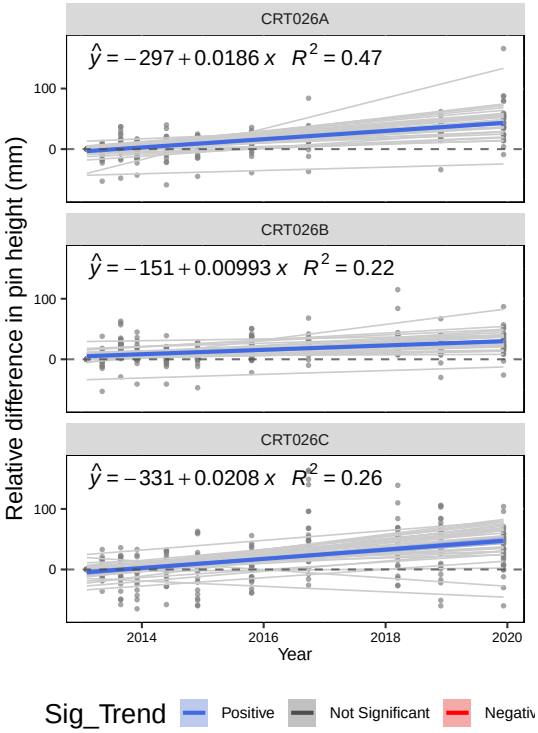
Summary of Currituck

Surface elevation table (SET) data were collected between 2013-2019 at A) 3 SET stations at Currituck within the Currituck NWR. The estimated trend in change in surface elevation (mean ± SE) was 6.42 ± 1.35 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

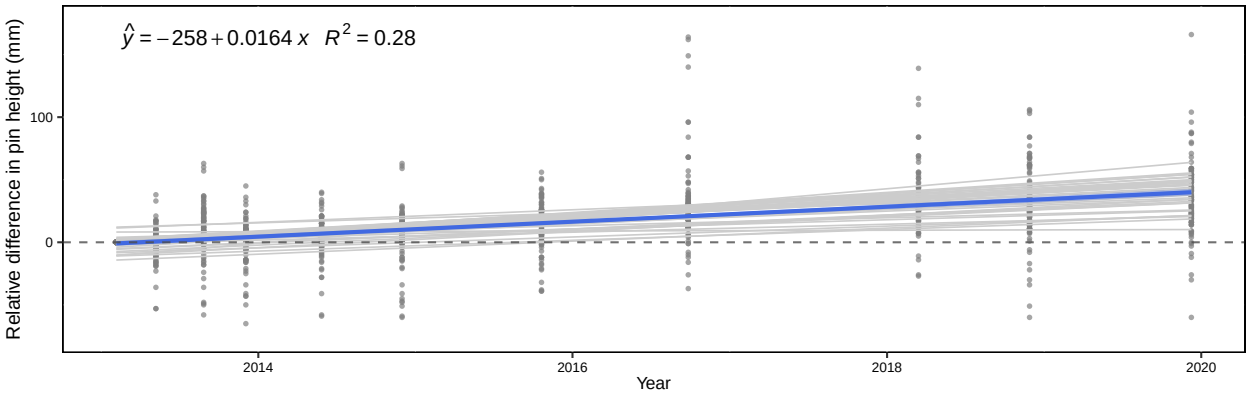
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



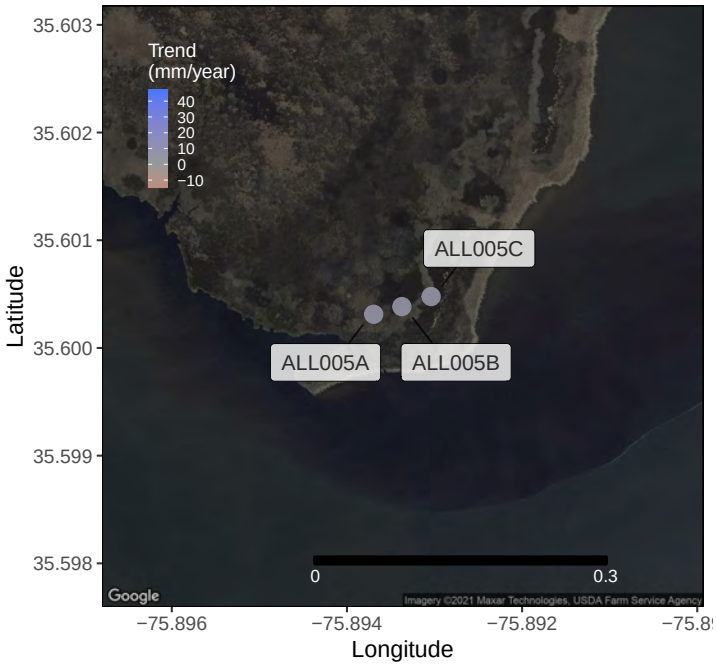
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Currituck site within Currituck NWR.



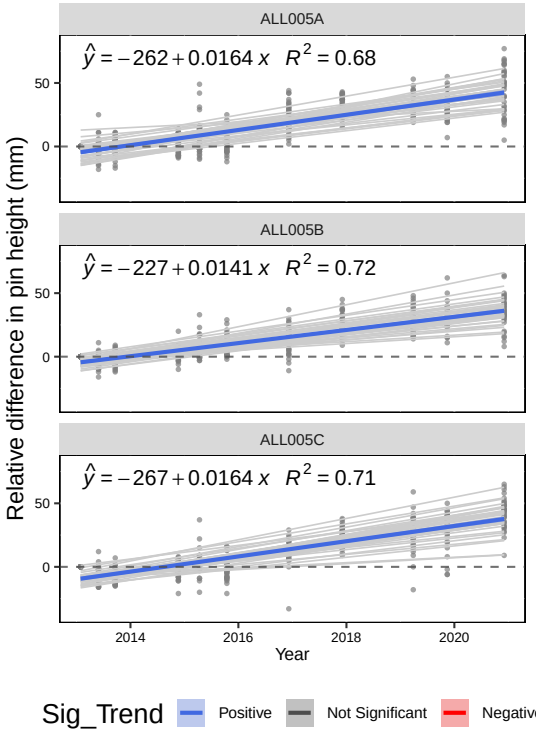
Summary of Alligator River - Salt Marsh

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Alligator River - Salt Marsh within the Alligator River NWR. The estimated trend in change in surface elevation (mean ± SE) was 5.99 ± 0.29 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

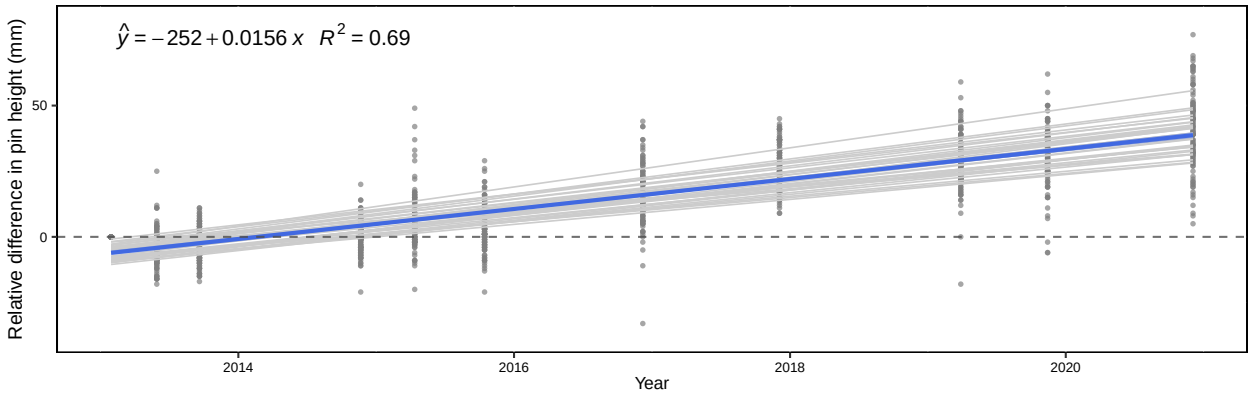
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Alligator River − Salt Marsh site within Alligator River NWR.

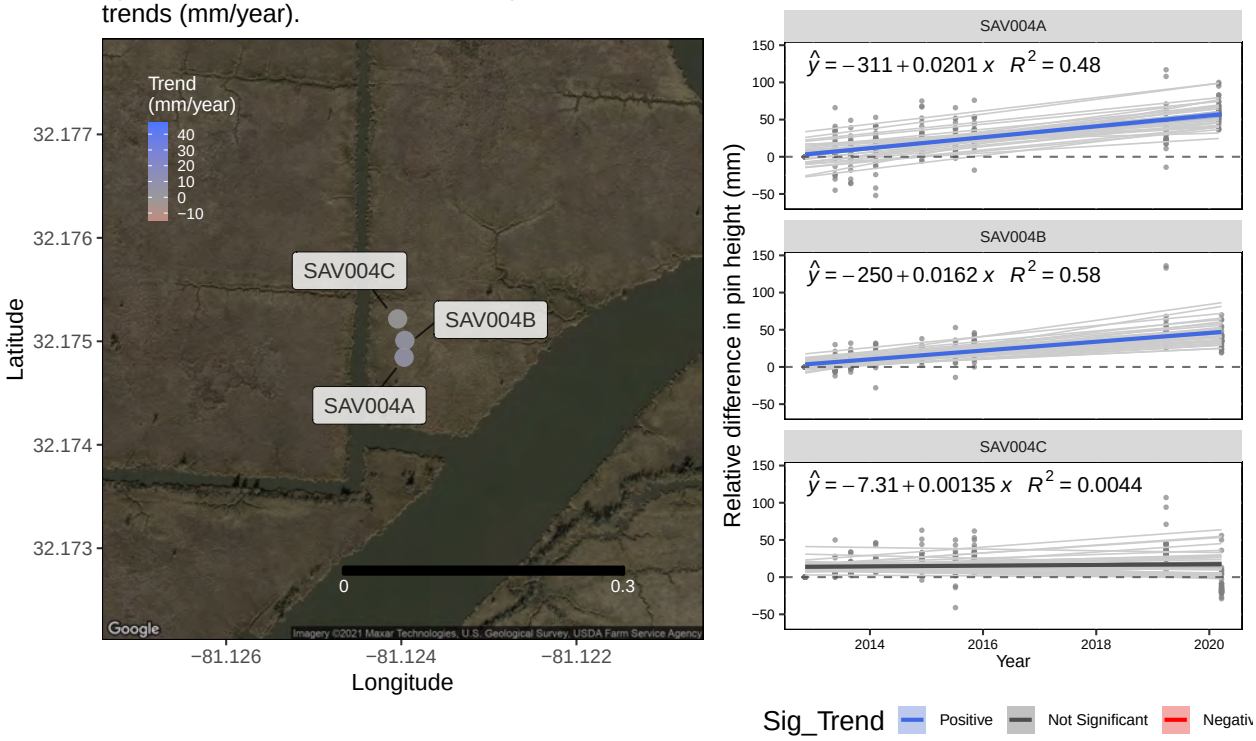


Summary of Savannah

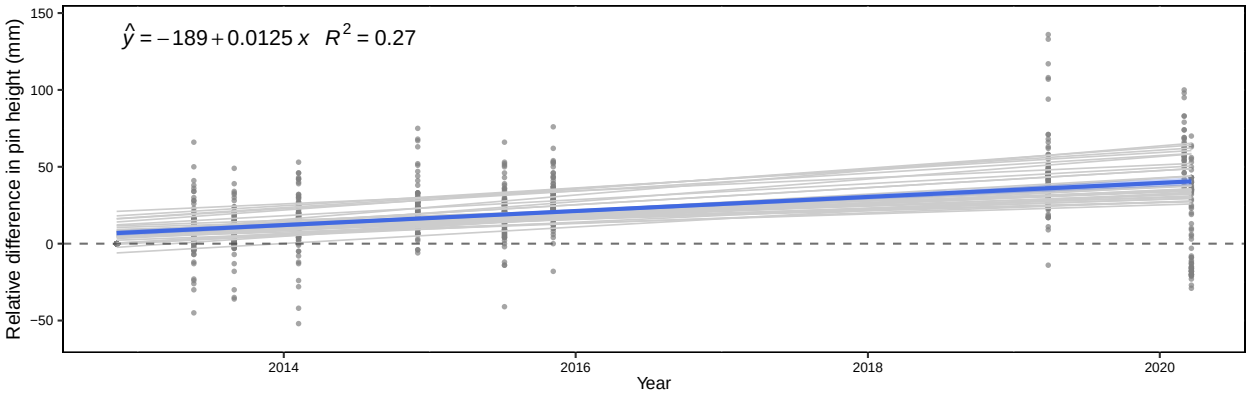
Surface elevation table (SET) data were collected between 2012-2020 at A) 3 SET stations at Savannah within the Savannah-Pinckney NWR. The estimated trend in change in surface elevation (mean ± SE) was 4.25 ± 1.95 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Savannah site within Savannah−Pinckney NWR.

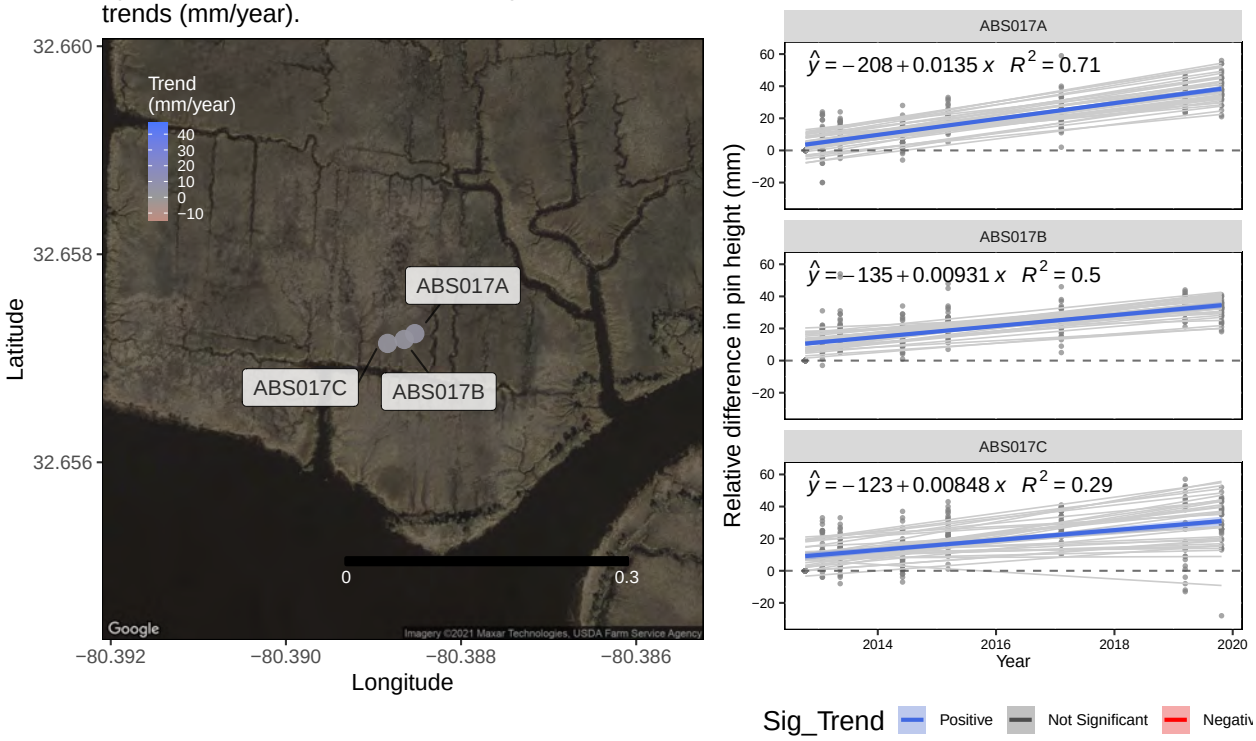


Summary of ACE Basin

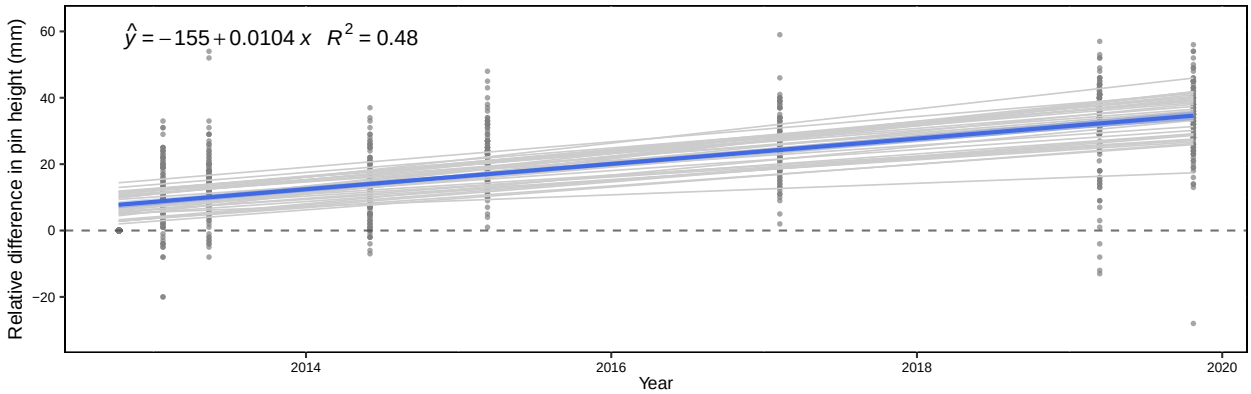
Surface elevation table (SET) data were collected between 2012-2019 at A) 3 SET stations at ACE Basin within the Ernest F. Hollings Ace Basin NWR. The estimated trend in change in surface elevation (mean ± SE) was 3.91 ± 0.54 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



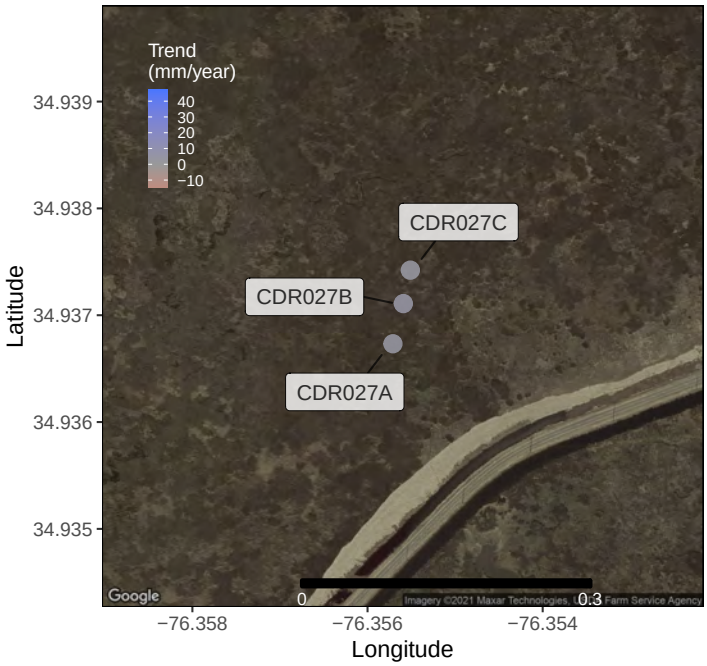
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at ACE Basin site within Ernest F. Hollings Ace Basin NWR.



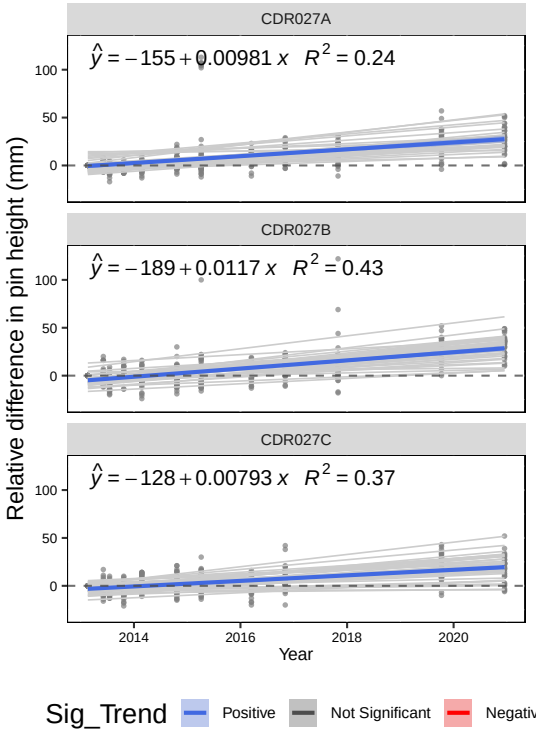
Summary of Cedar Island

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Cedar Island within the Cedar Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 3.84 ± 0.42 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

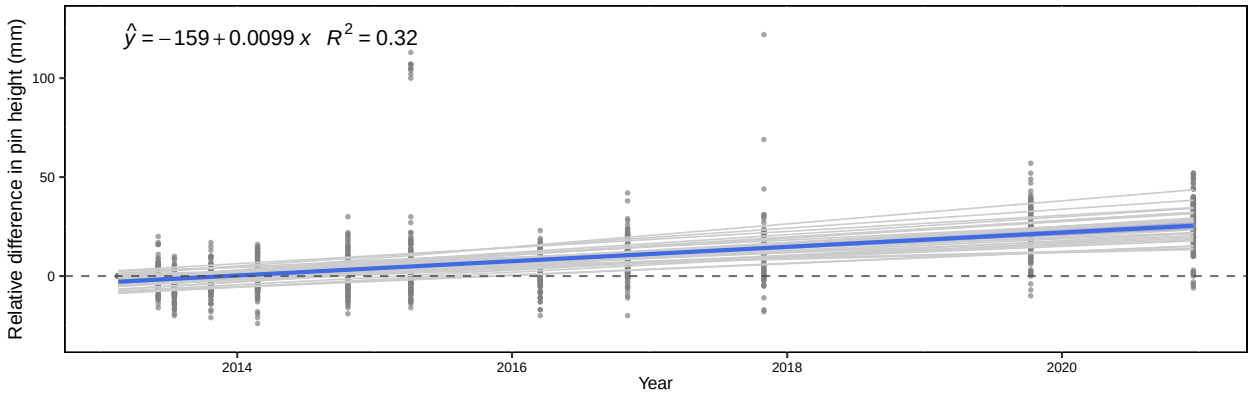
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



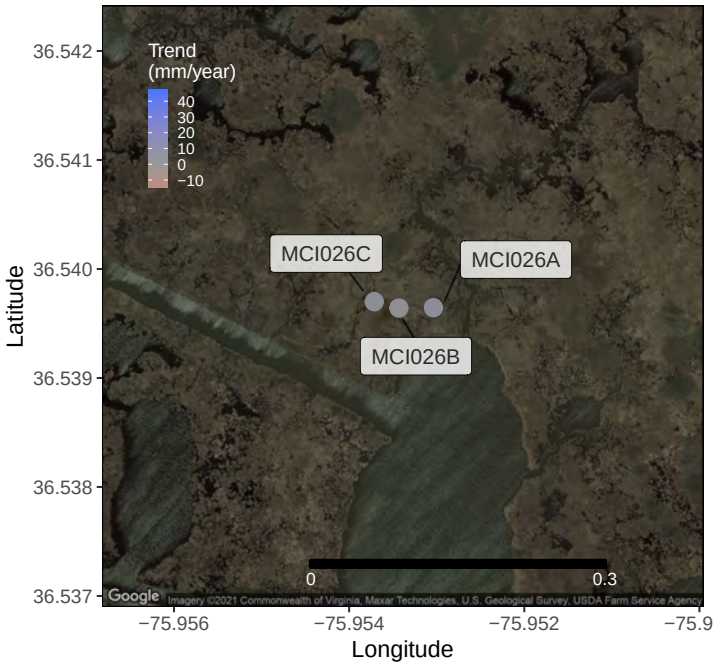
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Cedar Island site within Cedar Island NWR.



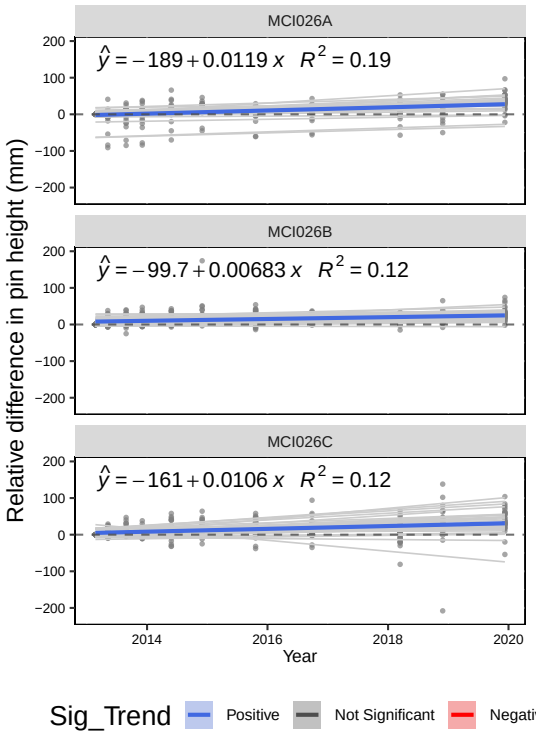
Summary of Mackay Island

Surface elevation table (SET) data were collected between 2013-2019 at A) 3 SET stations at Mackay Island within the Mackay Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 3.54 ± 0.6 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

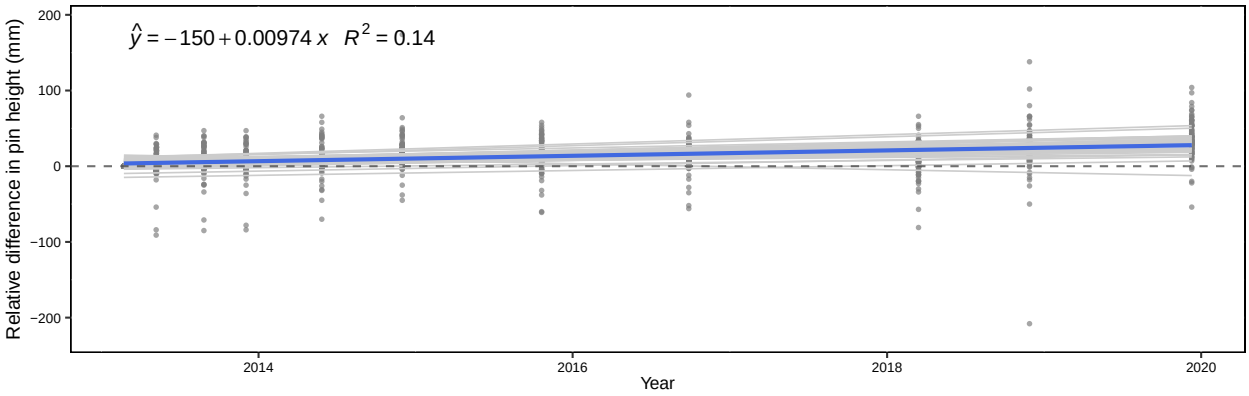
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



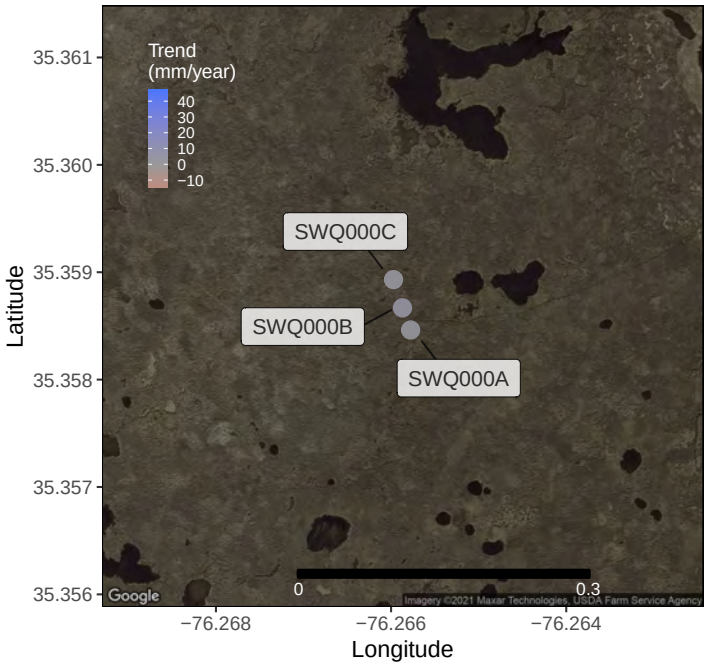
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Mackay Island site within Mackay Island NWR.



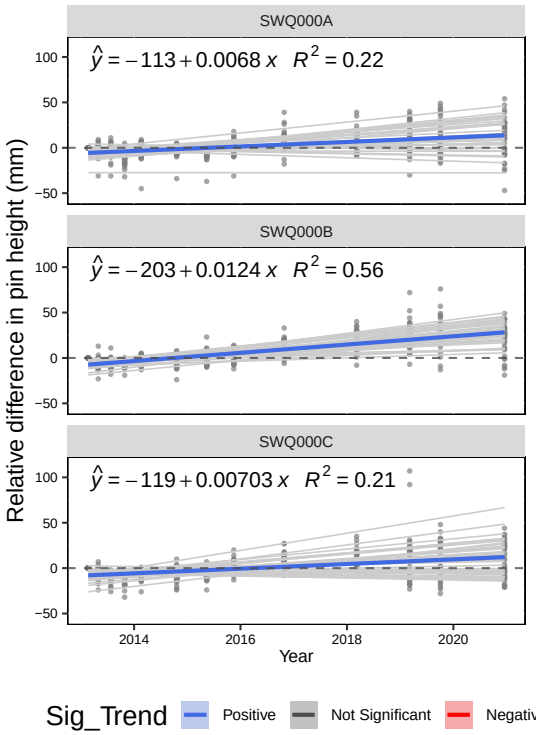
Summary of Swanquarter

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Swanquarter within the Swanquarter NWR. The estimated trend in change in surface elevation (mean ± SE) was 3.35 ± 0.7 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

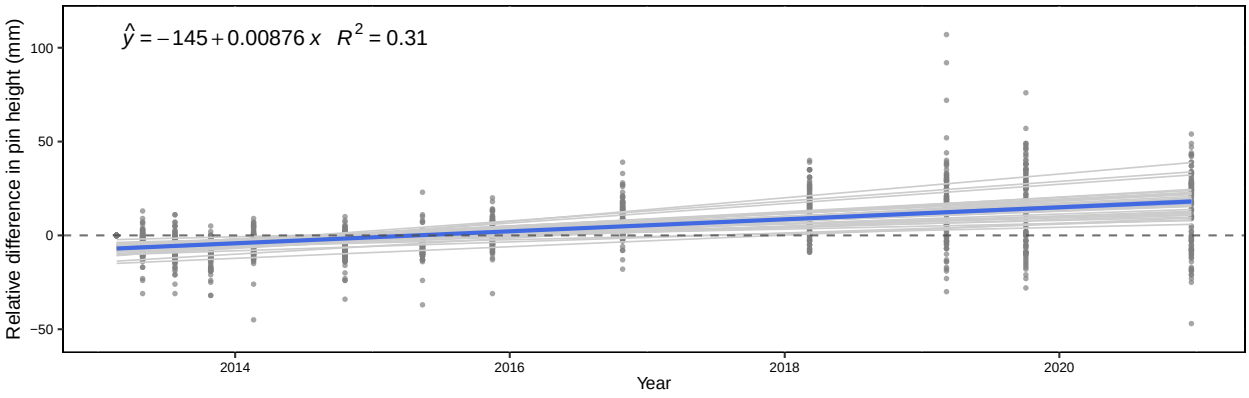
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



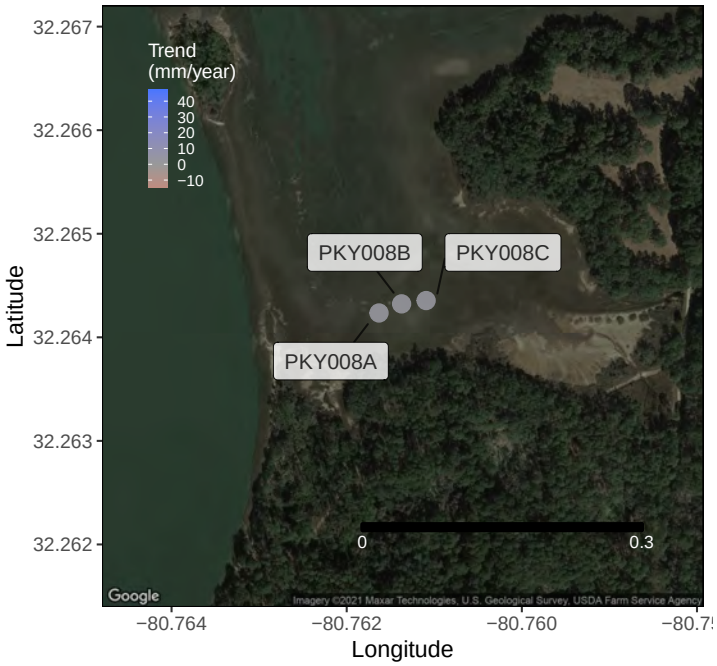
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Swanquarter site within Swanquarter NWR.



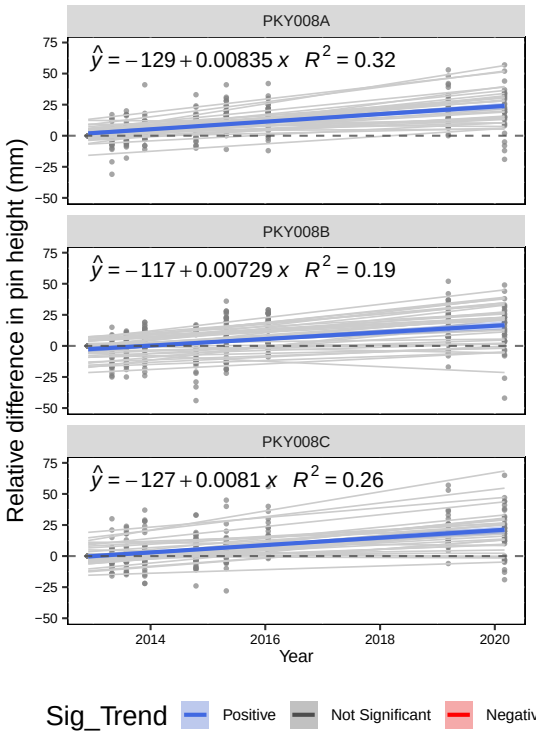
Summary of Pinckney Island

Surface elevation table (SET) data were collected between 2012-2020 at A) 3 SET stations at Pinckney Island within the Pinckney Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 2.67 ± 0.1 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

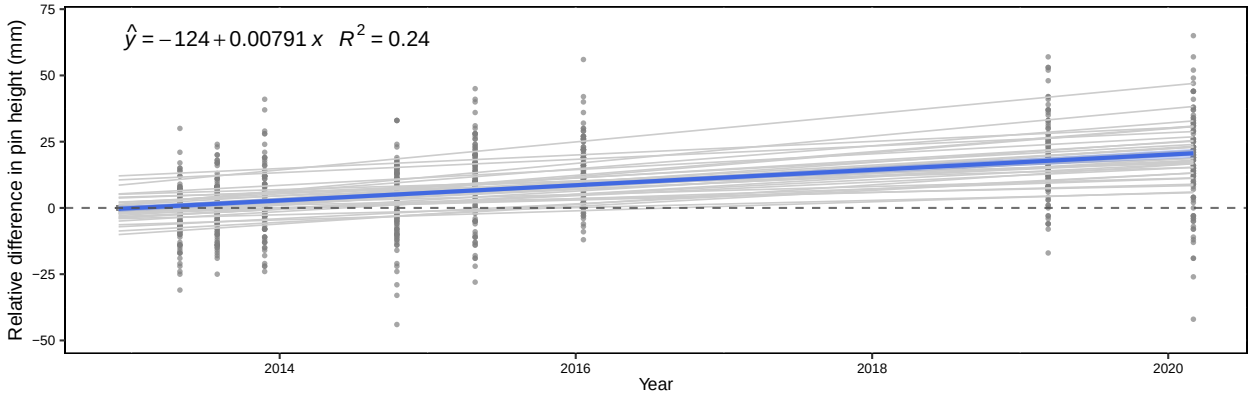
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



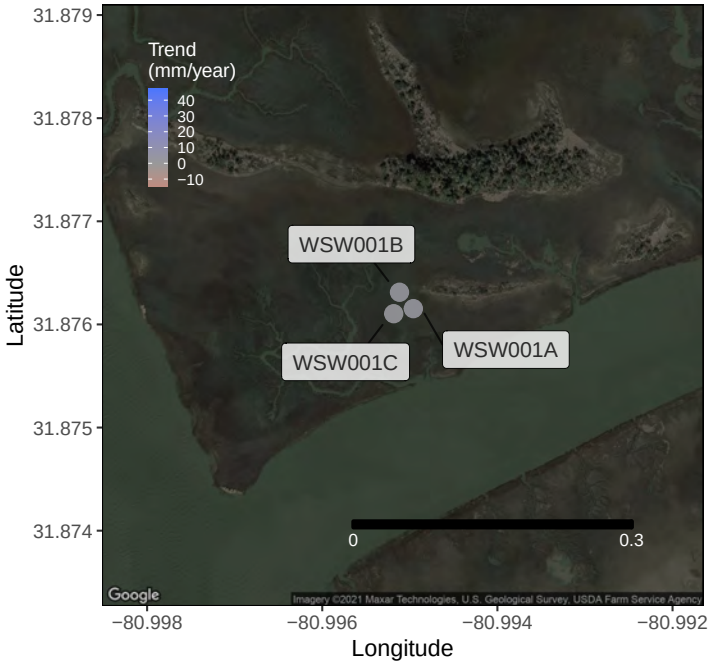
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Pinckney Island site within Pinckney Island NWR.



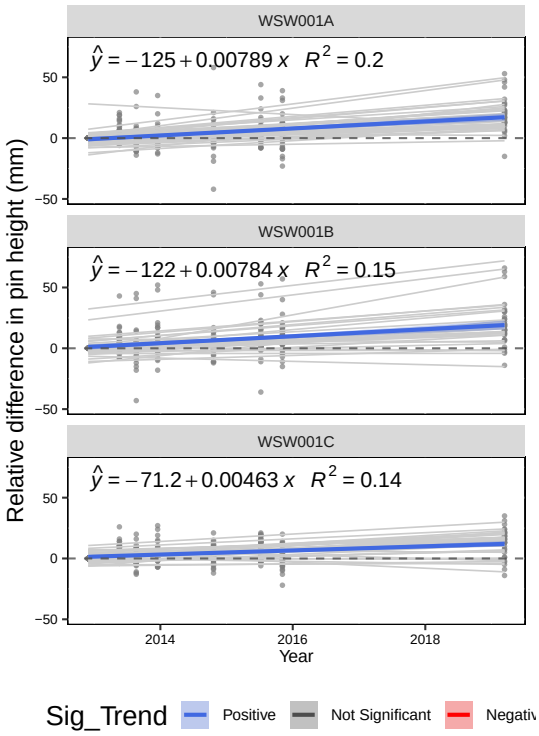
Summary of Wassaw

Surface elevation table (SET) data were collected between 2012-2019 at A) 3 SET stations at Wassaw within the Wassaw NWR. The estimated trend in change in surface elevation (mean ± SE) was 2.35 ± 0.35 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

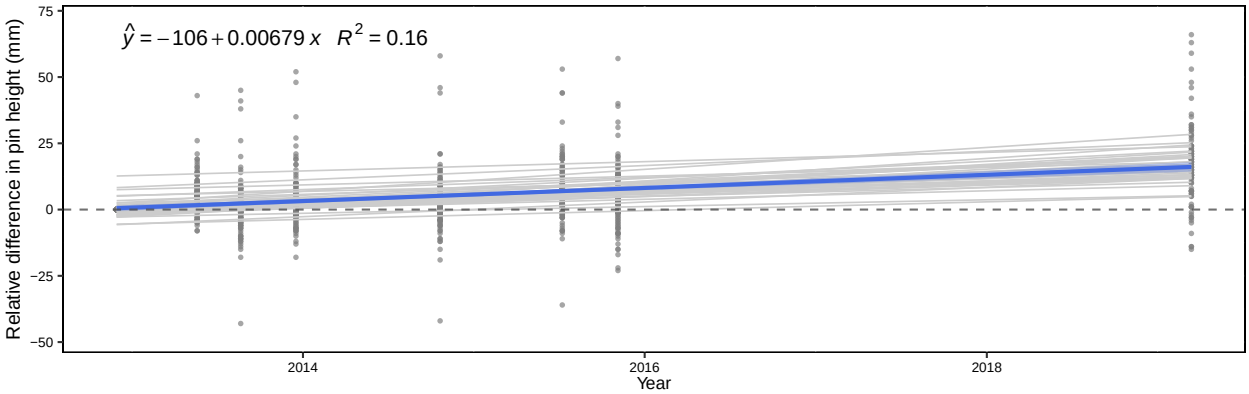
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Wassaw site within Wassaw NWR.

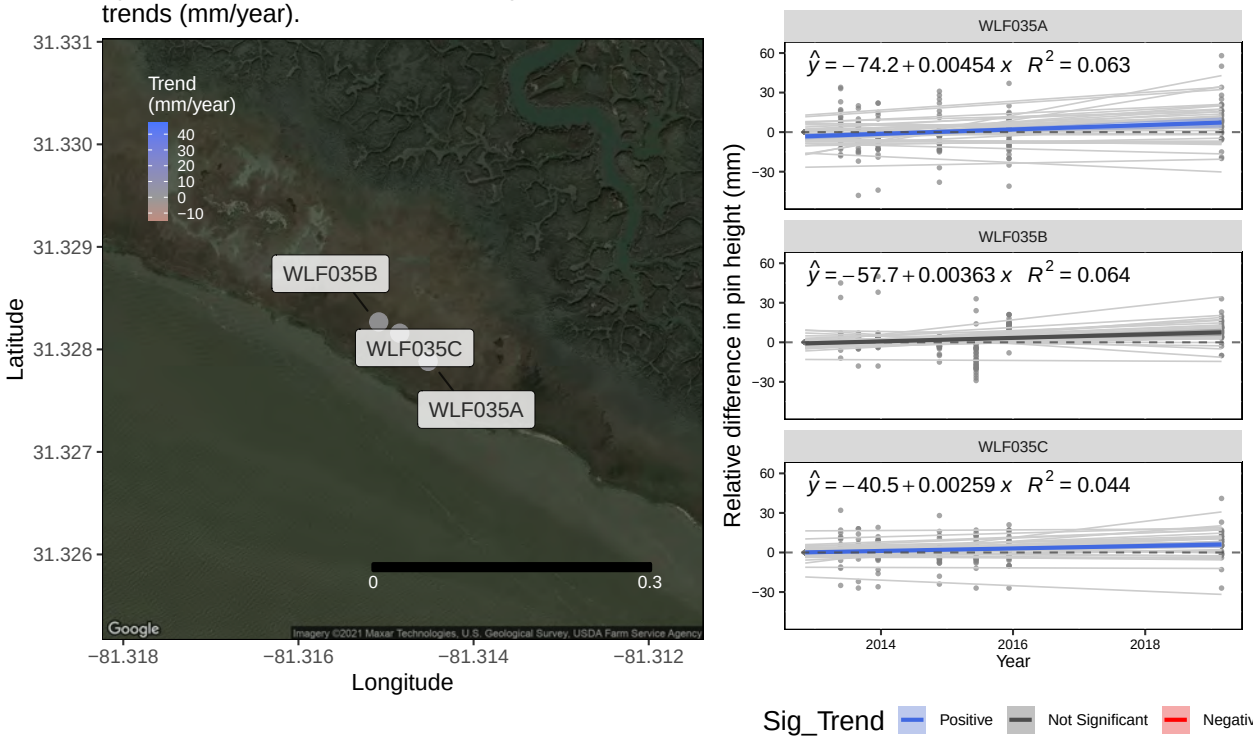


Summary of Wolf Island

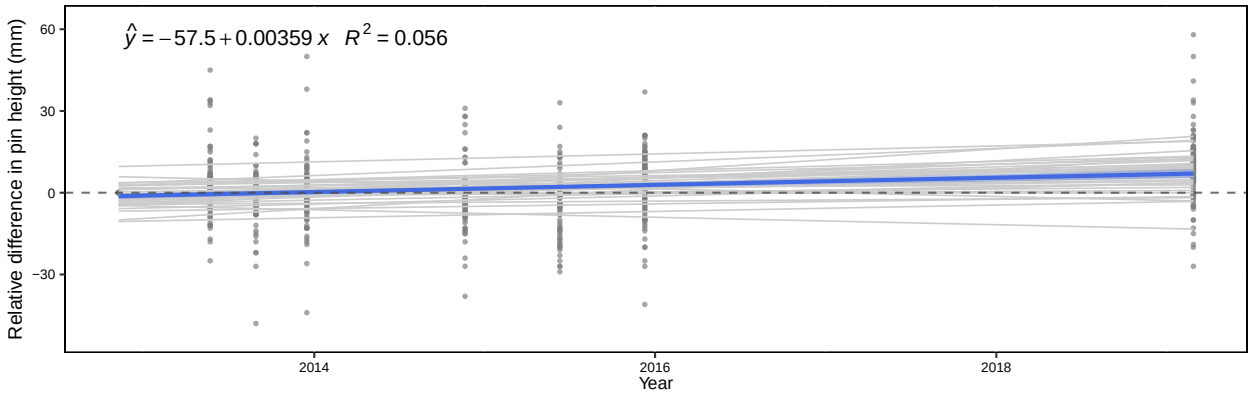
Surface elevation table (SET) data were collected between 2012-2019 at A) 3 SET stations at Wolf Island within the Wolf Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 1.22 ± 0.21 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



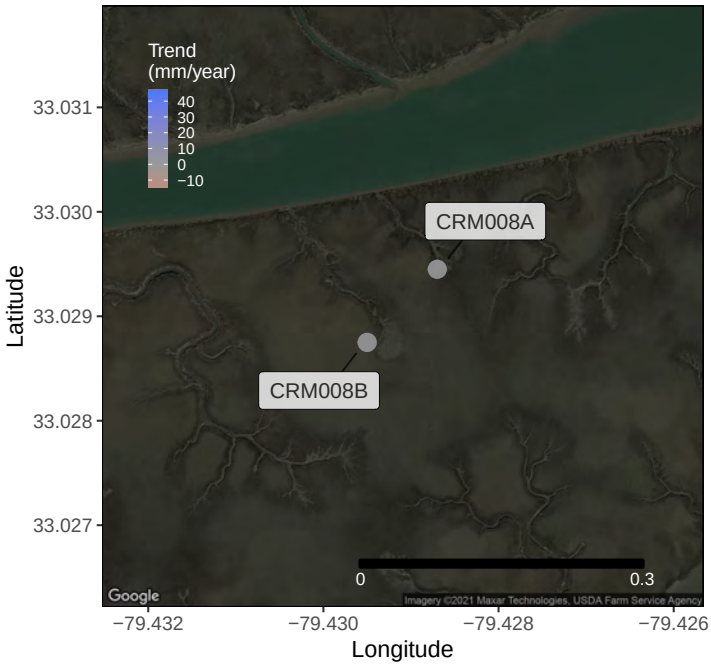
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Wolf Island site within Wolf Island NWR.



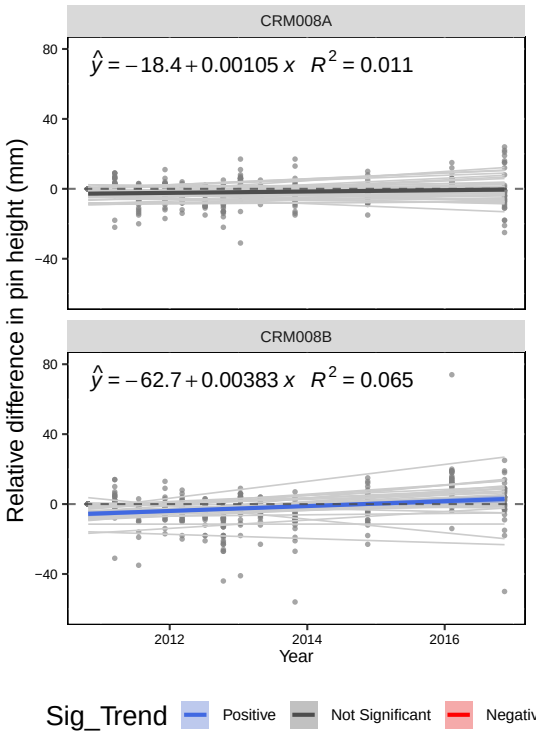
Summary of Cape Romain - Racoon Key

Surface elevation table (SET) data were collected between 2010-2016 at A) 2 SET stations at Cape Romain - Racoon Key within the Cape Romain NWR. The estimated trend in change in surface elevation (mean ± SE) was 1.03 ± 0.55 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

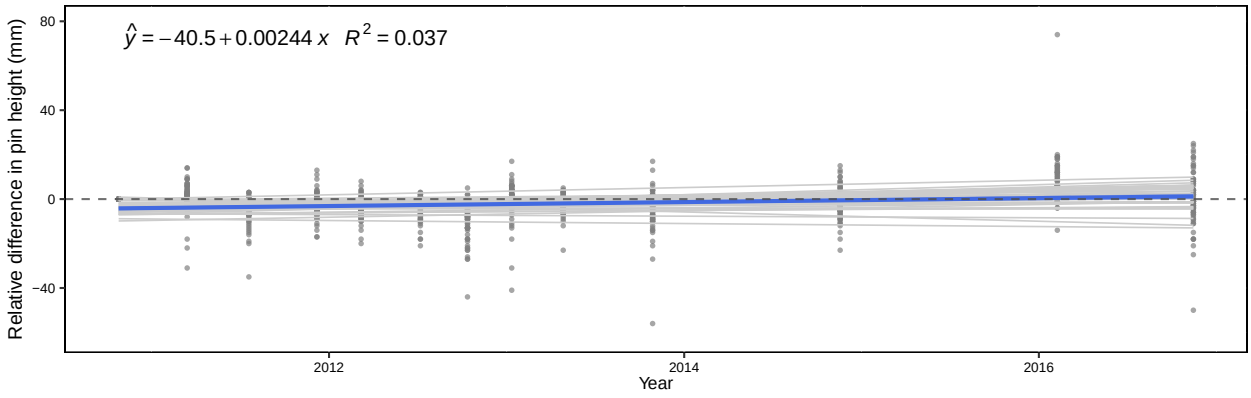
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Cape Romain − Racoon Key site within Cape Romain NWR.

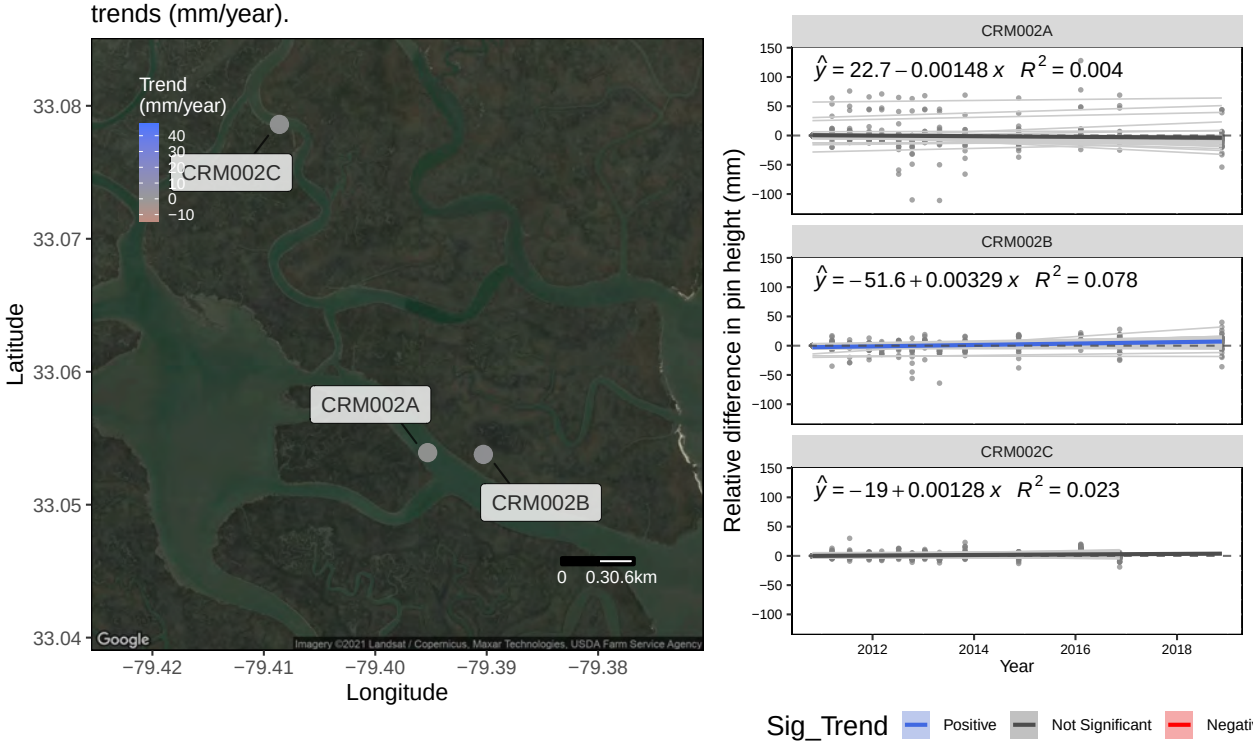


Summary of Cape Romain - Horsehead Key

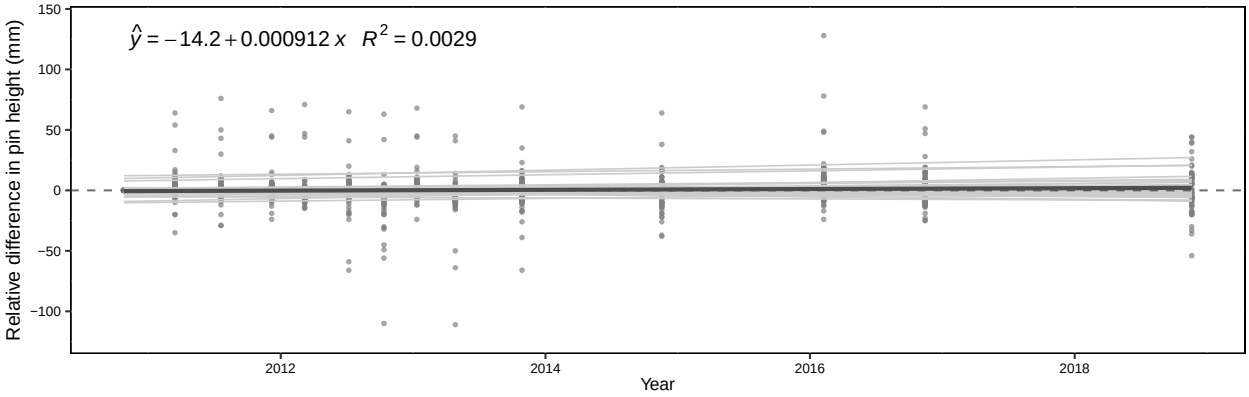
Surface elevation table (SET) data were collected between 2010-2018 at A) 3 SET stations at Cape Romain - Horsehead Key within the Cape Romain NWR. The estimated trend in change in surface elevation (mean ± SE) was 0.47 ± 0.49 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Cape Romain − Horsehead Key site within Cape Romain NWR.

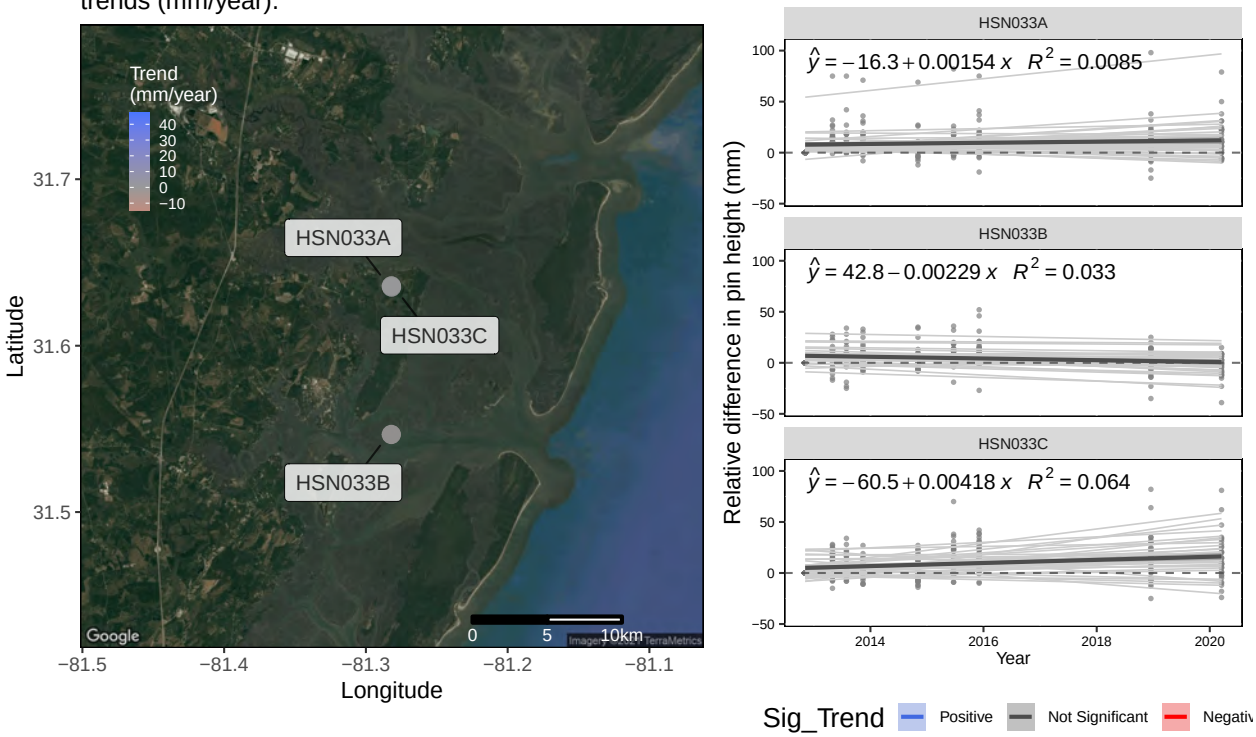


Summary of Harris Neck

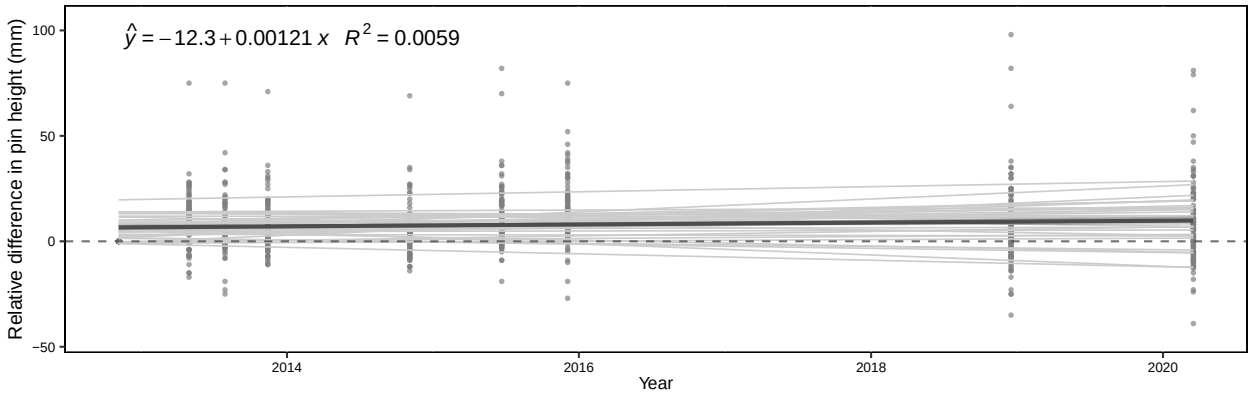
Surface elevation table (SET) data were collected between 2012-2020 at A) 3 SET stations at Harris Neck within the Harris Neck NWR. The estimated trend in change in surface elevation (mean ± SE) was 0.43 ± 0.68 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

A) Locations of SET stations showing elevation trends (mm/year).

B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



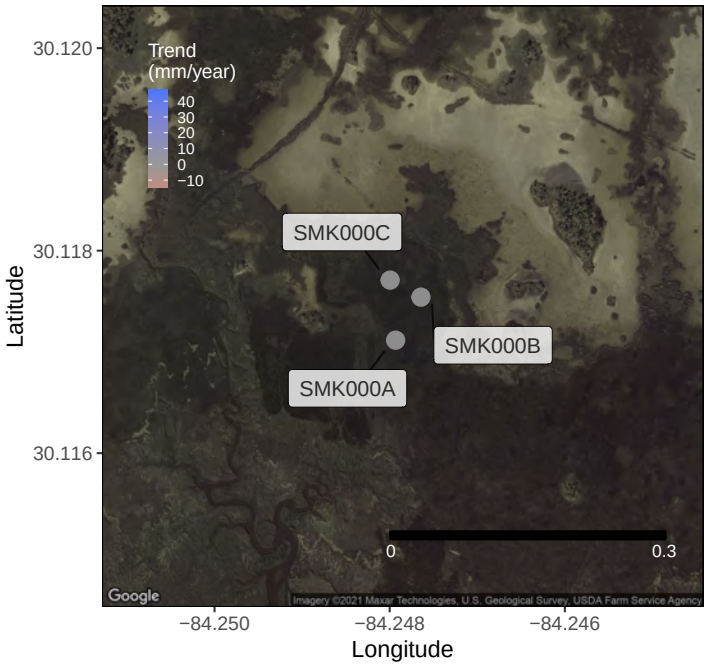
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Harris Neck site within Harris Neck NWR.



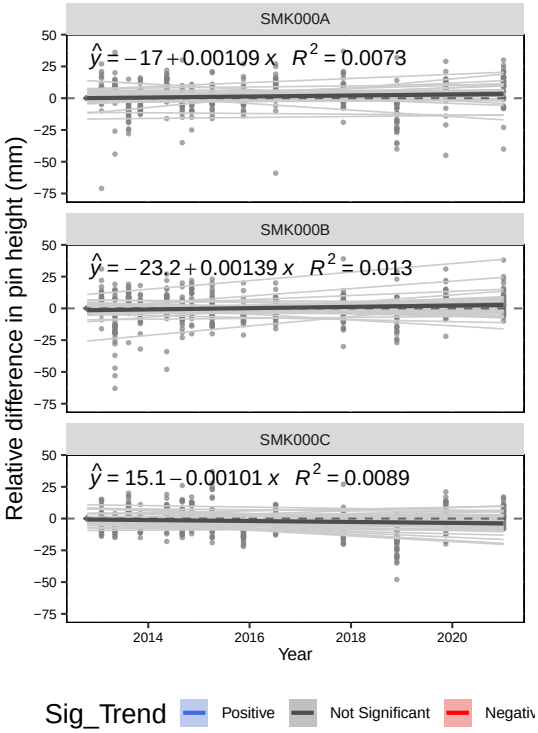
Summary of St. Marks

Surface elevation table (SET) data were collected between 2012-2021 at A) 3 SET stations at St. Marks within the St. Marks NWR. The estimated trend in change in surface elevation (mean ± SE) was 0.27 ± 0.26 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

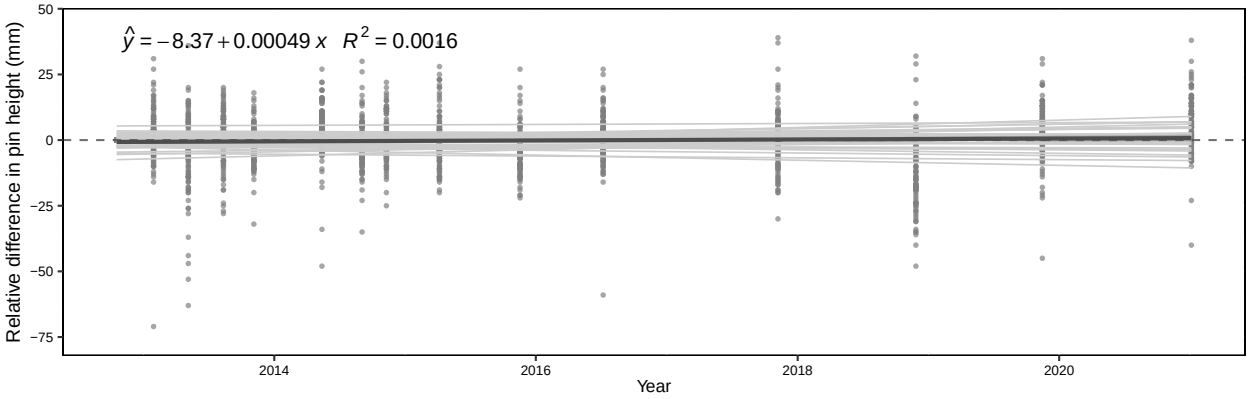
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



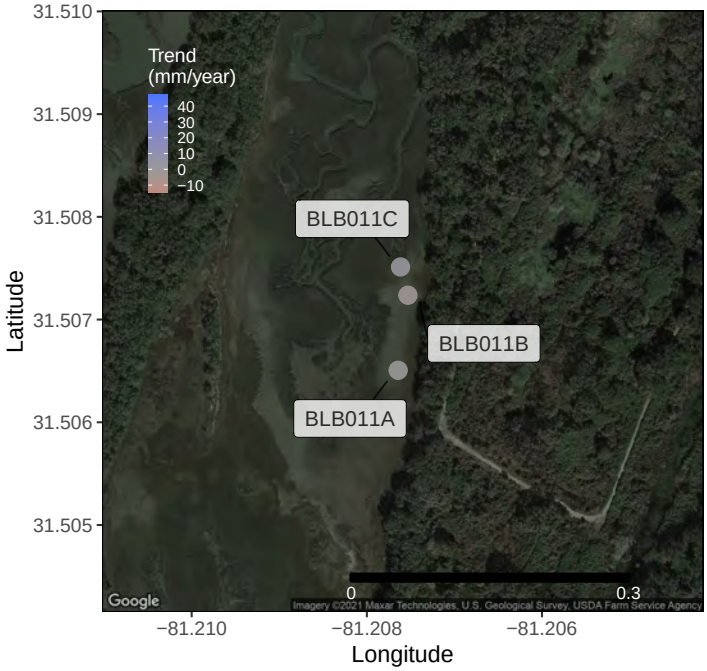
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at St. Marks site within St. Marks NWR.



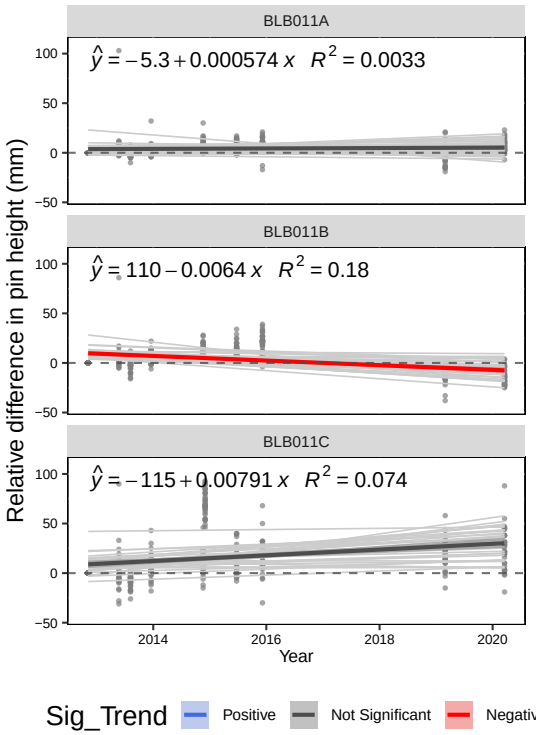
Summary of Blackbeard Island

Surface elevation table (SET) data were collected between 2012-2020 at A) 3 SET stations at Blackbeard Island within the Blackbeard Island NWR. The estimated trend in change in surface elevation (mean ± SE) was 0.08 ± 1.34 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

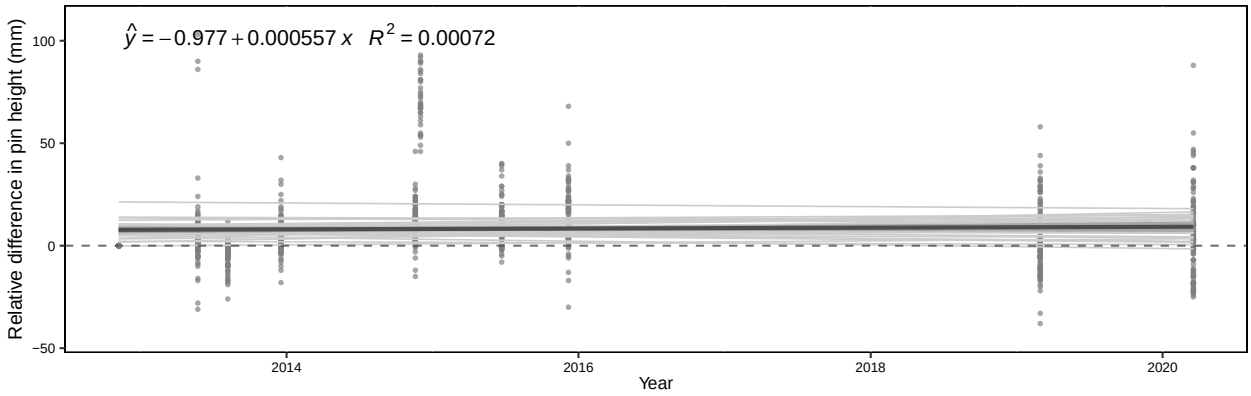
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



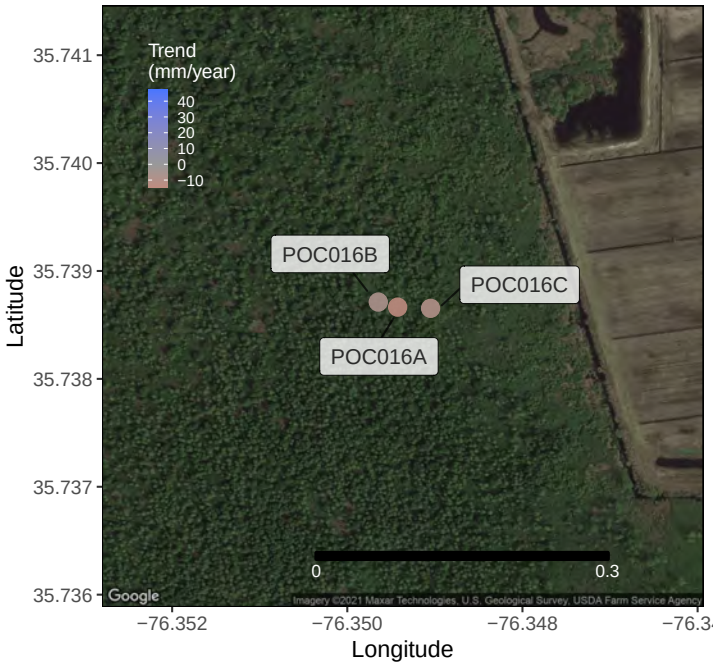
C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Blackbeard Island site within Blackbeard Island NWR.



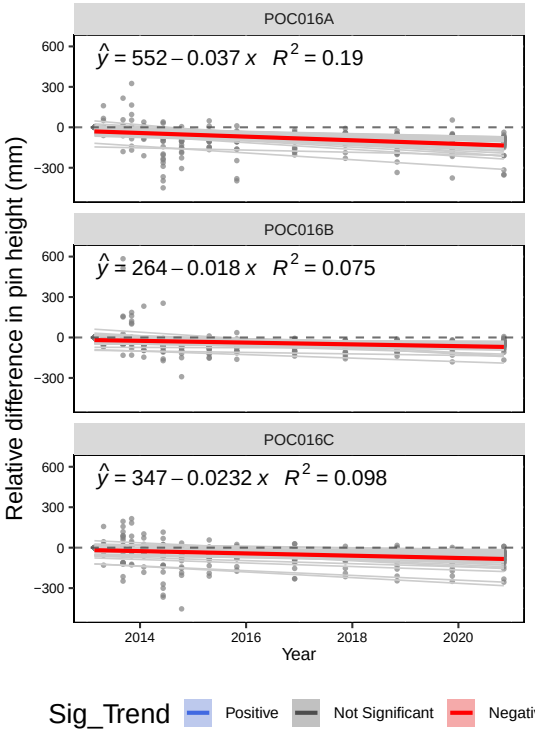
Summary of Pocosin Lakes

Surface elevation table (SET) data were collected between 2013-2020 at A) 3 SET stations at Pocosin Lakes within the Pocosin Lakes NWR. The estimated trend in change in surface elevation (mean ± SE) was -10.2 ± 2.18 mm/year. Slope equations for pin-level linear regression models represent mean trends (mm/year) and are shown below for B) individual stations and C) at the site level.

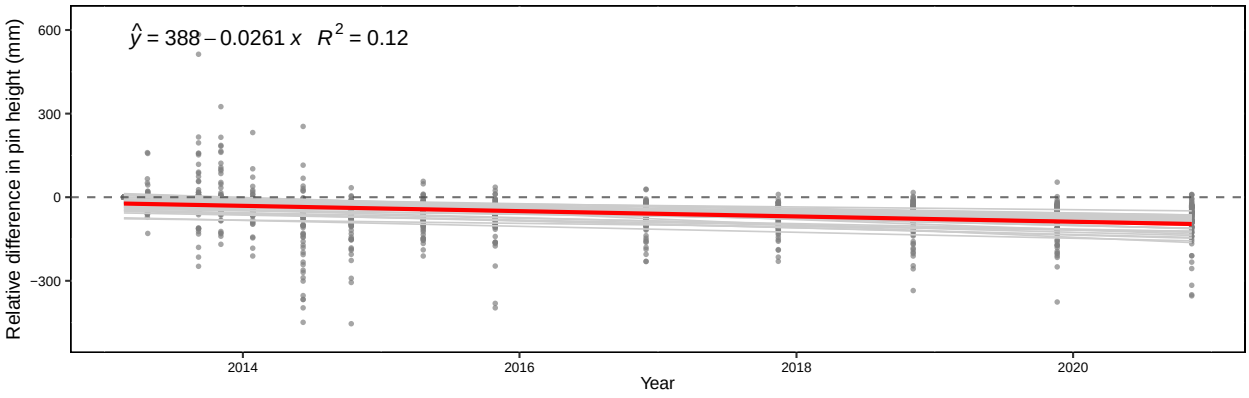
A) Locations of SET stations showing elevation trends (mm/year).



B) Pin−level linear regression of change in elevation by sampling date (mm/year) among SET stations.



C) Pin−level slopes (light gray lines) and linear model trend (mean ± SE; shown in color, if significant) of relative change in wetland elevation mm/year at Pocosin Lakes site within Pocosin Lakes NWR.



Sea-level Rise and SET trend (adjusted comparison)

Figure 8. NOAA sea-level trend estimates (mm/yr) among SET sites. NOAA station IDs are shown in white.

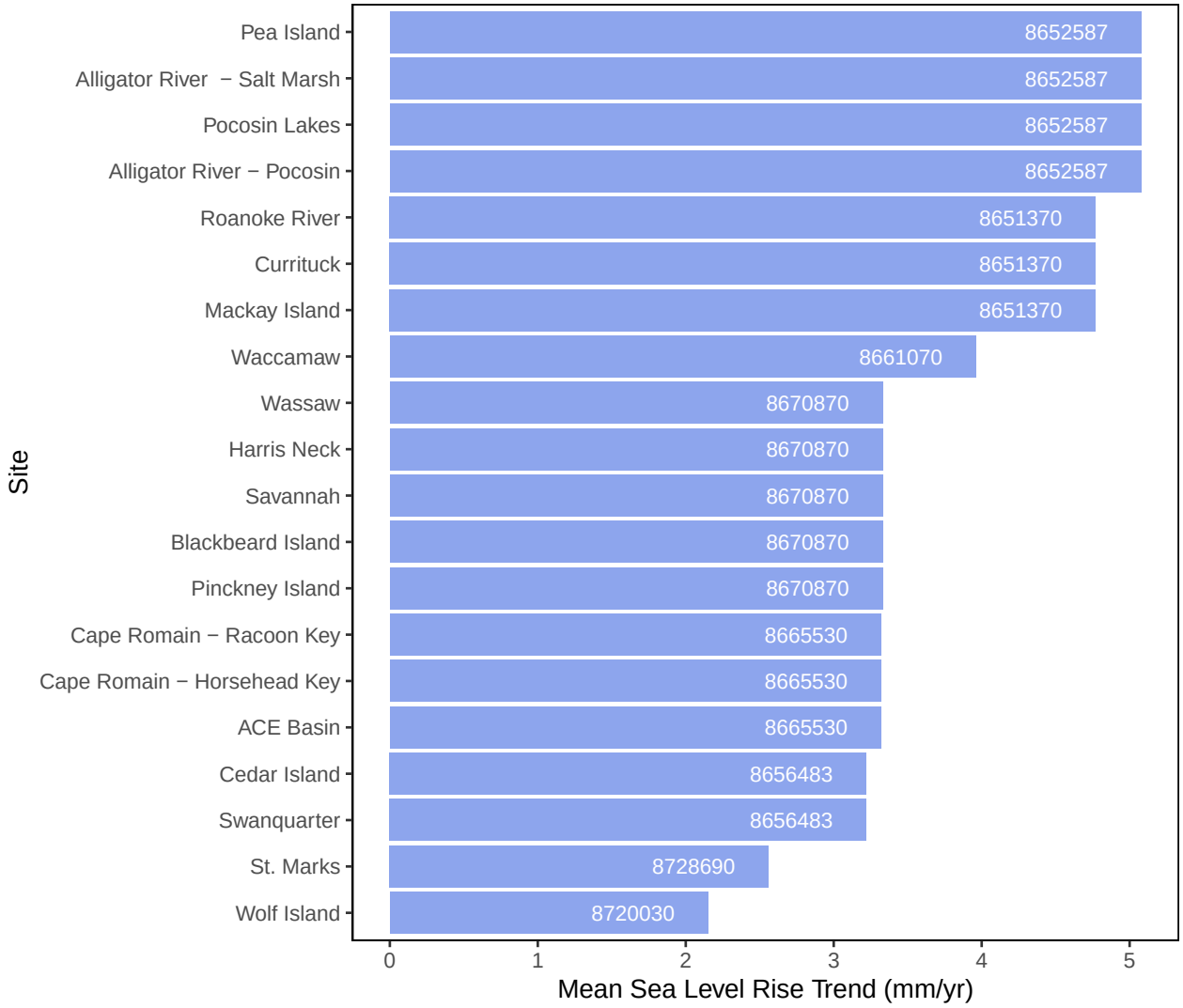


Figure 9. Plot of benchmark-adjusted surface elevation (m) in comparison with NOAA sea-level estimates (m).

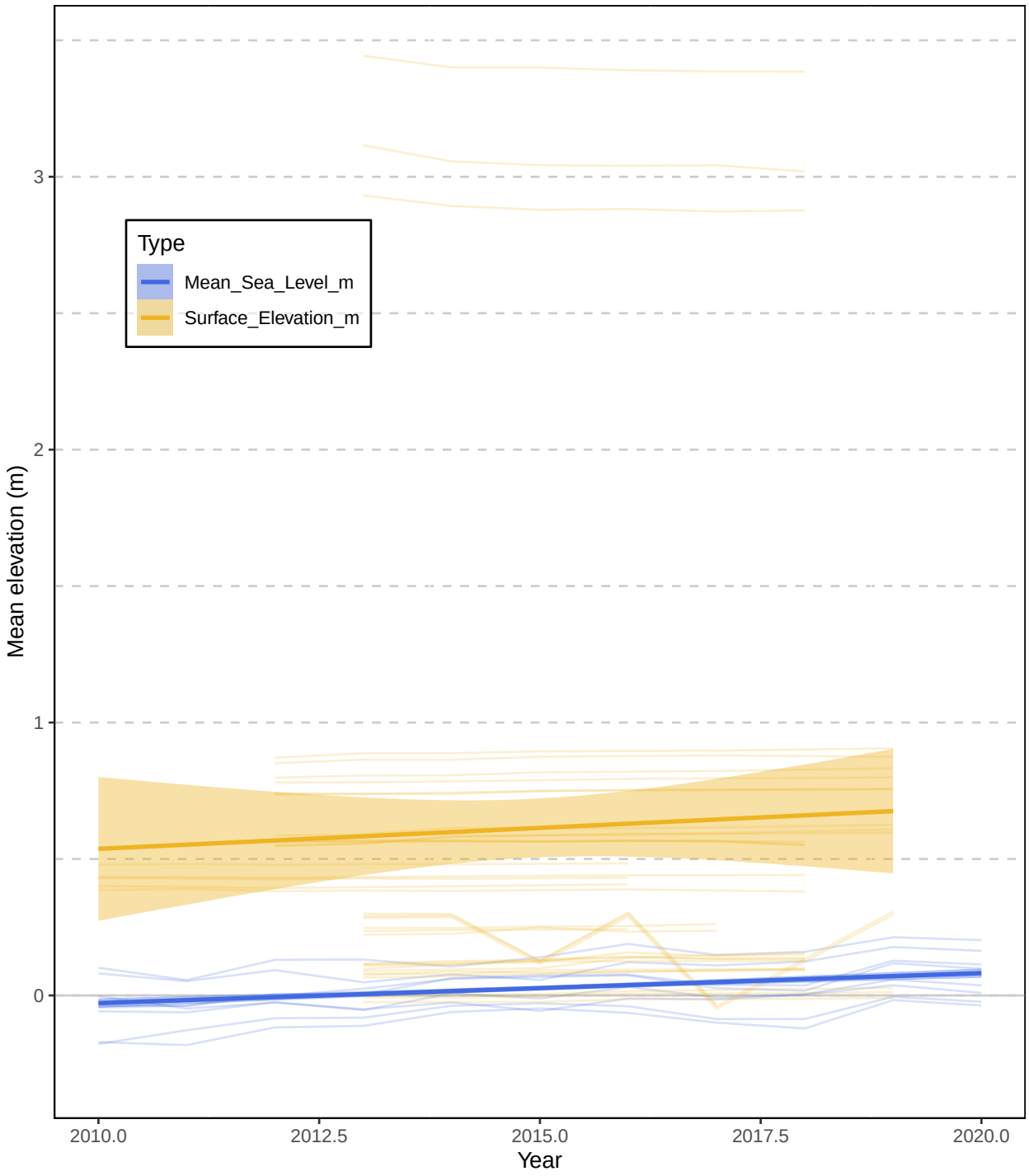


Figure 10. Plot of refuge-level benchmark-adjusted surface elevation (m) in comparison with NOAA sea-level estimates (m)*.

*Note Mackay Island missing SLR NOAA station (Station.ID = 8638660) data between 2010 and 2020.

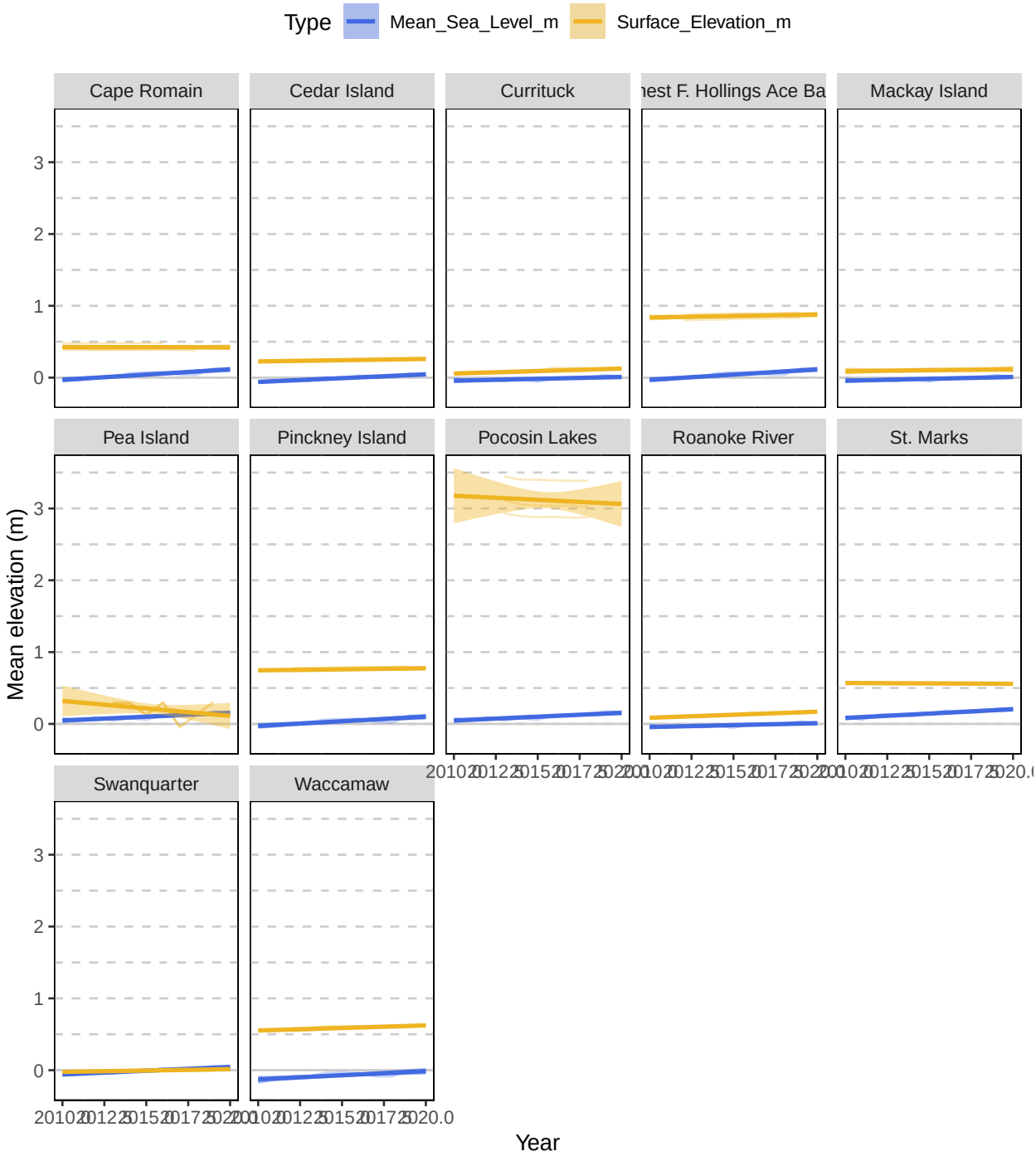
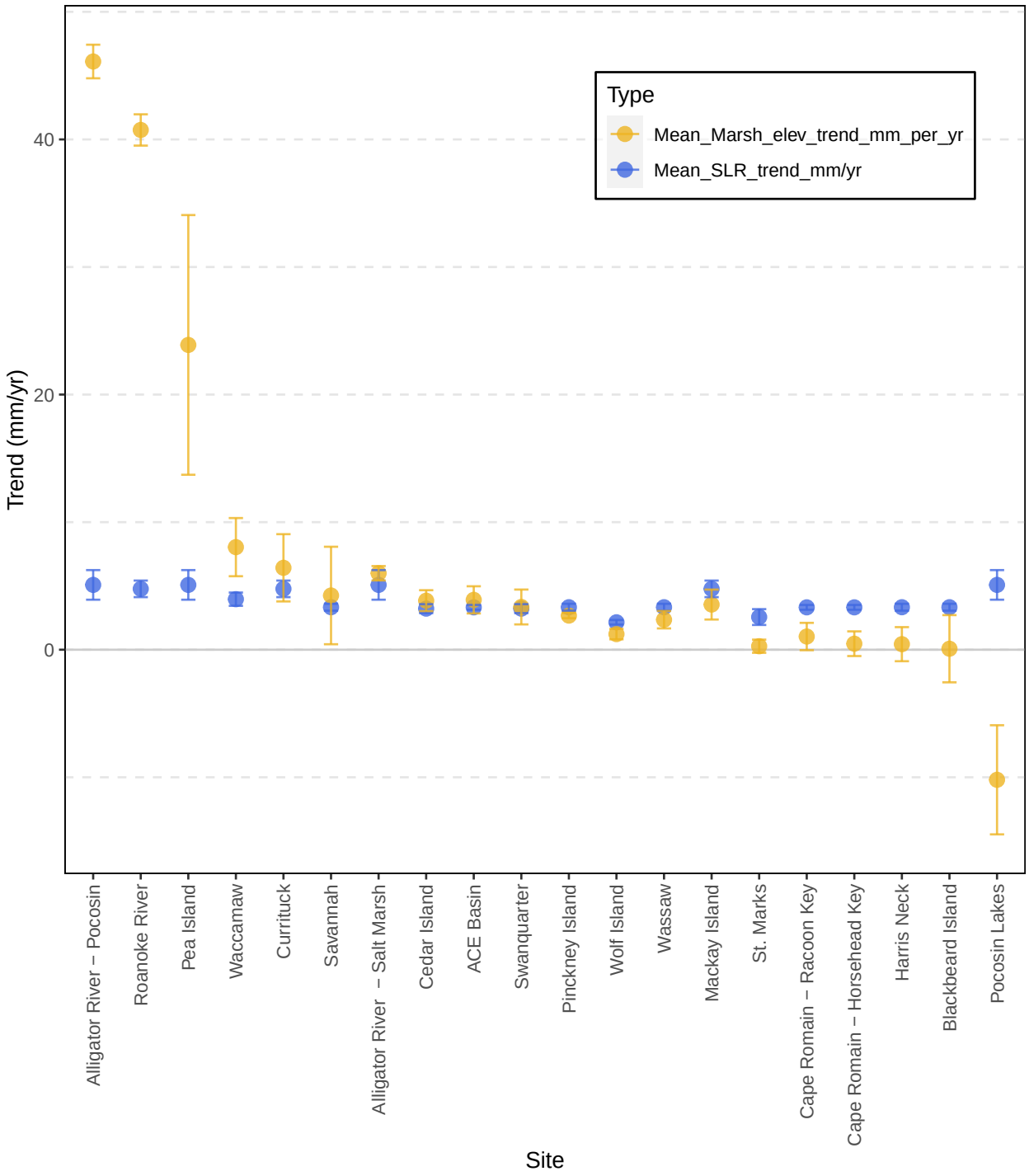


Figure 11. Comparison of mean and 95% CI trends (mm/year) in surface elevation table (yellow) and NOAA sea-level rise (blue).



Marker Horizon (MH) Analysis

Table 4. Summary of marker horizon data from 11 sites among National Wildlife Refuges

Site	State	NWR	Marker Horizons (N)	Core Samples (N)	Num. Years	Start Year	End Year
Mackay Island	NC	Mackay Island	3	9	2	2013	2014
Roanoke River	NC	Roanoke River	3	12	5	2013	2017
Alligator River - Pocosin	NC	Alligator River	3	18	6	2013	2018
Pocosin Lakes	NC	Pocosin Lakes	3	17	5	2013	2017
Pea Island	NC	Pea Island	3	18	7	2013	2019
Alligator River - Salt Marsh	NC	Alligator River	3	18	7	2013	2019
Swanquarter	NC	Swanquarter	2	5	3	2016	2018
Cedar Island	NC	Cedar Island	3	10	3	2013	2015
Waccamaw	SC	Waccamaw	3	9	3	2012	2014
ACE Basin	SC	Ernest F. Hollings Ace Basin	3	9	6	2012	2017
Pinckney Island	SC	Pinckney Island	3	5	2	2012	2013
Wassaw	GA	Wassaw	2	5	2	2012	2013
Harris Neck	GA	Harris Neck	3	9	4	2012	2015
Blackbeard Island	GA	Blackbeard Island	3	4	4	2012	2015
Wolf Island	GA	Wolf Island	2	4	4	2012	2015
St. Marks	FL	St. Marks	3	18	10	2012	2021

Figure 12. Mean annual trend (mean ± SE) of marsh accretion (mm/year) from marker horizon data among 17 sites.

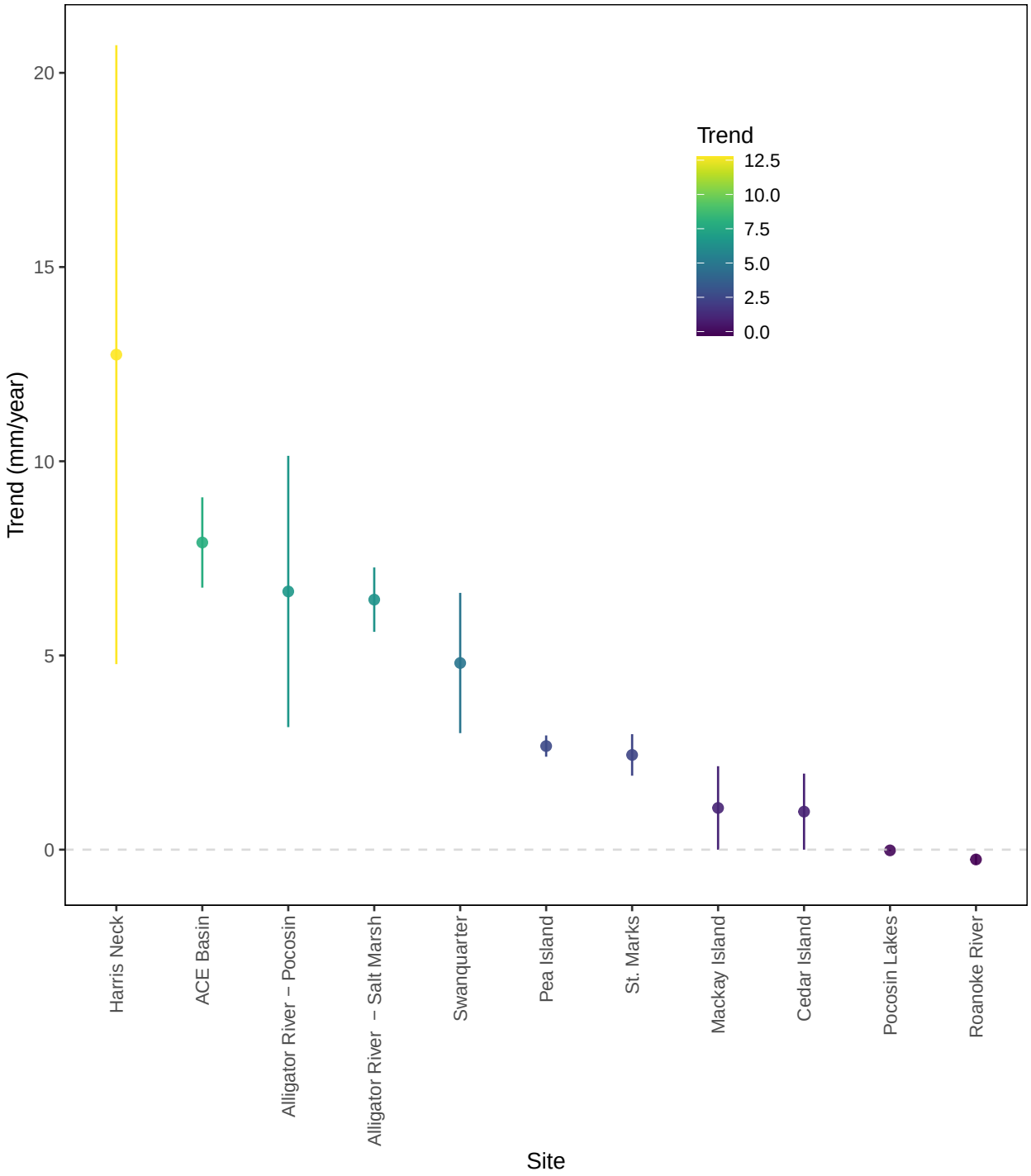
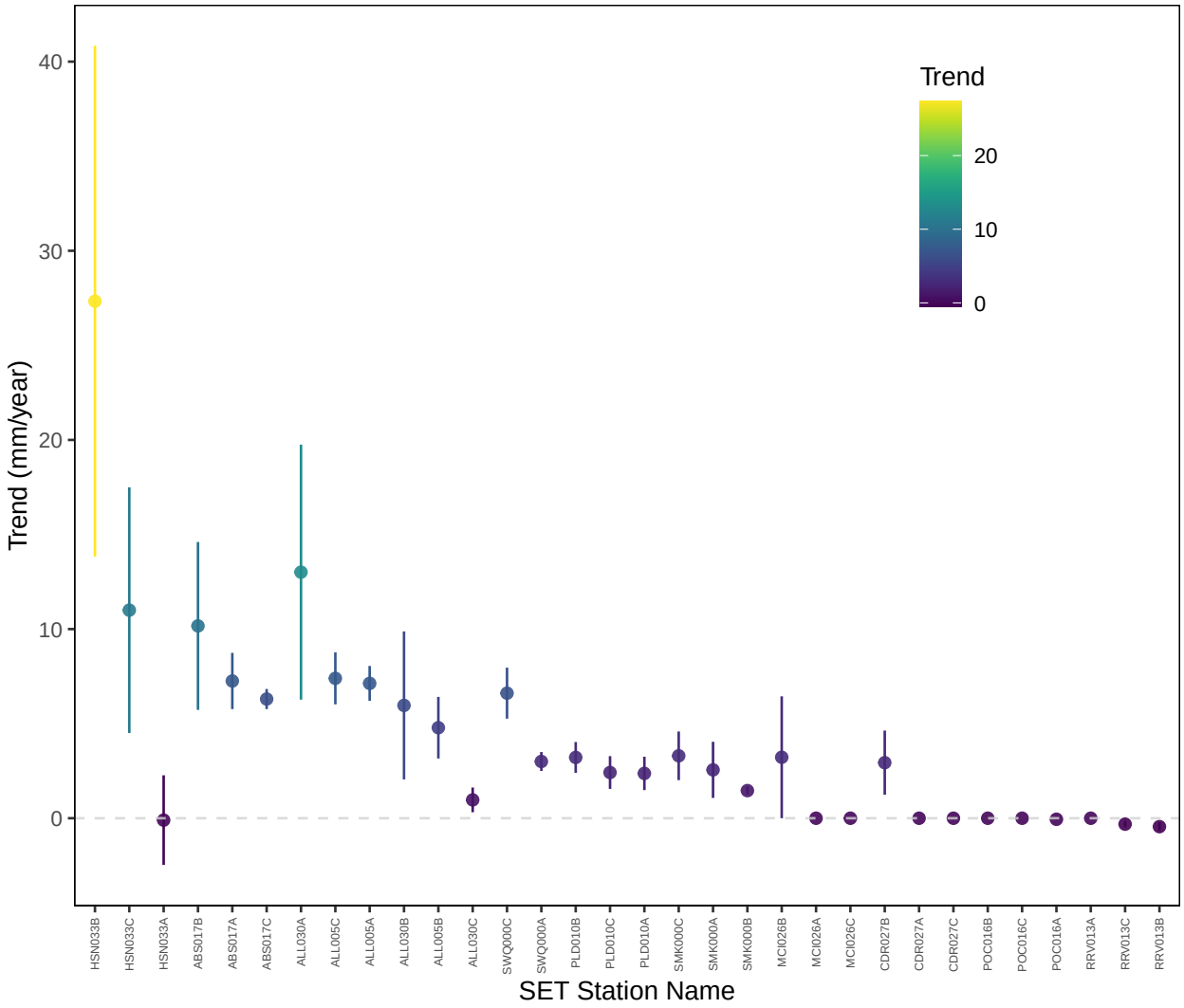


Figure 13. Mean Station-level trend (mean ± SE) in marsh accretion (mm/year) from marker horizon data.



Surface Elevation Table (SET) and Marker Horizon (MH) comparison

Figure 14. Plot of relative changes (mean ± SE) in elevation (mm) for station-level accretion (red) and SET (light blue) data for each station.

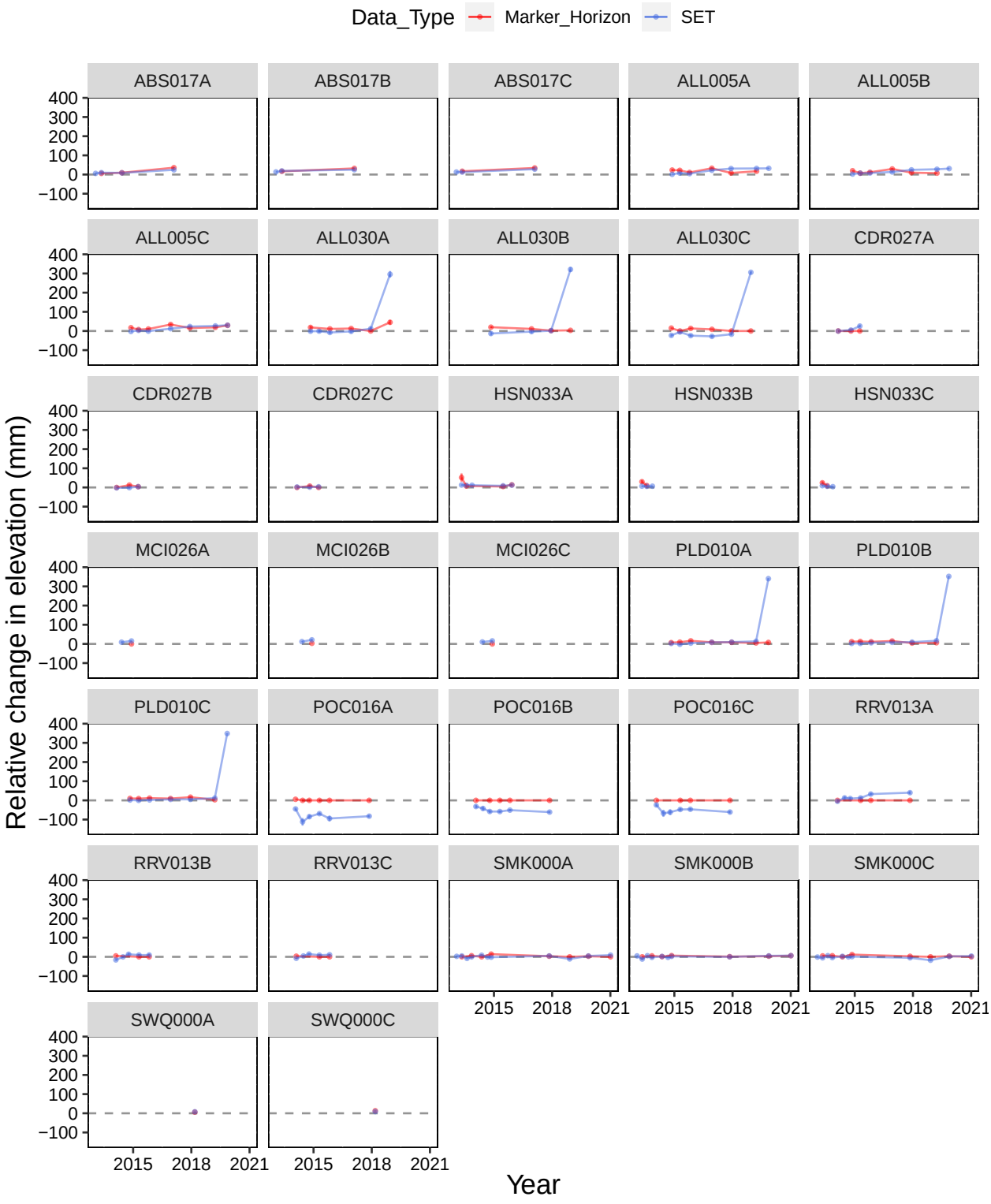
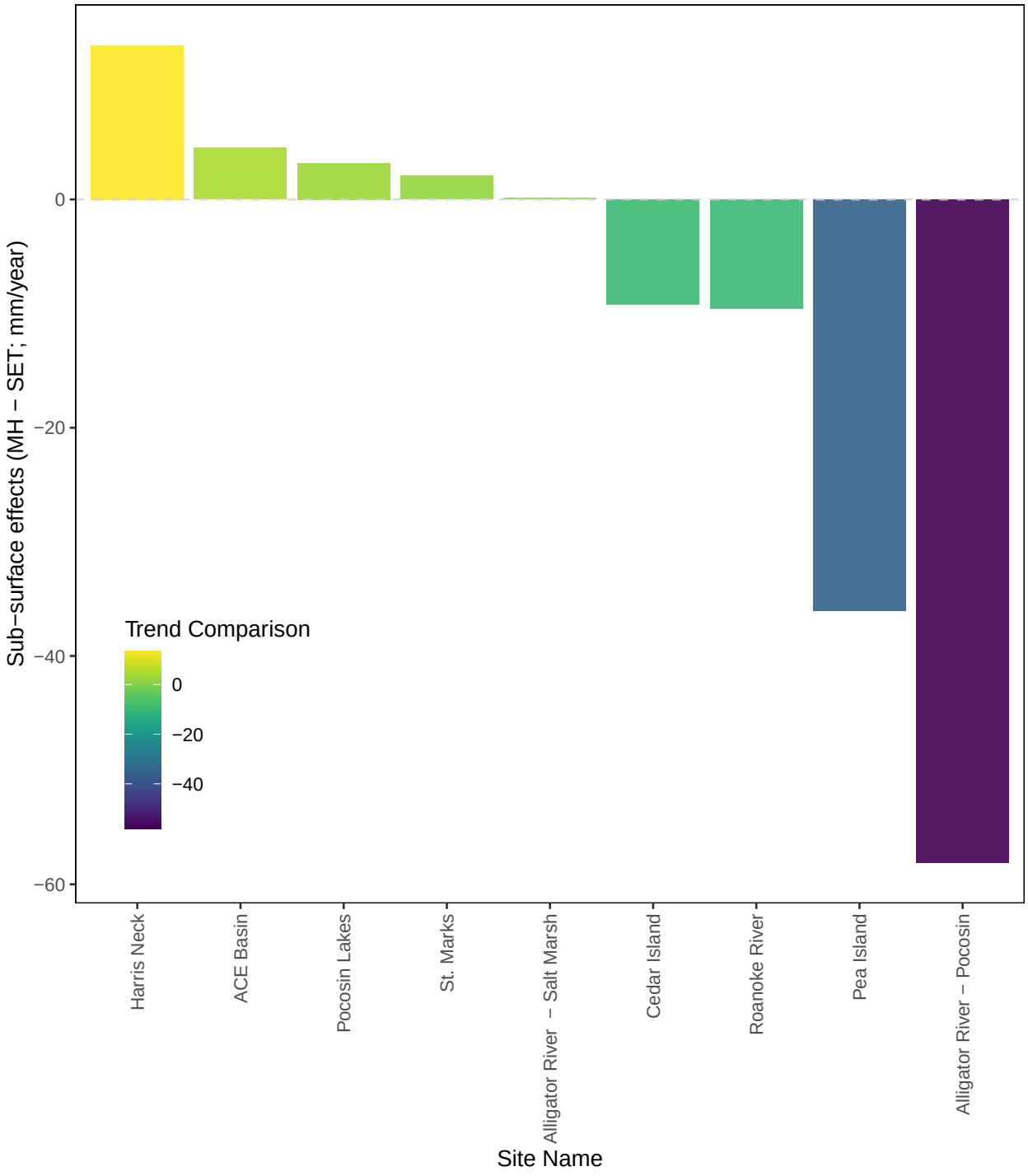


Figure 15. Plot of mean accretion rate (mm/year) - mean change in SET elevation (mm/year) to evaluate contributions of sub-surface processes to overall wetland elevation change*. *SET and MH data (trends of elevation change) can be compared to investigate the contribution of surface or subsurface processes to marsh elevation change. 3 heuristic rules include: 1) If accretion is greater than elevation: shallow subsidence (subsurface effect) 2) If accretion is equal to elevation: surface processes dominate (with no subsurface influence) 3) If accretion is less than elevation: shallow expansion (subsurface effect)



Acknowledgments

We thank the following individuals for their help in several areas, and for providing valuable feedback and input into this project and report: Brent Frakes, Erin King, Laura Mitchell, Greg Shriver, and Adam Smith. We are grateful to all the Refuge staff who have collected the surface elevation data over the past 9 years, and Nicole Rankin and Mike Chouinard.

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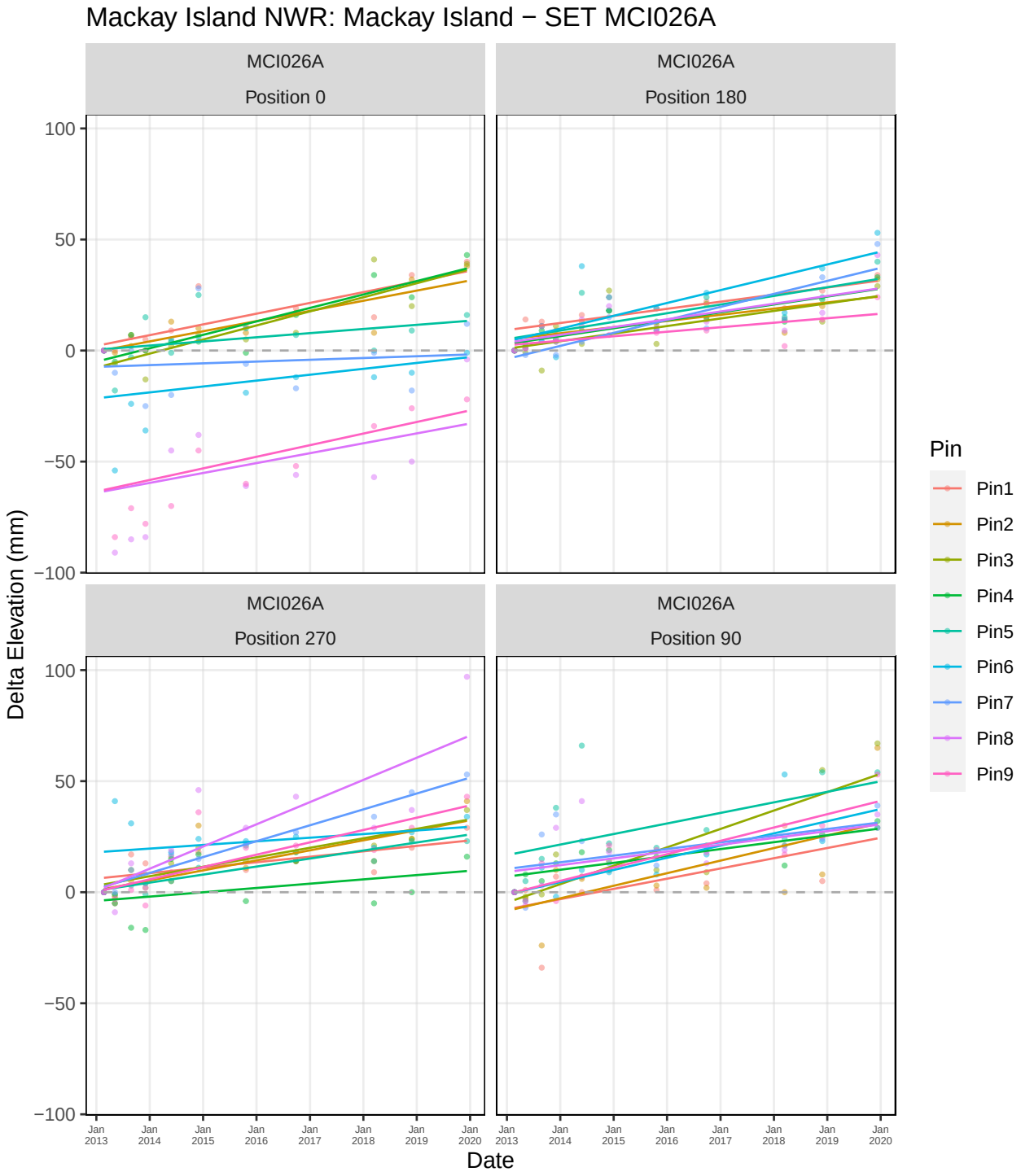
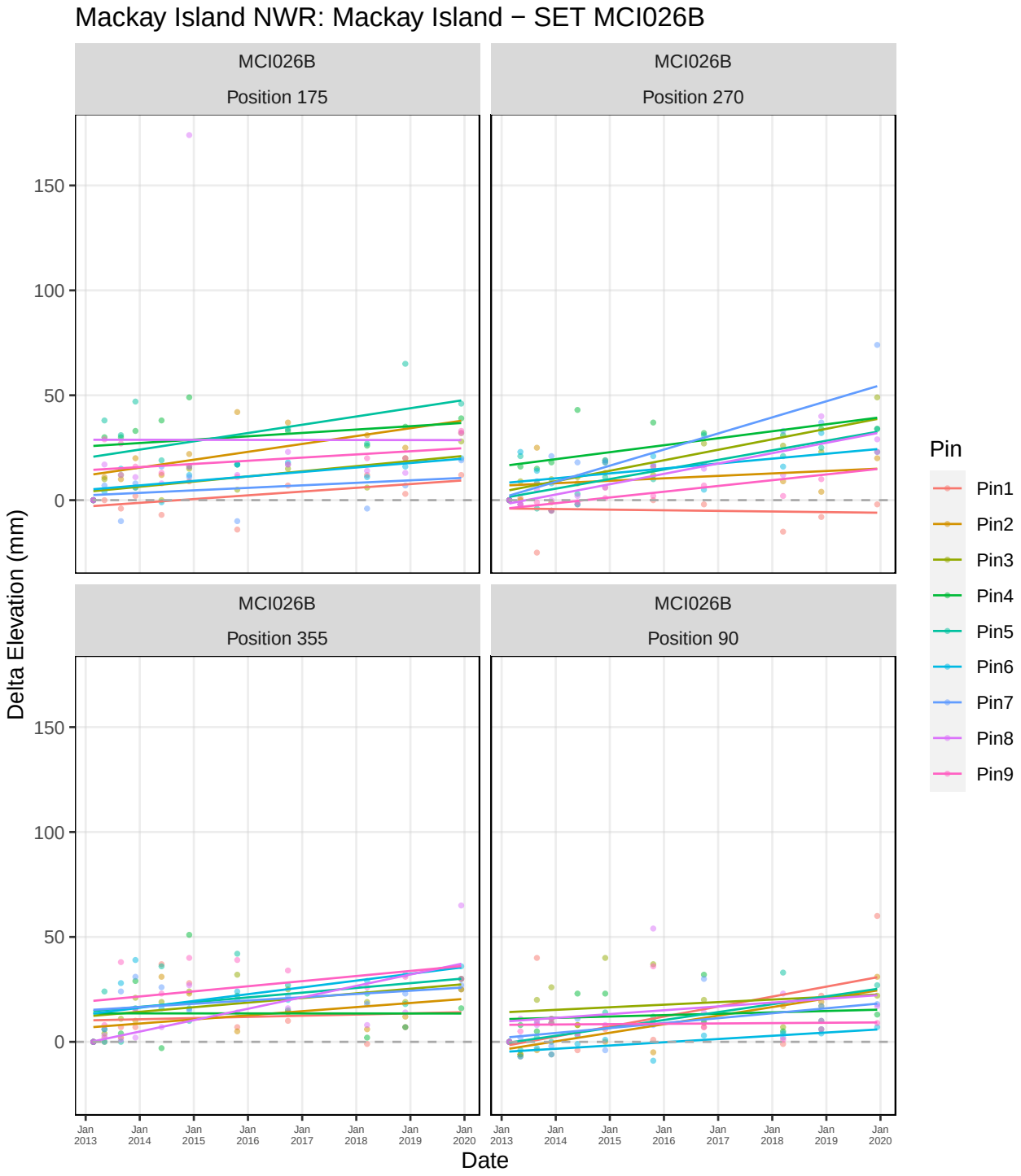
Appendix A. Pin-level regression plots at each SET station (among 4 arm positions)

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MCI026B
Position 270
MCI026B
Position 355
MCI026B
Position 90
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150
100
50
0
Jan 2013
Jan 2014
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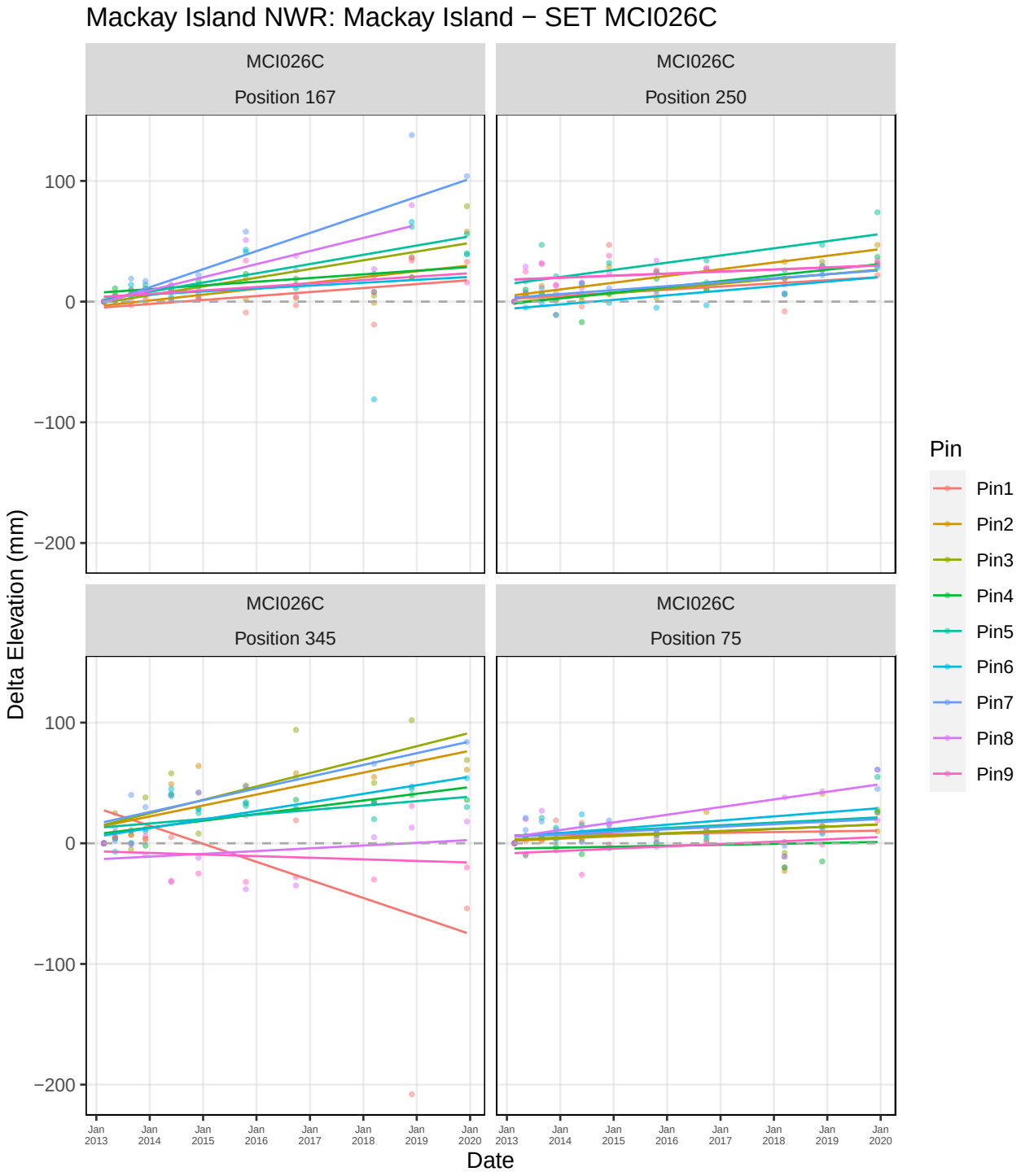
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MCI026C
Position 250
MCI026C
Position 345
MCI026C
Position 75
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0
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Jan 2013
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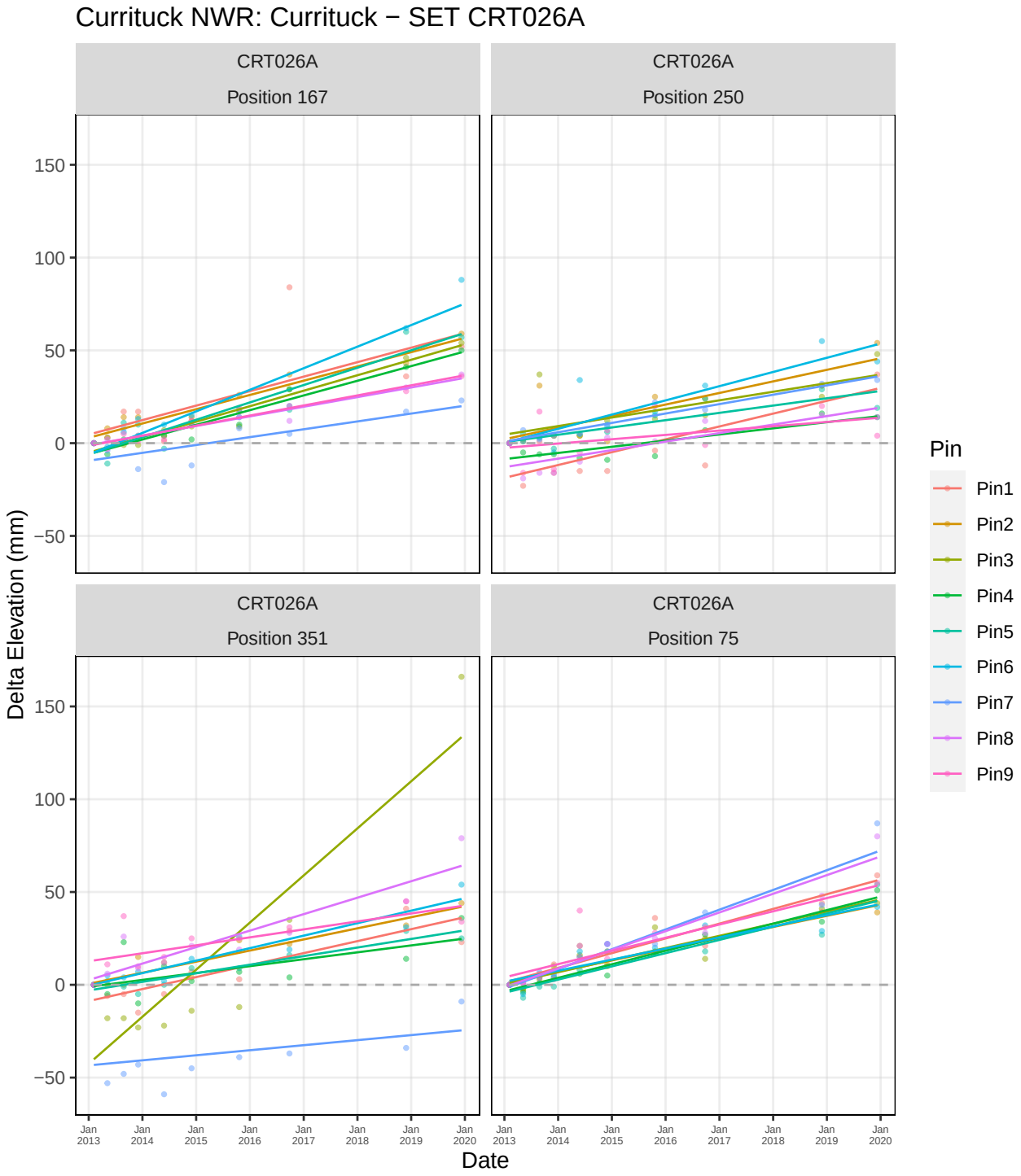
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CRT026A
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Position 75
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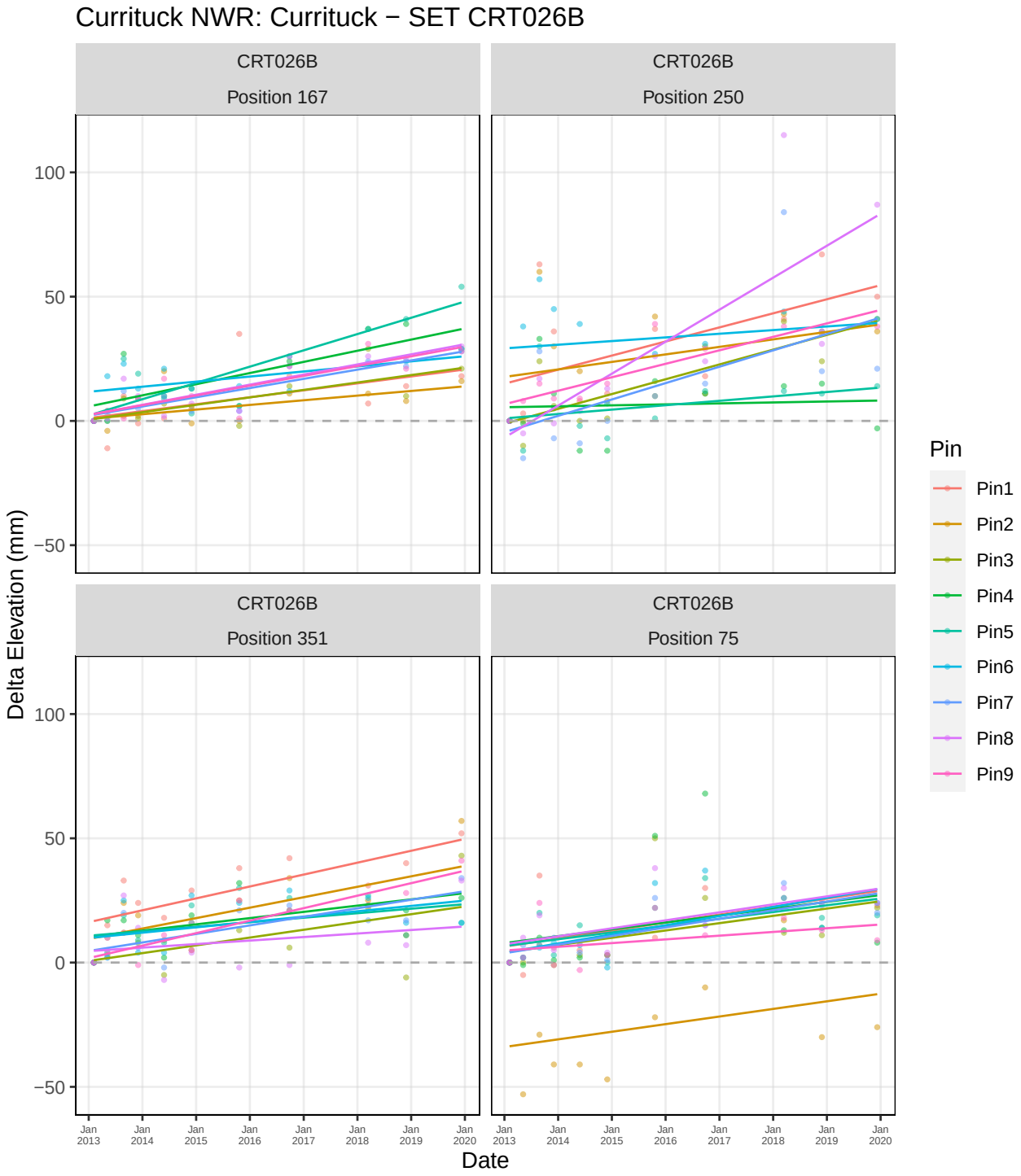
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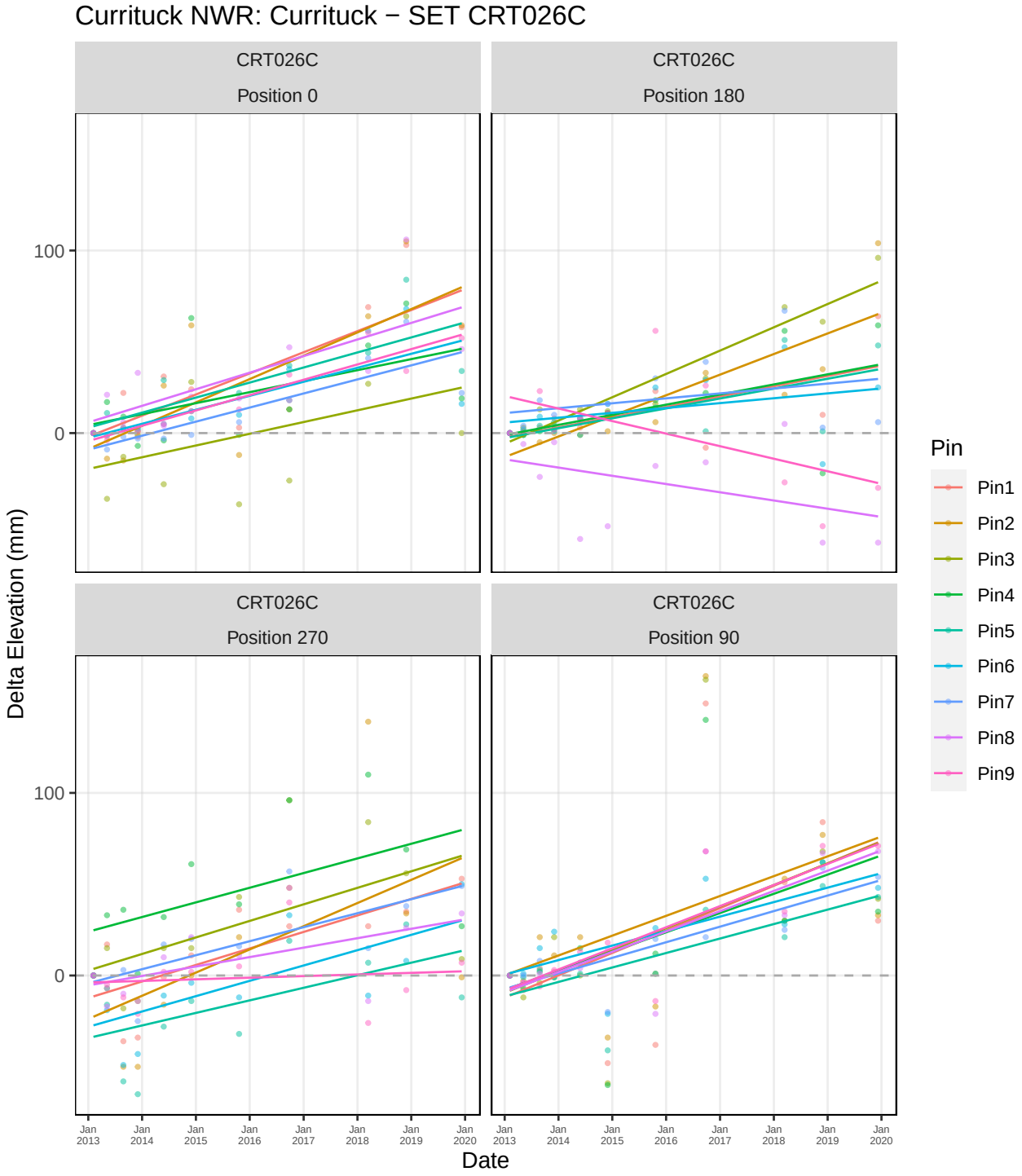
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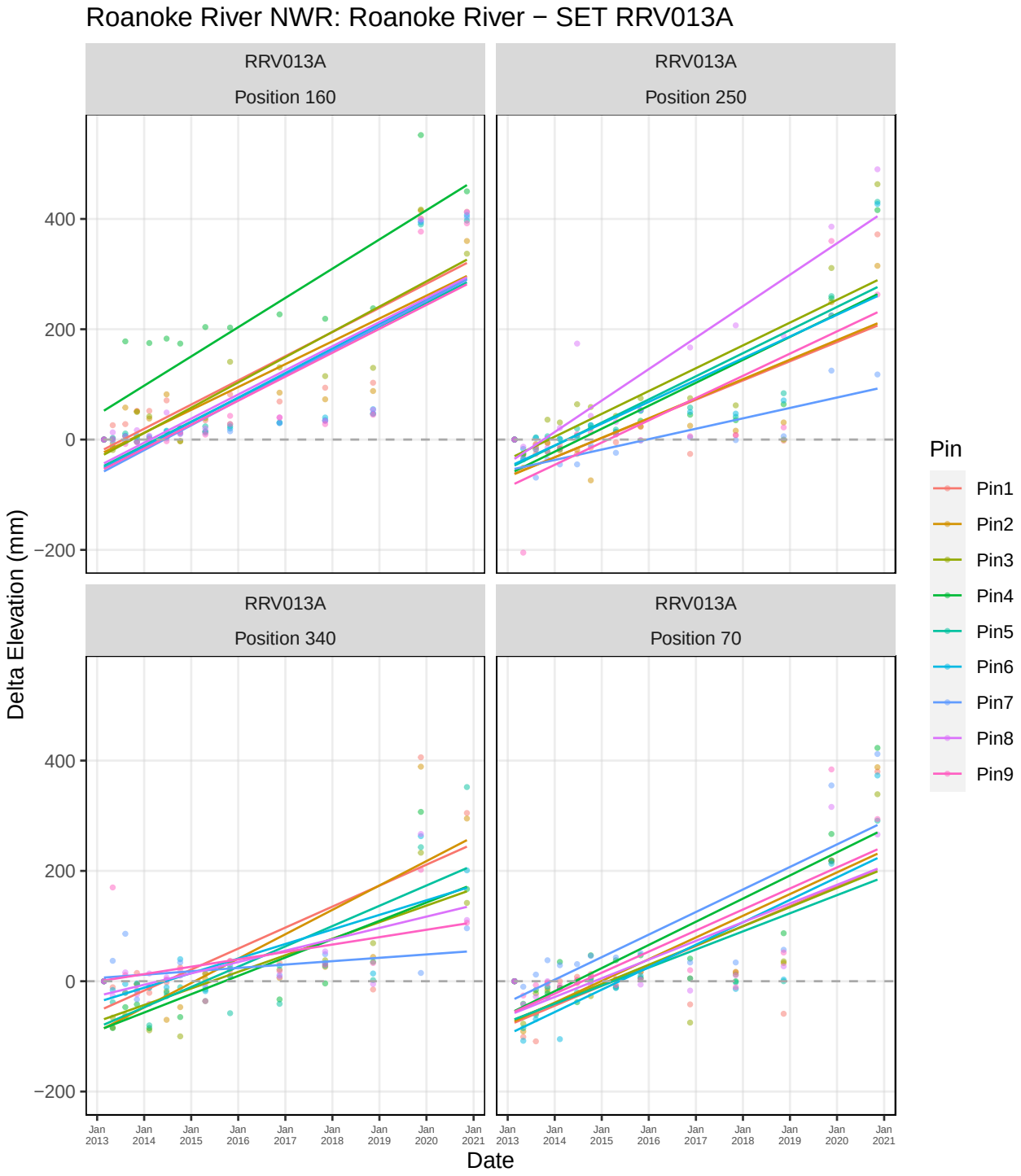
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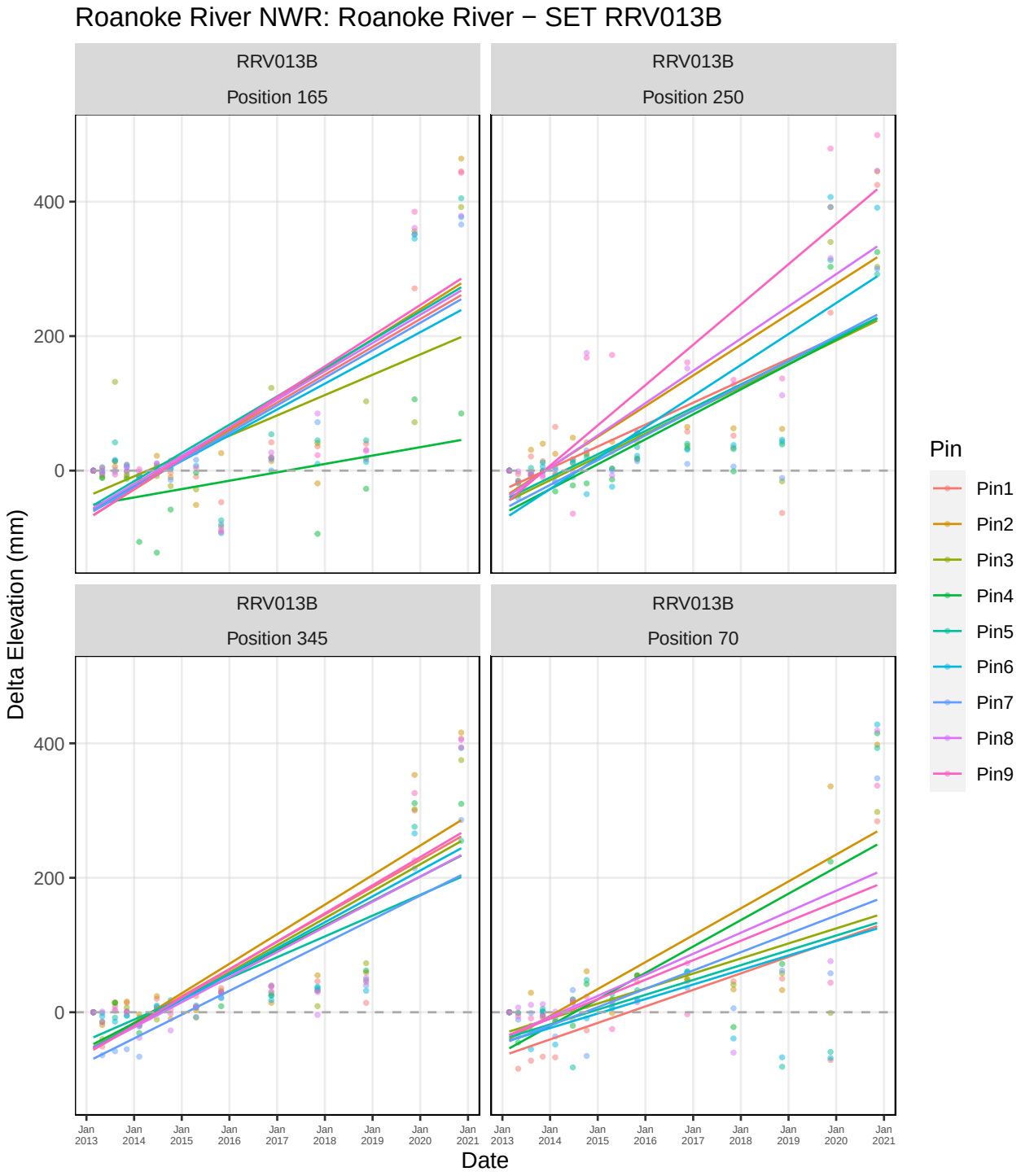
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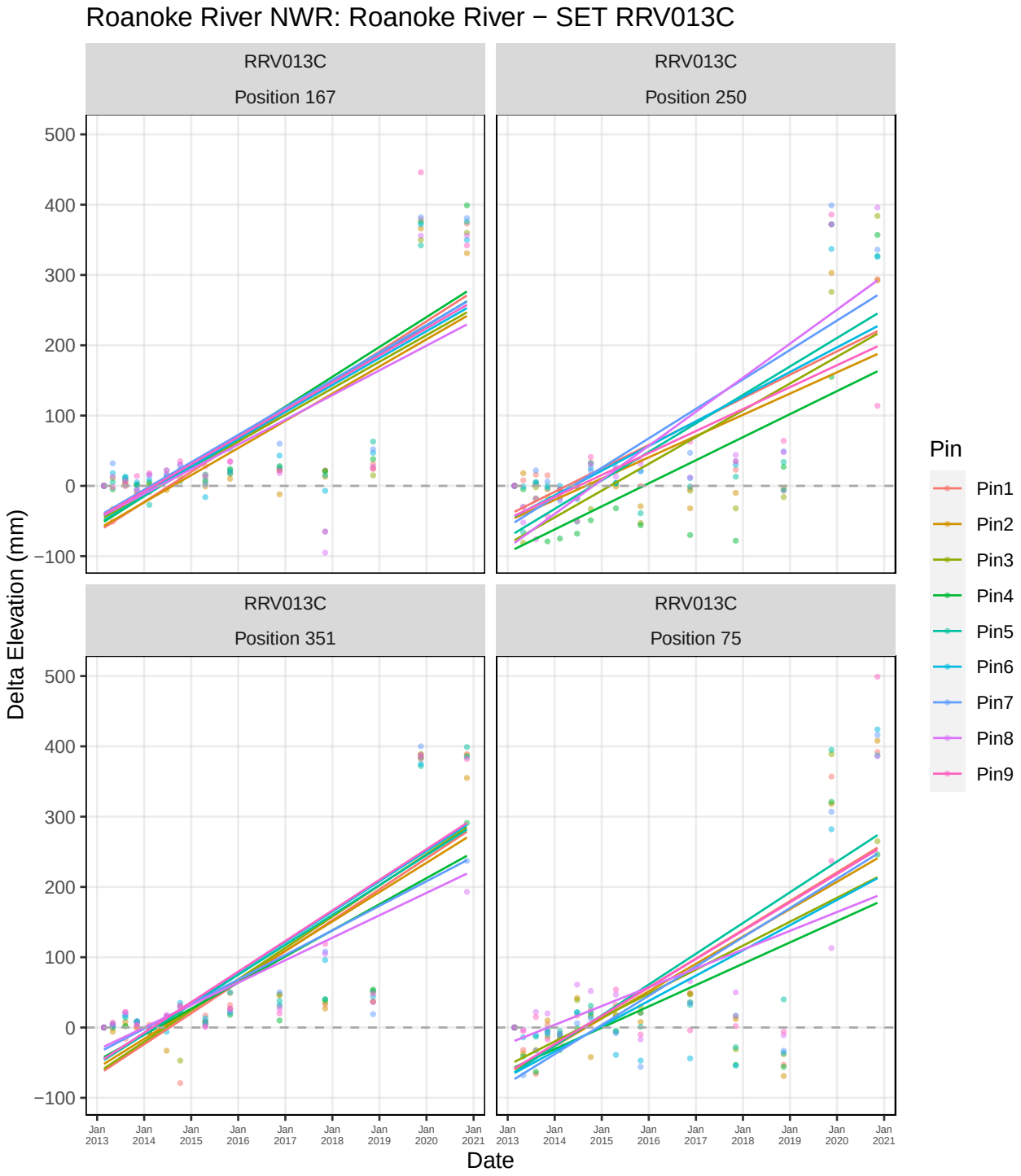
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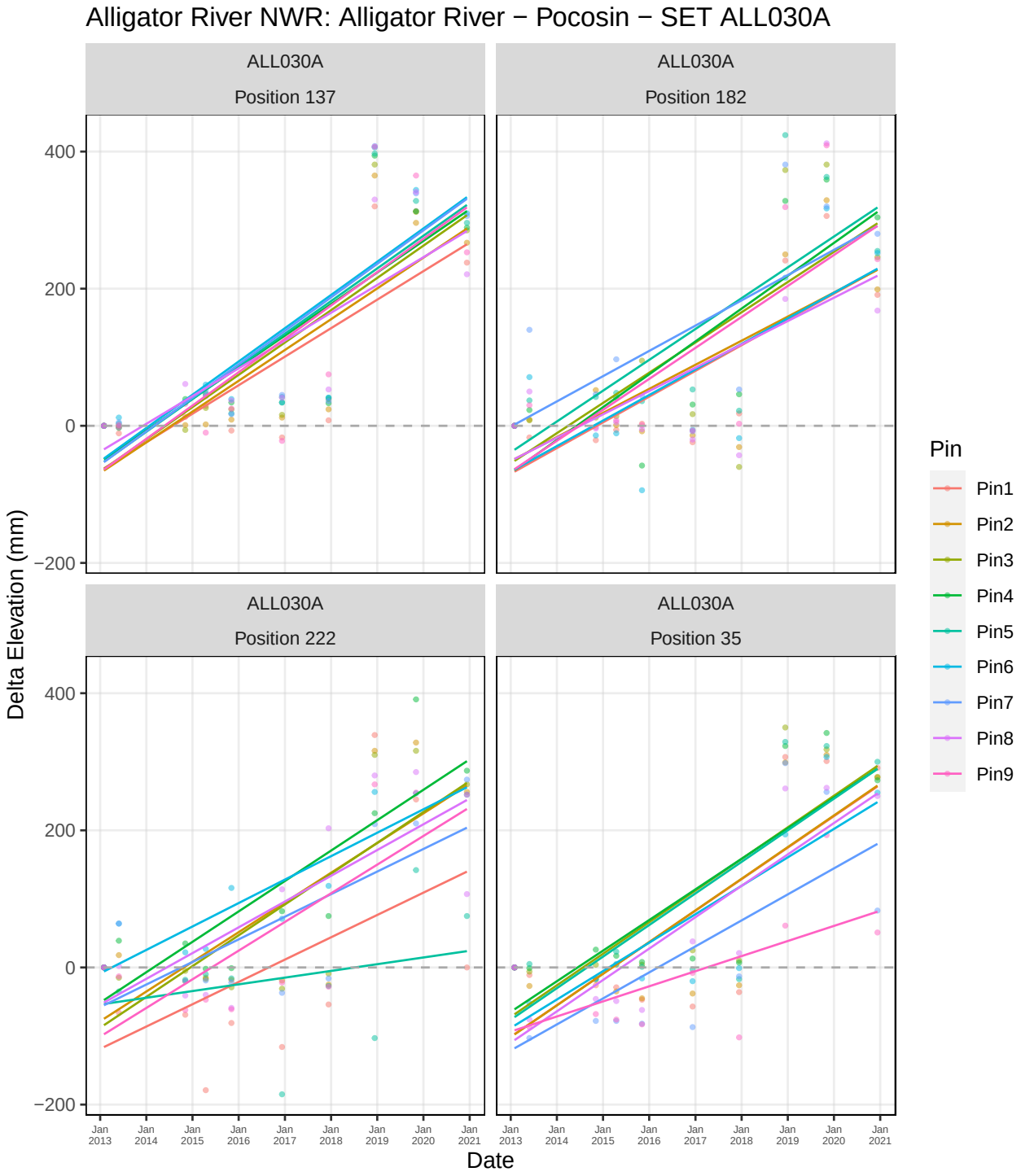
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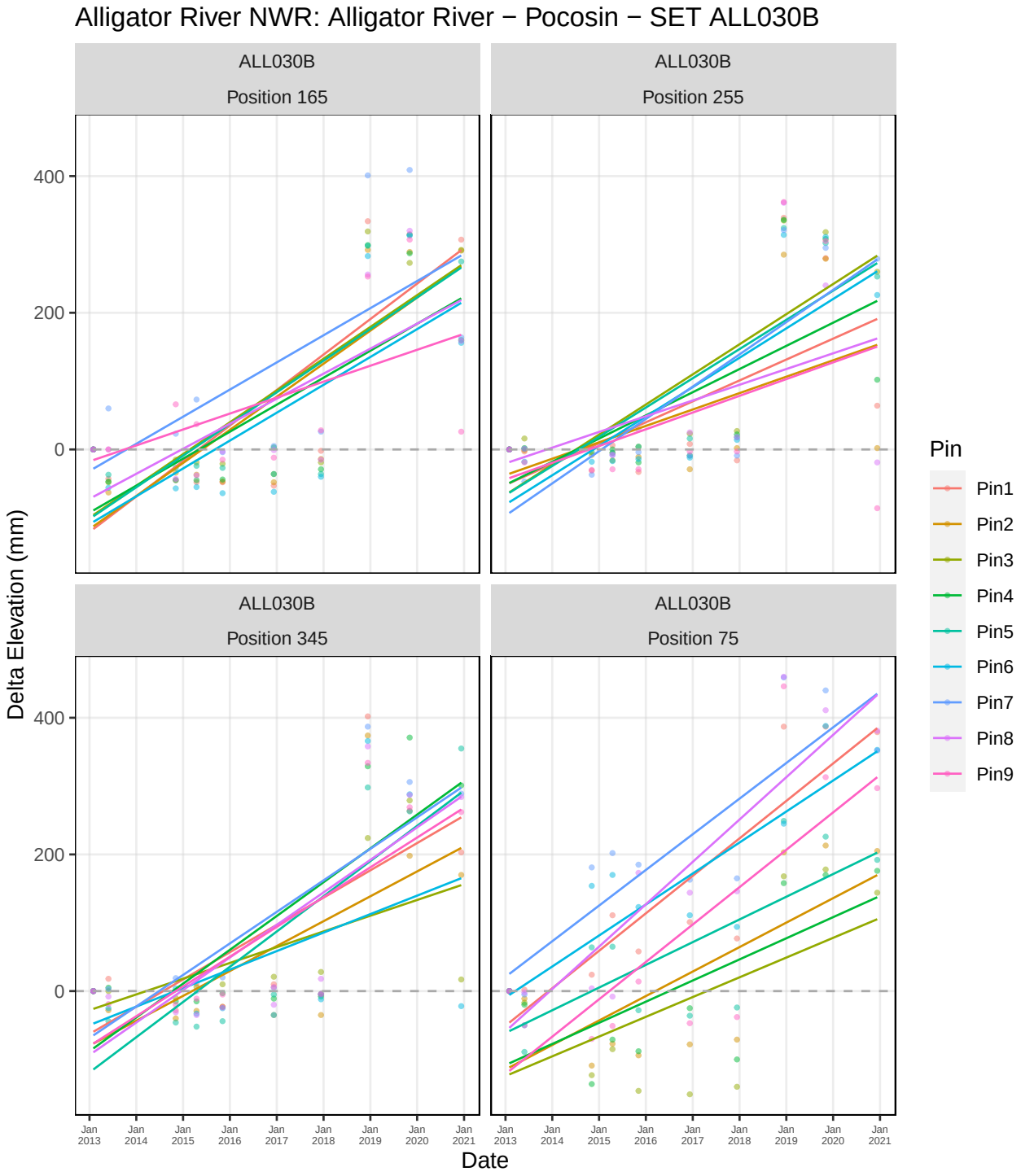
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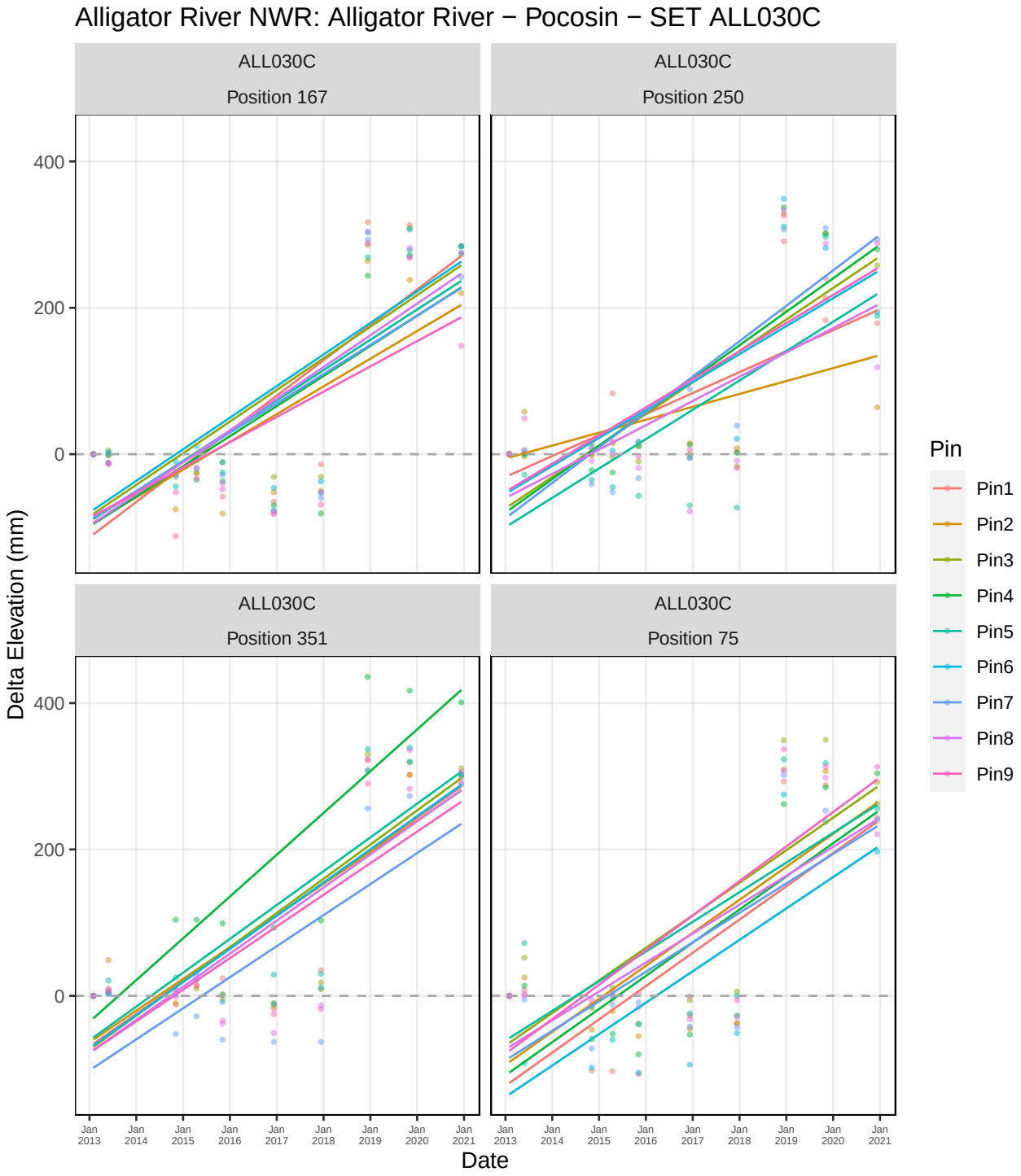
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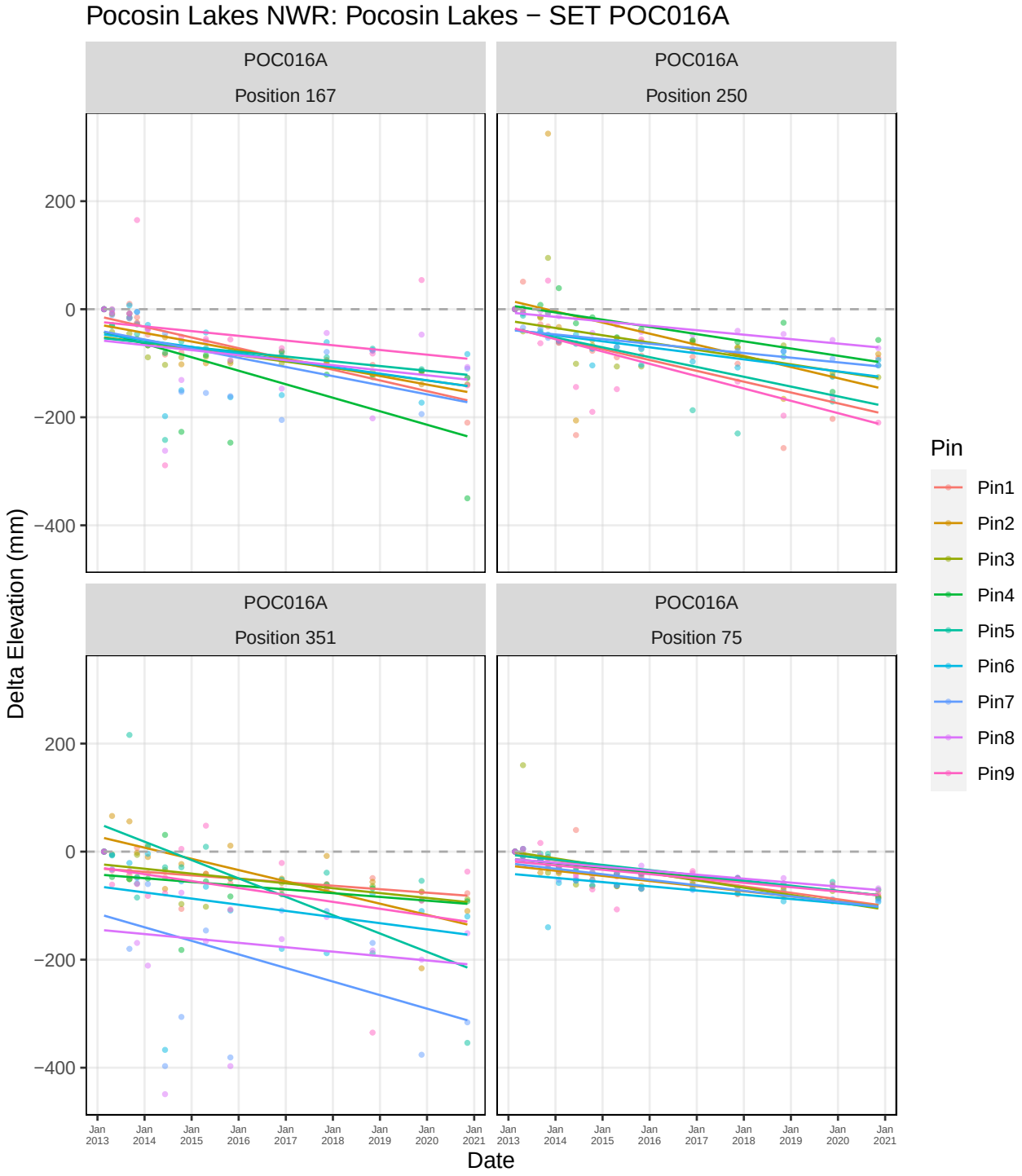
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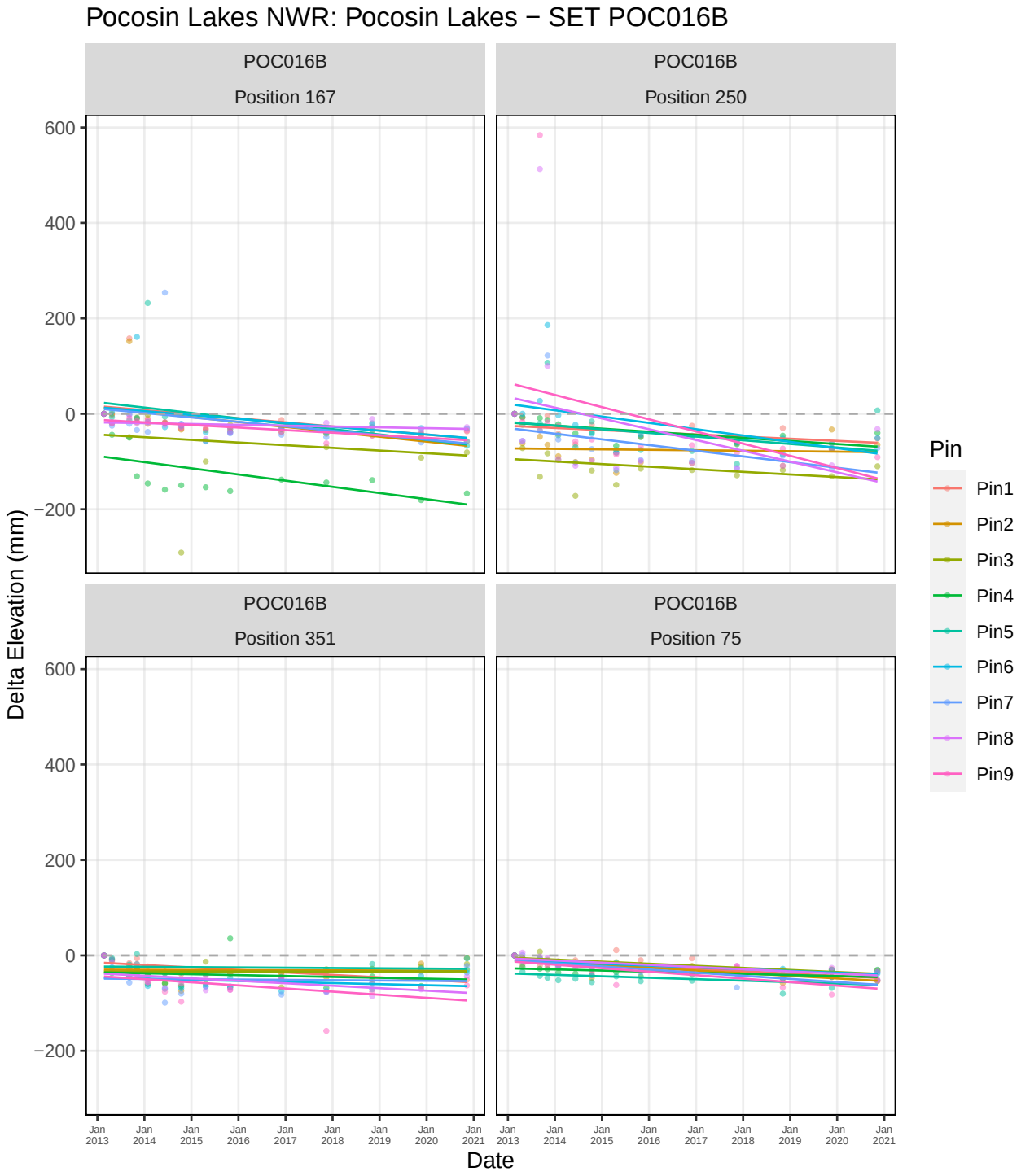
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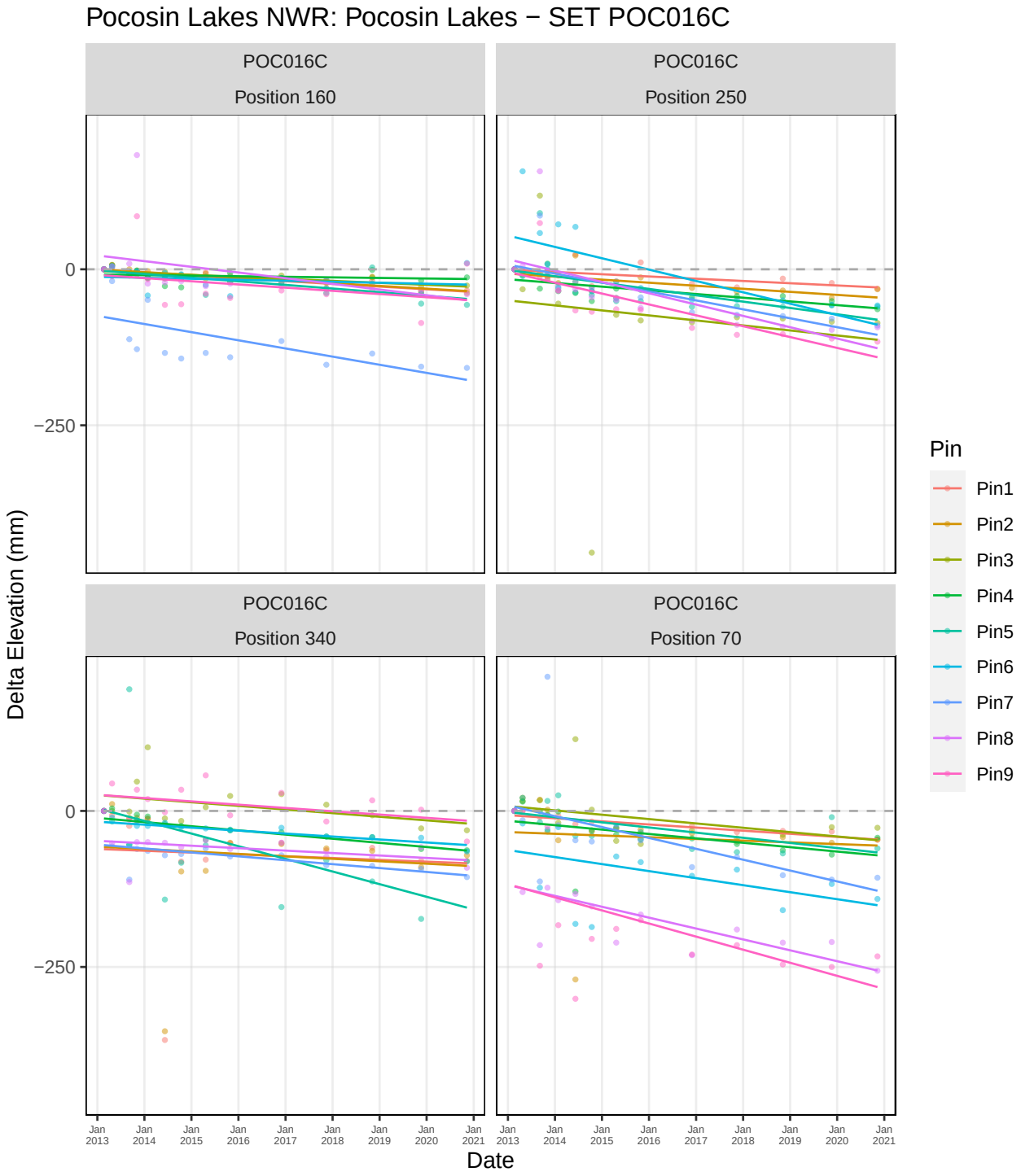
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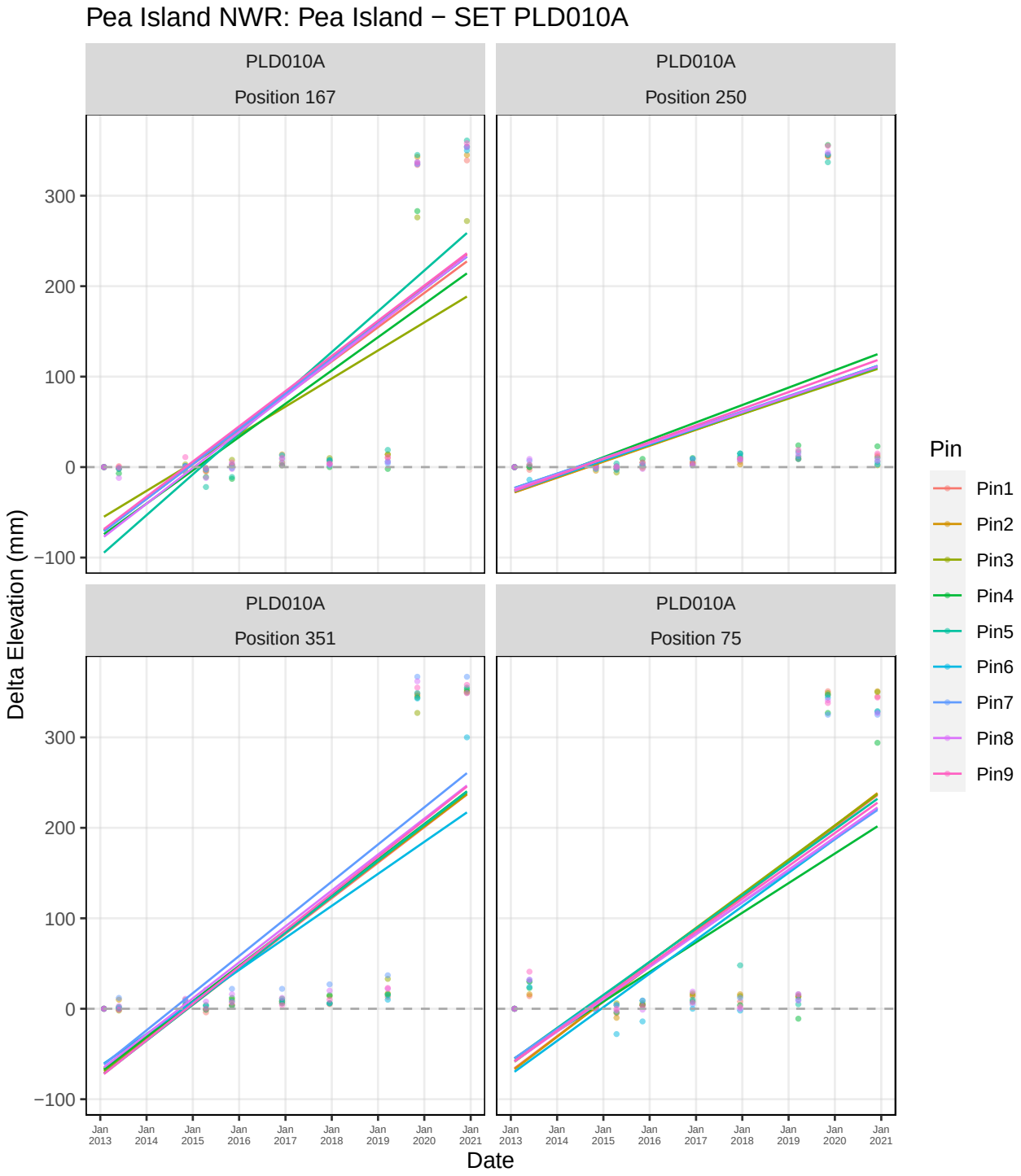
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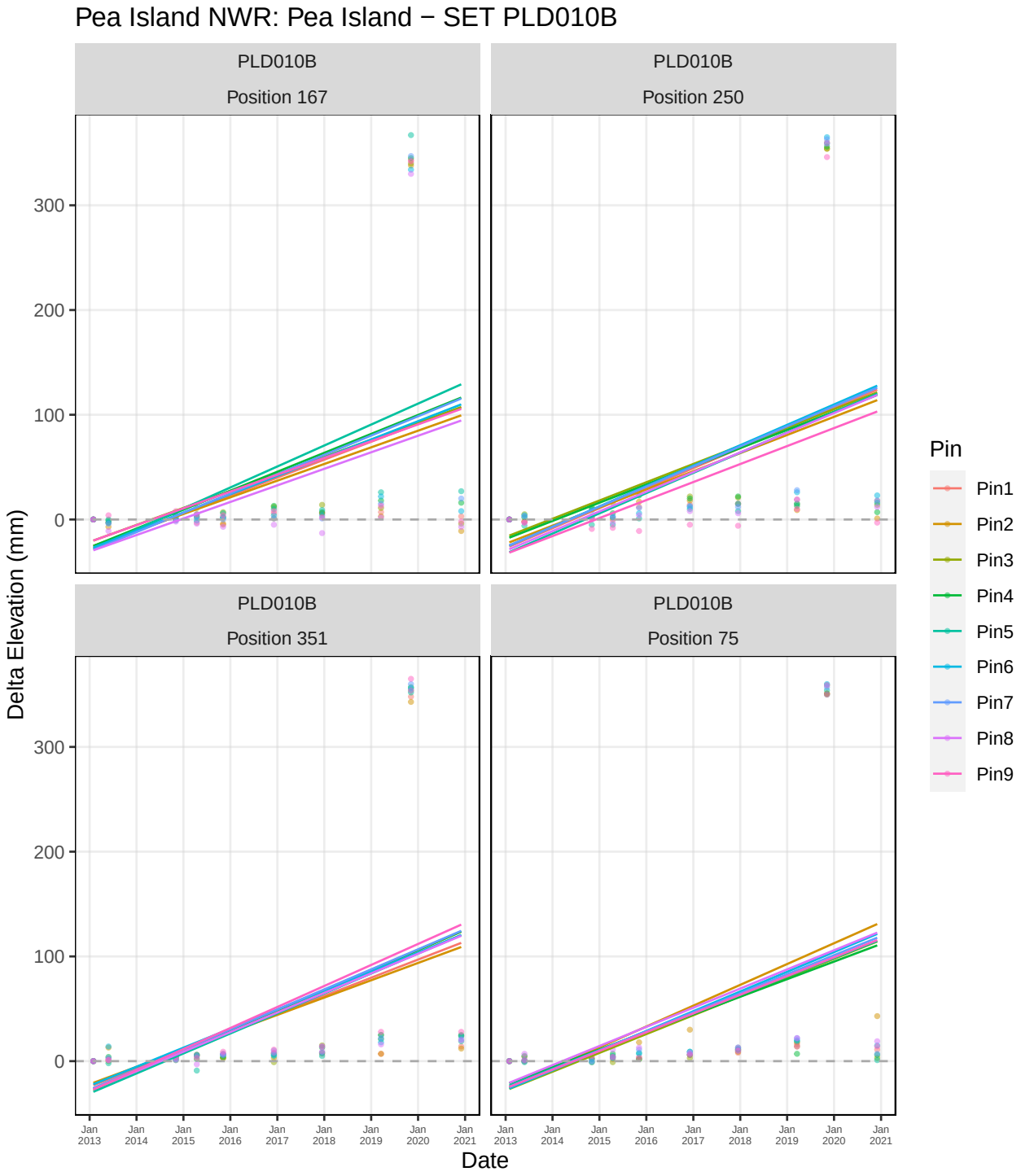
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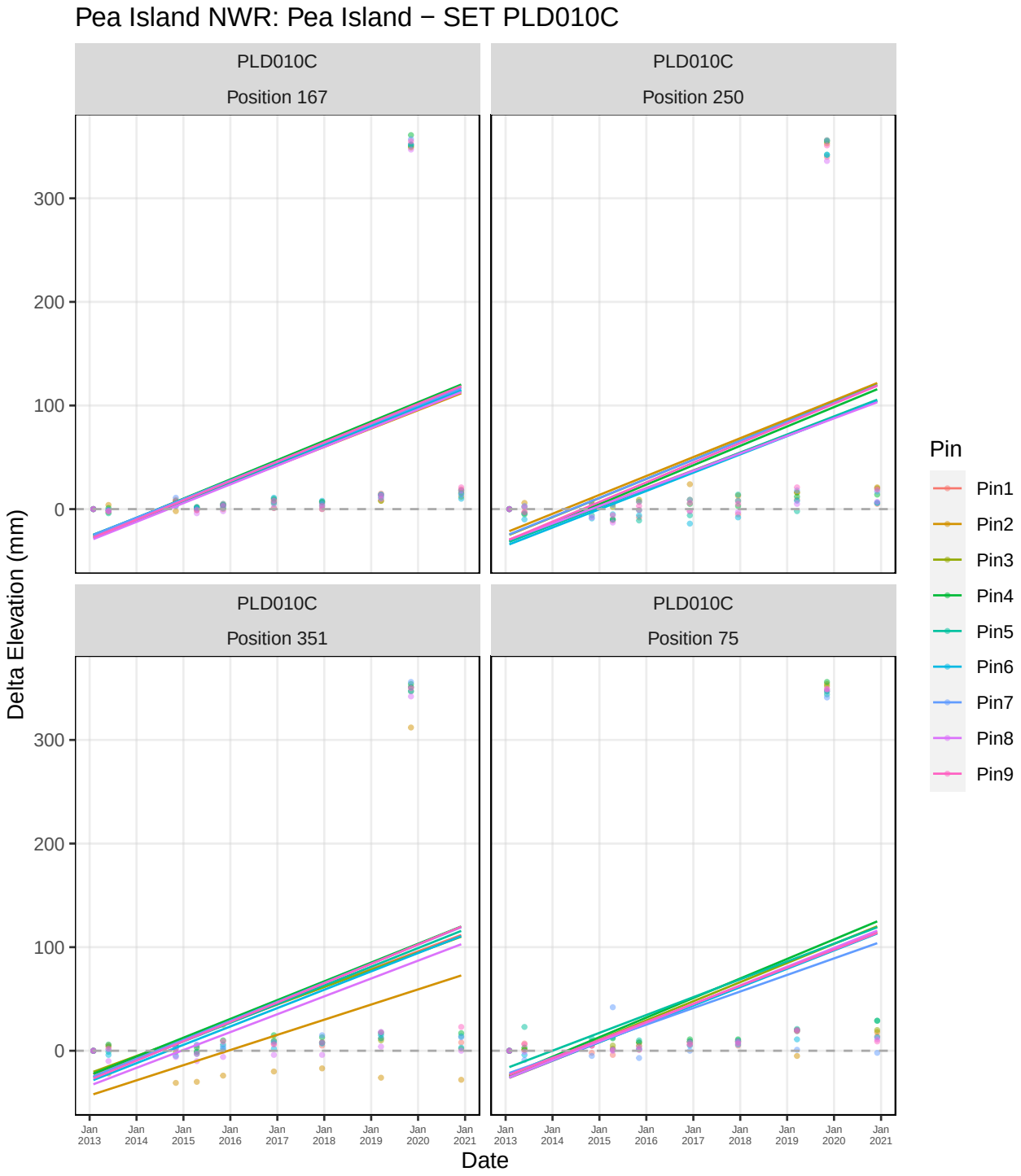
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200
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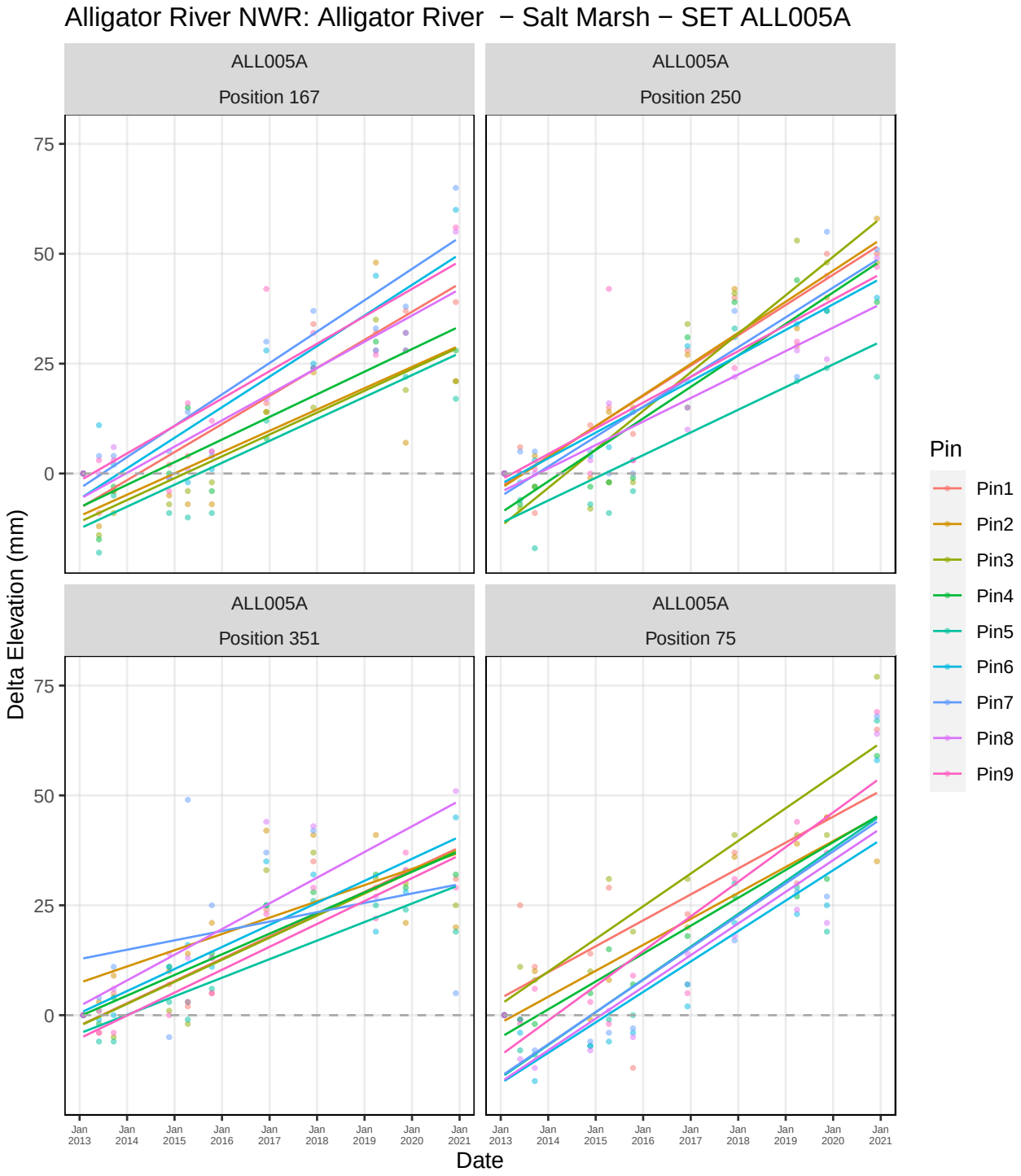
Alligator River NWR: Alligator River − Salt Marsh − SET ALL005A
ALL005A
Position 167
ALL005A
Position 250
ALL005A
Position 351
ALL005A
Position 75
Delta Elevation (mm)
75
50
25
0
Jan 2013
Jan 2014
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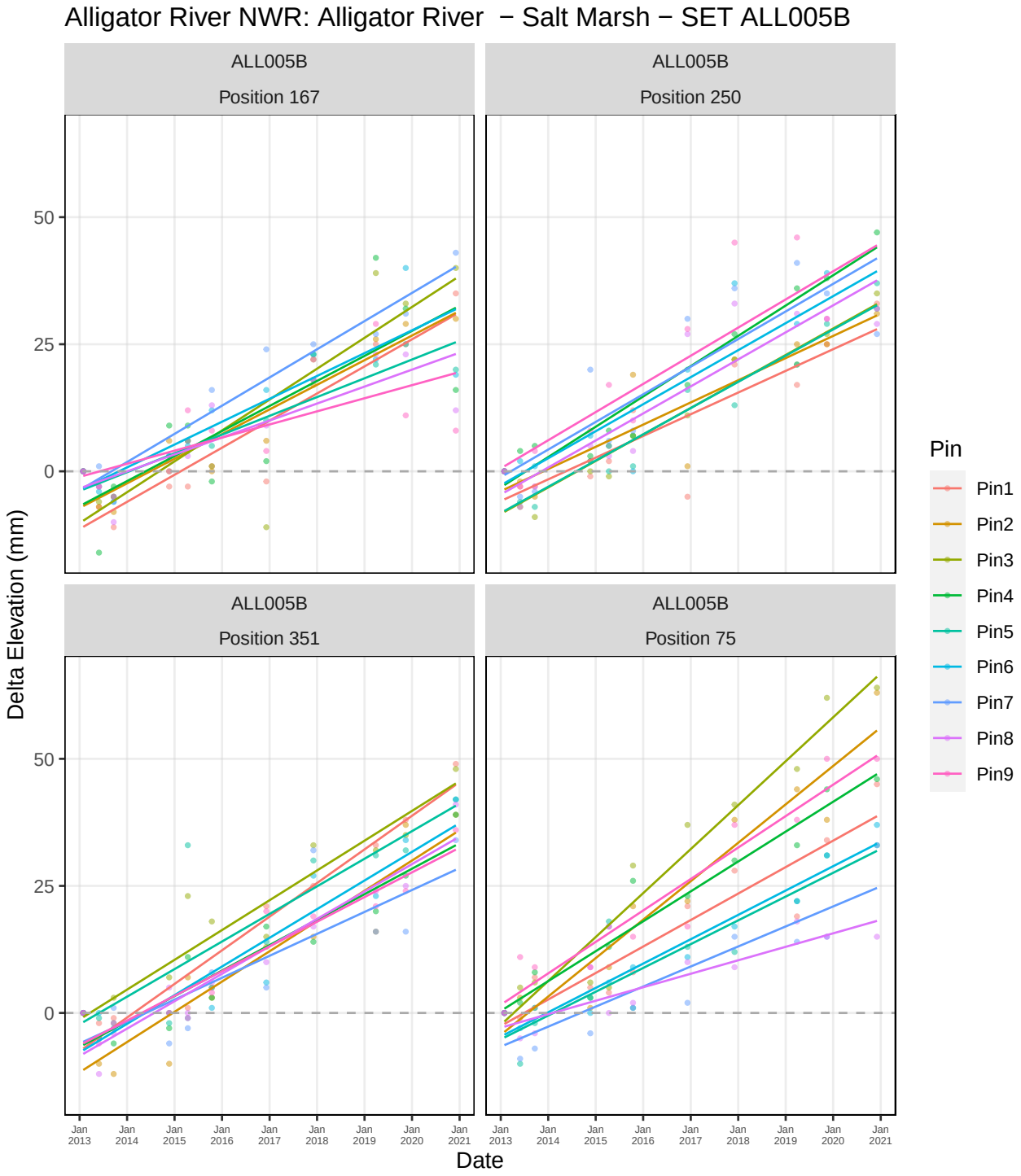
Alligator River NWR: Alligator River − Salt Marsh − SET ALL005B
ALL005B
Position 167
ALL005B
Position 250
ALL005B
Position 351
ALL005B
Position 75
Delta Elevation (mm)
50
25
0
Jan 2013
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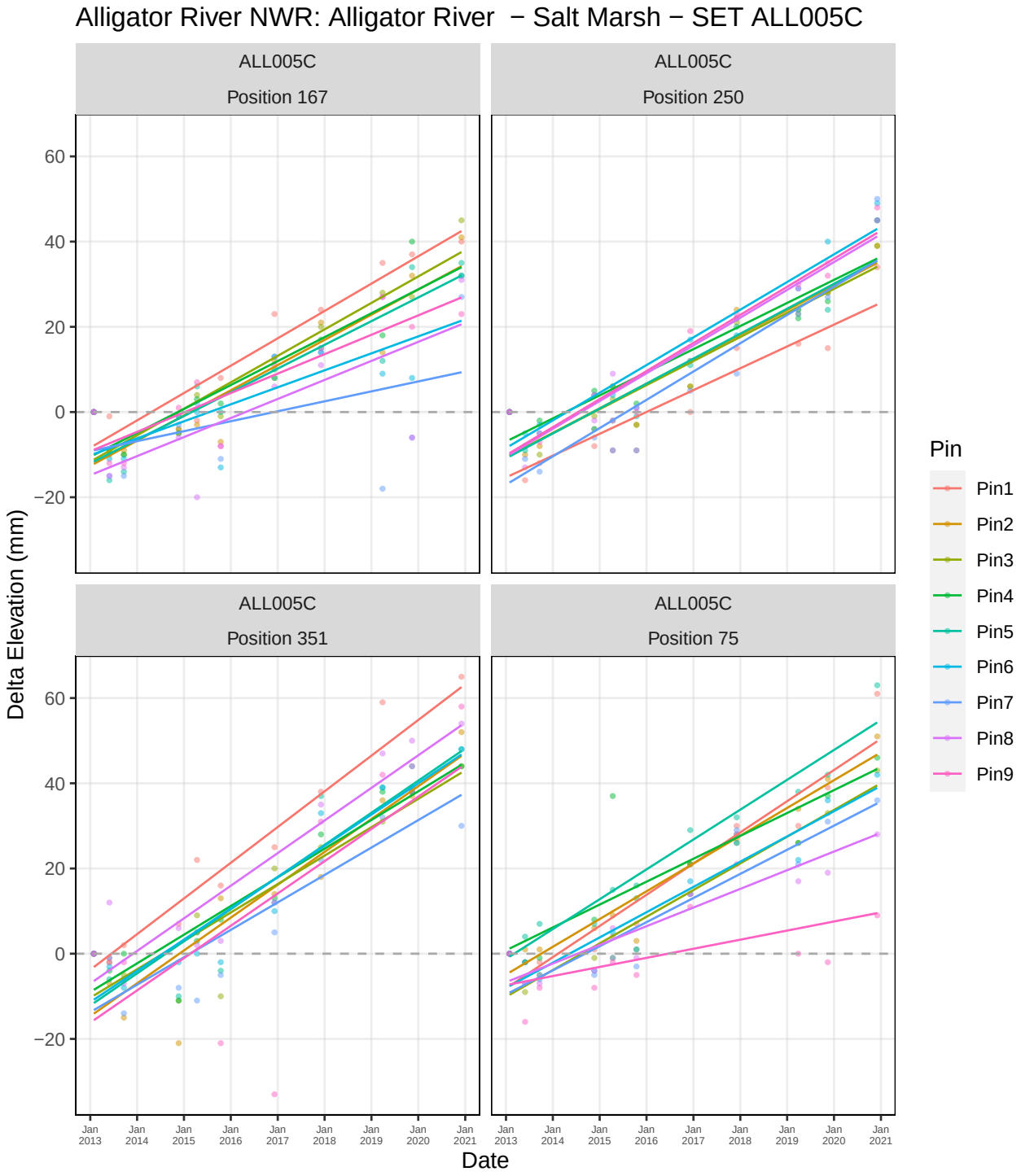
Alligator River NWR: Alligator River − Salt Marsh − SET ALL005C
ALL005C
Position 167
ALL005C
Position 250
ALL005C
Position 351
ALL005C
Position 75
Delta Elevation (mm)
60
40
20
0
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Jan 2013
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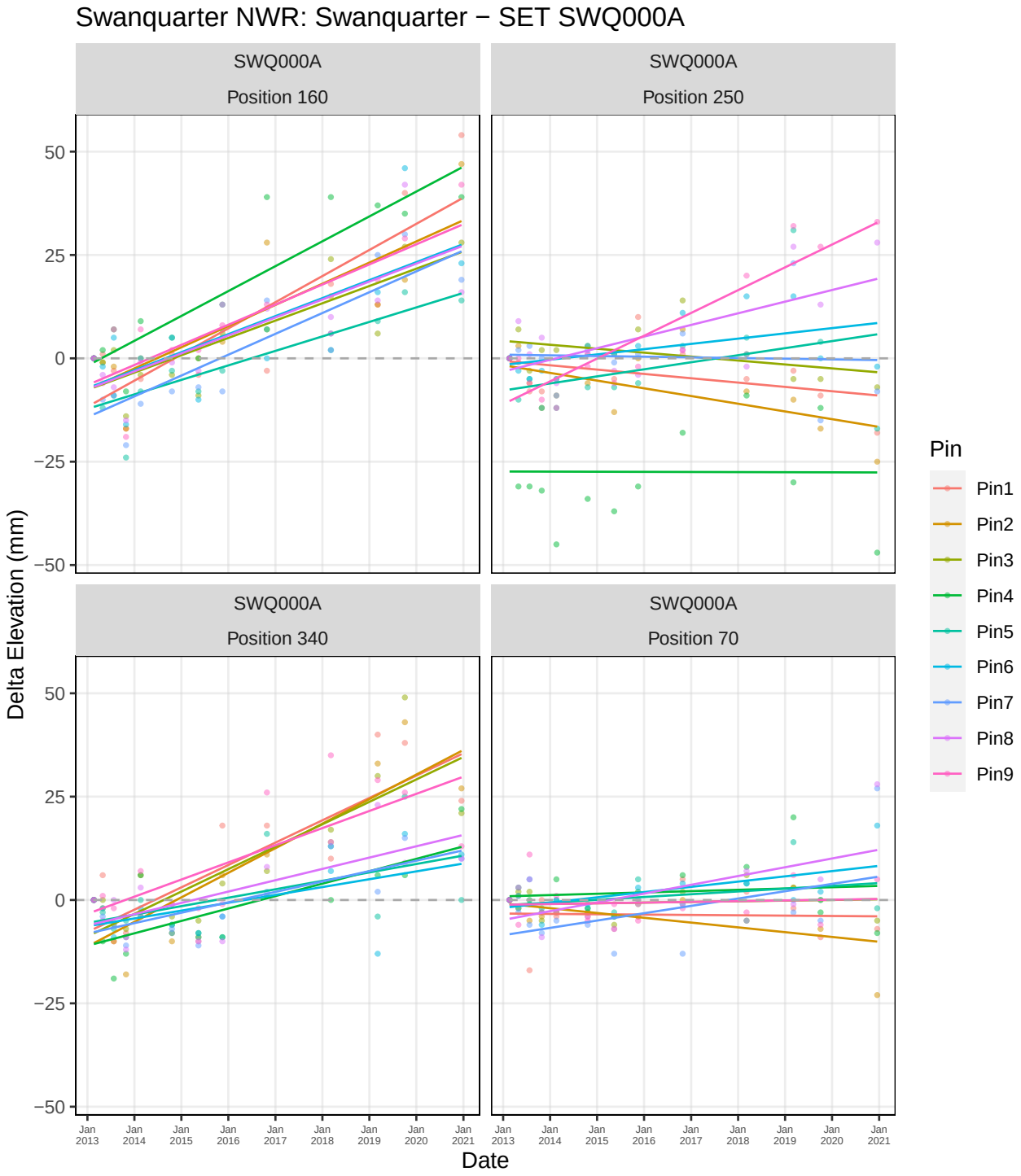
Swanquarter NWR: Swanquarter − SET SWQ000A
SWQ000A
Position 160
SWQ000A
Position 250
SWQ000A
Position 340
SWQ000A
Position 70
Delta Elevation (mm)
50
25
0
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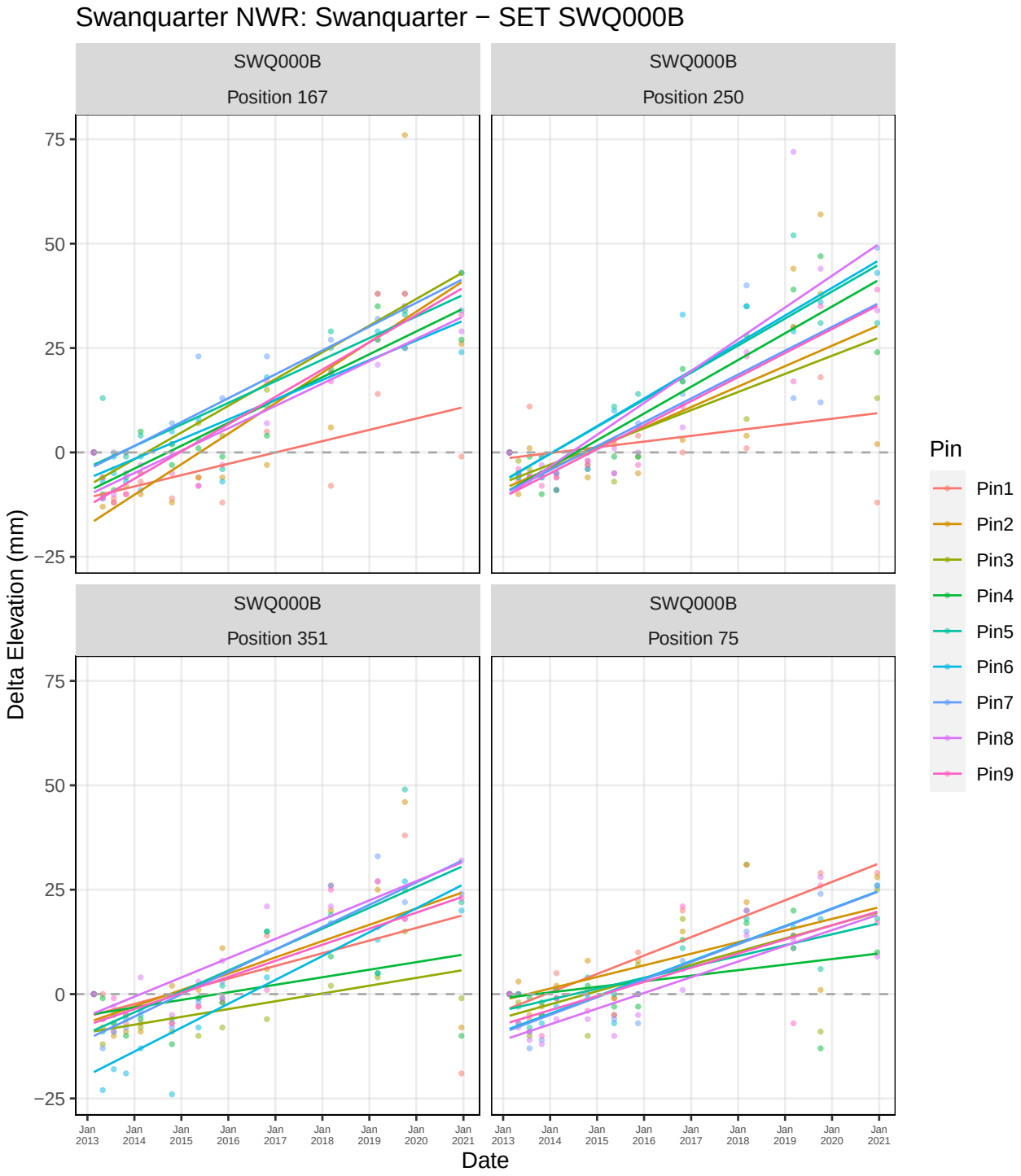
Swanquarter NWR: Swanquarter − SET SWQ000B
SWQ000B
Position 167
SWQ000B
Position 250
SWQ000B
Position 351
SWQ000B
Position 75
Delta Elevation (mm)
75
50
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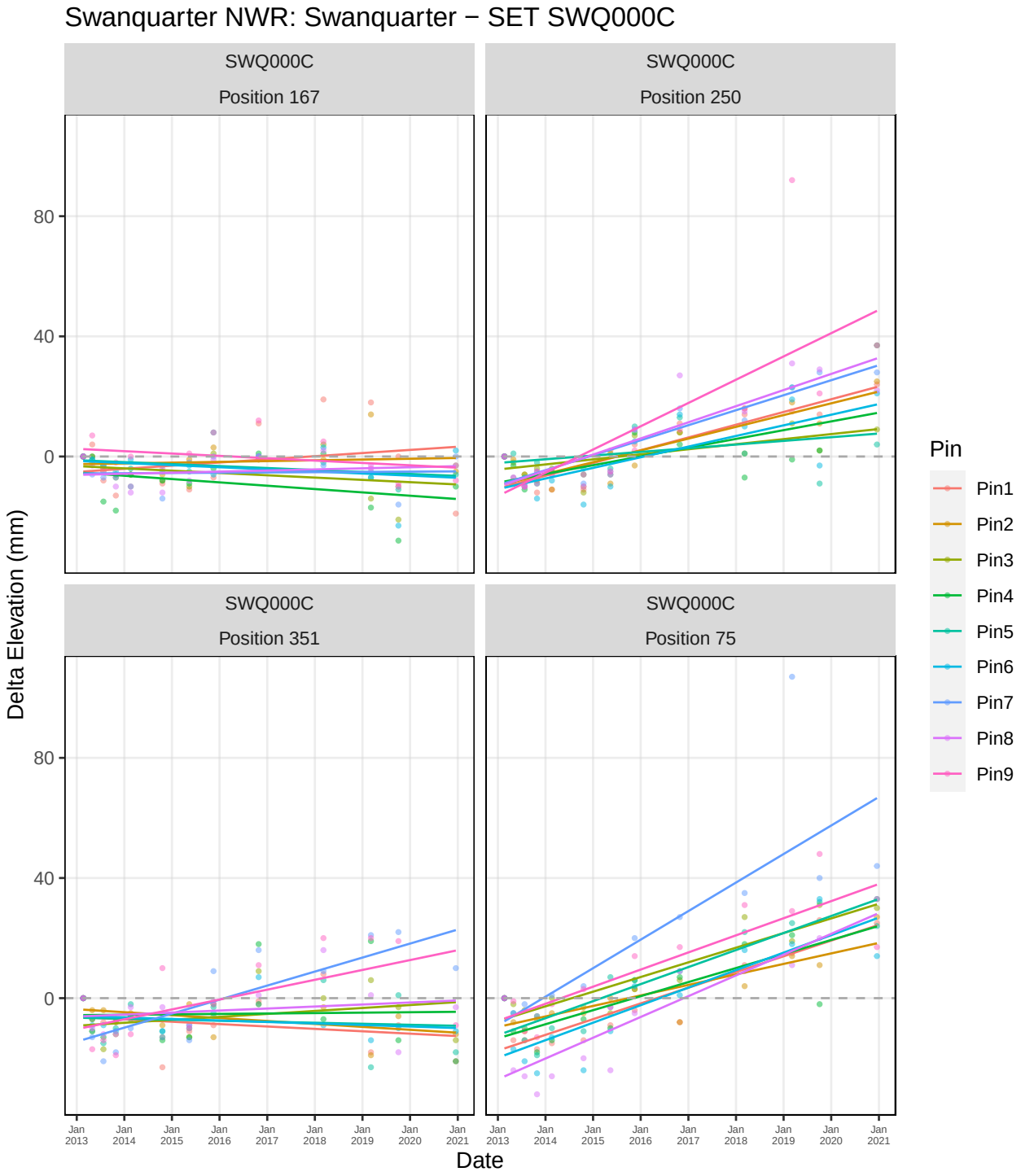
Swanquarter NWR: Swanquarter − SET SWQ000C
SWQ000C
Position 167
SWQ000C
Position 250
SWQ000C
Position 351
SWQ000C
Position 75
Delta Elevation (mm)
80
40
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Jan 2013
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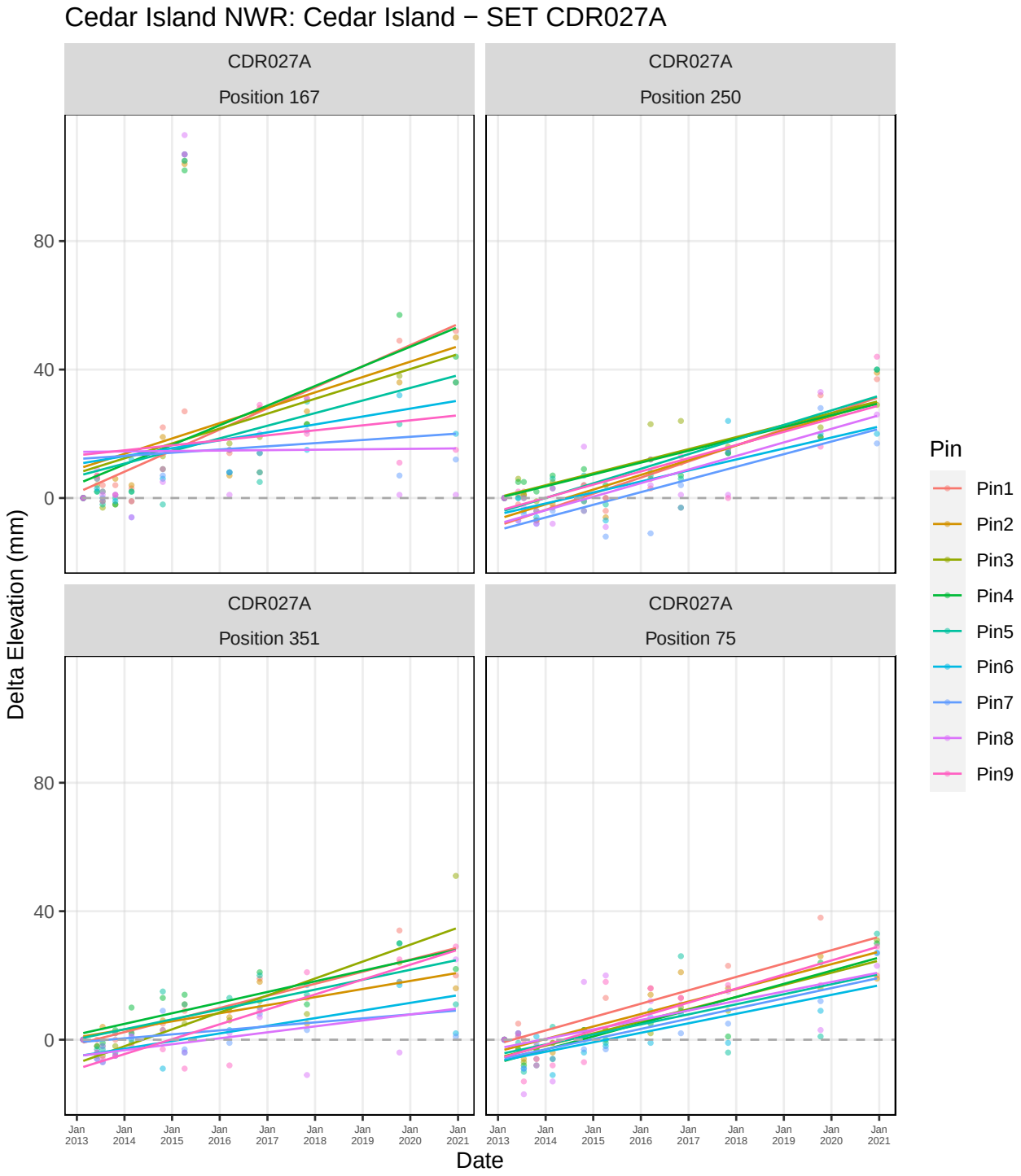
Cedar Island NWR: Cedar Island − SET CDR027A
CDR027A
Position 167
CDR027A
Position 250
CDR027A
Position 351
CDR027A
Position 75
Delta Elevation (mm)
80
40
0
Jan 2013
Jan 2014
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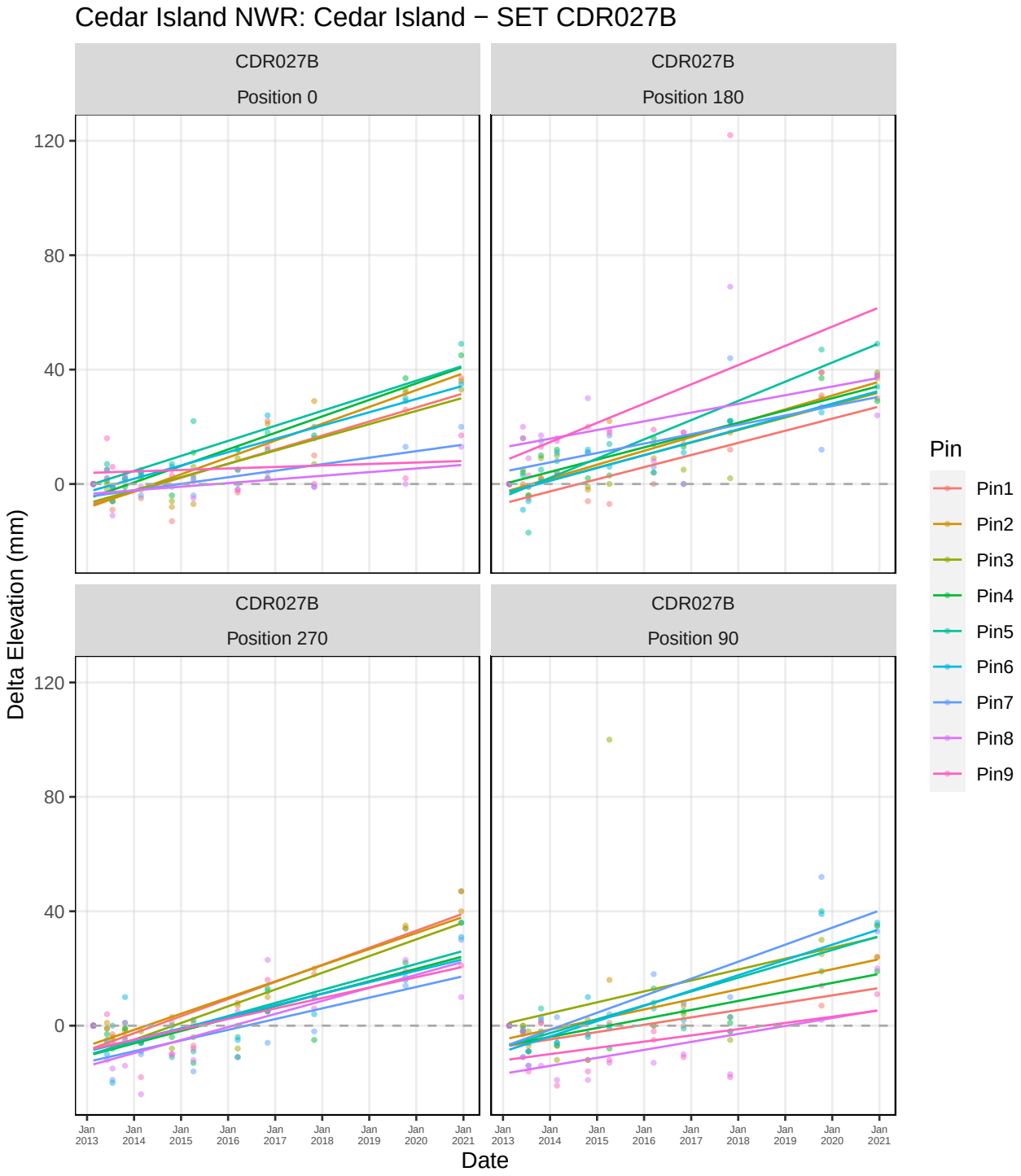
Cedar Island NWR: Cedar Island − SET CDR027B
CDR027B
Position 0
CDR027B
Position 180
CDR027B
Position 270
CDR027B
Position 90
Delta Elevation (mm)
120
80
40
0
Jan 2013
Jan 2014
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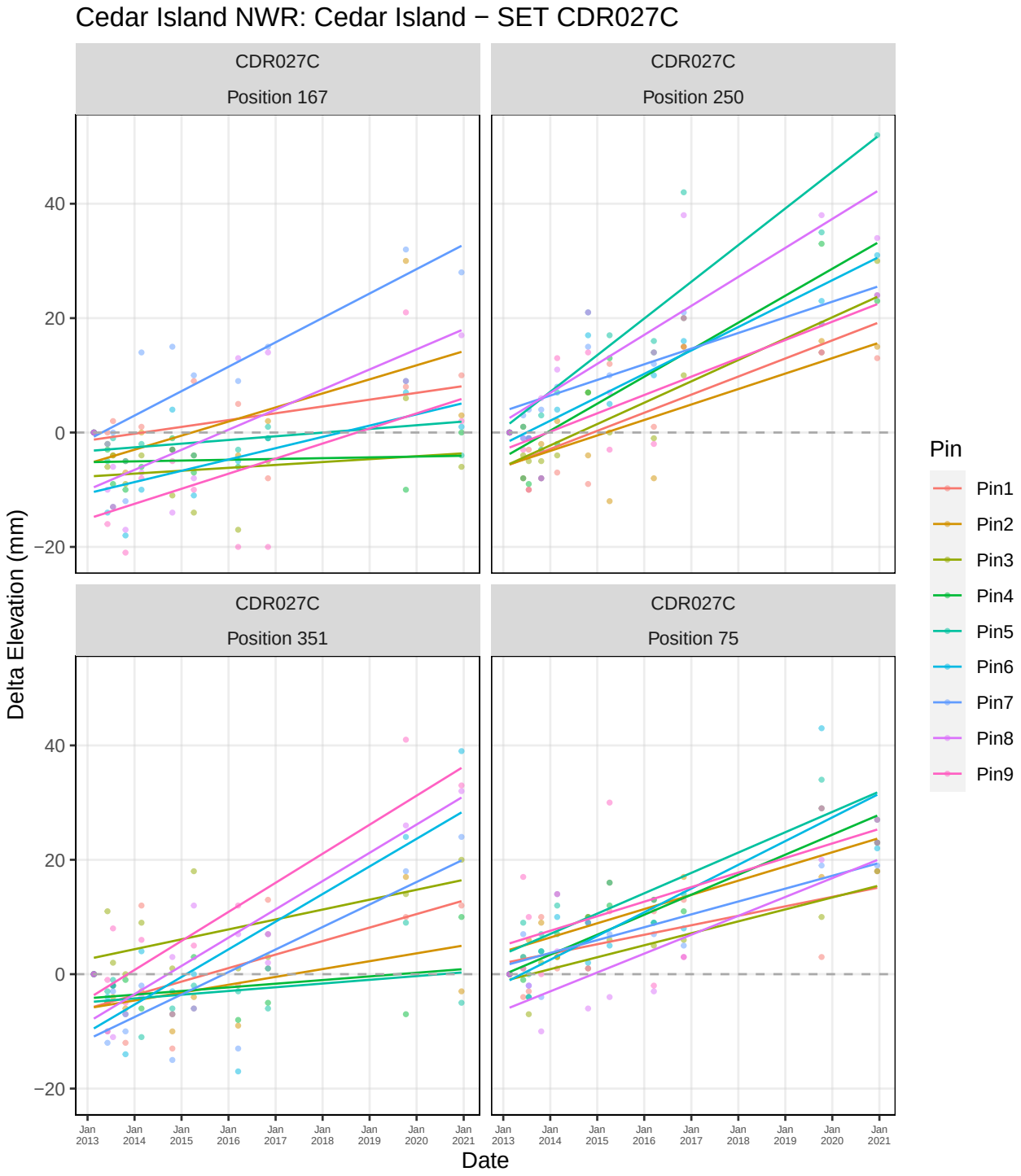
Cedar Island NWR: Cedar Island − SET CDR027C
CDR027C
Position 167
CDR027C
Position 250
CDR027C
Position 351
CDR027C
Position 75
Delta Elevation (mm)
40
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Jan 2013
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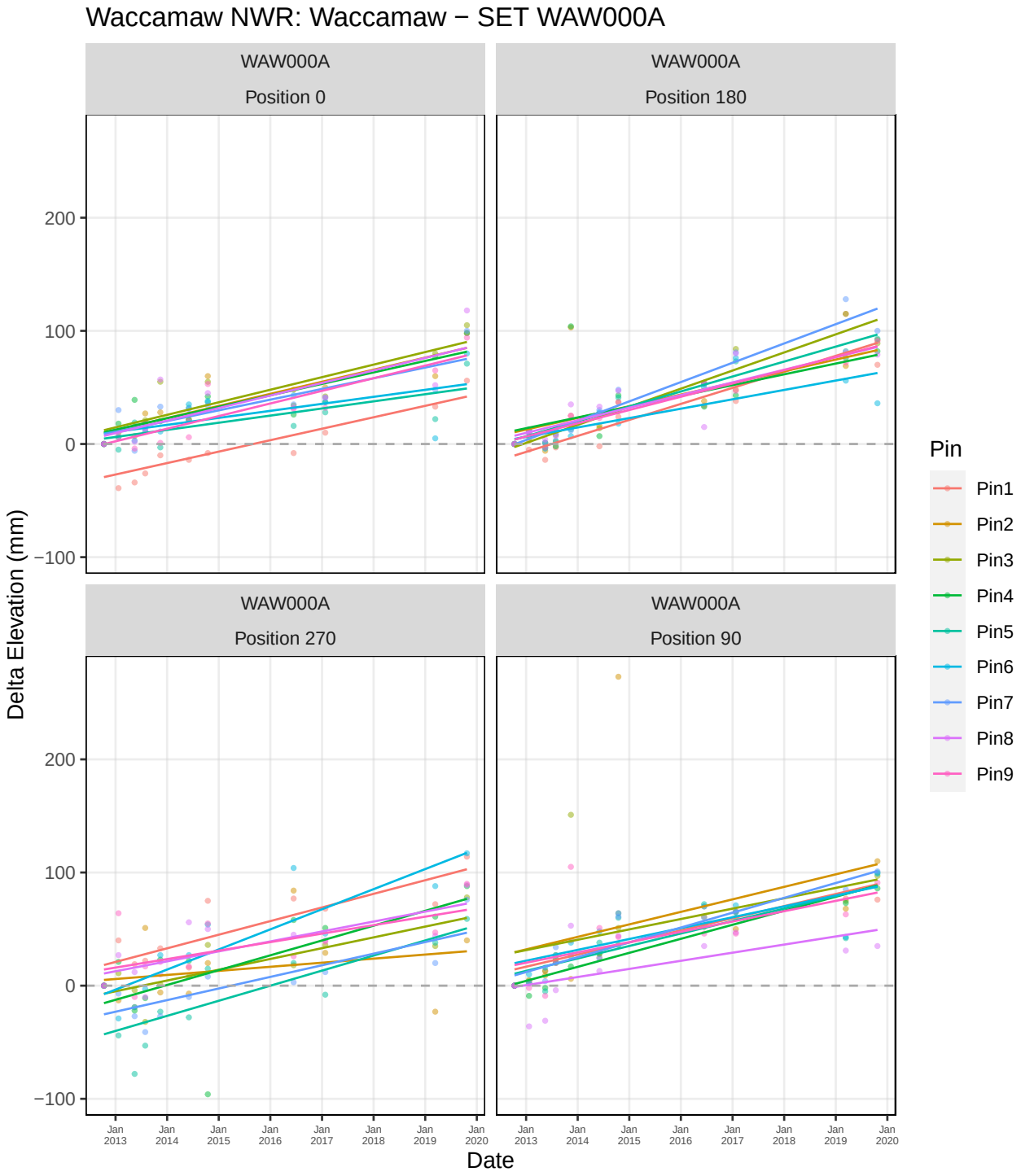
Waccamaw NWR: Waccamaw − SET WAW000A
WAW000A
Position 0
WAW000A
Position 180
WAW000A
Position 270
WAW000A
Position 90
Delta Elevation (mm)
200
100
0
−100
Jan 2013
Jan 2014
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Date
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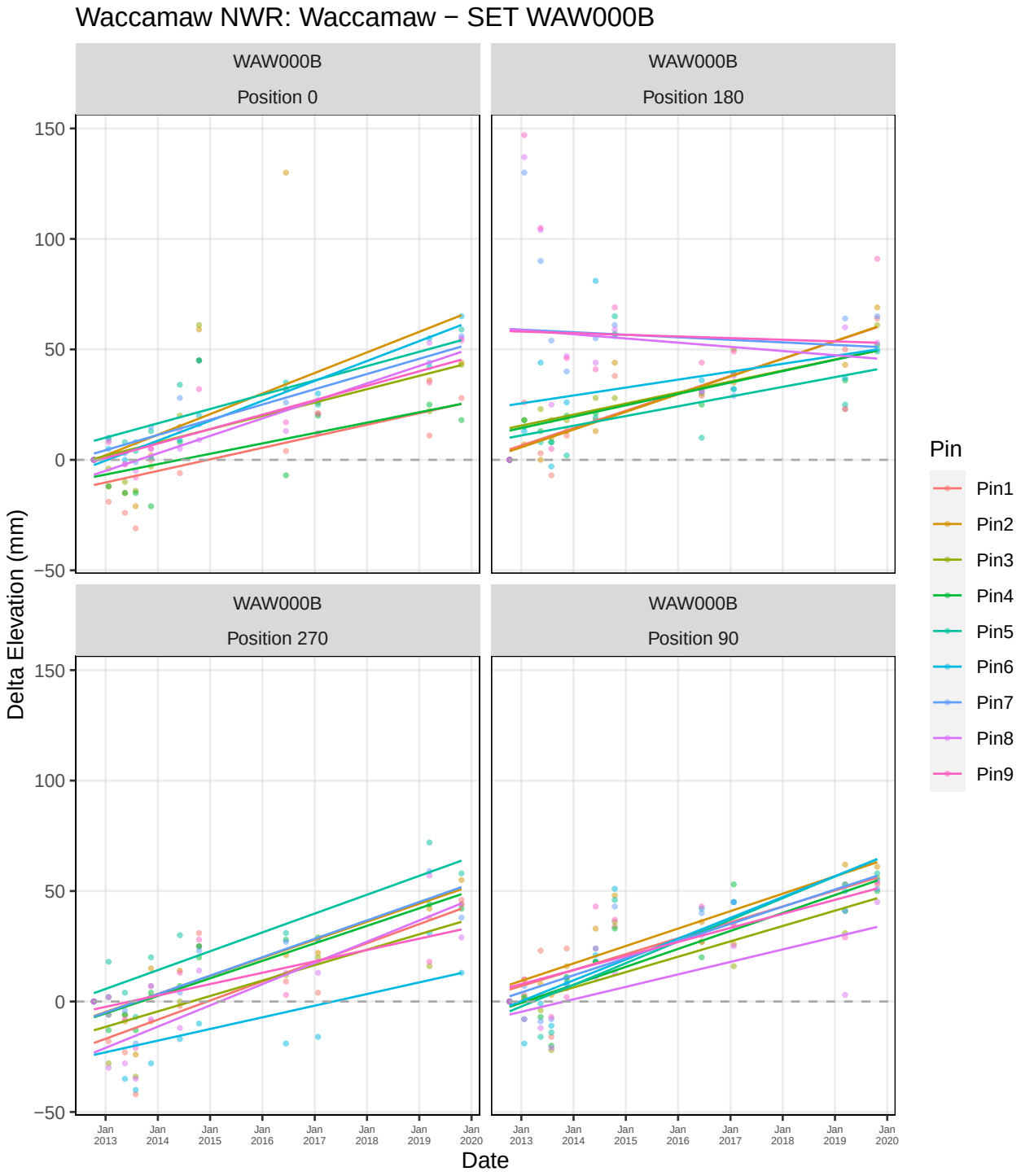
Waccamaw NWR: Waccamaw − SET WAW000B
WAW000B
Position 0
WAW000B
Position 180
WAW000B
Position 270
WAW000B
Position 90
Delta Elevation (mm)
150
100
50
0
−50
Jan 2013
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Date
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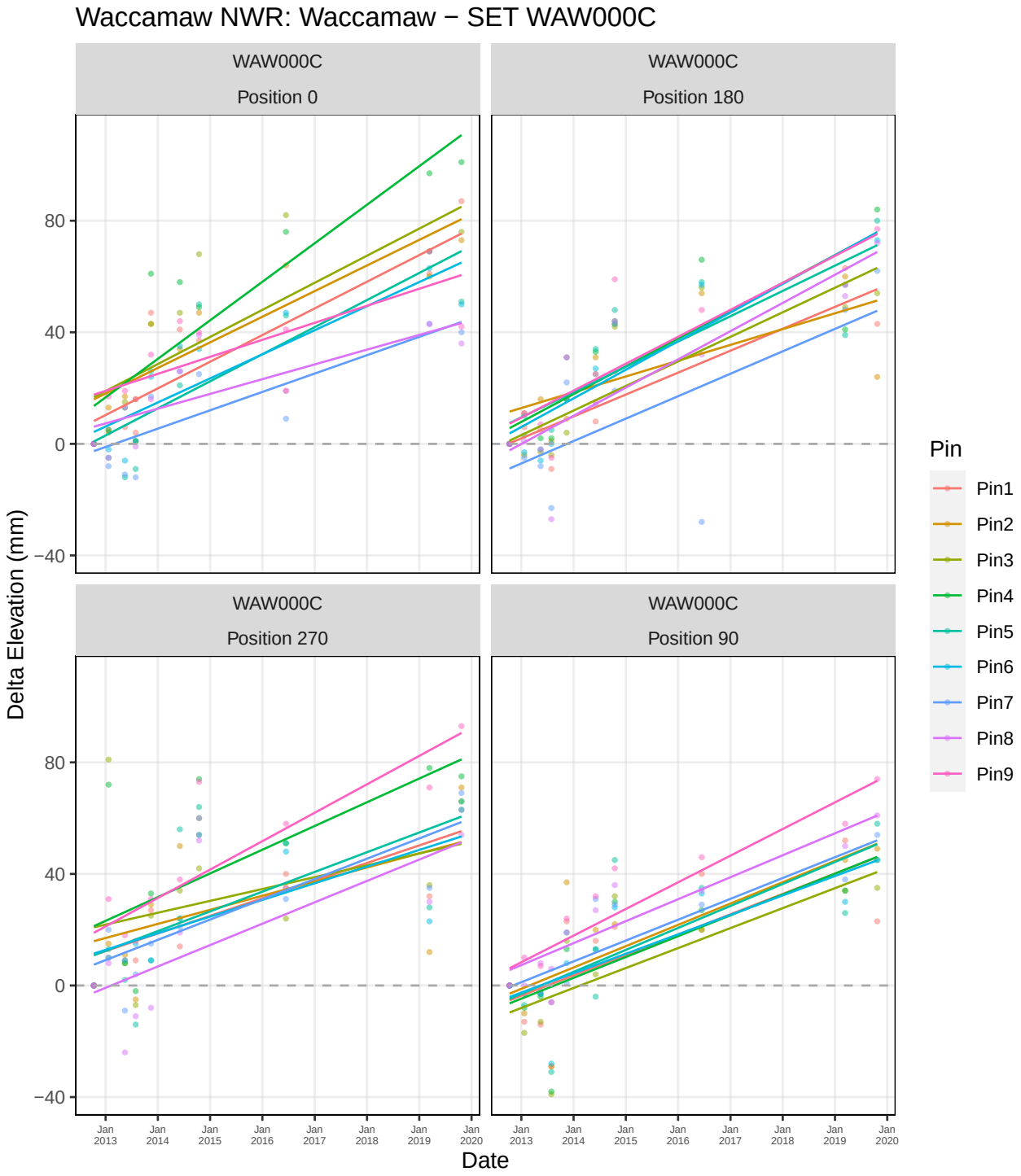
Waccamaw NWR: Waccamaw − SET WAW000C
WAW000C
Position 0
WAW000C
Position 180
WAW000C
Position 270
WAW000C
Position 90
Delta Elevation (mm)
80
40
0
−40
Jan 2013
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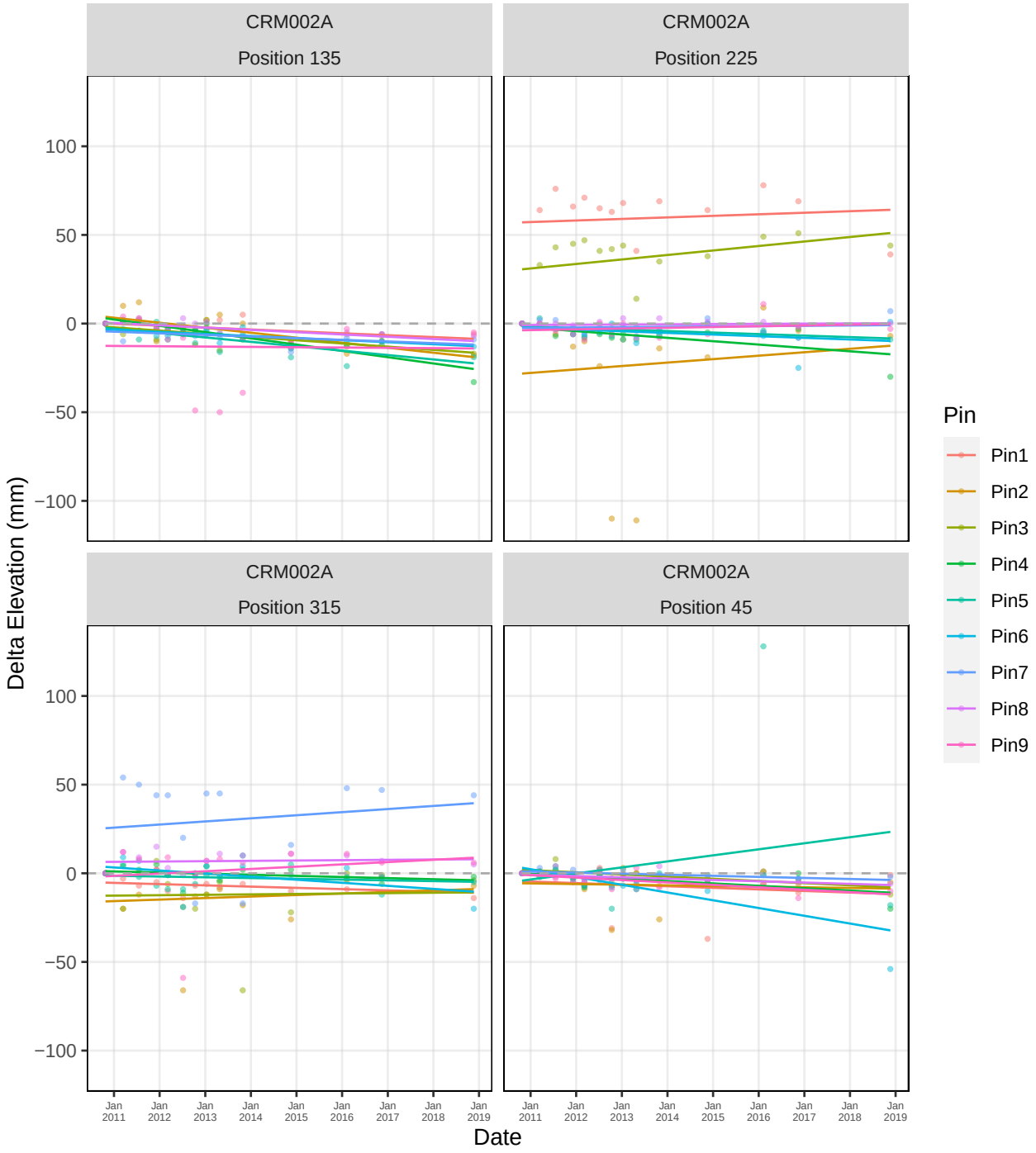
Cape Romain NWR: Cape Romain − Horsehead Key − SET CRM002A
CRM002A
Position 135
CRM002A
Position 225
CRM002A
Position 315
CRM002A
Position 45
Delta Elevation (mm)
100
50
0
−50
−100
Jan 2011
Jan 2012
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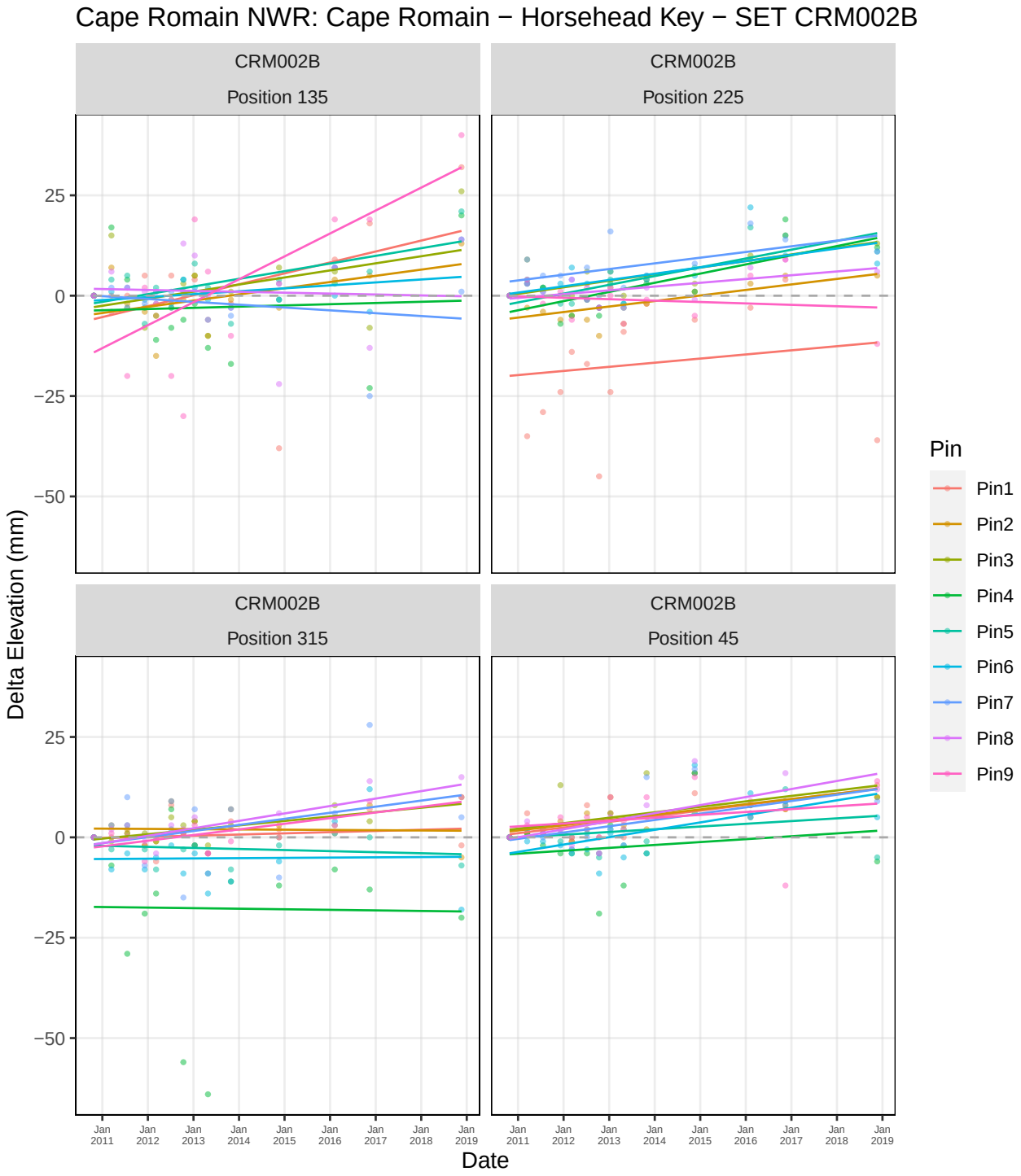
Cape Romain NWR: Cape Romain − Horsehead Key − SET CRM002B
CRM002B
Position 135
CRM002B
Position 225
CRM002B
Position 315
CRM002B
Position 45
Delta Elevation (mm)
25
0
−25
−50
Jan 2011
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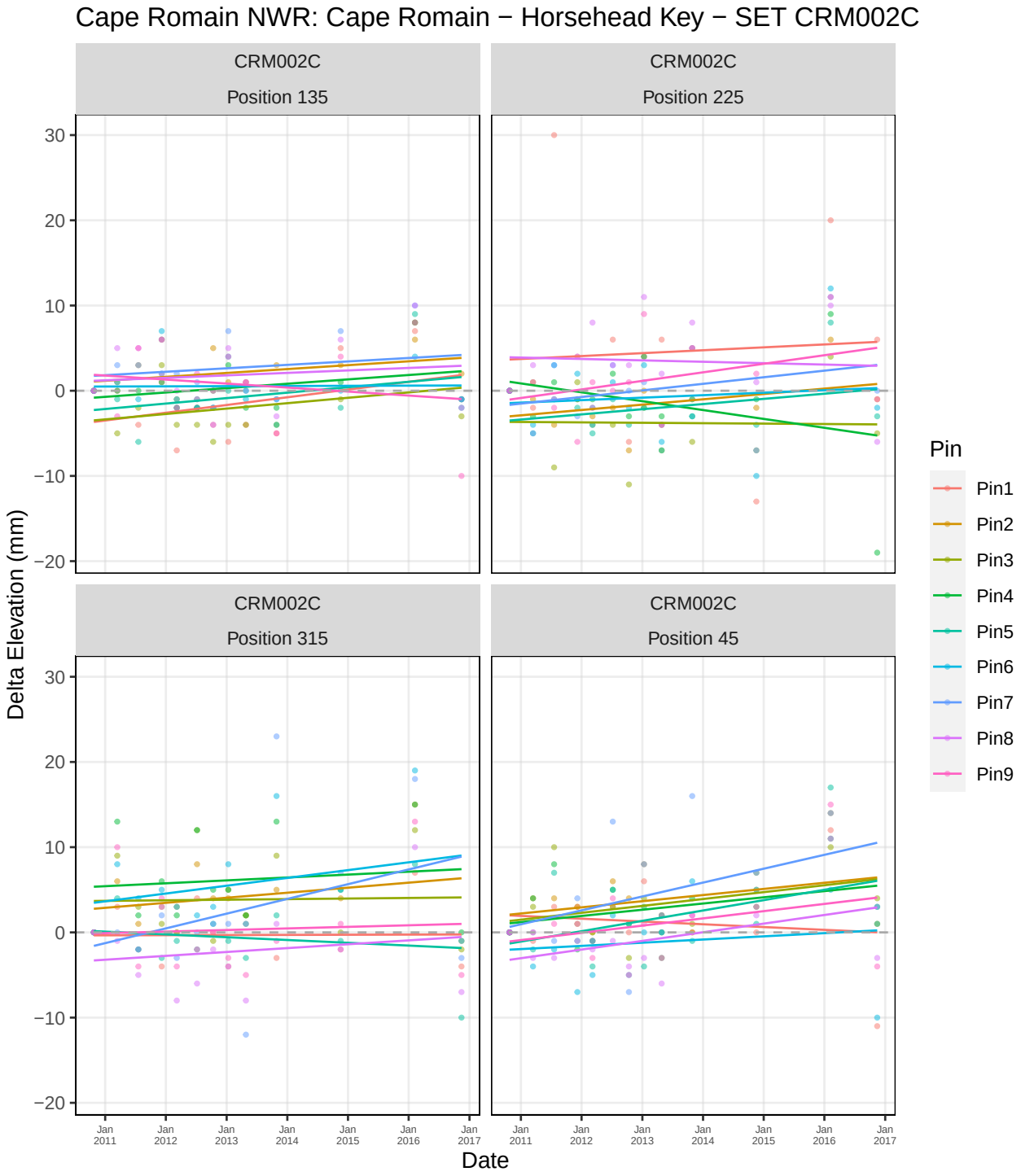
Cape Romain NWR: Cape Romain − Horsehead Key − SET CRM002C
CRM002C
Position 135
CRM002C
Position 225
CRM002C
Position 315
CRM002C
Position 45
Delta Elevation (mm)
30
20
10
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Jan 2011
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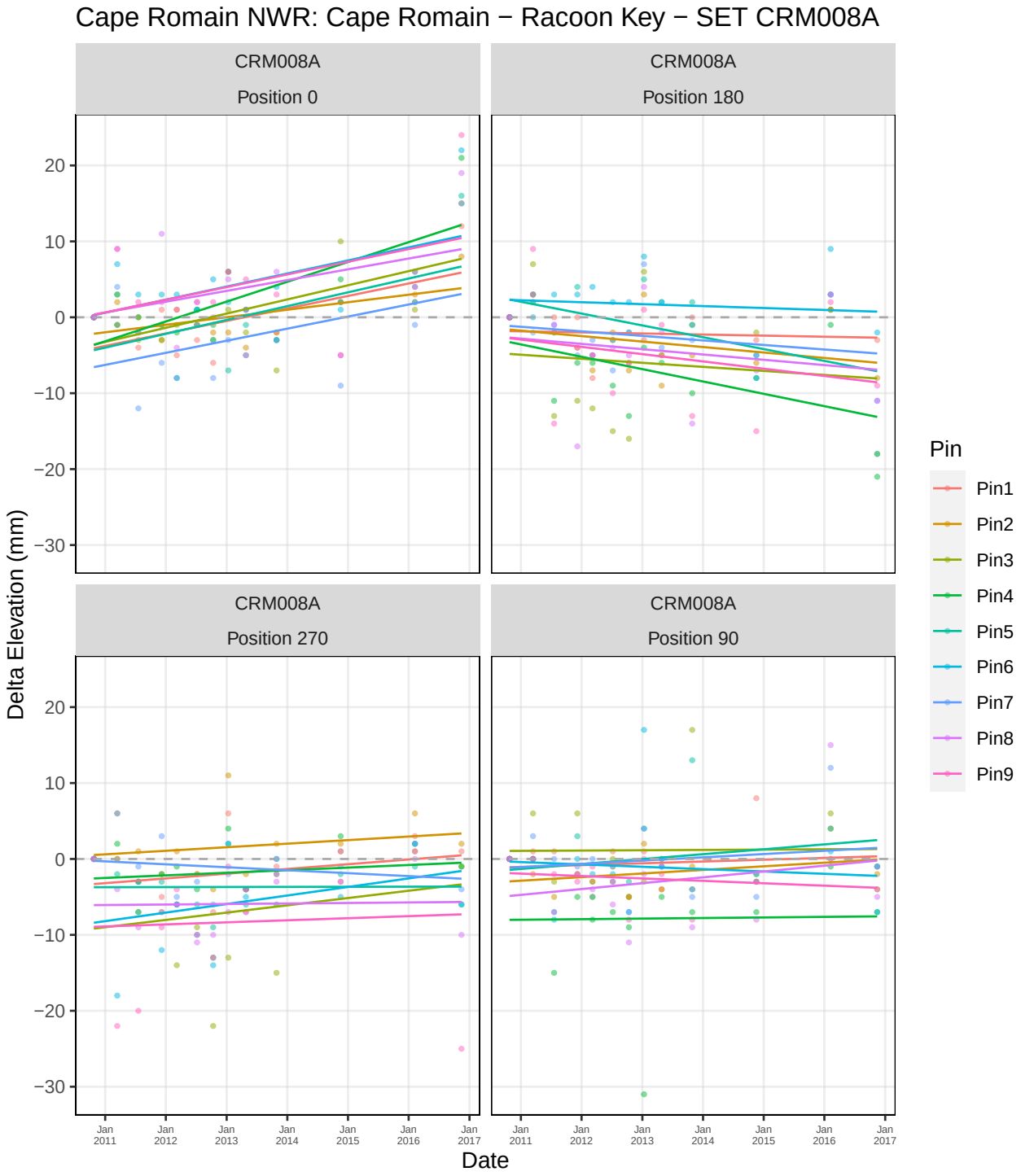
Cape Romain NWR: Cape Romain − Racoon Key − SET CRM008A
CRM008A
Position 0
CRM008A
Position 180
CRM008A
Position 270
CRM008A
Position 90
Delta Elevation (mm)
20
10
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Jan 2011
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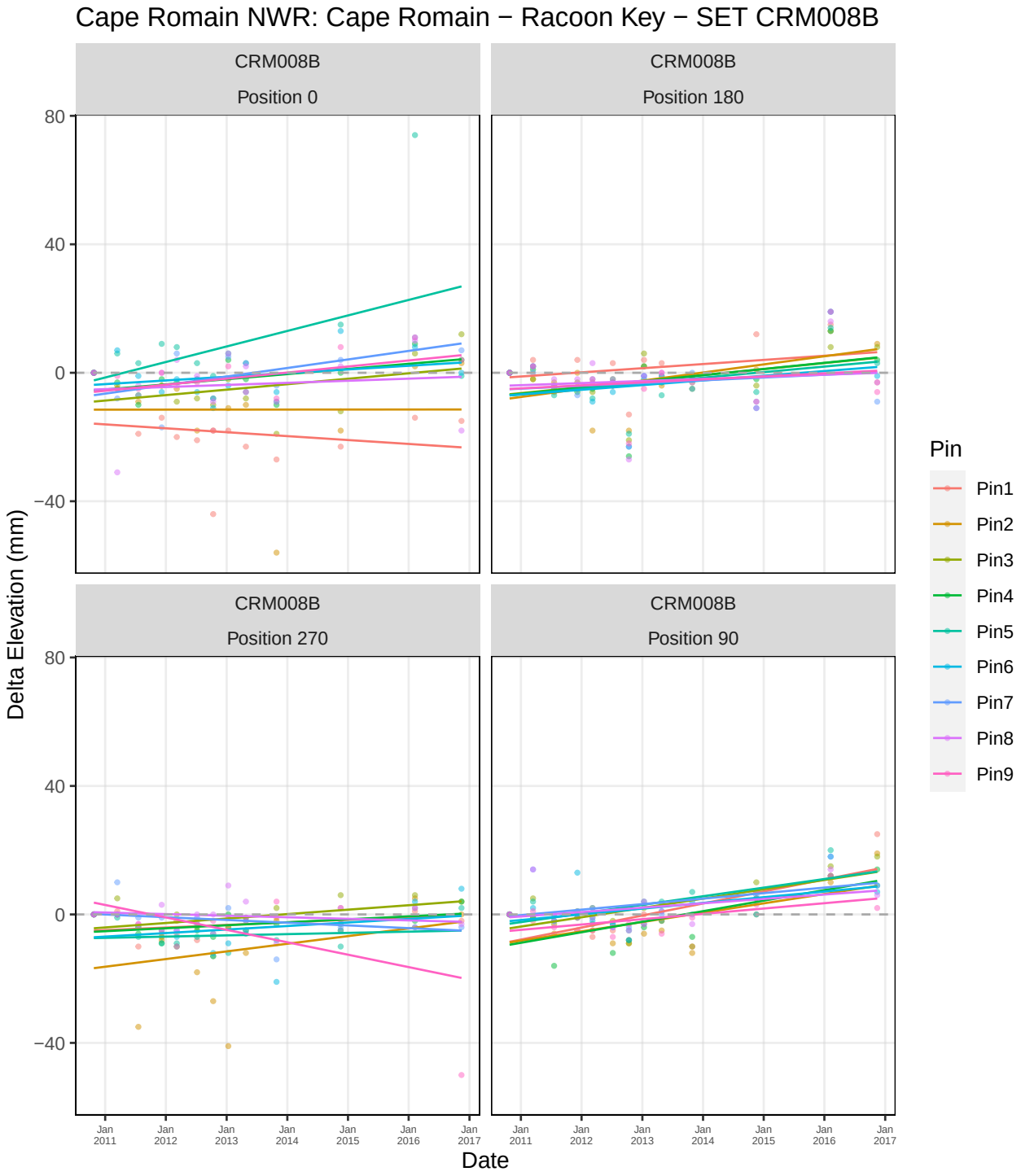
Cape Romain NWR: Cape Romain − Racoon Key − SET CRM008B
CRM008B
Position 0
CRM008B
Position 180
CRM008B
Position 270
CRM008B
Position 90
Delta Elevation (mm)
80
40
0
−40
Jan 2011
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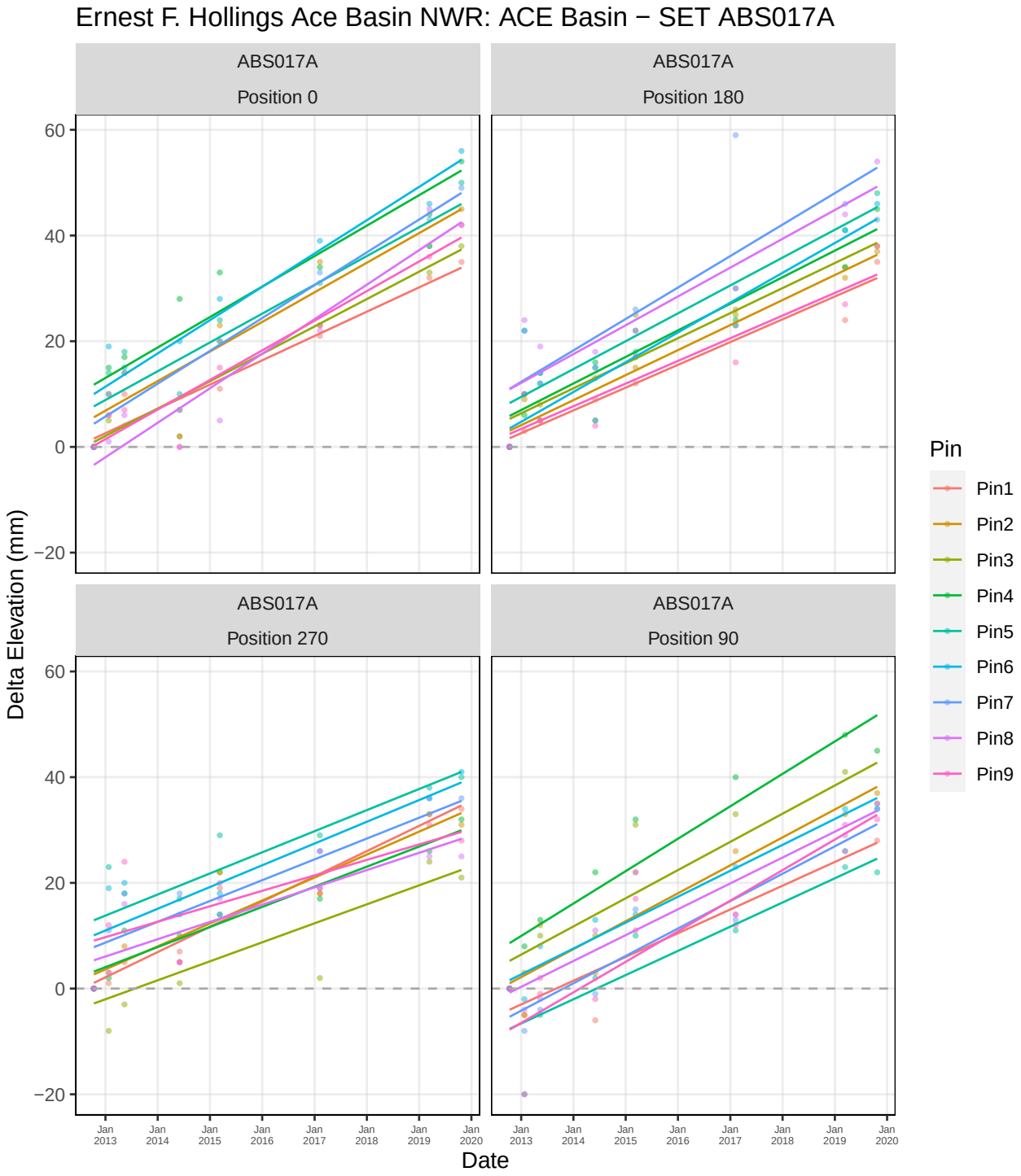
Ernest F. Hollings Ace Basin NWR: ACE Basin − SET ABS017A
ABS017A
Position 0
ABS017A
Position 180
ABS017A
Position 270
ABS017A
Position 90
Delta Elevation (mm)
60
40
20
0
−20
Jan 2013
Jan 2014
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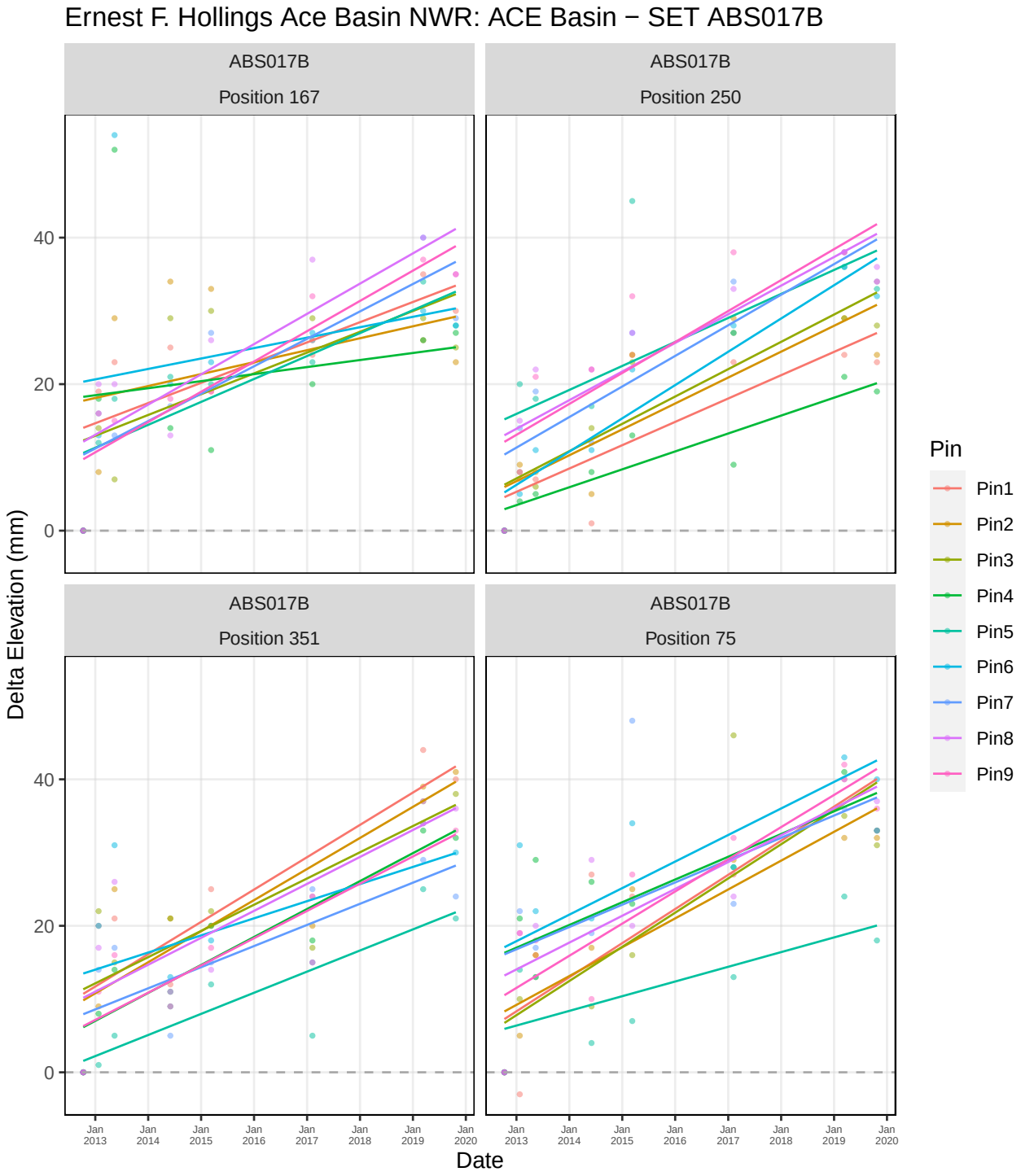
Ernest F. Hollings Ace Basin NWR: ACE Basin − SET ABS017B
ABS017B
Position 167
ABS017B
Position 250
ABS017B
Position 351
ABS017B
Position 75
Delta Elevation (mm)
40
20
0
Jan 2013
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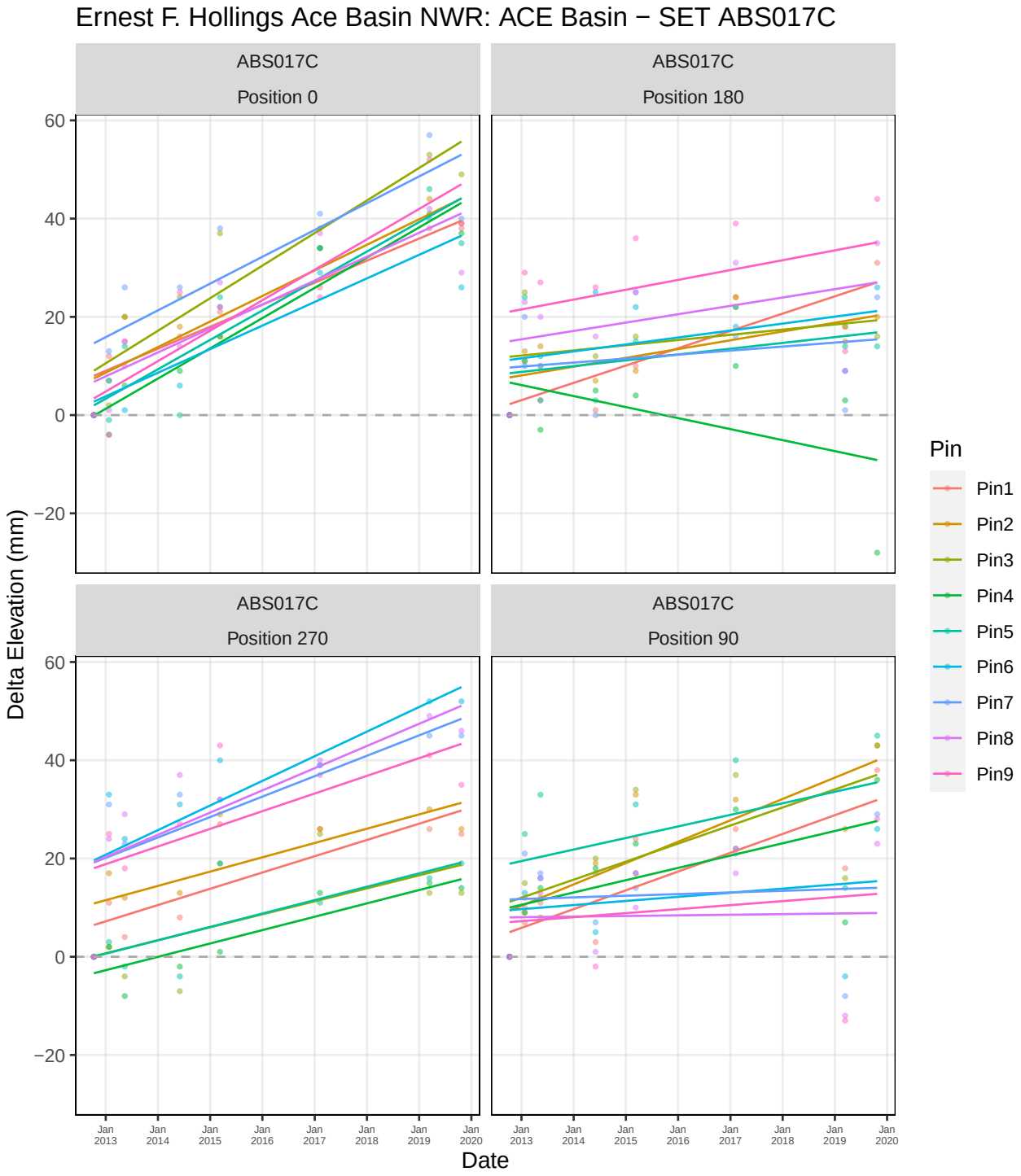
Ernest F. Hollings Ace Basin NWR: ACE Basin − SET ABS017C
ABS017C
Position 0
ABS017C
Position 180
ABS017C
Position 270
ABS017C
Position 90
Delta Elevation (mm)
60
40
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Jan 2013
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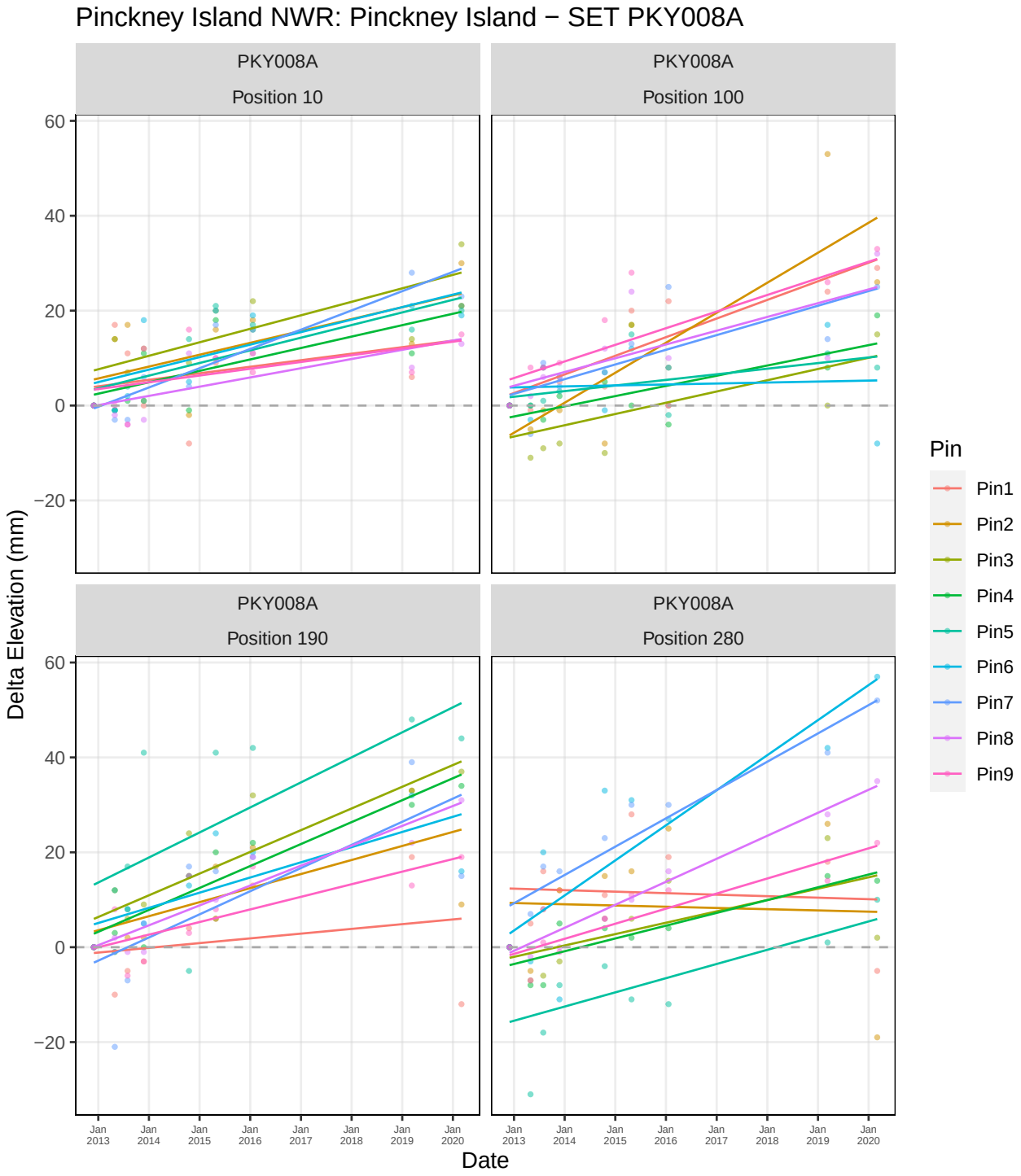
Pinckney Island NWR: Pinckney Island − SET PKY008A
PKY008A
Position 10
PKY008A
Position 100
PKY008A
Position 190
PKY008A
Position 280
Delta Elevation (mm)
60
40
20
0
−20
Jan 2013
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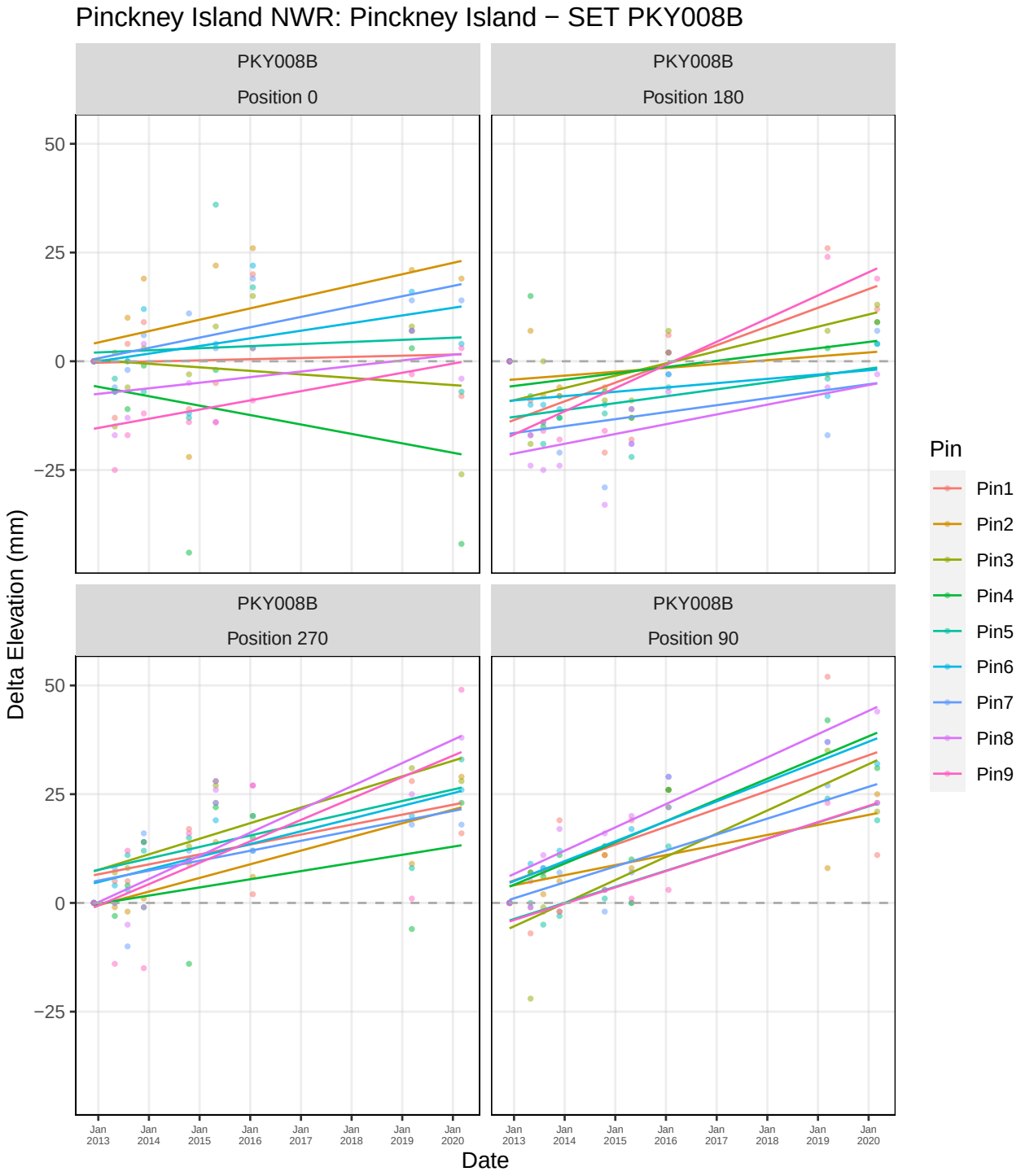
Pinckney Island NWR: Pinckney Island − SET PKY008B
PKY008B
Position 0
PKY008B
Position 180
PKY008B
Position 270
PKY008B
Position 90
Delta Elevation (mm)
50
25
0
−25
Jan 2013
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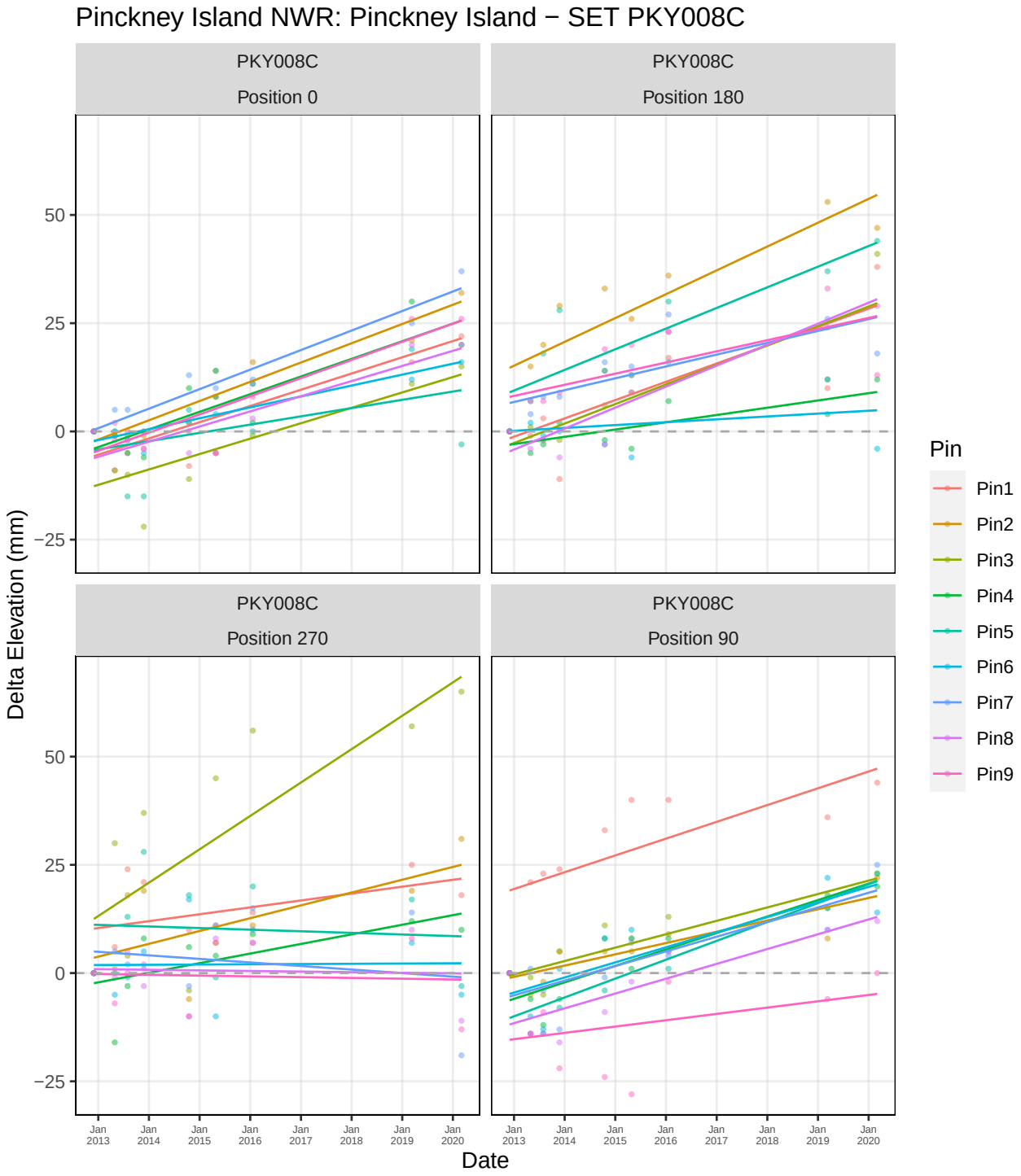
Pinckney Island NWR: Pinckney Island − SET PKY008C
PKY008C
Position 0
PKY008C
Position 180
PKY008C
Position 270
PKY008C
Position 90
Delta Elevation (mm)
50
25
0
−25
Jan 2013
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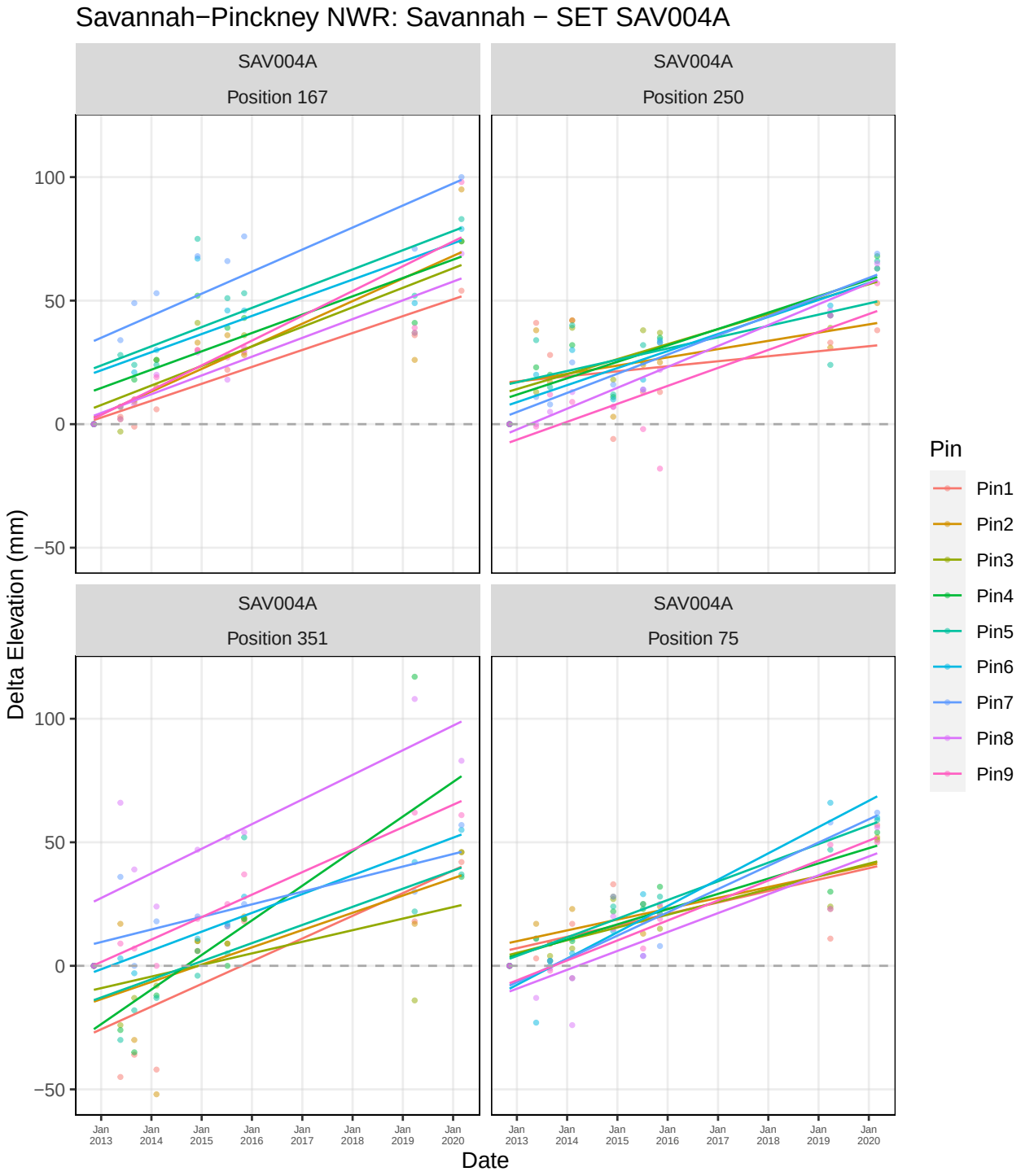
Savannah−Pinckney NWR: Savannah − SET SAV004A
SAV004A
Position 167
SAV004A
Position 250
SAV004A
Position 351
SAV004A
Position 75
Delta Elevation (mm)
100
50
0
−50
Jan 2013
Jan 2014
Jan 2015
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Date
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Pin1
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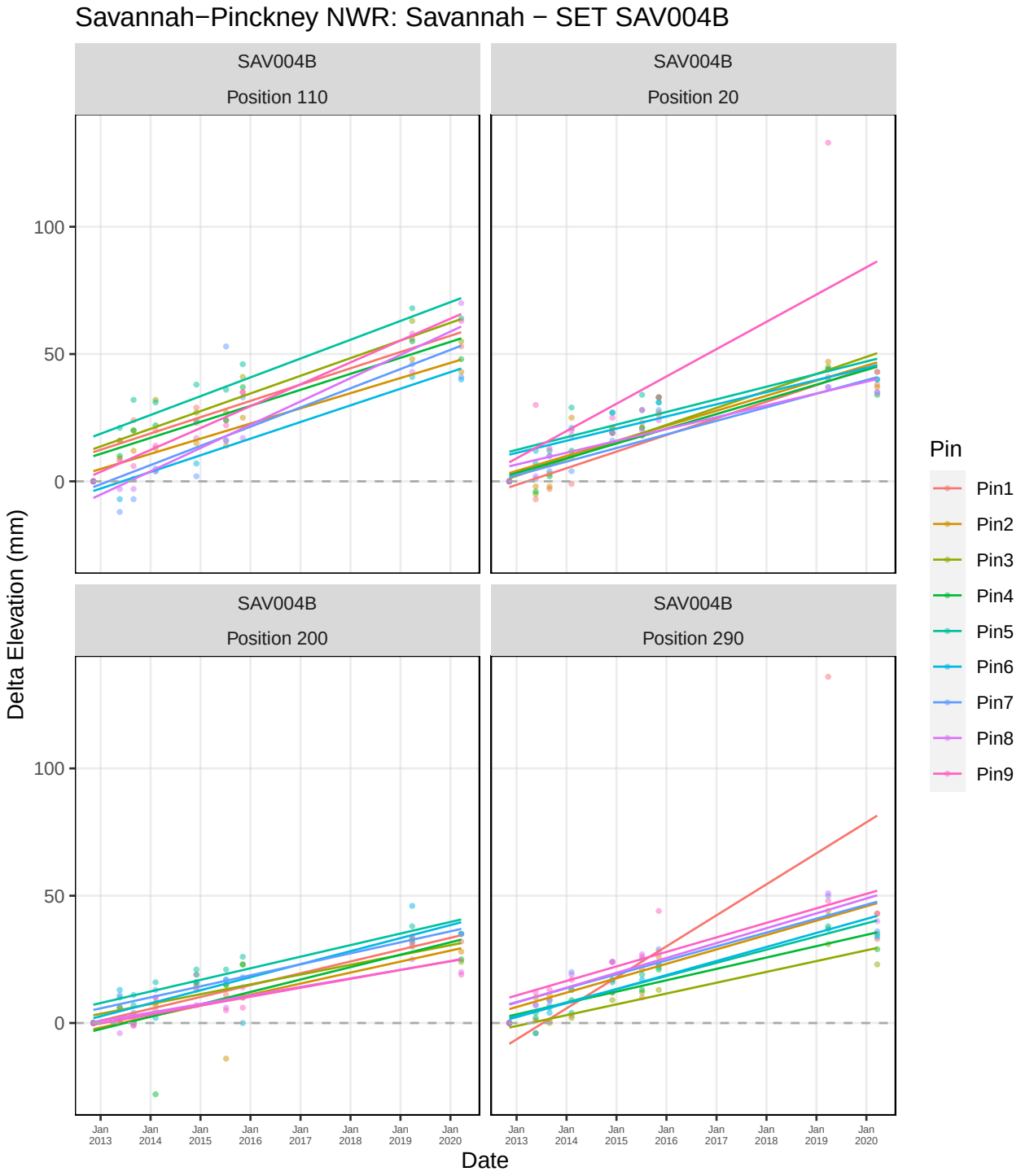
Savannah−Pinckney NWR: Savannah − SET SAV004B
SAV004B
Position 110
SAV004B
Position 20
SAV004B
Position 200
SAV004B
Position 290
Delta Elevation (mm)
100
50
0
Jan 2013
Jan 2014
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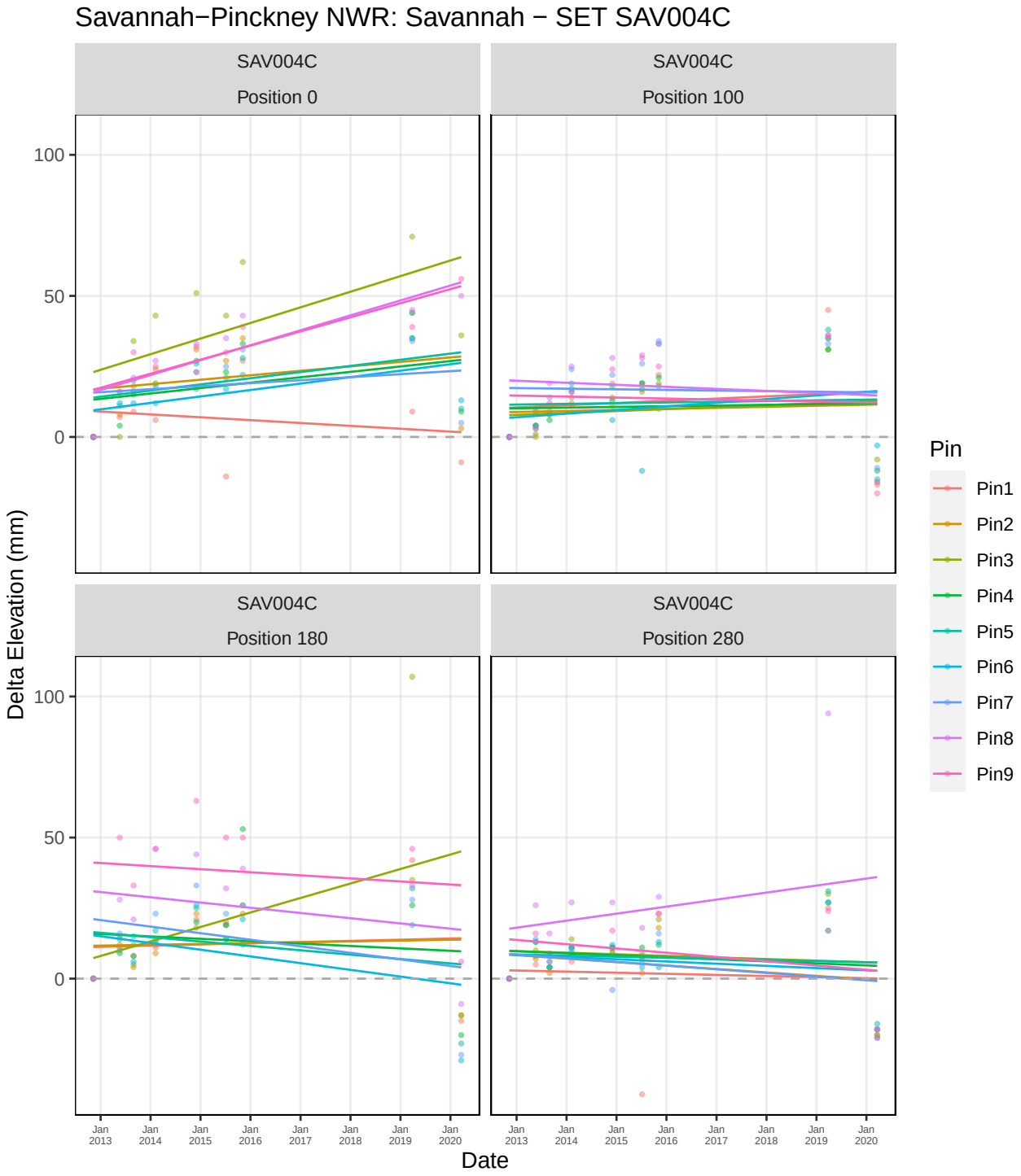
Savannah−Pinckney NWR: Savannah − SET SAV004C
SAV004C
Position 0
SAV004C
Position 100
SAV004C
Position 180
SAV004C
Position 280
Delta Elevation (mm)
100
50
0
Jan 2013
Jan 2014
Jan 2015
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Jan 2020
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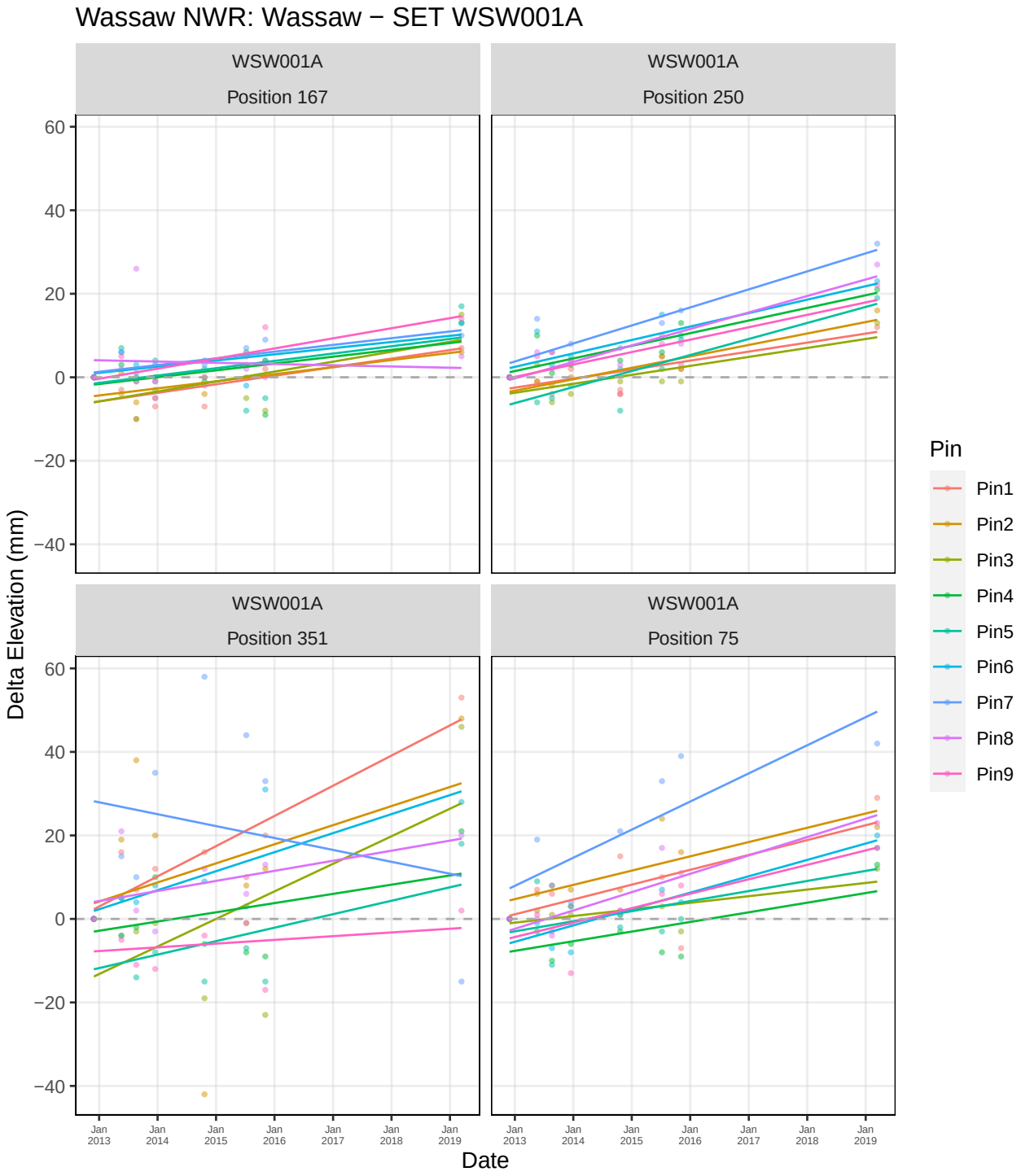
Wassaw NWR: Wassaw − SET WSW001A
WSW001A
Position 167
WSW001A
Position 250
WSW001A
Position 351
WSW001A
Position 75
Delta Elevation (mm)
60
40
20
0
−20
−40
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Date
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Pin1
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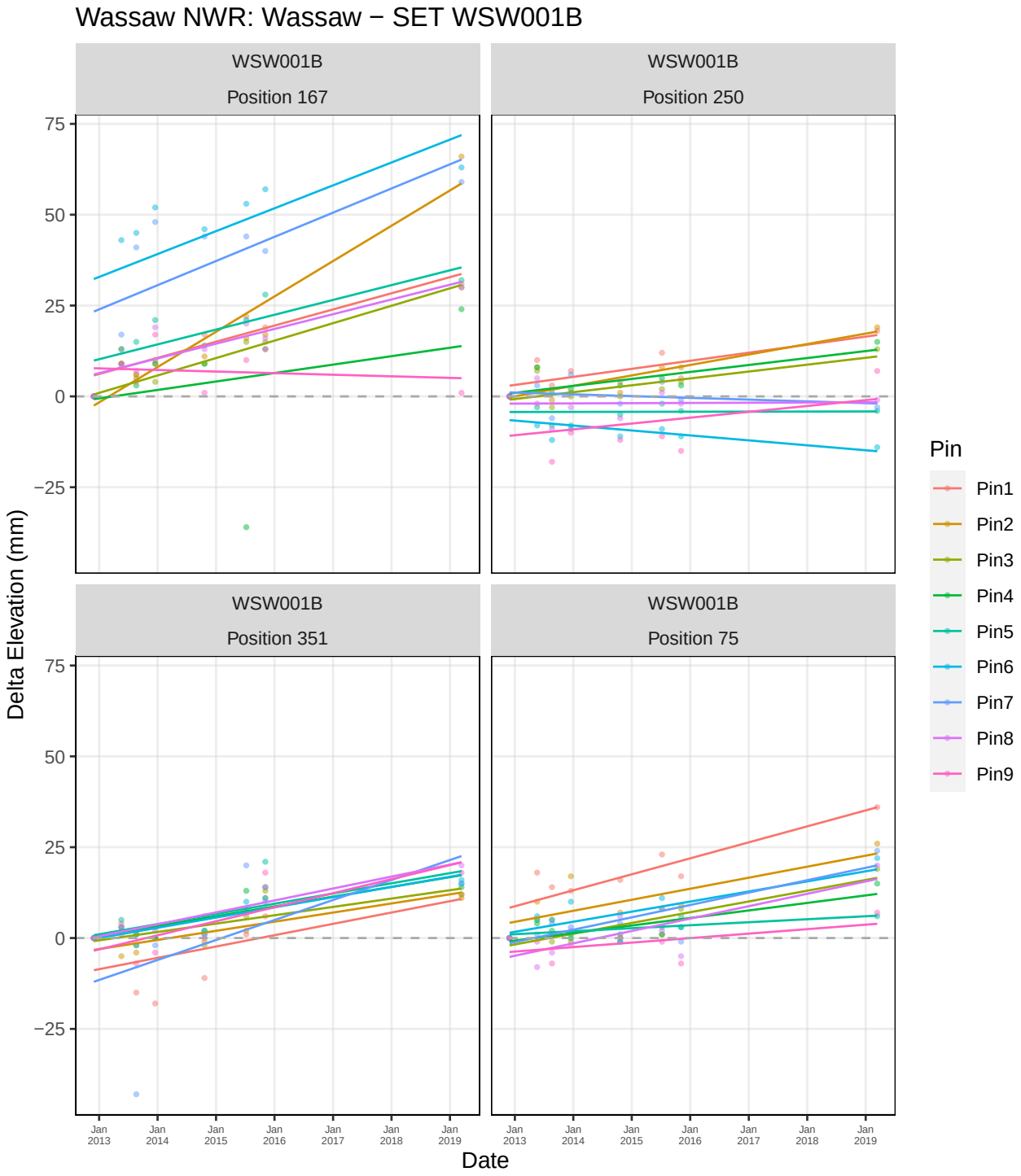
Pin8
Pin9


Wassaw NWR: Wassaw − SET WSW001B
WSW001B
Position 167
WSW001B
Position 250
WSW001B
Position 351
WSW001B
Position 75
Delta Elevation (mm)
75
50
25
0
−25
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Date
Pin
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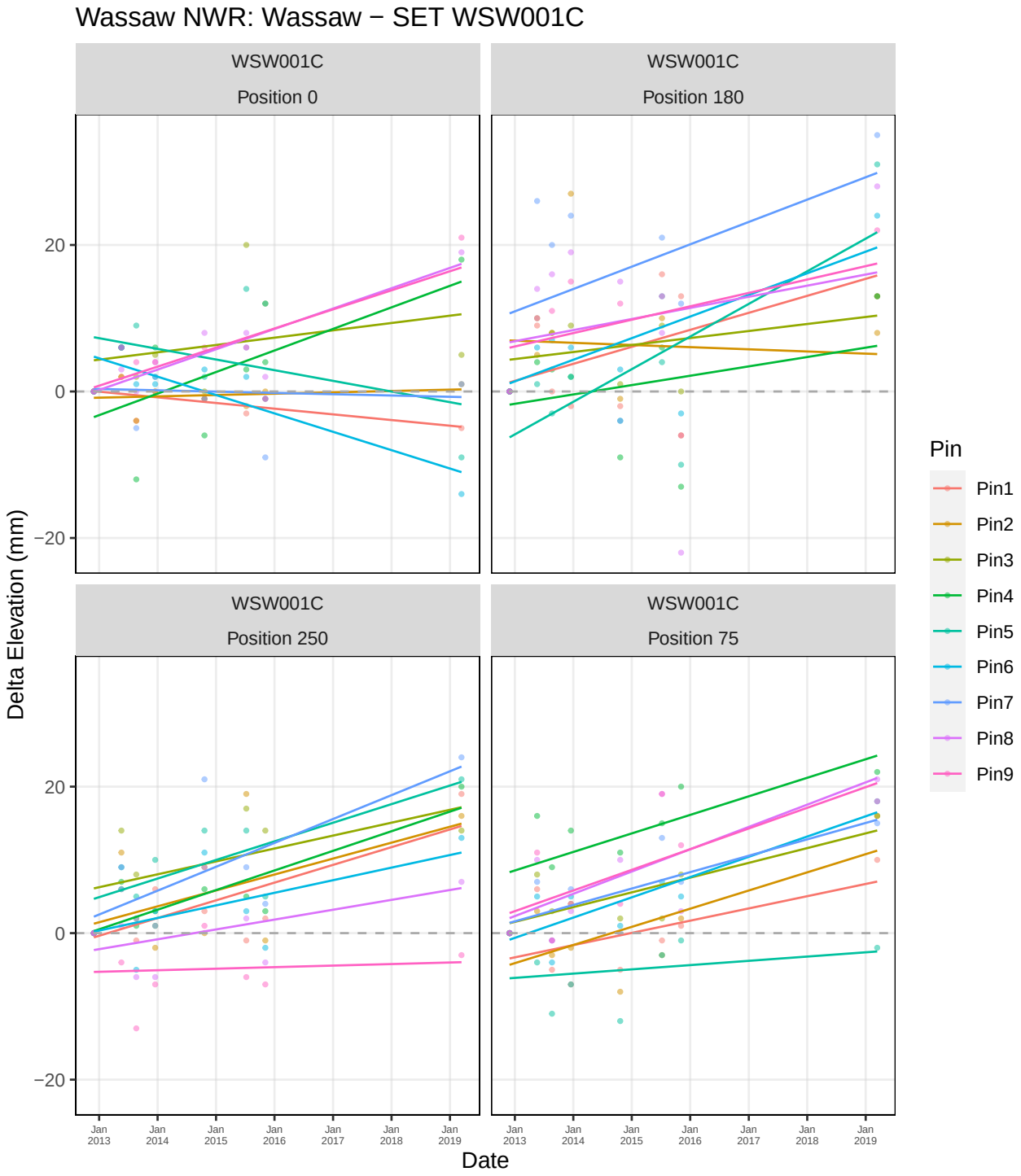
Pin4
Pin5
Pin6
Pin7
Pin8
Pin9


Wassaw NWR: Wassaw − SET WSW001C
WSW001C
Position 0
WSW001C
Position 180
WSW001C
Position 250
WSW001C
Position 75
Delta Elevation (mm)
20
0
−20
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Date
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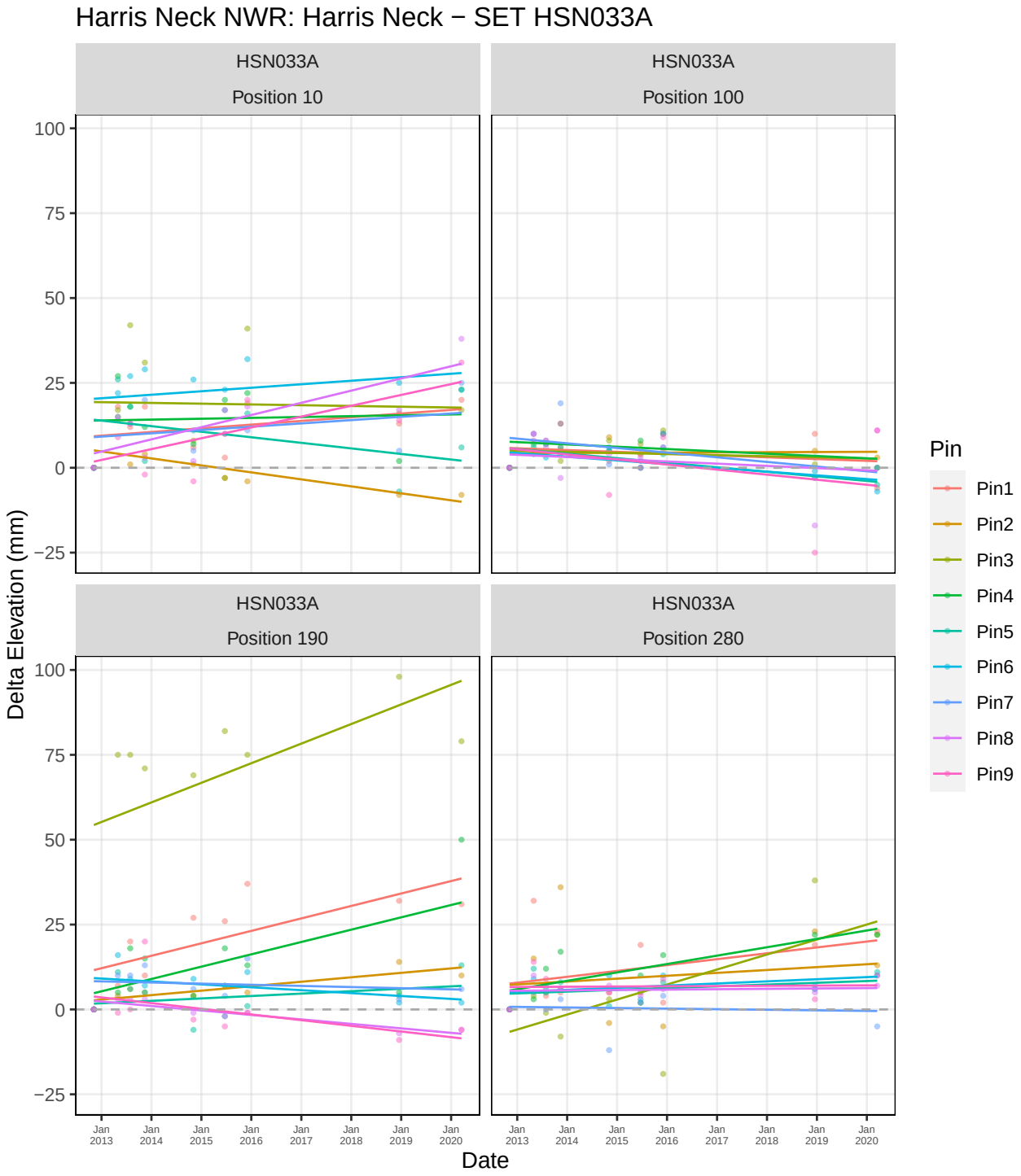
Harris Neck NWR: Harris Neck − SET HSN033A
HSN033A
Position 10
HSN033A
Position 100
HSN033A
Position 190
HSN033A
Position 280
Delta Elevation (mm)
100
75
50
25
0
−25
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Jan 2020
Date
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Pin1
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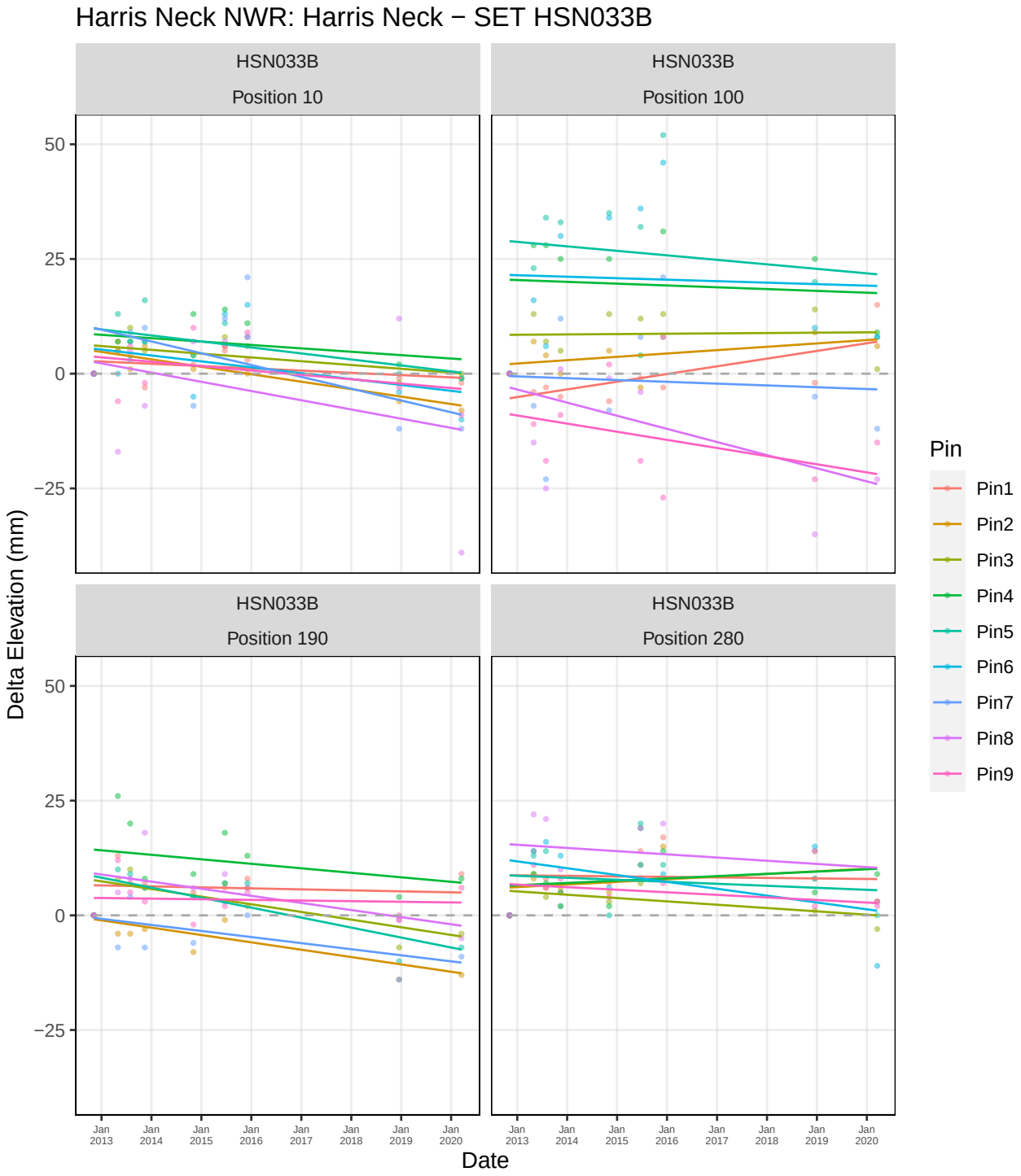
Pin9


Harris Neck NWR: Harris Neck − SET HSN033B
HSN033B
Position 10
HSN033B
Position 100
HSN033B
Position 190
HSN033B
Position 280
Delta Elevation (mm)
50
25
0
−25
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Jan 2020
Date
Pin
Pin1
Pin2
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Pin4
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Pin7
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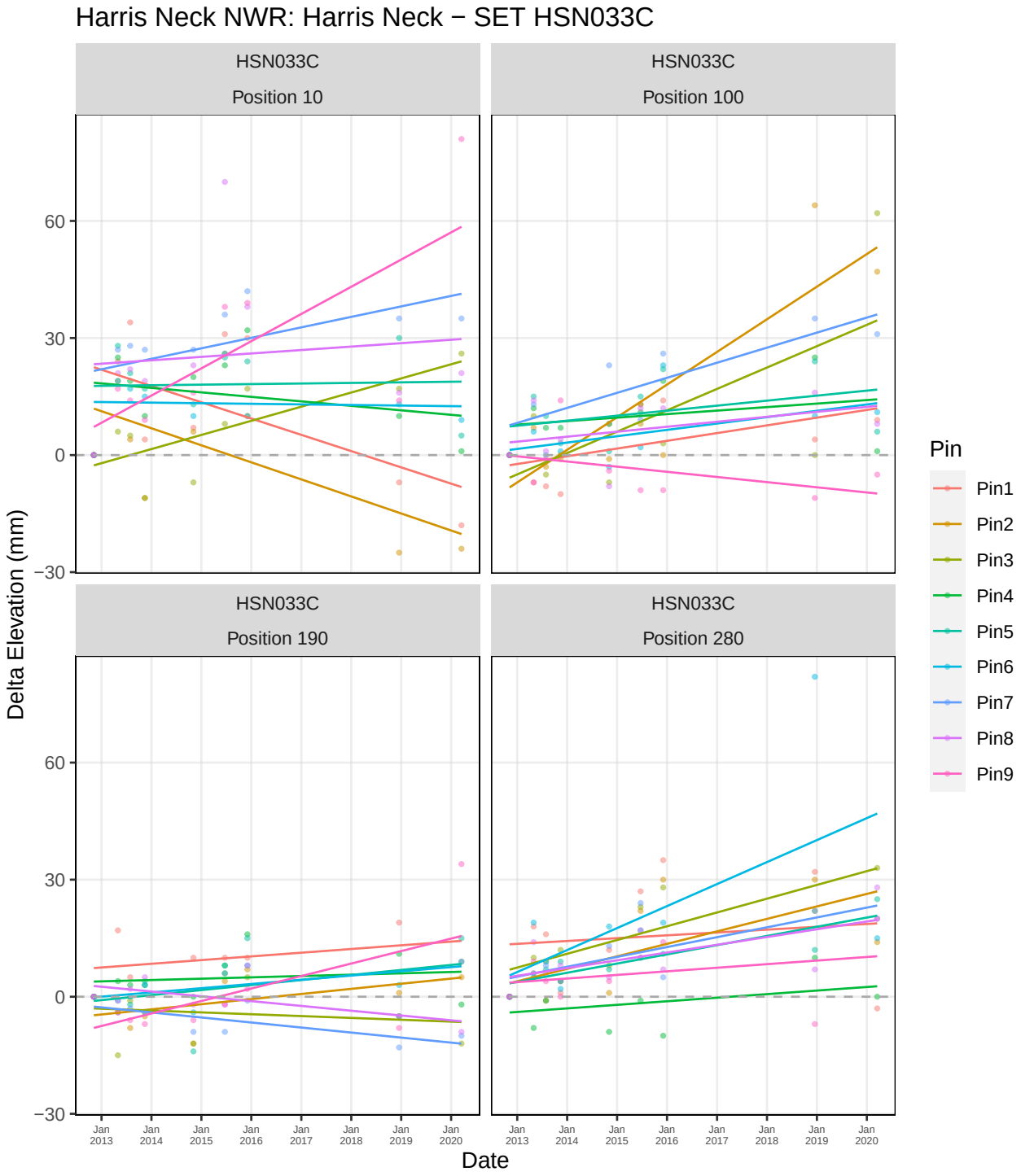
Harris Neck NWR: Harris Neck − SET HSN033C
HSN033C
Position 10
HSN033C
Position 100
HSN033C
Position 190
HSN033C
Position 280
Delta Elevation (mm)
60
30
0
−30
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
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Date
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Pin1
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Pin4
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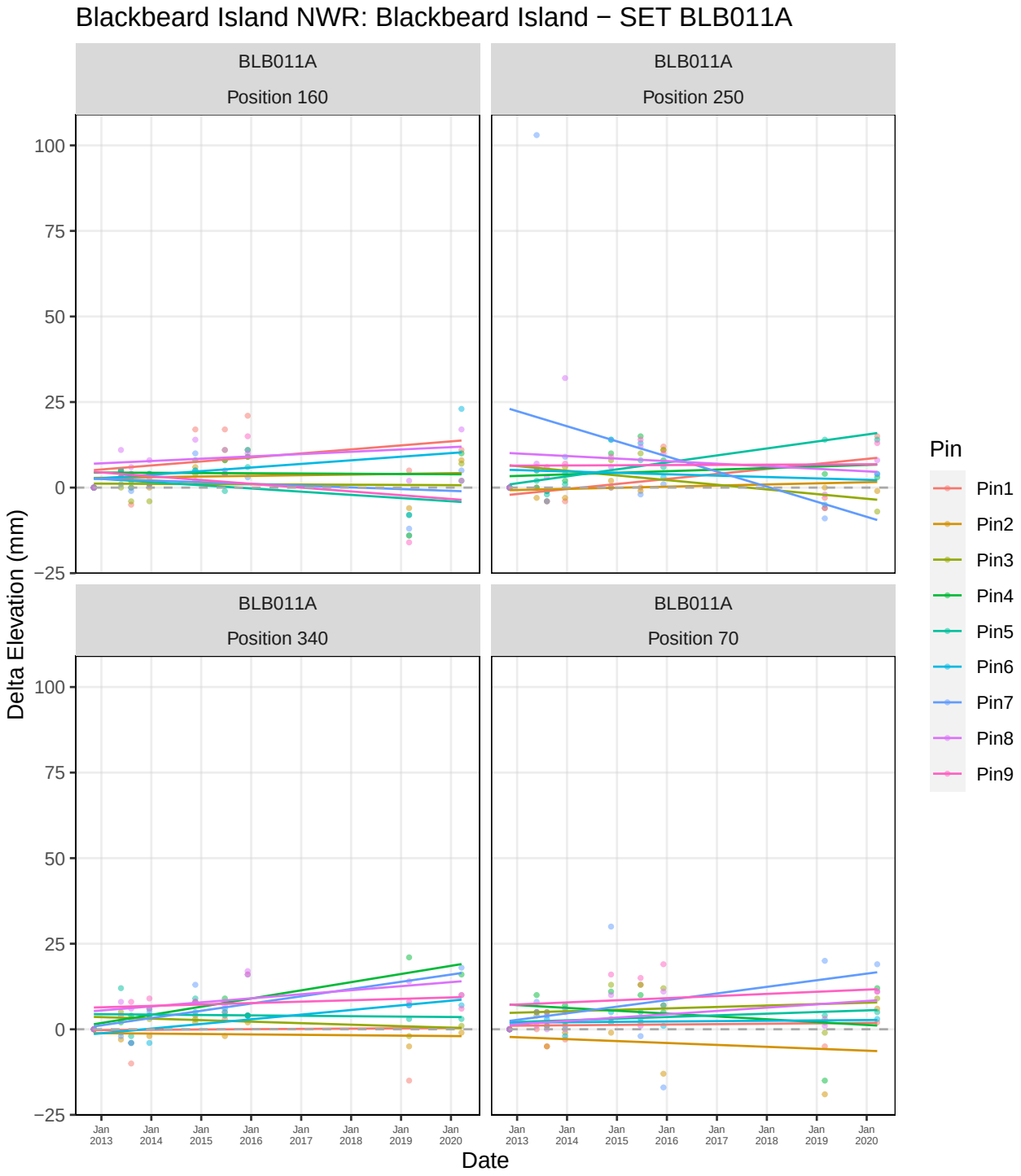
Blackbeard Island NWR: Blackbeard Island − SET BLB011A
BLB011A
Position 160
BLB011A
Position 250
BLB011A
Position 340
BLB011A
Position 70
Delta Elevation (mm)
100
75
50
25
0
−25
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
Jan 2019
Jan 2020
Date
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Pin1
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Pin4
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Pin7
Pin8
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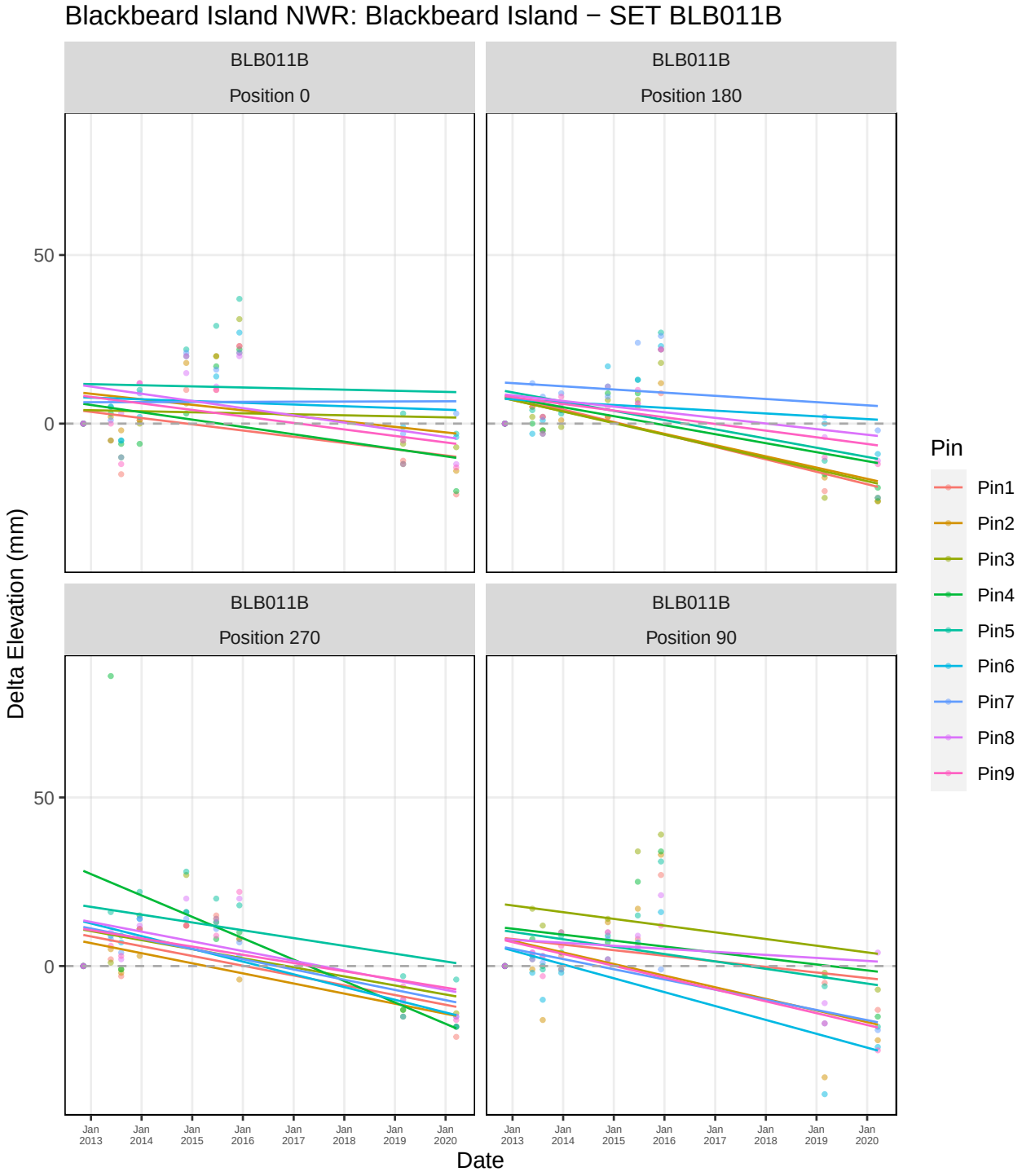
Blackbeard Island NWR: Blackbeard Island − SET BLB011B
BLB011B
Position 0
BLB011B
Position 180
BLB011B
Position 270
BLB011B
Position 90
Delta Elevation (mm)
50
0
Jan 2013
Jan 2014
Jan 2015
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Date
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Pin1
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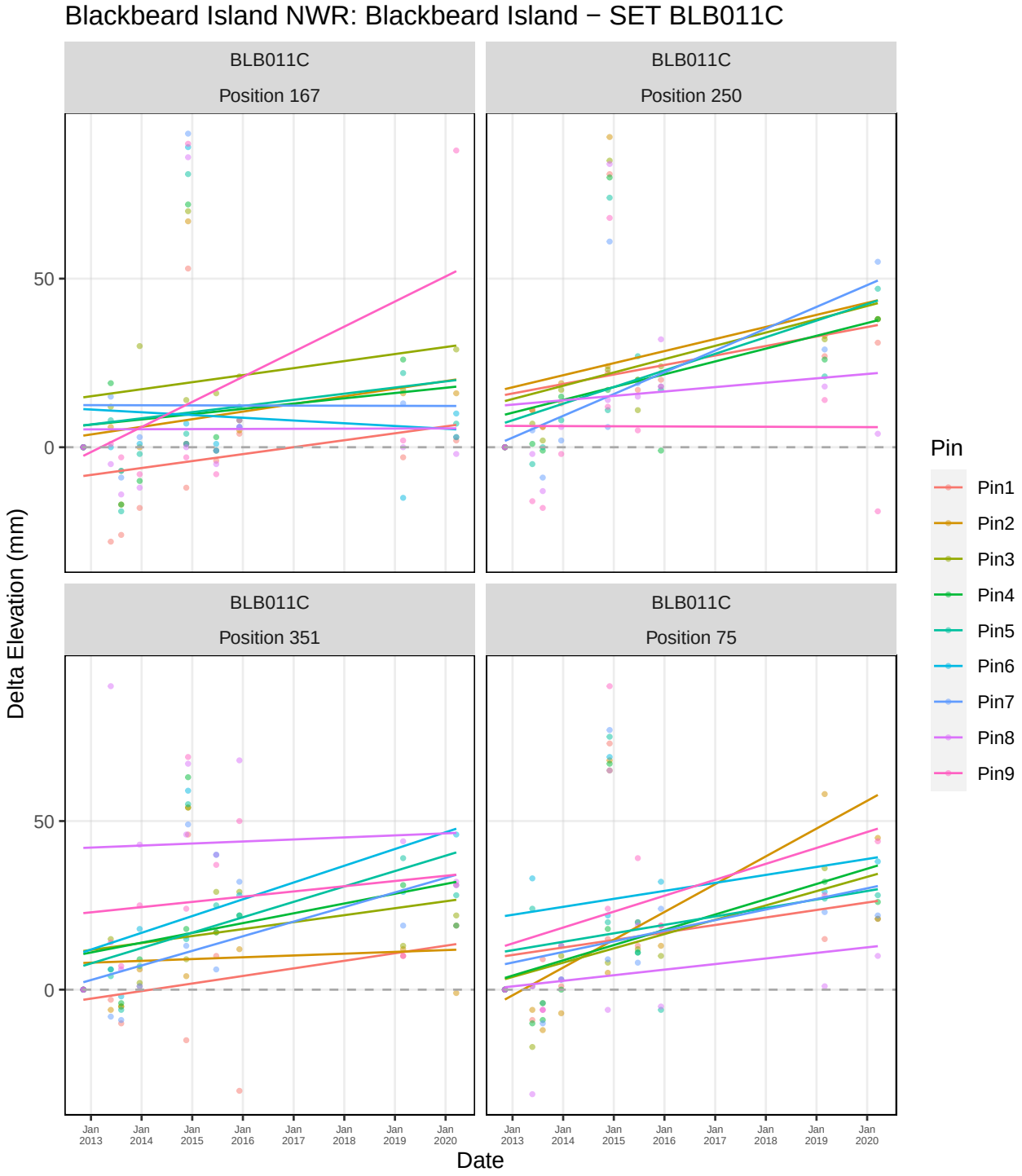
Blackbeard Island NWR: Blackbeard Island − SET BLB011C
BLB011C
Position 167
BLB011C
Position 250
BLB011C
Position 351
BLB011C
Position 75
Delta Elevation (mm)
50
0
Jan 2013
Jan 2014
Jan 2015
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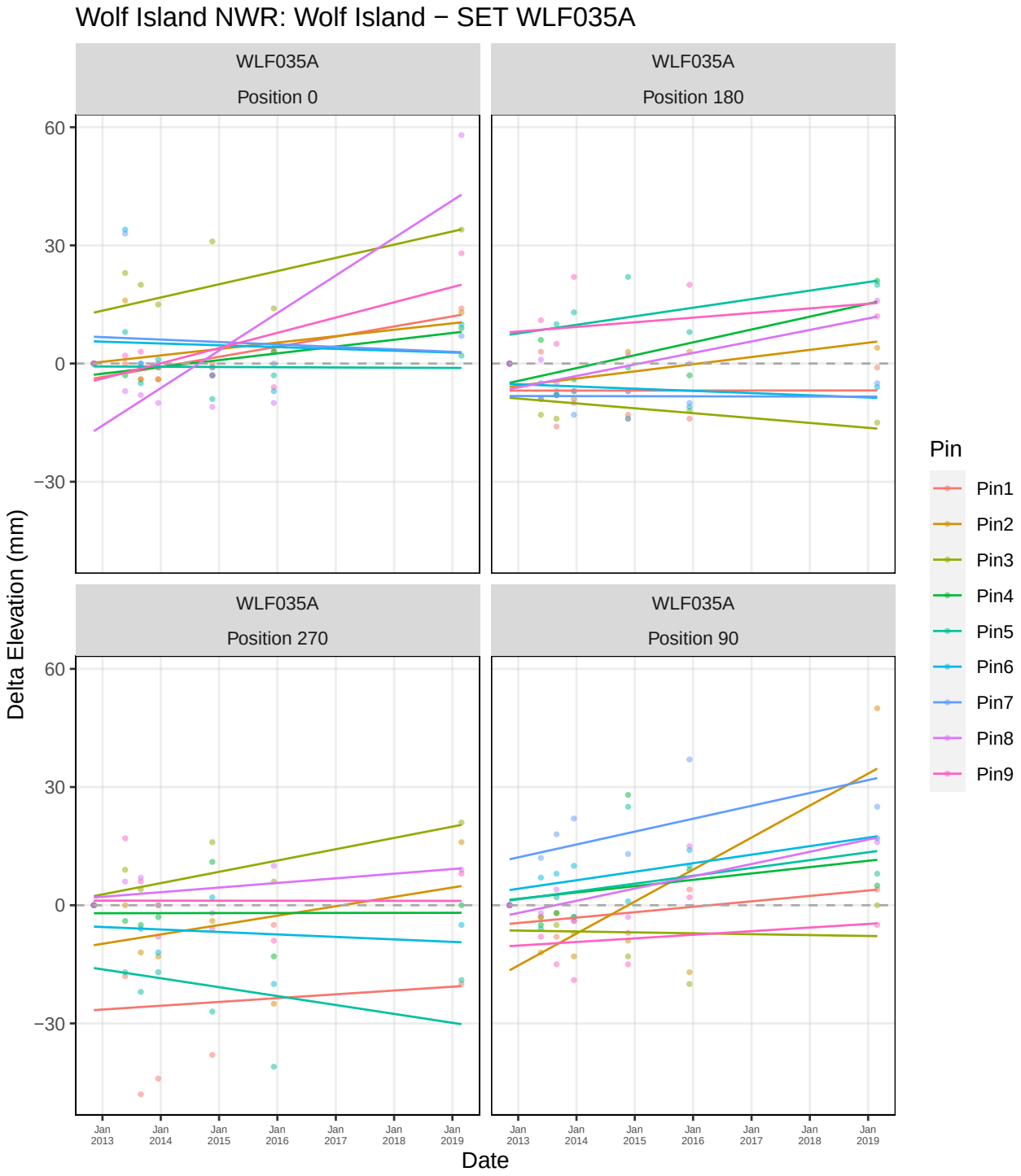
Wolf Island NWR: Wolf Island − SET WLF035A
WLF035A
Position 0
WLF035A
Position 180
WLF035A
Position 270
WLF035A
Position 90
Delta Elevation (mm)
60
30
0
−30
Jan 2013
Jan 2014
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Date
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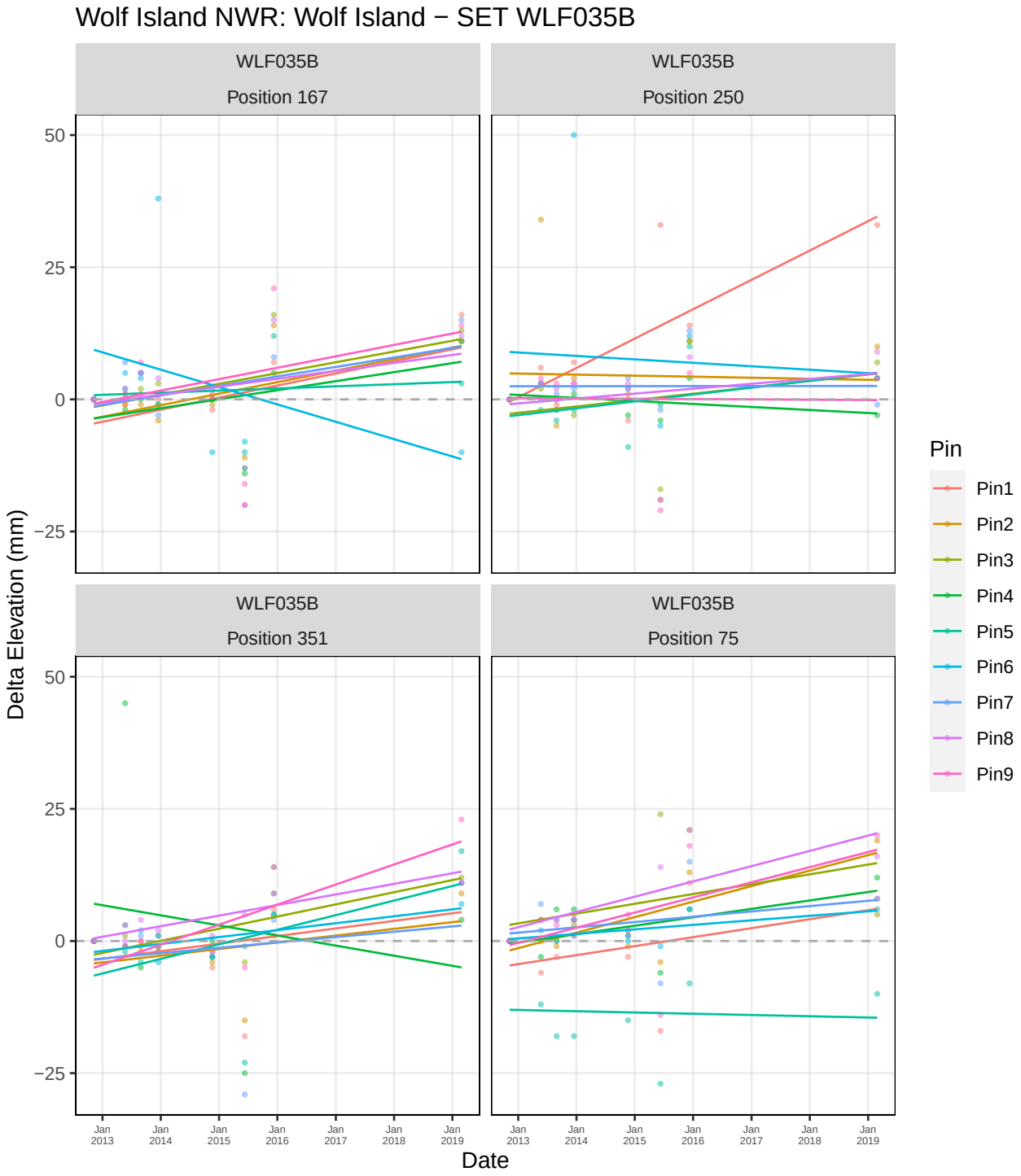
Wolf Island NWR: Wolf Island − SET WLF035B
WLF035B
Position 167
WLF035B
Position 250
WLF035B
Position 351
WLF035B
Position 75
Delta Elevation (mm)
50
25
0
−25
Jan 2013
Jan 2014
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Jan 2016
Jan 2017
Jan 2018
Jan 2019
Date
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Pin7
Pin8
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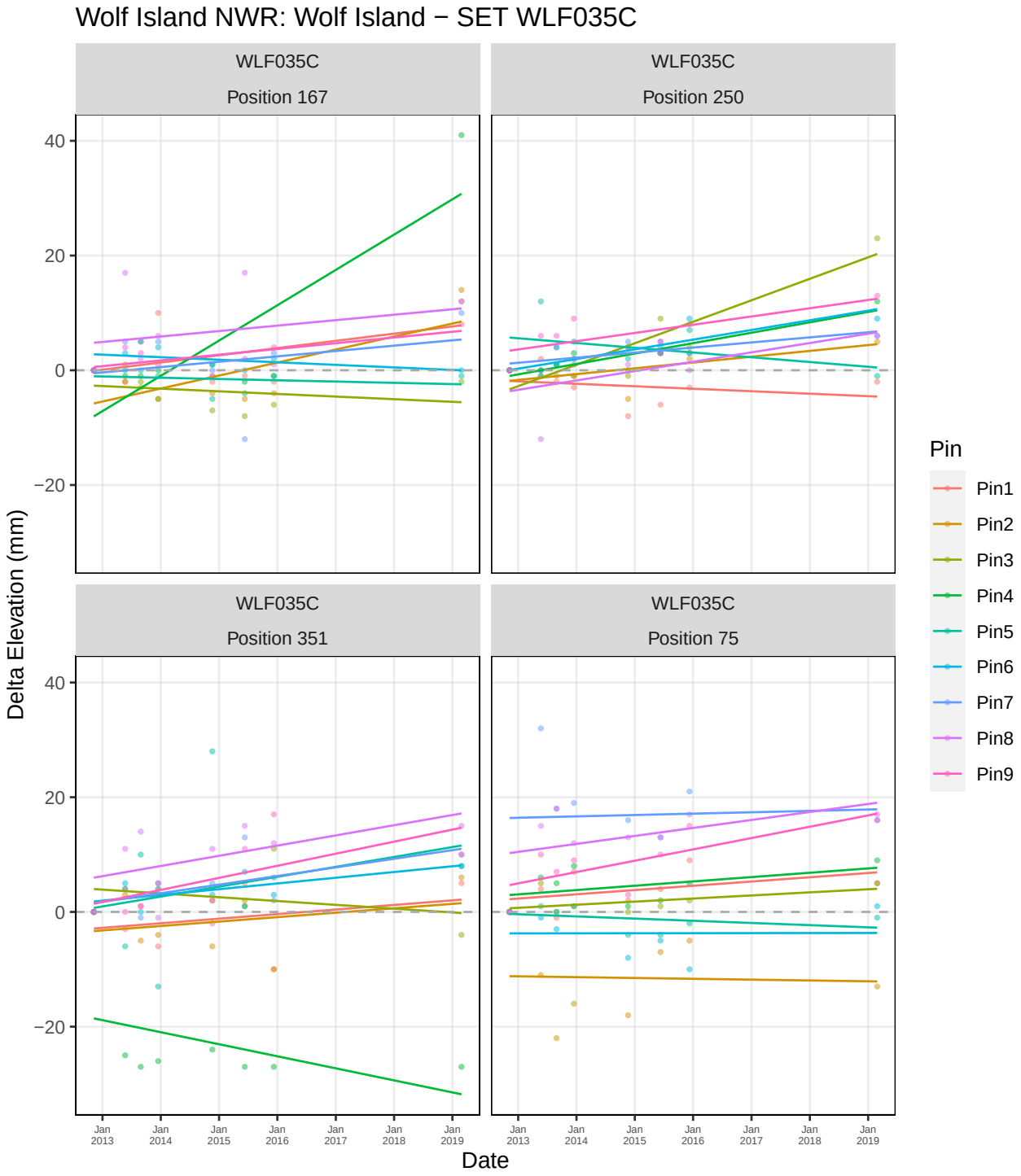
Wolf Island NWR: Wolf Island − SET WLF035C
WLF035C
Position 167
WLF035C
Position 250
WLF035C
Position 351
WLF035C
Position 75
Delta Elevation (mm)
40
20
0
−20
Jan 2013
Jan 2014
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Jan 2016
Jan 2017
Jan 2018
Jan 2019
Date
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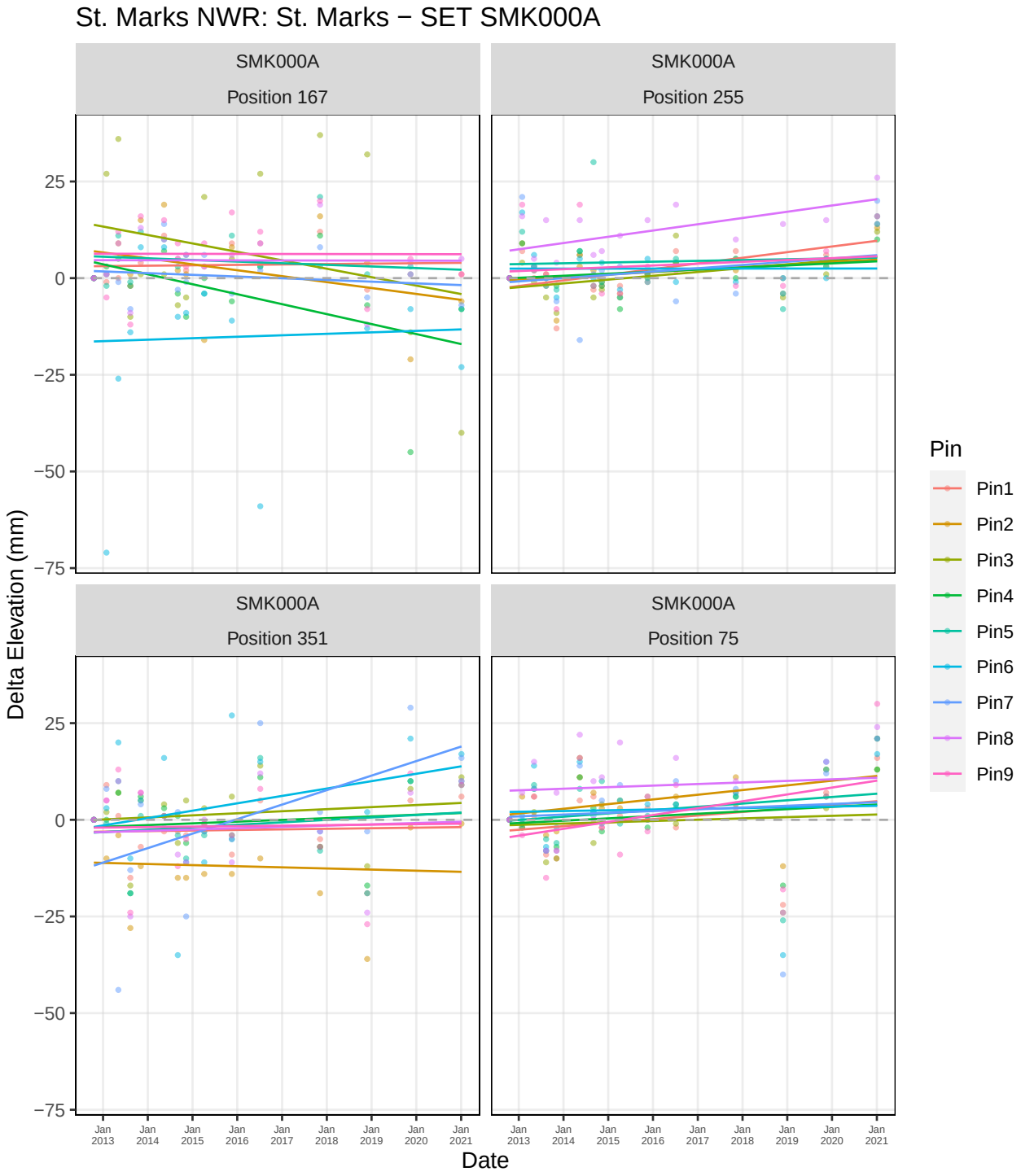
St. Marks NWR: St. Marks − SET SMK000A
SMK000A
Position 167
SMK000A
Position 255
SMK000A
Position 351
SMK000A
Position 75
Delta Elevation (mm)
25
0
−25
−50
−75
Jan 2013
Jan 2014
Jan 2015
Jan 2016
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Jan 2020
Jan 2021
Date
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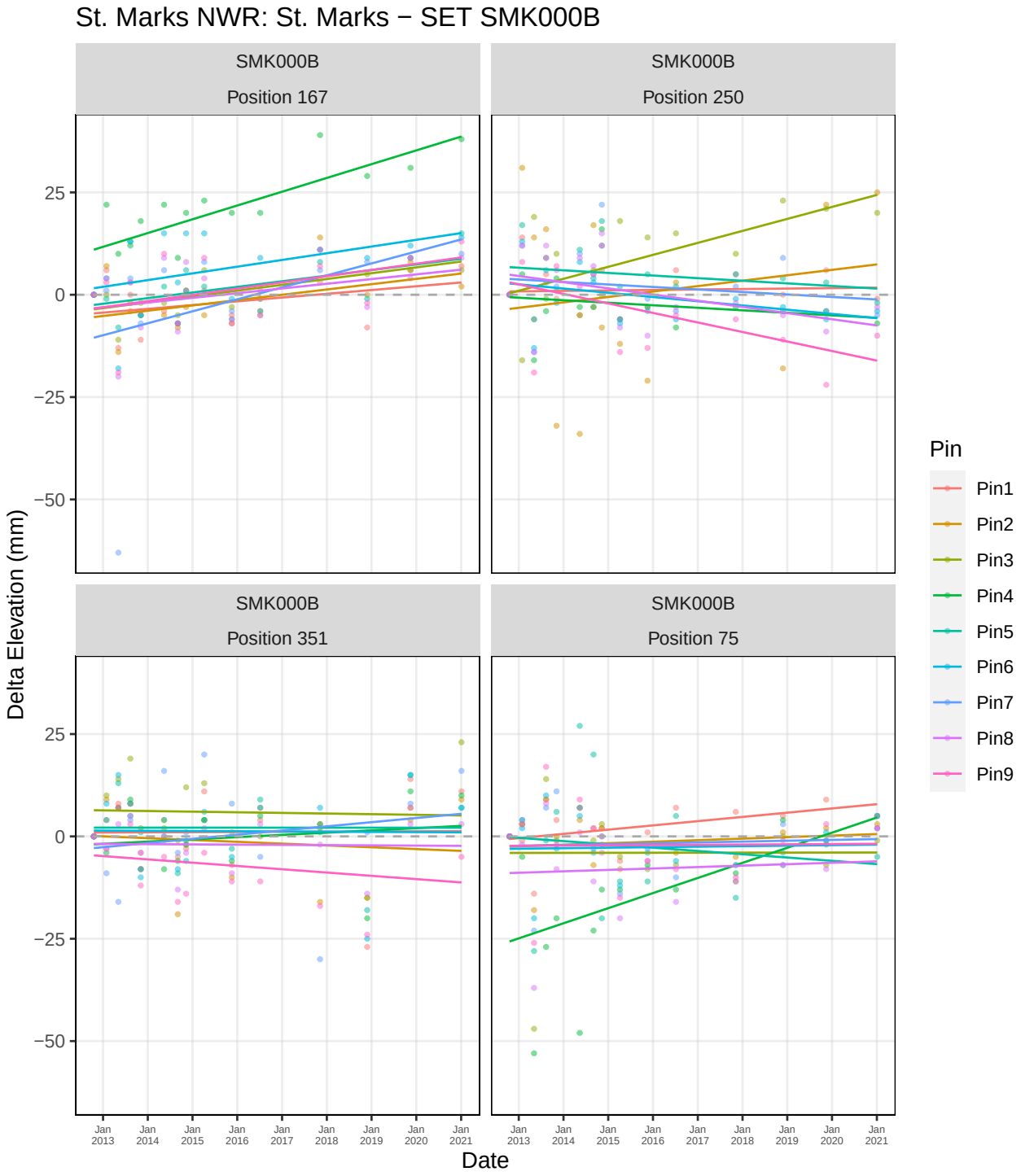
St. Marks NWR: St. Marks − SET SMK000B
SMK000B
Position 167
SMK000B
Position 250
SMK000B
Position 351
SMK000B
Position 75
Delta Elevation (mm)
25
0
−25
−50
Jan 2013
Jan 2014
Jan 2015
Jan 2016
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Jan 2020
Jan 2021
Date
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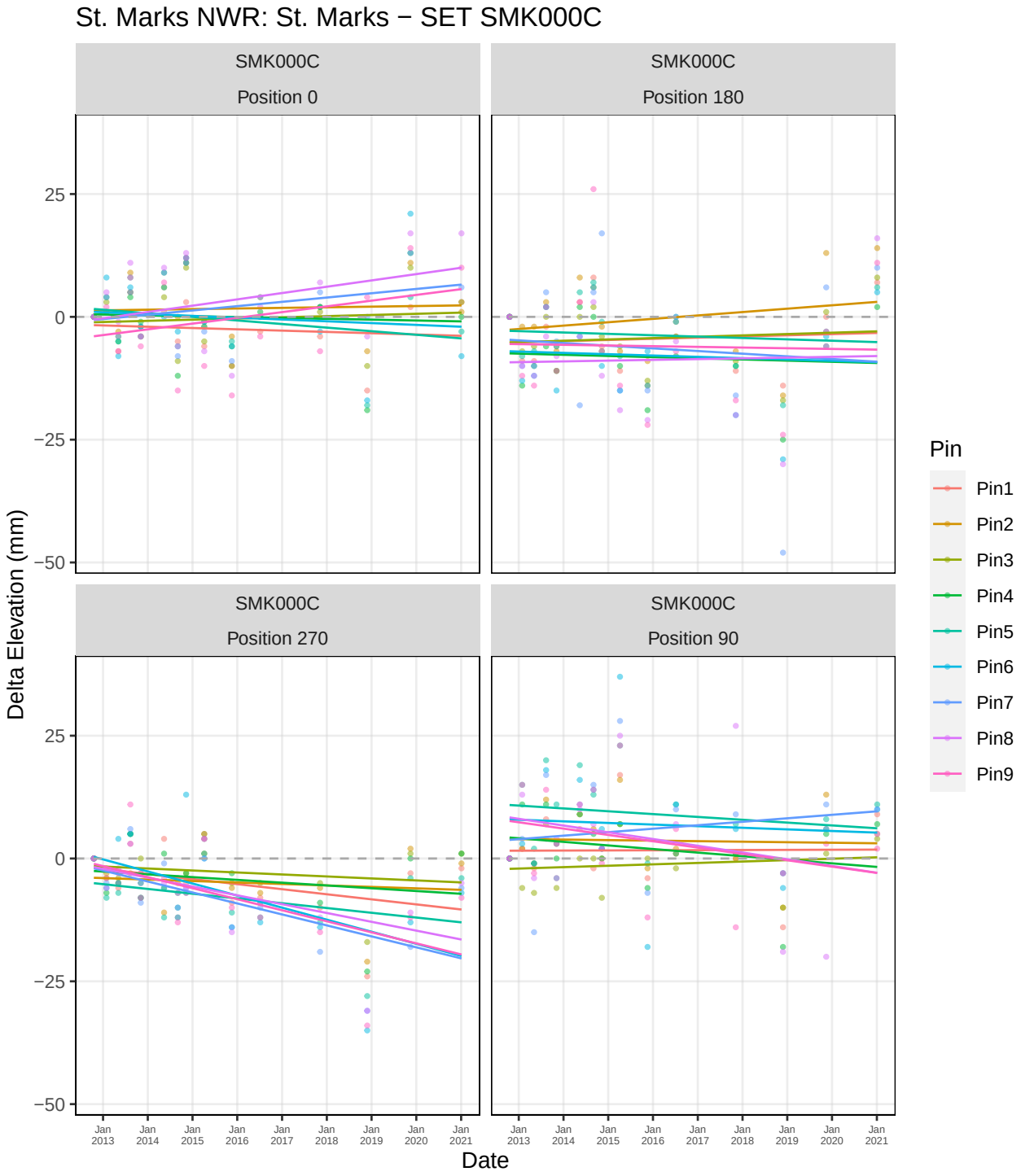
St. Marks NWR: St. Marks − SET SMK000C
SMK000C
Position 0
SMK000C
Position 180
SMK000C
Position 270
SMK000C
Position 90
Delta Elevation (mm)
25
0
−25
−50
Jan 2013
Jan 2014
Jan 2015
Jan 2016
Jan 2017
Jan 2018
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Jan 2020
Jan 2021
Date
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Appendix B. Table showing number of visits per year of sampling. NAs indicate no data collected in a given year.

Site_Name	Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Alligator River - Pocosin	ALL030A	NA	NA	NA	2	1	2	1	1	1	1	1	NA
Alligator River - Pocosin	ALL030B	NA	NA	NA	2	1	2	1	1	1	1	1	NA
Alligator River - Pocosin	ALL030C	NA	NA	NA	2	1	2	1	1	1	1	1	NA
Alligator River NWR - Salt Marsh	ALL005A	NA	NA	NA	3	1	2	1	1	NA	2	1	NA
Alligator River NWR - Salt Marsh	ALL005B	NA	NA	NA	3	1	2	1	1	NA	2	1	NA
Alligator River NWR - Salt Marsh	ALL005C	NA	NA	NA	3	1	2	1	1	NA	2	1	NA
Blackbeard Island NWR	BLB011A	NA	NA	1	3	1	2	NA	NA	NA	1	1	NA
Blackbeard Island NWR	BLB011B	NA	NA	1	3	1	2	NA	NA	NA	1	1	NA
Blackbeard Island NWR	BLB011C	NA	NA	1	3	2	2	NA	NA	NA	1	1	NA
Cape Romain - Horsehead Key	CRM002A	1	3	3	3	1	NA	2	NA	1	NA	NA	NA
Cape Romain - Horsehead Key	CRM002B	1	3	3	3	1	NA	2	NA	1	NA	NA	NA
Cape Romain - Horsehead Key	CRM002C	1	3	3	3	1	NA	2	NA	NA	NA	NA	NA
Cape Romain - Racoon Key	CRM008A	1	3	3	3	1	NA	2	NA	NA	NA	NA	NA
Cape Romain - Racoon Key	CRM008B	1	3	3	3	1	NA	2	NA	NA	NA	NA	NA
Cedar Island NWR	CDR027A	NA	NA	NA	4	2	1	2	1	NA	1	1	NA
Cedar Island NWR	CDR027B	NA	NA	NA	4	2	1	2	1	NA	1	1	NA
Cedar Island NWR	CDR027C	NA	NA	NA	4	2	1	2	NA	NA	1	1	NA
Currituck NWR	CRT026A	NA	NA	NA	4	2	1	1	NA	1	1	NA	NA
Currituck NWR	CRT026B	NA	NA	NA	4	2	1	1	NA	2	1	NA	NA
Currituck NWR	CRT026C	NA	NA	NA	4	2	1	1	NA	2	1	NA	NA
ACE Basin NWR	ABS017A	NA	NA	1	2	1	1	NA	1	NA	2	NA	NA
ACE Basin NWR	ABS017B	NA	NA	1	2	1	1	NA	1	NA	2	NA	NA
ACE Basin NWR	ABS017C	NA	NA	1	2	1	1	NA	1	NA	2	NA	NA
Harris Neck NWR	HSN033A	NA	NA	1	3	1	2	NA	NA	1	NA	1	NA
Harris Neck NWR	HSN033B	NA	NA	1	3	1	2	NA	NA	1	NA	1	NA
Harris Neck NWR	HSN033C	NA	NA	1	3	1	2	NA	NA	1	NA	1	NA
Lower Suwanee NWR - Oligohaline	SWE038A	NA	NA	NA	3	1	NA	NA	NA	NA	NA	NA	NA

Site_Name	Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Lower Suwanee NWR - Oligohaline	SWE038B	NA	NA	NA	3	1	NA	NA	NA	NA	NA	NA	NA
Lower Suwanee NWR - Oligohaline	SWE038C	NA	NA	NA	3	1	NA	NA	NA	NA	NA	NA	NA
Lower Suwanee NWR - Salt Marsh	SWE002A	NA	NA	1	2	1	NA	1	NA	NA	NA	NA	NA
Lower Suwanee NWR - Salt Marsh	SWE002B	NA	NA	1	2	1	NA	1	NA	NA	NA	NA	NA
Lower Suwanee NWR - Salt Marsh	SWE002C	NA	NA	1	2	1	NA	1	NA	NA	NA	NA	NA
Mackay Island NWR	MCI026A	NA	NA	NA	4	2	1	1	NA	2	1	NA	NA
Mackay Island NWR	MCI026B	NA	NA	NA	4	2	1	1	NA	2	1	NA	NA
Mackay Island NWR	MCI026C	NA	NA	NA	4	2	1	1	NA	2	1	NA	NA
Pea Island NWR	PLD010A	NA	NA	NA	2	1	2	1	1	NA	2	1	NA
Pea Island NWR	PLD010B	NA	NA	NA	2	1	2	1	1	NA	2	1	NA
Pea Island NWR	PLD010C	NA	NA	NA	2	1	2	1	1	NA	2	1	NA
Pinckney Island NWR	PKY008A	NA	NA	1	3	1	1	1	NA	NA	1	1	NA
Pinckney Island NWR	PKY008B	NA	NA	1	3	1	1	1	NA	NA	1	1	NA
Pinckney Island NWR	PKY008C	NA	NA	1	3	1	1	1	NA	NA	1	1	NA
Pocosin Lakes NWR	POC016A	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Pocosin Lakes NWR	POC016B	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Pocosin Lakes NWR	POC016C	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Roanoke River NWR	RRV013A	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Roanoke River NWR	RRV013B	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Roanoke River NWR	RRV013C	NA	NA	NA	4	3	2	1	1	1	1	1	NA
Savannah NWR	SAV004A	NA	NA	1	2	2	2	NA	NA	NA	1	1	NA
Savannah NWR	SAV004B	NA	NA	1	2	2	2	NA	NA	NA	1	1	NA
Savannah NWR	SAV004C	NA	NA	1	2	2	2	NA	NA	NA	1	1	NA
St. Marks NWR	SMK000A	NA	NA	1	4	3	2	1	1	1	1	NA	1
St. Marks NWR	SMK000B	NA	NA	1	4	3	2	1	1	1	1	NA	1
St. Marks NWR	SMK000C	NA	NA	1	4	3	2	1	1	1	1	NA	1
Swanquarter NWR	SWQ000A	NA	NA	NA	4	2	2	1	NA	1	2	1	NA
Swanquarter NWR	SWQ000B	NA	NA	NA	4	2	2	1	NA	1	2	1	NA

Site_Name	Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Swanquarter NWR	SWQ000C	NA	NA	NA	4	2	2	1	NA	1	2	1	NA
Waccamaw NWR	WAW000A	NA	NA	1	4	2	NA	1	1	NA	2	NA	NA
Waccamaw NWR	WAW000B	NA	NA	1	4	2	NA	1	1	NA	2	NA	NA
Waccamaw NWR	WAW000C	NA	NA	1	4	2	NA	1	NA	NA	2	NA	NA
Wassaw NWR	WSW001A	NA	NA	1	3	1	2	NA	NA	NA	1	NA	NA
Wassaw NWR	WSW001B	NA	NA	1	3	1	2	NA	NA	NA	1	NA	NA
Wassaw NWR	WSW001C	NA	NA	1	3	1	2	NA	NA	NA	1	NA	NA
Wolf Island NWR	WLF035A	NA	NA	1	3	1	1	NA	NA	NA	1	NA	NA
Wolf Island NWR	WLF035B	NA	NA	1	3	1	2	NA	NA	NA	1	NA	NA
Wolf Island NWR	WLF035C	NA	NA	1	3	1	2	NA	NA	NA	1	NA	NA

Appendix C. Table of list of records where replicate data were collected during a single sampling event.

Refuge	Site	Station	EventDate	Reader
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008A	4/28/2015	Wayne Harris
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008B	4/28/2015	Wayne Harris
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008C	4/28/2015	Chuck Hayes
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016A	1/27/2014	Rosetta Railey
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016B	1/27/2014	Rosetta Railey
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016C	1/27/2014	Rosetta Railey
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000A	9/3/2014	Mike Keys
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000A	11/7/2017	M. Forbes Boyle
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000B	9/3/2014	Mike Keys
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000B	11/7/2017	M. Forbes Boyle
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000C	9/3/2014	Mike Keys
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000C	11/7/2017	M. Forbes Boyle
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000A	5/14/2015	Pete Campbell
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000A	3/8/2018	Michelle Moorman
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000B	5/14/2015	Pete Campbell
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000B	3/8/2018	Michelle Moorman
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000C	5/14/2015	Pete Campbell
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000C	3/8/2018	Michelle Moorman
Waccamaw National Wildlife Refuge	Waccamaw NWR	WAW000A	1/24/2017	Nicole Rankin
Waccamaw National Wildlife Refuge	Waccamaw NWR	WAW000B	1/24/2017	Nicole Rankin
Ernest F. Hollings Ace Basin National Wildlife Refuge	ACE Basin NWR	ABS017B	2/7/2017	Nicole Rankin
Ernest F. Hollings Ace Basin National Wildlife Refuge	ACE Basin NWR	ABS017C	2/7/2017	Nicole Rankin
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002A	6/23/2016	Larry Woodward
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002B	6/23/2016	Larry Woodward

Refuge	Site	Station	EventDate	Reader
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002C	6/23/2016	Larry Woodward

Appendix D. Table of list of raw (R) or provisional (P) data not included within analyses.

Refuge	Site	Station	EventDate	Reader	Data_Process_Level
NA	NA	NA	NA	NA	NA

Appendix E. Table of all SET pipe azimuth directions

Refuge	Site_Name	Station_Name	PipeDirectionAzimuths
Alligator River National Wildlife Refuge	Alligator River - Pocosin	ALL030A	137, 182, 222, 35
Alligator River National Wildlife Refuge	Alligator River - Pocosin	ALL030B	165, 255, 345, 75
Alligator River National Wildlife Refuge	Alligator River - Pocosin	ALL030C	167, 252, 351, 75
Alligator River National Wildlife Refuge	Alligator River NWR - Salt Marsh	ALL005A	170, 260, 350, 80
Alligator River National Wildlife Refuge	Alligator River NWR - Salt Marsh	ALL005B	170, 260, 350, 80
Alligator River National Wildlife Refuge	Alligator River NWR - Salt Marsh	ALL005C	170, 260, 350, 80
Blackbeard Island National Wildlife Refuge	Blackbeard Island NWR	BLB011A	160, 250, 340, 70
Blackbeard Island National Wildlife Refuge	Blackbeard Island NWR	BLB011B	0, 180, 270, 90
Blackbeard Island National Wildlife Refuge	Blackbeard Island NWR	BLB011C	170, 260, 350, 80
Cape Romain National Wildlife Refuge	Cape Romain - Horsehead Key	CRM002A	135, 45, 315, 225
Cape Romain National Wildlife Refuge	Cape Romain - Horsehead Key	CRM002B	135, 45, 315, 225
Cape Romain National Wildlife Refuge	Cape Romain - Horsehead Key	CRM002C	315, 225, 135, 45
Cape Romain National Wildlife Refuge	Cape Romain - Racoon Key	CRM008A	270, 180, 90, 0
Cape Romain National Wildlife Refuge	Cape Romain - Racoon Key	CRM008B	90, 0, 270, 180
Cedar Island National Wildlife Refuge	Cedar Island NWR	CDR027A	170, 260, 350, 80
Cedar Island National Wildlife Refuge	Cedar Island NWR	CDR027B	0, 180, 270, 90
Cedar Island National Wildlife Refuge	Cedar Island NWR	CDR027C	170, 260, 350, 80
Currituck National Wildlife Refuge	Currituck NWR	CRT026A	170, 260, 350, 80
Currituck National Wildlife Refuge	Currituck NWR	CRT026B	170, 260, 350, 80
Currituck National Wildlife Refuge	Currituck NWR	CRT026C	0, 180, 270, 90
Ernest F. Hollings Ace Basin National Wildlife Refuge	ACE Basin NWR	ABS017A	0, 180, 270, 90
Ernest F. Hollings Ace Basin National Wildlife Refuge	ACE Basin NWR	ABS017B	170, 260, 350, 80
Ernest F. Hollings Ace Basin National Wildlife Refuge	ACE Basin NWR	ABS017C	0, 180, 270, 90
Harris Neck National Wildlife Refuge	Harris Neck NWR	HSN033A	100, 10, 190, 280
Harris Neck National Wildlife Refuge	Harris Neck NWR	HSN033B	100, 10, 190, 280

Refuge	Site_Name	Station_Name	PipeDirectionAzimuths
Harris Neck National Wildlife Refuge	Harris Neck NWR	HSN033C	100, 10, 190, 280
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Oligohaline	SWE038A	164, 254, 344, 75
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Oligohaline	SWE038B	0, 180, 265, 92
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Oligohaline	SWE038C	172, 259, 352, 80
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002A	170, 260, 350, 80
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002B	0, 180, 270, 90
Lower Suwannee National Wildlife Refuge	Lower Suwanee NWR - Salt Marsh	SWE002C	170, 260, 350, 80
Mackay Island National Wildlife Refuge	Mackay Island NWR	MCI026A	0, 180, 270, 90
Mackay Island National Wildlife Refuge	Mackay Island NWR	MCI026B	175, 270, 355, 90
Mackay Island National Wildlife Refuge	Mackay Island NWR	MCI026C	170, 260, 345, 80
Pea Island National Wildlife Refuge	Pea Island NWR	PLD010A	170, 260, 350, 80
Pea Island National Wildlife Refuge	Pea Island NWR	PLD010B	170, 260, 350, 80
Pea Island National Wildlife Refuge	Pea Island NWR	PLD010C	170, 260, 350, 80
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008A	100, 10, 190, 280
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008B	0, 180, 270, 90
Pinckney Island National Wildlife Refuge	Pinckney Island NWR	PKY008C	0, 180, 270, 90
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016A	170, 260, 350, 80
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016B	170, 250, 350, 80
Pocosin Lakes National Wildlife Refuge	Pocosin Lakes NWR	POC016C	160, 250, 340, 70
Roanoke River National Wildlife Refuge	Roanoke River NWR	RRV013A	160, 250, 340, 70
Roanoke River National Wildlife Refuge	Roanoke River NWR	RRV013B	165, 250, 345, 70
Roanoke River National Wildlife Refuge	Roanoke River NWR	RRV013C	170, 250, 350, 80
Savannah-Pinckney National Wildlife Refuges	Savannah NWR	SAV004A	170, 260, 350, 80
Savannah-Pinckney National Wildlife Refuges	Savannah NWR	SAV004B	110, 200, 20, 290
Savannah-Pinckney National Wildlife Refuges	Savannah NWR	SAV004C	0, 100, 180, 280
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000A	170, 255, 350, 80

Refuge	Site_Name	Station_Name	PipeDirectionAzimuths
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000B	170, 260, 350, 80
St. Marks National Wildlife Refuge	St. Marks NWR	SMK000C	0, 180, 270, 90
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000A	160, 250, 340, 70
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000B	170, 260, 350, 80
Swanquarter National Wildlife Refuge	Swanquarter NWR	SWQ000C	170, 260, 350, 80
Waccamaw National Wildlife Refuge	Waccamaw NWR	WAW000A	0, 180, 270, 90
Waccamaw National Wildlife Refuge	Waccamaw NWR	WAW000B	0, 180, 270, 90
Waccamaw National Wildlife Refuge	Waccamaw NWR	WAW000C	0, 180, 270, 90
Wassaw National Wildlife Refuge	Wassaw NWR	WSW001A	170, 260, 350, 80
Wassaw National Wildlife Refuge	Wassaw NWR	WSW001B	170, 260, 350, 80
Wassaw National Wildlife Refuge	Wassaw NWR	WSW001C	0, 180, 260, 80
Wolf Island National Wildlife Refuge	Wolf Island NWR	WLF035A	0, 180, 270, 90
Wolf Island National Wildlife Refuge	Wolf Island NWR	WLF035B	170, 260, 350, 80
Wolf Island National Wildlife Refuge	Wolf Island NWR	WLF035C	170, 260, 350, 80

Appendix F. Sourced functions used throughout the analysis.

Function to format raw SET data.

```
#Format SET data function SETformat for Region 4
formatSETdataR4<-function(dataIn, dataDir,IncludeUncorrected=TRUE){

  myDir<-as.character(dataDir)

  message("Reading raw data in.")
  new.data<-dataIn

  #remove (or retain) records with NAs for pin heights
  ifelse(isTRUE(IncludeUncorrected),
                  new.data<-new.data,
                  new.data<-subset(new.data,
                     c(! is.na(PinHeight_mm) & ! is.na(PinHeight_mm_Uncorrected)))
                  )


  #change Station_Name to Station_Name
  names(new.data)[names(new.data)=="Plot_Name"]<-"Station_Name"

  #look at data
  #head(new.data)

  #look at column header names
  #names(new.data)

  #unique(new.data$DataProcessingLevelCode)
  ################################
  #are there double observers?  Yes, however, it appears the same observer made
  #two measurements during a single sampling event, so these can't help us
  estimate observer-based measurement bias).

  #new.data$plot.date<-paste(new.data$Station_Name, new.data$EventDate, sep="_")
  doubObs<-aggregate(ReaderFullName~Station_Name+EventDate, data=new.data, FUN=length)
  #check if there are cases with > 36 observations (i.e., 4 arms X 9 pins = 36), if
  #so indicates two observers, typically.
  doubObsSub<-subset(doubObs, ReaderFullName >36)

  ################################
  # #Issue found on 11-24-2020 where replicate rows have different
  # DataLevelProcessingCode factor levels, so they are being included
  # within the data as independent records.  Fixing this now in the
  # formatSETdataR4 funciton.

  #get list of replicits
  replicateList<-paste(doubObsSub$Station_Name, doubObsSub$EventDate,sep="_")

  #get these rows that have apparent replicated rows with different
  #DataLevelProcessingCodes
  new.data$Station_Event<-paste(new.data$Station_Name, new.data$EventDate,sep="_")
```

```
replicate.data<-subset(new.data, Station_Event %in% replicateList)

replicate.data.sub<-subset(replicate.data, ObservationTypeCode != "R")

################################

#remove all Raw "R" and "P" data from
#replicate.data.sub.accepted<-subset(replicate.data.sub,
#DataProcessingLevelCode == "A")

#or use lax version including all dataProcessing levels
ifelse(isTRUE(IncludeUncorrected),
       replicate.data.sub.accepted<-replicate.data.sub,
       replicate.data.sub.accepted<-subset(replicate.data.sub,
                                           DataProcessingLevelCode == "A"))

#remove any replicate rows
replicate.data.sub.accepted.2<-unique(replicate.data.sub.accepted)

#prepare table for export as .csv for including in
#Appendix (all records with replicates)
replicate.data.out<-unique(replicate.data.sub.accepted.2[,c("Refuge",
                "Site_Name","Station_Name","EventDate","ReaderFullName")])

#save as .csv
write.csv(replicate.data.out, file=paste(paste(myDir,"Data","Tables",sep="/"),
                      "Table_records_with_replicates.csv",sep="/"),row.names=FALSE)

#############################################################################################
#create and save table of data omitted from Analysis: Provisional and Raw data types

#remove all "R"eplicate observations
new.data.1<-subset(new.data, ObservationTypeCode !="R")

#subset all "P"rovisional and "R"aw data types
#data.omitted<-subset(new.data.1, c(DataProcessingLevelCode != "A"))

#or use lax version including all dataProcessing levels
ifelse(isTRUE(IncludeUncorrected),
       {
       data.omitted<-data.frame(matrix(ncol=6))
       colnames(data.omitted)<-c("Refuge","Site_Name","Station_Name","EventDate",
                                 "ReaderFullName","DataProcessingLevelCode")
       },
       data.omitted<-subset(new.data.1, c(DataProcessingLevelCode != "A")))


#simplify
data.omitted.out<-unique(data.omitted[,c("Refuge","Site_Name","Station_Name",
                         "EventDate","ReaderFullName","DataProcessingLevelCode")])

#save as .csv
write.csv(data.omitted.out, file=paste(paste(myDir,"Data","Tables",sep="/"),
```

```
                "Table_records_omitted_from_anlaysis.csv",sep="/"),row.names=FALSE)

#################################################################################################
#create table of all stations with info and Pipe Azimuth directions

#get all "A"ccepted data to use in analysis
all.stations.pipe.dirs<-unique(new.data.1[,c("Refuge","Site_Name","Station_Name",
                                             "PipeDirectionAzimuth")])

#add factor for pipe direction for each SET
all.stations.pipe.dirs$Station_Name<-as.factor(all.stations.pipe.dirs$Station_Name)

#convert to data.table
all.stations.pipe.dirs.dt<-all.stations.pipe.dirs
setDT(all.stations.pipe.dirs.dt)    ## change format

all.stations.pipe.dirs.dt[, PipeDirectionCode:=1:.N, by=Station_Name]

#make PipeDirectionCode a factor
all.stations.pipe.dirs.dt$PipeDirectionCode<-
       as.factor(all.stations.pipe.dirs.dt$PipeDirectionCode)

#melt and cast data to create column with list of PipeAzimuth directions
all.stations.pipe.melt<-data.table::melt(all.stations.pipe.dirs.dt,
                                         id.vars=c("Refuge","Site_Name","Station_Name",
                                                   "PipeDirectionCode"),
                                         measure.vars=c("PipeDirectionAzimuth"))

all.stations.pipe.cast<-as.data.frame(data.table::dcast(Refuge+Site_Name+
          Station_Name~PipeDirectionCode, data=all.stations.pipe.melt,
          value.var="value"))


#Alligator River (ALL030C) has two sets of PipeDirectionAzimuths:
#167, 252, 351, 75, / 170, 260, 350, 80

#make columns of pipe directions
all.stations.pipe.cast$PipeDirectionAzimuths<-paste(all.stations.pipe.cast$'1',
                 all.stations.pipe.cast$'2', all.stations.pipe.cast$'3',
                 all.stations.pipe.cast$'4',sep=", ")

#simplify
all.stations.pipe.out<-all.stations.pipe.cast[,c("Refuge",
                           "Site_Name","Station_Name",
                           "PipeDirectionAzimuths")]

#save csv file
write.csv(all.stations.pipe.out, file=paste(paste(myDir,"Data","Tables",sep="/"),
                          "Table_all_SET_pipe_directions.csv",sep="/"),row.names=FALSE)

#################################################################################################
#create a table of all records with out Uncorrected or Corrected Pin Heights
```

```
#get a list of data with no Corrected pin heights entered.
uncorrected.df<-subset(new.data, is.na(PinHeight_mm))

missing.pin.df<-subset(new.data, c(is.na(PinHeight_mm) | is.na(PinHeight_mm_Uncorrected)))

#simplify
missing.pin.df.sub<-unique(missing.pin.df[,c("Refuge","Site_Name","Station_Name","EventDate",
                "PipeDirectionAzimuth","PinPosition","PinLength_mm","PinLength_mm_Baseline",
                                          "PinHeight_mm_Uncorrected", "PinHeight_mm")])

#save csv file
write.csv(missing.pin.df.sub, file=paste(paste(myDir,"Data","Tables",sep="/"),
                          "Table_all_SET_missing_height_data.csv",sep="/"),row.names=FALSE)


##############################################################################################
#get all "A"ccepted data to use in analysis
#data.use<-subset(new.data.1, c(DataProcessingLevelCode == "A"))

#or use lax version including all dataProcessing levels
ifelse(isTRUE(IncludeUncorrected),
       data.use<-new.data.1,
       data.use<-subset(new.data.1, c(DataProcessingLevelCode == "A")))


 #create plot.event.position column
position.df<-as.data.frame(unique(data.use[, c("Station_Name","EventDate",
                                               "PipeDirectionAzimuth")]))


ifelse(position.df$Station_Name=="ALL030C",
       {
       position.df$PipeDirectionAzimuth[position.df$PipeDirectionAzimuth == 170] <- 167
       position.df$PipeDirectionAzimuth[position.df$PipeDirectionAzimuth == 80] <-  75
       position.df$PipeDirectionAzimuth[position.df$PipeDirectionAzimuth == 260] <- 252
       position.df$PipeDirectionAzimuth[position.df$PipeDirectionAzimuth == 350] <- 351
       },
      ifelse(position.df$Station_Name=="POC016B",
       position.df$PipeDirectionAzimuth[position.df$PipeDirectionAzimuth == 252] <- 250,
             position.df$PipeDirectionAzimuth<-position.df$PipeDirectionAzimuth)
)

#find NAs in data.use$PipeDirectionAzimuth
pipe.dir.NA<-subset(position.df, is.na(PipeDirectionAzimuth))

ifelse(data.use$Station_Name=="ALL030C",
       {
         data.use$PipeDirectionAzimuth[data.use$PipeDirectionAzimuth == 170] <- 167
         data.use$PipeDirectionAzimuth[data.use$PipeDirectionAzimuth == 80] <-  75
         data.use$PipeDirectionAzimuth[data.use$PipeDirectionAzimuth == 260] <- 252
         data.use$PipeDirectionAzimuth[data.use$PipeDirectionAzimuth == 350] <- 351
       },
       ifelse(data.use$Station_Name=="POC016B",
```

```
            data.use$PipeDirectionAzimuth[data.use$PipeDirectionAzimuth == 252] <- 250,
            data.use$PipeDirectionAzimuth<-data.use$PipeDirectionAzimuth)


  )



  #get stationList
  stationList<-unique(position.df$Station_Name)

  positionFactor.save<-list()
  for(i in 1:length(stationList)){

    #print(i)

    position.df.sub<-subset(position.df, Station_Name==stationList[i])

    #get unique postions
    unique.positions<-unique(position.df.sub$PipeDirectionAzimuth)

    #get length of unique positions
    count.positions<-length(unique.positions)

    if(count.positions != 4){
           position.df.sub<-subset(position.df.sub,
                                   PipeDirectionAzimuth %in% c(unique.positions[1:4]))
}
    #check unique postions
    #unique.positions.chk<-unique(position.df.sub$PipeDirectionAzimuth)

    positionFactor.df<-data.frame("PipeDirectionAzimuth" =unique.positions,
                                  "Position_Name"=c("A","B","C","D"))

    #merge
    position.df.merge<-merge(position.df.sub, positionFactor.df,
                             by="PipeDirectionAzimuth",all.x=TRUE)

    positionFactor.save<-rbind(positionFactor.save, position.df.merge)

  }

  #now merge back with data.1
  data.1<-merge(data.use, positionFactor.save, by=c("Station_Name",
                                  "EventDate","PipeDirectionAzimuth"), all.x=TRUE)

  unique(positionFactor.save$Position_Name)

  #change Position_Name to character string
  data.1$Position_Name<-as.character(data.1$Position_Name)

  #change PinPosition to character string
  data.1$PinPosition<-as.character(data.1$PinPosition)
```

```
#Add Year, Month, and Day columns to data.
message("Adding year, month, and day columns to data.")
date.data<-data.frame(EventDate=data.1$EventDate)
date.data$EventDate<-as.character(date.data$EventDate)
date.string<-read.table(text=as.character(date.data$EventDate),
                        sep="/",colClasses = "character")
colnames(date.string)<-c("Month","Day","Year")
date.string$Year<-as.factor(date.string$Year)

date.string$new.date<-as.Date(as.character(paste(date.string$Year,
                                                 date.string$Month,
                                                 date.string$Day,sep="-"),
                                           format = "%Y-%b-%d"))
#Make column for ordinal day.
date.string$ord.Day <- as.integer(format(date.string$new.date, "%j"))

#Compile data
data.2<-cbind(data.1,date.string)

#############################################################################

#Fix names that can be confusing when defining file paths,
#by replacing any "/" with "-" to not confuse with filepath definitions
#data.2$Station_Name<-gsub("/","-",as.character(data.2$Station_Name))

#Create new columns for "station.position.year", "station.year", and
#"station.year.day", using paste() function.
data.2$station.position.year<-paste(data.2$Station_Name,
                                    data.2$Position_Name, data.2$Year,sep=".")
data.2$station.year<-as.factor(paste(data.2$Station_Name, data.2$Year,sep="."))
data.2$station.year.ord.day<-as.factor(paste(data.2$Station_Name,
                                             data.2$Year, data.2$ord.Day,sep="."))
#View first few rows of data.frame.
head(data.2)

#Create column for visits by each factor level of SET stations (Station_Name).
#Use 'data.table' package to add sequential visit numbers by
#each factor (i.e., Station_Name)

#Truncate data.frame
data.1.events<-data.2[,c("Station_Name","Year","Month","Day","ord.Day",
                         "station.year","station.year.ord.day")]

#Convert from data.frame to data.table
data.1.events<- as.data.table(unique(data.1.events))

#Get the maximum number of visits to each SET per year.
max.visits<-max(table(data.1.events$Station_Name, data.1.events$Year))
max.visits

#order
data.1.events$Station_Name<-as.character(data.1.events$Station_Name)
data.1.events<-data.1.events[order(data.1.events$Station_Name,
```

```
                                    data.1.events$Year, data.1.events$ord.Day)]

#Sequentially order visits by a factor. NEED TO CHECK THIS
data.1.events[, Visit := 1:.N, by = station.year]

#Convert back to data.frame
data.1.events<-as.data.frame(data.1.events)

#Take a peek at first 6 rows.
#head(data.1.events)

#Now merge visits back with data.
data.1.events<-data.1.events[,c("Station_Name","Year","Month","Day",
                                "ord.Day","Visit")]
data.1.merge<-merge(data.2,data.1.events, by=c("Station_Name","Year","Month",
                                               "Day","ord.Day"),all.x=TRUE)

#Take a look.
head(data.1.merge)

#Redefine data as 'data.out'.
data.out<-as.data.frame(data.1.merge)

#create two-digit number for zero (if nchar=1, prepend zero)
data.out$VisitPad<-ifelse(nchar(as.character(data.out$Visit))<2,
                          paste("0",as.character(data.out$Visit),sep=""),
                          as.character(data.out$Visit))



data.out$year.visit<-paste(data.out$Year, data.out$VisitPad,sep=".")
head(data.out)

##############################################################################
#create table with # of visits per SET per year

data.out.sub<-unique(data.out[,c("Refuge","Site_Name","Station_Name","Year","Month",
        "Day","EventDate","Visit","year.visit","station.year","station.year.ord.day")])

num.visits.agg<-aggregate(EventDate~Refuge+Site_Name+Station_Name+Year,
                          FUN="length", data=data.out.sub)

#melt and cast

####################################
#convert to data.table
num.visits.agg.dt<-num.visits.agg
setDT(num.visits.agg.dt)    ## change format

#melt
num.visits.melt<-data.table::melt(num.visits.agg.dt,id.vars=c("Refuge","Site_Name",
                                        "Station_Name","Year"),measure.vars=c("EventDate")
)
```

```
#cast
num.visits.cast<-as.data.frame(data.table::dcast(Refuge+Site_Name+Station_Name~Year,
                                                 data=num.visits.melt,
                                                 value.var="value"))

#save csv file
write.csv(num.visits.cast, file=paste(paste(myDir,"Data","Tables",sep="/"),
                              "Table_all_SET_num_visits_per_year.csv",sep="/"),
          row.names=FALSE)

###############################################################################
#check that each station has more than 1 visit
message("Checking data for inconsistencies.")
check.data<-aggregate(year.visit~Station_Name, data=data.out,
                      FUN=function(x){length(unique(x))})
check.data$enoughVisits<-ifelse(check.data[,2]>1,"Yes","NO")

#remove any plots with only 1 year.visit
check.data.keep<-check.data[check.data$enoughVisits!="NO",]

#subset data out by list of check.data.keep
keepPlots<-unique(as.character(check.data.keep$Station_Name))

data.out$Station_Name<-as.character(data.out$Station_Name)
data.out.keep<-data.out[data.out$Station_Name %in% keepPlots,]
data.out.keep$Station_Name<-as.factor(as.character(data.out.keep$Station_Name))

#check if each has all arm data
message("Checking to ensure SET arm data looks good.")
check.arms<-aggregate(Position_Name~Station_Name, data=data.out.keep,
                      FUN=function(x){length(unique(x))})
check.arms$all4<-ifelse(check.arms[,2]==4,"Yes","NO")

#fix NWR names
#remove "National Wildlife Refuge" from Refuge
data.out.keep$Refuge<-trimws(gsub("National Wildlife Refuge","",
                        gsub("National Wildlife Refuges","",data.out.keep$Refuge)))

#remove "NWR" from Site_Name
data.out.keep$Site_Name<-trimws(gsub("NWR","",data.out.keep$Site_Name))

###############################################################################
#now move pin height data from 'PinHeight_mm_Uncorrected" to 'PinHeight_mm' columns


#or use lax version use all Pin height data (uncorrected and corrected)
ifelse(isTRUE(IncludeUncorrected),
         data.out.keep$PinHeight_mm<-ifelse(is.na(data.out.keep$PinHeight_mm),
                                            data.out.keep$PinHeight_mm_Uncorrected,
                                            data.out.keep$PinHeight_mm),
        data.out.keep<-data.out.keep)

###############################################################################
```

```
#Use package 'data.table' (reshape is depreciated) to reorganize data
#(like Pivot table in Excel) using melt().
message("Computing elevation change (mm) for SET data. . .")
#melt function .

#convert to data.table
data.out.keep.dt<-data.out.keep
setDT(data.out.keep.dt)

unique(data.out.keep.dt$Position_Name)

#find data.out.keep.dt NAs position name
postionName.NA<-subset(data.out.keep.dt, is.na(Position_Name))

  data.melt<-data.table::melt(data.out.keep.dt, id=c("Refuge","Station_Name",
                                                     "ReaderFullName","Year",
                                                     "Position_Name",
                                                     "PipeDirectionAzimuth",
                                                     "PinPosition","Visit",
                                                     "year.visit"),
                              measure=c("PinHeight_mm"))
#####################################################################
  #Generate lists

  #Get stationList. (FYI, using the "<<-" sign puts object
  #into the Global Environment).
  stationList<-unique(as.character(data.melt$Station_Name))

  #Get yearList from data.
  yearList<-unique(as.character(data.melt$Year))

  #Get visitList from data.
  visitList<-unique(as.character(data.melt$Visit))

  #Get positionList.
  positionList<-unique(as.character(data.melt$Position_Name))

  #check how many NAs
  positionNAlist<-subset(data.melt, is.na(Position_Name))

  #Get pinList from data.
  pinList<-unique(as.character(data.melt$PinPosition))

  #Create deltaPinList.
  deltaPinList<-c("deltaPin1","deltaPin2","deltaPin3","deltaPin4",
            "deltaPin5","deltaPin6","deltaPin7","deltaPin8","deltaPin9")

  ###################################################################

  #Compute change in marsh height between ti and t0
  station.out<-list()
  for(k in 1:length(stationList)){
    #print(stationList[k])
```

```
station.data<-subset(data.melt, Station_Name==stationList[k])
station.name<-unique(as.character(station.data$Station_Name))

position.out<-list()
for(j in 1:length(positionList)){
  position.data<-NULL
  position.data<-subset(station.data, Position_Name==positionList[j])
  position.name<-unique(as.character(position.data$Position_Name))
  #position.data$year.visit<-as.numeric(position.data$year.visit)

  #convert to data.table
  position.data.dt<-position.data
  setDT(position.data.dt)

    #now cast
    cast.data<-as.data.frame(data.table::dcast(position.data.dt,
                      PinPosition~year.visit+variable, value.var="value"))

    #get length of total visits
    nVisits<-length(colnames(cast.data))-1

    #now get deltas
    all.delta.list<-list()
    for (i in 1:9){
      #print(i)
      sub.data<-cast.data[i,-1]

      delta.list<-list()
      for(p in 1:nVisits){
        #print(p)
        delta.list[p]<-sub.data[,p] - sub.data[,1]
      }

      delta.out<-as.data.frame(delta.list)
      colnames(delta.out)<-colnames(sub.data)

    all.delta.list<-rbind(all.delta.list, delta.out)
    }

    #transpose raw values
    cast.data.trans<-as.data.frame(as.matrix(t(cast.data)))[-1,]

    #transpose deltas
    all.delta.trans<-as.data.frame(t(all.delta.list))

    #add pin column headers back in
    colnames(all.delta.trans)<-c("deltaPin1","deltaPin2","deltaPin3",
                                 "deltaPin4","deltaPin5","deltaPin6",
                                 "deltaPin7", "deltaPin8","deltaPin9")

    pin.df<-cbind(cast.data.trans, all.delta.trans)

    #add year.visit back in
```

```
          pin.df$year.visit<-gsub("_PinHeight_mm","",row.names(pin.df))
          row.names(pin.df)<-NULL

          #add position back in
          pin.df$Position_Name<-position.name

          #gather deltas for each postion
          position.out<-rbind(position.out, pin.df)

        }

          #add station name
        position.out$Station_Name<-station.name

        #gather station deltas
        station.out<-rbind(station.out, position.out)

    }
#####################################################################
#combine deltas with all data
station.out$Plot_Year_Visit_Position<-paste(station.out$Station_Name,
                                            station.out$year.visit,
                                            station.out$Position_Name, sep=".")
#remove columns
station.out$year.visit<-NULL
station.out$Station_Name<-NULL
station.out$Position_Name<-NULL

#trim data.out.keep to include only needed columns
names(data.out.keep)

#need to merge with event data
data.out.keep$Plot_Year_Visit_Position<-paste(data.out.keep$Station_Name,
                                              data.out.keep$year.visit,
                                              data.out.keep$Position_Name,
                                              sep=".")

data.out.keep.1<-unique(data.out.keep[,c("Refuge","Site_Name","Station_Name",
                                         "EventDate","Year","Month","Day",
                                         "ord.Day","Visit","year.visit",
                                         "ReaderFullName","ReaderID",
                                         "PipeDirectionAzimuth",
                                         "Position_Name",
                                         "Plot_Year_Visit_Position")])

new.data.out.1<-unique(merge(station.out, data.out.keep.1,
                             by=c("Plot_Year_Visit_Position"),all.x=TRUE))

#write.csv(new.data.out.1, file=paste(myDir, "Data",
#"new.SET.data.melt.csv",sep="/"),row.names=FALSE)
#####################################################################
#Read in R4_SET to get location info
```

```
#add Lat/Long if needed to rawData
#SETcoords.1<-read.csv(file=paste(myDir,"SET_Station_coords_all.csv",sep="/"),
#header=TRUE)
SETcoords.1<-read.csv(file="./Data/SET_Station_coords_all.csv",
                      header=TRUE)

#Bring in State field (add To do list)
SETstates<-read.csv(file="./Data/R4_SET.csv",header=TRUE)

SETstates.sub<-unique(SETstates[,c("State","Refuge")])

#merge with SETcoords
SETcoords<-merge(SETcoords.1, SETstates.sub,by="Refuge",all.x=TRUE)

R4_coords<-subset(SETcoords, RegionNumber==4)
R4_coords.sub<-unique(R4_coords[,c("State","StationName","StationLatitude",
                                   "StationLongitude")])
colnames(R4_coords.sub)<-c("State","Station_Name","Latitude","Longitude")

#Merge new.data.out.1 and Region.lookup.
#new.data.out.2<-merge(new.data.out.1, Region.lookup, by="Unit_Code",all.x=TRUE)
new.data.out.2<-new.data.out.1

  #Add Longitude and Latitude coords for making maps.
  message("Adding State and Lat/Long coords for SET stations to data.")

  XYdata<-R4_coords.sub

  #Merge new.data.out with XYdata.
  data.out.3<-merge(new.data.out.2, XYdata, by="Station_Name",all.x=TRUE)

  #Save data (as a .csv file).
  message("Saving SET with delta height data to .csv file.")
  write.csv(data.out.3, file=paste(myDir,"Data",
                                   paste(paste("All_R4_SET_data_formatted_",
                                               Sys.Date(),sep=""),
                                         "csv",sep="."),sep="/"),
            row.names=FALSE)

  ######################################################################
  #Create and save melted data.frame.

  #Redefine data as 'set.data'
  set.data<-as.data.frame(data.out.3)

  #create Date column
  set.data$Date<-as.Date(set.data$EventDate, tryFormats = c("%m-%d-%Y",
                                                            "%m/%d/%Y"))

  set.delta.data<-set.data[,c("State","Refuge","Site_Name","Station_Name",
                              "Date","EventDate","Year","Month","Day","ord.Day",
                              "Visit","year.visit","ReaderFullName","ReaderID",
                              "PipeDirectionAzimuth","Position_Name",
```

```
                              "Plot_Year_Visit_Position","Longitude","Latitude",
                              "deltaPin1","deltaPin2","deltaPin3","deltaPin4",
                              "deltaPin5","deltaPin6","deltaPin7","deltaPin8",
                              "deltaPin9")]

  #Rename columns.
  colnames(set.delta.data)<-c("State","Refuge","Site_Name","Station_Name",
                              "Date","EventDate","Year","Month","Day","ord.Day",
                              "Visit","year.visit","ReaderFullName","ReaderID",
                              "PipeDirectionAzimuth","Position_Name",
                              "Plot_Year_Visit_Position","Longitude",
                              "Latitude","Pin1","Pin2","Pin3","Pin4",
                              "Pin5","Pin6","Pin7","Pin8","Pin9")

  #convert to data.table
  set.delta.data.dt<-set.delta.data
  setDT(set.delta.data.dt)

  #Melt data to stack all Pins (Pin1, Pin2, . . .) in one column.
  delta.set.melt.dt<-data.table::melt(set.delta.data.dt,
                                      id.vars=c("State","Refuge","Site_Name",
                                                "Station_Name","Date","EventDate",
                                                "Year","Month","Day","ord.Day",
                                                "Visit","year.visit","ReaderFullName",
                                                "ReaderID","PipeDirectionAzimuth",
                                                "Position_Name","Plot_Year_Visit_Position",
                                                "Longitude","Latitude"),
                                    measure.vars=c("Pin1","Pin2","Pin3","Pin4",
                                                "Pin5","Pin6","Pin7","Pin8","Pin9"))

  #convert back to data.frame
  delta.set.melt<-as.data.frame(delta.set.melt.dt)

  #Add pos.pin column using paste()
  delta.set.melt$pos.pin<-paste(delta.set.melt$Position_Name,
                                delta.set.melt$variable,sep="_")

#convert -Inf and Inf to NAs
  delta.set.melt$value<-ifelse(delta.set.melt$value==-Inf,NA,
                               ifelse(delta.set.melt$value==Inf,NA,
                                      delta.set.melt$value))


  #Save file.
  message("Finalizing data and saving file.")
  write.csv(delta.set.melt, file=paste(myDir,"Data",
                                       paste(paste("R4_SET_formatted_data.melt",
                                                   Sys.Date(),sep="_"),"csv",sep="."),
                                       sep="/"),row.names=FALSE)

  return(delta.set.melt)

}
```

Function to compute SET trends.

```
computeTrendsSET <- function(dataIn) {

    set.data <- dataIn

    # get list of unique NWRs
    refugeList <- sort(unique(as.character(set.data$Refuge)))

    all.set.pins <- list()
    all.set.positions <- list()
    all.set.stations <- list()
    all.set.sites <- list()
    all.set.refuges <- list()
    for (j in 1:length(refugeList)) {

        # print refuge to show progress
        print(refugeList[j])

        refuge.data <- subset(set.data, Refuge == refugeList[j])

        # get refugeName
        refugeName <- as.character(unique(refuge.data$Refuge))

        # get siteList
        siteList <- sort(unique(as.character(refuge.data$Site_Name)))

        refuge.pins <- list()
        refuge.positions <- list()
        refuge.stations <- list()
        refuge.sites <- list()
        for (k in 1:length(siteList)) {

            site.data <- subset(refuge.data, Site_Name == siteList[k])

            siteName <- as.character(unique(site.data$Site_Name))

            # print Site_Name to show progress
            print(siteName)

            # get stationList
            stationList <- sort(unique(as.character(site.data$Station_Name)))

            # get refuge covariates
            refugeCovs <- unique(site.data[, c("State", "Refuge",
                "Site_Name", "Station_Name", "Latitude", "Longitude")])

            # get siteCovs
            siteCovs <- unique(site.data[, c("State", "Refuge",
                "Site_Name")])

            site.pin.slopes <- list()
            site.positions <- list()
            site.stations <- list()
```

```
for (i in 1:length(stationList)) {
    # print(stationList[i])

    # print Station_Name (Station) to show progress
    print(stationList[i])

    new.data <- subset(site.data, Station_Name ==
      stationList[i])

    stationName <- as.character(unique(new.data$Station_Name))

    # get pospinList
    pospinList <- unique(sort(as.character(new.data$pos.pin)))

    # get covariates
    stationCovs <- unique(new.data[, c("State", "Refuge",
      "Site_Name", "Station_Name", "Latitude", "Longitude")])

    positionCovs <- unique(new.data[, c("State",
      "Refuge", "Site_Name", "Station_Name", "Position_Name",
      "Latitude", "Longitude")])

    message("Getting slope and intercept from delta at each pin vs.
    time regressions.")

    regResults.out <- list()
    for (k in 1:length(pospinList)) {
      # print(pospinList[k])
      sub.data <- subset(new.data, pos.pin == pospinList[k])
      sub.data$value <- as.numeric(sub.data[, "value"])
      sub.data$ReaderFullName <- as.factor(as.character(sub.data$ReaderFullName))
      sub.dataCovs <- unique(sub.data[, c("State",
        "Refuge", "Site_Name", "Station_Name", "Position_Name",
        "variable", "pos.pin")])

      # linear model with Visit nested within Year, and if there is
      # only 1 visit, fit just Year
      mod.1 <- tryCatch({
        lm(value ~ Year, data = sub.data)
      }, error = function(cond2) {
        cond2 = NA
      })

      # get slope over years
      slope <- NULL
      try(slope <- coef(summary(mod.1))[, "Estimate"][2])
      intercept <- NULL
      try(intercept <- coef(summary(mod.1))[, "Estimate"][1])

      # combine slope with station covs
      regResults <- NULL
      regResults <- tryCatch({
        data.frame(sub.dataCovs, slope = slope, intercept = intercept)
```

```
        }, error = function(cond2) {
          cond2 = data.frame(sub.dataCovs, slope = NA,
            intercept = NA)
          cond2
        })

        # compile regResults over each pin
        regResults.out <- rbind(regResults.out, regResults)
      }

      # get means for each position
      station.positions <- summaryFunction(dataIn = regResults.out,
        factor = "Position_Name", response = "slope")
      station.positions.out.1 <- merge(station.positions,
        positionCovs, by = "Position_Name")
      station.positions.out <- station.positions.out.1[,
        c("State", "Refuge", "Site_Name", "Station_Name",
          "Latitude", "Longitude", "Position_Name",
          "n", "mean", "var", "SD", "SE", "CV", "lwr",
          "upr")]

      # get station means
      station.slopes <- summaryFunction(dataIn = station.positions.out,
        factor = "Station_Name", response = "mean")
      station.merge.1 <- merge(station.slopes, refugeCovs,
        by = "Station_Name")
      station.merge <- station.merge.1[, c("State",
        "Refuge", "Site_Name", "Station_Name", "Latitude",
        "Longitude", "n", "mean", "var", "SD", "SE",
        "CV", "lwr", "upr")]

      # compile pin-level slopes for each site
      site.pin.slopes <- rbind(site.pin.slopes, regResults.out)

      # compile position means
      site.positions <- rbind(site.positions, station.positions.out)

      # compile station means
      site.stations <- rbind(site.stations, station.merge)
    }

    # get site means
    site.slopes <- summaryFunction(dataIn = site.stations,
        factor = "Site_Name", response = "mean")
    site.merge.1 <- merge(site.slopes, siteCovs, by = "Site_Name")
    site.merge <- site.merge.1[, c("State", "Refuge",
        "Site_Name", "n", "mean", "var", "SD", "SE",
        "CV", "lwr", "upr")]

    refuge.pins <- rbind(refuge.pins, site.pin.slopes)

    refuge.positions <- rbind(refuge.positions, site.positions)
```

```
            refuge.stations <- rbind(refuge.stations, site.stations)

            refuge.sites <- rbind(refuge.sites, site.merge)

            # get refuge-level means
            refuge.slopes <- summaryFunction(dataIn = refuge.stations,
                factor = "Refuge", response = "mean")
            refuge.merge.1 <- merge(refuge.slopes, sub.dataCovs,
                by = "Refuge")
            refuge.merge <- refuge.merge.1[, c("State", "Refuge",
                "n", "mean", "var", "SD", "SE", "CV", "lwr",
                "upr")]
        }

        # compile all results
        all.set.pins <- rbind(all.set.pins, refuge.pins)

        all.set.positions <- rbind(all.set.positions, refuge.positions)

        all.set.stations <- rbind(all.set.stations, refuge.stations)

        all.set.sites <- rbind(all.set.sites, refuge.sites)

        all.set.refuges <- rbind(all.set.refuges, refuge.merge)

    }

    all.set.pins <<- all.set.pins
    all.set.positions <<- all.set.positions
    all.set.stations <<- all.set.stations
    all.set.sites <<- all.set.sites
    all.set.refuges <<- all.set.refuges
}
```

```
#### Convenience function for getting summary statistics.

# summary function creates table of n, mean, var, SD, and SE
summaryFunction <- function(dataIn, factor, response) {
    summaryOut <- ddply(dataIn, factor, .fun = function(xx) {
        c(n = length(xx[, response]), mean = mean(xx[, response],
            na.rm = TRUE), var = var(xx[, response], na.rm = TRUE),
            SD = sd(xx[, response], na.rm = TRUE), SE = sqrt(var(xx[,
                response], na.rm = TRUE)/length(xx[, response])),
            CV = sd(xx[, response], na.rm = TRUE)/mean(xx[, response],
                na.rm = TRUE), lwr = mean(xx[, response], na.rm = TRUE) -
                sqrt(var(xx[, response], na.rm = TRUE)/length(xx[,
                  response])) * 1.96, upr = mean(xx[, response],
                na.rm = TRUE) + sqrt(var(xx[, response], na.rm = TRUE)/length(xx[,
                response])) * 1.96)
    })
    return(summaryOut)
    dev.off()
}
```

Appendix G. R code chunks used to analyze and produce all tables and figures from this report.

```
library(knitr)
library(rmdformats)
library(formatR)

## Global options
options(max.print="85")
opts_chunk$set(echo=FALSE,
               message=FALSE,
                 cache=TRUE,
               prompt=FALSE,
               comment=NA,
               message=FALSE,
               warning=FALSE,
               fig.align="center"
               # out.width=6.5,
               # out.height=9
               )
opts_knit$set(width=80)

#here, you'll use your file path.
opts_knit$set(root.dir = 'YOUR WORKING DIRECTORY')

#library(shadowtext)
```

```
suppressMessages({

    # load packages
    library(httr)
    library(markdown)
    library(rmdformats)
    library(stringr)
    library(lme4)
    library(lmerTest)
    library(plyr)
    library(reshape)
    library(RColorBrewer)
    library(colorRamps)
    library(ggplot2)
    library(ggrepel)
    library(grid)
    library(lubridate)
    library(ggmap)
    library(scales)
    library(spatstat)
    library(ggsn)
    library(data.table)
    library(ggpmisc)
    library(xtable)
    library(pander)
    library(readr)
    library(raster)
```

```
    library(pals)

    # library(shadowtext)

    options(xtable.floating = FALSE)
    options(xtable.timestamp = "")

    # Load functions
    message("Loading source files (these are all the functions).")
    source("./R_source/summaryFunction.R")
    source("./R_source/formatSETdataR4.R")
    source("./R_source/formatMHdataR4.R")
    source("./R_source/computeTrendsSET.R")
    source("./R_source/computeTrendsMH.R")

    # register Google Maps API key
    register_google(key = "YOUR GOOGLE API KEY")

})
```

```
# build function to read in and combine data
combineData <- function(fileList) {

    data.comb <- list()
    for (i in 1:length(fileList)) {

        new.data <- read.csv(fileList[i], skip = 3, header = TRUE)
        data.comb <- rbind(data.comb, new.data)
    }
    return(data.comb)
}

myFileList <- list.files("./Data/Refuge_Data_2-27-2021", full.names = TRUE)

data.comb <- combineData(fileList = myFileList)

# Export data
write.csv(data.comb, file = "./Data/Refuge_Data_2-27-2021.csv",
    row.names = FALSE)
```

```
# read in raw data from USFWS SET database
raw.set.data <- read.csv(file = "./Data/Refuge_Data_2-27-2021.csv",
    header = TRUE, as.is = TRUE)

# convert Plot_Name to Station_Name
names(raw.set.data)[names(raw.set.data) == "Plot_Name"] <- "Station_Name"
```

```
# my working dir
mydir <- "/Users/zach/Dropbox (ZachTeam)/Projects/SET_USFWS_Region_4/
Reports/RMarkdown_pdf"

# format data providing raw.set.data object and mydir (a
# filepath to a folder named 'Data' where SET_coords.csv file
# is saved), now has choice to include missing Uncorrected or
# Corrected data (NAs)
```

```
set.data.formatted <- try(formatSETdataR4(dataIn = raw.set.data,
    dataDir = mydir, IncludeUncorrected = TRUE))
```

```
# read in Marker Horizon data and format it
raw.mh.data <- read.csv("./Data/Accretion_Data_2-27-2021/Export Accretion Data.csv",
    skip = 3)

# format data providing raw.mh.data object and mydir (a
# filepath to a folder named 'Data' where SET_coords.csv file
# is saved)
mh.data.formatted <- try(formatMHdataR4(dataIn = raw.mh.data,
    dataDir = mydir))
```

```
#### Table 1. List of 22 sites among 19 US Fish and Wildlife
#### Service National Wildlife Refuge (NWR) units included in
#### SET data analyses along with corresponding State, count of
#### SET stations, count of unique observers, duration of years,
#### and starting and ending years of data collection.

# re-define data
set.data <- set.data.formatted

# make Year an integer
set.data$Year <- as.integer(as.character(set.data$Year))

set.data.table.1 <- unique(set.data[, c("State", "Refuge", "Site_Name")])

# remove NAs
set.data.table.1 <- set.data.table.1[complete.cases(set.data.table.1),
    ]

# get freqency of SET stations per refuge
sub.set.data <- unique(set.data[, c("State", "Refuge", "Site_Name",
    "Station_Name")])
count.stations <- table(sub.set.data$Site_Name, sub.set.data$Station_Name)
count.stations.total <- rowSums(count.stations)
count.stations.total.1 <- data.frame(Site_Name = names(count.stations.total),
    N = as.data.frame(count.stations.total))

# get years sampled (start and end), and get number of
# observers
sub.set.data.years <- unique(set.data[, c("Site_Name", "Year",
    "ReaderFullName")])

# get refugeList
siteList <- unique(sort(as.character(sub.set.data.years$Site_Name)))

# loop over refugeList to get range of years per refuge
range.years <- list()
for (i in 1:length(siteList)) {
    # subset set.data for 1 refuge
    new.set.data <- subset(sub.set.data.years, Site_Name == siteList[i])
    # get Refuge
    siteName <- as.character(unique(new.set.data$Site_Name))
```

```
    # get starting year
    startYear <- min(new.set.data$Year)
    # get ending year
    endYear <- max(new.set.data$Year)
    # get total years
    nYears <- endYear - startYear + 1
    # get n unique observers (set.data recorders)
    nObs <- length(unique(new.set.data$ReaderFullName))

    range.years.1 <- data.frame(Site_Name = siteName, startYear = startYear,
        endYear = endYear, nYears = nYears, nObs = nObs)
    range.years <- rbind(range.years, range.years.1)

}

# combine with SummaryTable.1
set.data.table.2 <- na.omit(merge(set.data.table.1, count.stations.total.1,
    by = "Site_Name", all.x = TRUE))

# now combine with range.years
set.data.table.3 <- merge(set.data.table.2, range.years, by = "Site_Name")

# get Site order sorted North to South
siteLat <- aggregate(Latitude ~ Site_Name, data = set.data, FUN = "mean")
siteOrder <- siteLat[order(siteLat$Latitude, decreasing = TRUE),
    ]
siteOrderList <- unique(siteOrder$Site_Name)
# length(refugeOrderList)

# Now sort table by Latitude (reorder Refuge factor) create
# data.frame with NWRs ordered from North to South
SiteOrder.df <- data.frame(Site = siteOrderList, orderNum = seq(1:length(siteOrderList)))

# rename column headers
colnames(set.data.table.3) <- c("Site", "State", "Refuge", "N",
    "Start_Year", "End_Year", "Num_Years", "Num_Obs")

# reorder columns
set.data.table.4 <- set.data.table.3[, c("Site", "State", "Refuge",
    "N", "Num_Obs", "Num_Years", "Start_Year", "End_Year")]

# create integer column of order for NWRs
set.data.table.order <- merge(set.data.table.4, SiteOrder.df,
    by = c("Site"), all.x = TRUE)
set.data.table.order <- set.data.table.order[order(set.data.table.order$orderNum),
    ]
set.data.table.5 <- set.data.table.order
set.data.table.5$orderNum <- NULL

# remove row.names from table
row.names(set.data.table.5) <- NULL

# rename column headers
```

```r
colnames(set.data.table.5) <- c("Site", "State", "NWR", "SETs (N)",
    "Observers (N)", "Num. Years", "Start Year", "End Year")

panderOptions("table.alignment.default", function(df) ifelse(sapply(df,
    is.numeric), "right", "left"))
panderOptions("table.split.table", Inf)

pander(set.data.table.5)
```

```r
#### Figure 1. Study Area showing sites (*N* = 22)
# where SET benchmarks are located among 19 USFWS National
# Wildlife Refuges, Southeast Region.


#Map with study area locations

#get locations of SETs
SETcoords<-unique(set.data[, c("Refuge","Site_Name",
                               "Station_Name","Longitude",
                               "Latitude")])

#aggregate to get Site coords
site.long<-aggregate(Longitude~Site_Name+Refuge, data=SETcoords,
                     FUN=mean)
site.lat<-aggregate(Latitude~Site_Name+Refuge, data=SETcoords,
                    FUN=mean)
site.coords.merge<-merge(site.long, site.lat, by=c("Site_Name",
                                                   "Refuge"),
                         all=TRUE)

meanLong<-mean(SETcoords$Longitude)
meanLat<-mean(SETcoords$Latitude)

#get basemap
basemap<-get_map(location=c(meanLong, meanLat),zoom=6,
                 maptype="terrain-background")
#ggmap(basemap)

#get map extent
mapExtent<-attr(basemap, "bb")


studyAreaMap<-ggmap(basemap)+
  geom_point(data=site.coords.merge, aes(x=Longitude,
                                         y=Latitude),
             color="black",size=3)+
  labs(x="Longitude",y="Latitude")+
  theme(
    axis.text=element_text(size=18),
    axis.title=element_text(size=22),
    panel.border=element_rect(fill="transparent", color="black"),
    legend.position = "none"
    # legend.position = c(0.15,0.7),
    # legend.key.size = unit(2,"line"),
```

```
    # legend.text = element_text(size=14),
    # legend.title=element_text(size=20),
    # legend.background = element_rect(fill=alpha("white",0.9),
    color="black")
  )+
  # geom_label_repel(data=site.coords.merge,aes(x=Longitude,y=Latitude,
  label=Site_Name), fill="gray30",color="white", show.legend=FALSE,
  label.padding=0.4, size=4, segment.alpha=0.7, alpha=0.8)+
  geom_text_repel(data=site.coords.merge,aes(x=Longitude,y=Latitude,
      label=Site_Name), show.legend=FALSE, size=4.5, segment.alpha=0.7,
                  color = "black", bg.color = "white", bg.r = 0.16)+
  guides(fill = guide_legend(title = "National Wildlife Refuge",
                             label = FALSE))+
  ggsn::scalebar(x.min=mapExtent$ll.lon, x.max=mapExtent$ur.lon,
                 y.min=mapExtent$ll.lat, y.max=mapExtent$ur.lat,transform=TRUE,
                 dist_unit="km",dist=200, st.dist=0.015,
                 \height = 0.01,anchor=c(x=-73,y=28))

studyAreaMap
```

```
#### Figure 2. Plot change in elevation data relative to initial
#### height (mm) over time for all pin-level SET data.

# check for outliers set.data.outliers<-subset(set.data,
# c(value > 200 | value < -200))

set.data.all <- set.data

SETallDatesPlot <- ggplot(data = set.data.all, aes(x = Date,
    y = value, group = 1)) + geom_point(aes(color = value), alpha = 0.7,
    size = 1, shape = 16) + scale_color_gradient2(low = "tomato",
    mid = "gray60", high = "royalblue1", guide_colorbar(title = "Delta Elev. (mm)")) +
    geom_smooth(method = lm, fullrange = TRUE, linetype = 1,
        color = "gray20", se = TRUE) + scale_y_continuous(expand = c(0.1,
    0.1)) + scale_x_date(date_breaks = "1 year", date_labels = "%Y") +
    theme(panel.background = element_rect(color = "black", fill = "transparent"),
        panel.border = element_rect(color = "black", fill = "transparent"),
        axis.text.x = element_text(size = 12, color = "black"),
        axis.text.y = element_text(size = 12, color = "black"),
        axis.title.x = element_text(size = 14, hjust = 0.5, vjust = 1.9),
        axis.title.y = element_text(angle = 90, vjust = 1.2,
            size = 14), legend.position = c(0.11, 0.2), legend.key.size = unit(1,
            "line")) + geom_hline(yintercept = 0, linetype = 2,
    color = "gray30", alpha = 0.8) + stat_poly_eq(formula = y ~
    x, eq.with.lhs = "italic(hat(y))~`=`~", aes(label = paste(..eq.label..,
    ..rr.label.., sep = "~~~")), parse = TRUE) + labs(x = "Year",
    y = "Relative change in pin height (mm)")

SETallDatesPlot
```

```
#### Table 2. List of SETs with fewer than 5 years of data which
#### are omitted from analyses

# get total number of years per SET in a data.frame
```

```
set.freq.years <- aggregate(Year ~ Refuge + Site_Name + Station_Name,
    FUN = function(x) length(unique(x)), data = set.data.all)

# subset set.freq.years to get all SETs with fewer than 5
# years
set.freq.years.sub <- subset(set.freq.years, Year < 5)
colnames(set.freq.years.sub) <- c("NWR Refuge", "Site Name",
    "SET Station", "Number of Years")
row.names(set.freq.years.sub) <- NULL

panderOptions("table.alignment.default", function(df) {
    ifelse(sapply(df, is.numeric), "right", "left")
})

panderOptions("table.split.table", Inf)

pander(set.freq.years.sub)
```

```
#### Figure 3. Plot change in elevation data relative to initial
#### height (mm) over time with SETs with fewer than 5 years of
#### data omitted.

setOmit <- as.character(set.freq.years.sub$`SET Station`)

set.data.SETomit <- subset(set.data.all, !Station_Name %in% setOmit)

SETallDatesPlot_SETomit <- ggplot(data = set.data.SETomit, aes(x = Date,
    y = value, group = 1)) + geom_point(aes(color = value), alpha = 0.7,
    size = 1, shape = 16) + scale_color_gradient2(low = "tomato",
    mid = "gray60", high = "royalblue1", guide_colorbar(title = "Delta Elev. (mm)")) +
    geom_smooth(method = lm, fullrange = TRUE, linetype = 1,
        color = "gray20", se = TRUE) + scale_y_continuous(expand = c(0.1,
    0.1)) + scale_x_date(date_breaks = "1 year", date_labels = "%Y") +
    theme(panel.background = element_rect(color = "black", fill = "transparent"),
        panel.border = element_rect(color = "black", fill = "transparent"),
        axis.text.x = element_text(size = 12, color = "black"),
        axis.text.y = element_text(size = 12, color = "black"),
        axis.title.x = element_text(size = 14, hjust = 0.5, vjust = 1.9),
        axis.title.y = element_text(angle = 90, vjust = 1.2,
            size = 14), legend.position = c(0.11, 0.2), legend.key.size = unit(1,
            "line")) + geom_hline(yintercept = 0, linetype = 2,
    color = "gray30", alpha = 0.8) + stat_poly_eq(formula = y ~
    x, eq.with.lhs = "italic(hat(y))~`=`~", aes(label = paste(..eq.label..,
    ..rr.label.., sep = "~~~")), parse = TRUE) + labs(x = "Year",
    y = "Relative change in pin height (mm)")

SETallDatesPlot_SETomit
```

```
# test computeTrends
computeTrendsSET(dataIn = set.data.SETomit)
```

```
#### Figure 4. Station-level change in elevation data relative
#### to initial height (mm) over time.
```

```r
# find significant trends: For this section we need to use
# the regress, then average method, with no observer effects
# use values from computeTrends() above 'all

stationList <- unique(set.data.SETomit$Station_Name)

station.sig.trends.out <- list()
for (i in 1:length(stationList)) {

    # subset data
    new.station.set.data <- subset(set.data.SETomit, Station_Name ==
        stationList[i])

    # print stationList[i]

    # get regressions among pins
    pin.regressions <- stats::aggregate(value ~ Date + Position_Name,
        data = new.station.set.data, FUN = mean)

    # fit simple linear regression model
    station.mod <- NULL
    station.mod <- lm(value ~ Date, data = pin.regressions)

    # get model summary stats
    mod.summary <- NULL
    mod.summary <- summary(station.mod)

    # create data.frame
    mod.summary.stats <- data.frame(Station_Name = stationList[i],
        t(mod.summary$coefficients[2, ]))

    # add column indicating significance
    mod.summary.stats$Significant <- ifelse(mod.summary.stats$Pr...t.. <=
        0.01, "Yes", "No")

    # add column indicating direction of trend
    mod.summary.stats$Trend <- ifelse(mod.summary.stats$Estimate >
        0, "Positive", "Negative")
    # compile station model results
    station.sig.trends.out <- rbind(station.sig.trends.out, mod.summary.stats)
}

# now merge these results back with set.data.noOutliers
set.data.merge <- merge(set.data.SETomit, station.sig.trends.out,
    by = "Station_Name", all.x = TRUE)

# add sig.trend column
set.data.merge$Sig_Trend <- ifelse(set.data.merge$Significant ==
    "Yes" & set.data.merge$Trend == "Positive", "Positive", ifelse(set.data.merge$Significant ==
    "Yes" & set.data.merge$Trend == "Negative", "Negative", "Not Significant"))

# set factor level order for Sig_Trend
set.data.merge$Sig_Trend <- factor(set.data.merge$Sig_Trend,
```

```
    levels = c("Positive", "Not Significant", "Negative"))

mySigColors <- c("royalblue1", "gray20", "tomato")
mySigFills <- c(alpha("royalblue1", 0.3), alpha("gray20", 0.3),
    alpha("tomato", 0.3))

SETallDatesPlot_SETomit <- ggplot(data = set.data.merge, aes(x = Date,
    y = value, group = 1)) + geom_point(color = "gray50", alpha = 0.7,
    size = 0.8, shape = 16) + # geom_path(aes(color=Station_Name),alpha=0.2)+
geom_smooth(aes(color = Sig_Trend, fill = Sig_Trend), method = lm,
    fullrange = TRUE, linetype = 1, se = TRUE) + scale_color_manual(values = mySigColors) +
    scale_fill_manual(values = mySigFills) + scale_y_continuous(expand = c(0.1,
    0.1)) + scale_x_date(date_breaks = "2 year", date_labels = "%Y") +
    theme(panel.background = element_rect(color = "black", fill = "transparent"),
        panel.border = element_rect(color = "black", fill = "transparent"),
        axis.text.x = element_text(size = 10, color = "black"),
        axis.text.y = element_text(size = 10, color = "black"),
        axis.title.x = element_text(size = 12, hjust = 0.5, vjust = 1.9),
        axis.title.y = element_text(angle = 90, vjust = 1.2,
            size = 12), legend.position = "top", legend.key.size = unit(1,
            "line"), legend.text = element_text(size = 10), legend.title = element_text(size = 12),
        legend.background = element_rect(fill = alpha("white",
            0.9), color = "black")) + geom_hline(yintercept = 0,
    linetype = 2, color = "gray30", alpha = 0.8) + stat_poly_eq(formula = y ~
    x, eq.with.lhs = "italic(hat(y))~`=`~", aes(label = paste(..eq.label..,
    ..rr.label.., sep = "~~~")), parse = TRUE, size = 4) + labs(x = "Year",
    y = "Relative difference in pin height (mm)")



# try facet by SET
SETallDatesPlot_SETomit_Facet <- SETallDatesPlot_SETomit + facet_wrap(~Station_Name,
    scales = "free", drop = TRUE, ncol = 5) + theme(strip.text = element_text(size = 13))

SETallDatesPlot_SETomit_Facet
```

```
#### Table 3. Site-level trend estimates mean, and upper and
#### lower 95% confidence intervals for change in wetland
#### elevation (mm/year).

# get sorted Refuge levels
refuge.order <- all.set.refuges[order(all.set.refuges$mean, decreasing = TRUE),
    ]
refuge.order$Refuge <- factor(refuge.order$Refuge, levels = unique(as.character(refuge.order$Refuge)))

site.order <- all.set.sites
# order by Latitude from SiteOrder.df
site.order$Site_Name <- factor(site.order$Site_Name, levels = unique(SiteOrder.df$Site),
    ordered = TRUE)
# levels(site.order$Site_Name)

site.order <- site.order[order(site.order$Site_Name, decreasing = FALSE),
    ]
```

```
site.order.table <- site.order[, c("Site_Name", "Refuge", "State",
    "n", "mean", "SE", "lwr", "upr")]
colnames(site.order.table) <- c("Site", "NWR", "State", "N",
    "Mean", "SE", "Lower 95% CI", "Upper 95% CI")

row.names(site.order.table) <- NULL

panderOptions("table.alignment.default", function(df) ifelse(sapply(df,
    is.numeric), "right", "left"))
panderOptions("table.split.table", Inf)

pander(site.order.table)
```

```
#### Figure 5. Site-level trend (mean $\pm$ SE) in change in
#wetland elevation (mm/year).

#get sorted Refuge levels
refuge.order<-all.set.refuges[order(all.set.refuges$mean,decreasing=TRUE),]
refuge.order$Refuge<-factor(refuge.order$Refuge,
                            levels=unique(as.character(refuge.order$Refuge)))

#sort site by mean
site.order<-all.set.sites[order(all.set.sites$mean, decreasing=TRUE),]

#add refuge-level mean values to site-level data to plot
site.mean.df<-site.order[,c("Site_Name","mean")]
colnames(site.mean.df)<-c("Site_Name","Site_Mean")

#get station.order
#sort by mean
station.order<-all.set.stations[order(c(all.set.stations$mean),decreasing=TRUE),]
#order Station levels
station.order$Station_Name<-factor(station.order$Station_Name,
                          levels=rev(unique(as.character(station.order$Station_Name))))
#order Station levels
station.order$Site_Name<-factor(station.order$Site_Name,
                          levels=rev(unique(as.character(station.order$Site_Name))))

#order by Site_Name
station.order$Site_Name<-factor(station.order$Site_Name,
                                levels=site.order$Site_Name,
                                ordered=TRUE)

#merge with station.order
station.order.merge<-merge(station.order, site.mean.df,
                           by="Site_Name",all.x=TRUE)


#boxplot
site.trend.plot<-ggplot(data=station.order.merge, aes(x=Site_Name,
                                                      y=mean))+
  #coord_flip()+
  geom_boxplot(aes(fill=Site_Mean))+
  #geom_point()+
```

```
  # geom_bar(stat="identity",aes(fill=mean),alpha=0.9)+
  # geom_errorbar(aes(ymin=mean-SE, ymax=mean+SE, color=mean),width=0,
  show.legend=FALSE)+
  geom_hline(yintercept = 0, linetype=2, color=alpha("lightgray",0.8))+
  #scale_color_gradient2(low="tomato",mid="gray60",high="royalblue1")+
  scale_fill_gradient2(low="tomato",mid="gray60",high="royalblue1")+
  theme(panel.background = element_rect(fill="white"),
        panel.border=element_rect(fill="transparent",color="black"),
        axis.text.x=element_text(angle=90,  vjust=0.5, hjust=1),
        legend.position = c(0.08,0.22),
        legend.background = element_rect(fill = "white",
                                         colour = "transparent"))+
  labs(y="Trend (mm/year)", x="Site", fill="Trend", color=NULL)


print(site.trend.plot)
```

```
#### Figure 6. SET Station-level trend (mean $\pm$ SE) in
#### change in wetland elevation (mm/year).

# add refuge-level mean values to site-level data to plot
station.mean.df <- station.order[, c("Station_Name", "mean")]
colnames(station.mean.df) <- c("Station_Name", "Station_Mean")

# order by Site_Name
station.order$Site_Name <- factor(station.order$Site_Name, levels = site.order$Site_Name,
    ordered = TRUE)

# merge with station.order
position.order.merge <- merge(all.set.positions, station.mean.df,
    by = "Station_Name", all.x = TRUE)

# set factor levels
position.order.merge$Station_Name <- factor(position.order.merge$Station_Name,
    levels = unique(station.order$Station_Name))

station.trend.plot <- ggplot(data = position.order.merge, aes(x = Station_Name,
    y = mean)) + geom_boxplot(aes(fill = Station_Mean)) + geom_hline(yintercept = 0,
    linetype = 2, color = alpha("lightgray", 0.8)) + scale_color_gradient2(low = "tomato",
    mid = "gray60", high = "royalblue1") + scale_fill_gradient2(low = "tomato",
    mid = "gray60", high = "royalblue1") + theme(panel.background = element_rect(fill = "white"),
    panel.border = element_rect(fill = "transparent", color = "black"),
    axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1,
        size = 5), legend.position = c(0.08, 0.22), legend.background = element_rect(fill = "white",
        colour = "transparent")) + labs(y = "Trend (mm/year)",
    x = "SET Station Name", fill = "Trend", color = NULL)

print(station.trend.plot)
```

```
#### Figure 7. Regional map showing site-level trends.

#Map with study area locations

#get locations of SETs
```

```
SETcoords<-unique(set.data.formatted[, c("Refuge","Site_Name",
                                         "Station_Name","Longitude",
                                         "Latitude")])

#aggregate to get Site coords
site.long<-aggregate(Longitude~Site_Name+Refuge, data=SETcoords,
                     FUN=mean)
site.lat<-aggregate(Latitude~Site_Name+Refuge, data=SETcoords,
                    FUN=mean)
site.coords.merge<-merge(site.long, site.lat, by=c("Site_Name","Refuge"),
                         all=TRUE)

#merge with site-level means
site.order.merge<-merge(site.order, site.coords.merge, by=c("Site_Name","Refuge"),
                        all.x=TRUE)

#add magnitude column with multiple
site.order.merge$Magnitude<-abs(site.order.merge$mean)

meanLong<-mean(SETcoords$Longitude)
meanLat<-mean(SETcoords$Latitude)

#get basemap
meanLong<-mean(SETcoords$Longitude)
meanLat<-mean(SETcoords$Latitude)

#get basemap
basemap<-get_map(location=c(meanLong, meanLat),zoom=6, maptype="satellite")
#ggmap(basemap)

#get map extent
mapExtent<-attr(basemap, "bb")


trendMapRegion<-ggmap(basemap,darken = c(0.3, "gray20"))+
  geom_point(data=site.order.merge,
             aes(x=Longitude, y=Latitude, color=mean),
             size=4,alpha=0.8, position=position_jitter(width=0.1,
                                                        height=0.1))+
  scale_color_gradient2(low="tomato",mid="gray60",high="royalblue1",
                        guide_colorbar(title="Trend (mm/year)"))+
  #scale_size_binned(range=c(4,30))+
  labs(x="Longitude",y="Latitude")+
  theme(
    axis.text=element_text(size=14),
    axis.title=element_text(size=16),
    panel.border=element_rect(fill="transparent", color="black"),
    #legend.position = "none"
    legend.position = c(0.8,0.23),
    legend.key.size = unit(2,"line"),
    legend.text = element_text(size=12, color="white"),
    legend.title=element_text(size=14, color="white"),
    legend.background = element_rect(fill="transparent")
```

```
  )+
    geom_text_repel(data=site.order.merge,aes(x=Longitude,y=Latitude,
                                              label=Site_Name,
                                              color=mean), show.legend=FALSE,
                    size=4.5, segment.alpha=0.7,
                   bg.color = "white", bg.r = 0.16)+
  ggsn::scalebar(x.min=mapExtent$ll.lon, x.max=mapExtent$ur.lon,
                 y.min=mapExtent$ll.lat,
                 y.max=mapExtent$ur.lat,transform=TRUE,
                 dist_unit="km",dist=200, st.dist=0.015,
                 height = 0.01,anchor=c(x=-73,y=28),st.color = "white")

trendMapRegion
```

```
### Site-level summaries showing map of SET stations with trends,
#and station-level trend plots.

#load a few needed functions:

#subchunkify function to produce figures of differing
#dimensions within the same r chunk
subchunkify <- function(g, fig_height=6, fig_width=4) {
  g_deparsed <- paste0(deparse(
    function() {g}
  ), collapse = '')

  sub_chunk <- paste0("
  `","``{r sub_chunk_", floor(runif(1) * 10000), ", fig.height=",
  fig_height, ", fig.width=", fig_width, ", echo=FALSE}",
  "\n(",
    g_deparsed
    , ")()",
  "\n`","``
  ")

  cat(knitr::knit(text = knitr::knit_expand(text = sub_chunk),
                  quiet = TRUE))
}

#function to wrap long titles
wrapper <- function(x, ...)
{
  paste(strwrap(x, ...), collapse = "\n")
}

#get site-level means (set order for sites)
siteList<-sort(unique(station.order$Site_Name))

for(i in 1:length(siteList)){

  #get locations of SETs
  new.SETcoords<-subset(station.order, Site_Name==siteList[i])

  #get site sampling info
```

```
  site.sampling.info<-subset(set.data.table.5, Site==siteList[i])

  #get site name
  siteName<-as.character(unique(new.SETcoords$Site_Name))

  #get refugeName
  refugeName<-as.character(unique(new.SETcoords$Refuge))

  #get overall, site-level mean
  site.mean.df<-subset(site.order, Site_Name==siteList[i])

  #aggregate to get Site coords
  site.long<-aggregate(Longitude~Site_Name+Refuge, data=new.SETcoords,
                       FUN=mean)
  site.lat<-aggregate(Latitude~Site_Name+Refuge, data=new.SETcoords,
                      FUN=mean)

  meanLong<-mean(new.SETcoords$Longitude)
  meanLat<-mean(new.SETcoords$Latitude)

  left.coord=meanLong- (meanLong-min(new.SETcoords$Longitude))
  bottom.coord=meanLat-(meanLat-min(new.SETcoords$Latitude))
  right.coord=meanLong+(max(new.SETcoords$Longitude)-meanLong)
  top.coord=meanLat+(max(new.SETcoords$Latitude)-meanLat)

  #set zoom
  plotZoom=ifelse(siteName=="Harris Neck", 11,
                  ifelse(siteName=="Cape Romain - Horsehead Key",14,17))

  #scale location multiple
  plotScaleAnchorX=ifelse(siteName=="Cape Romain - Horsehead Key",0.99983,
                          ifelse(siteName=="Harris Neck",0.998,0.99993))
  plotScaleAnchorY=ifelse(siteName=="Cape Romain - Horsehead Key",0.99975,
                          ifelse(siteName=="Harris Neck",0.99641,0.999935))

  #scalebarDist
  scalebarDist=ifelse(siteName=="Harris Neck",5, 0.3)

  #get basemap
  basemap<-get_map(location=c(lon=meanLong, lat=meanLat),zoom=plotZoom,
                   maptype="satellite")
#ggmap(basemap)

  #get map extent
  mapExtent<-attr(basemap, "bb")

trendMapSite<-ggmap(basemap,darken = c(0.2, "gray10"))+
  geom_point(data=new.SETcoords, aes(x=Longitude, y=Latitude,
                                     color=mean), size=4,alpha=0.9)+
  scale_color_gradient2(low="tomato",mid="gray60",high="royalblue1",
                        limits=c(min(station.order$mean,na.rm=TRUE),
                                 max(station.order$mean, na.rm=TRUE)),
                        guide_colorbar(title="Trend\n(mm/year)"))+
```

```
  #scale_size_binned(range=c(4,30))+
  labs(x="Longitude",y="Latitude")+
  theme(
    axis.text=element_text(size=10),
    axis.title=element_text(size=12),
    title=element_text(size=11),
    panel.border=element_rect(fill="transparent", color="black"),
    #legend.position = "none"
    legend.position = c(0.15,0.82),
    legend.key.size = unit(0.7,"line"),
    legend.text = element_text(size=8, color="white"),
    legend.title=element_text(size=10, color="white"),
    legend.background = element_rect(fill="transparent")
  )+
  geom_label_repel(data=new.SETcoords,aes(x=Longitude,y=Latitude,
                                          label=Station_Name),
                   fill="white",color="black", show.legend=FALSE,
                   point.padding=0.8, label.padding=0.4, size=4,
                   segment.alpha=0.7, alpha=0.8)+
  ggsn::scalebar(x.min=mapExtent$ll.lon, x.max=mapExtent$ur.lon,
                 y.min=mapExtent$ll.lat, y.max=mapExtent$ur.lat,
                 transform=TRUE, dist_unit="km",dist=scalebarDist,
                 st.dist=0.02, st.size=3,
                 height = 0.01,st.color = "white",
                 anchor=c(x=right.coord*plotScaleAnchorX,
                          y=bottom.coord*plotScaleAnchorY))+
  ggtitle(wrapper("A) Locations of SET stations showing elevation trends (mm/year).",
                  width=50))

#add blank lines
#cat("\\newline")

#make pos.pin a factor
set.data.merge$pos.pin<-as.factor(set.data.merge$pos.pin)

#make column with colors
set.data.merge$trendColor<-ifelse(set.data.merge$Sig_Trend=="Positive",
                                  "royalblue2",
                           ifelse(set.data.merge$Sig_Trend=="Negative",
                                  "tomato","gray20"))


plot.data<-subset(set.data.merge, Site_Name==siteName)

#get site level trend by regressing station-level means

  #fit simple linear regression model
  site.mod<-lm(value~Date, data=plot.data)

  #get model summary stats
  site.mod.summary<-summary(site.mod)

  #create data.frame
```

```
  site.mod.summary.stats<-data.frame(Station_Name=siteList[i],
                                     t(site.mod.summary$coefficients[2,]))

  #add column indicating significance
  site.mod.summary.stats$Significant<-ifelse(site.mod.summary.stats$Pr...t.. <= 0.01,
                                             "Yes","No")

  #add column indicating direction of trend
  site.mod.summary.stats$Trend<-ifelse(site.mod.summary.stats$Significant =="Yes" & site.mod.summary.sta
        ifelse(site.mod.summary.stats$Significant =="Yes" &
                 site.mod.summary.stats$Estimate<0,"Negative", "Not Significant"))


#site-level sig. trend
plot.data$Site_Sig_Trend<-site.mod.summary.stats$Trend

#site-level significant trends factors
plot.data$Site_Sig_Trend<-factor(plot.data$Site_Sig_Trend,
                                 levels=c("Positive",
                                          "Not Significant",
                                          "Negative"))


#station-level significant trends factors
plot.data$Sig_Trend<-factor(plot.data$Sig_Trend,
                            levels=c("Positive","Not Significant",
                                     "Negative"))
levels(plot.data$Sig_Trend)

#choose line and fill colors
mycolors<-c("royalblue",I("gray30"),"red")
myfills<-c(alpha("royalblue",0.6),alpha(I("gray30"),0.6),
           alpha("red",0.6))


#now plot trends by EventDate
  SETallDatesSite_noOutliers<-ggplot(data=plot.data,
                                     aes(x=Date, y=value, group=1))+
    geom_point(color="gray50",alpha=0.7, size=1, shape=16)+
    #geom_path(aes(color=Station_Name),alpha=0.2)+
        geom_smooth(aes(x=Date, y=value, group=pos.pin),
                    method="lm",color="gray80",size=0.4,alpha=0.1,
                    inherit.aes = FALSE, se=FALSE)+
geom_smooth(aes(color=Site_Sig_Trend, fill=Site_Sig_Trend),
            method=lm, fullrange=TRUE, linetype=1, se=TRUE,alpha=0.3)+
    scale_color_manual(values=mycolors, drop=FALSE)+
    scale_fill_manual(values=myfills,drop=FALSE)+
    scale_y_continuous(expand=c(0.1,0.1))+
    scale_x_date(date_breaks = "2 year",date_labels = "%Y")+
        theme(panel.background = element_rect(color="black",fill="transparent"),
          panel.border = element_rect(color="black", fill="transparent"),
          axis.text.x = element_text(size=7, color="black"),
          axis.text.y = element_text(size=7, color="black"),
```

```
          axis.title.x = element_text(size=9, hjust=0.5, vjust=1.9),
          axis.title.y = element_text(angle = 90, vjust=1.2, size=10),
          title=element_text(size=13),
          legend.position = "none",
          legend.key.size = unit(1,"line"),
          legend.text = element_text(size=8),
          legend.title=element_text(size=14),
          legend.background = element_rect(fill=alpha("white",0.9),
                                           color="transparent"))+
    geom_hline(yintercept=0, linetype=2, color="gray30",alpha=0.8)+
    stat_poly_eq(formula = y~ x,eq.with.lhs = "italic(hat(y))~`=`~",
                 aes(label = paste(..eq.label.., ..rr.label.., sep = "~~~")),
                 parse = TRUE)+
    labs(x="Year", y="Relative difference in pin height (mm)",
         title = wrapper(paste("C) Pin-level slopes (light gray lines) and linear
                               model trend (mean ± SE; shown in color, if significant)
                               of relative change in wetland elevation mm/year at ",
                               siteName, " site within ",refugeName, " NWR.",sep=""),
                         width=80))


  #now set up plot for stations
    SETallDatesPlot_noOutliers<-ggplot(data=plot.data,
                                       aes(x=Date, y=value, group=1))+
    geom_point(color="gray50",alpha=0.7, size=1, shape=16)+
    #geom_path(aes(color=Station_Name),alpha=0.2)+
        geom_smooth(aes(x=Date, y=value, group=pos.pin),
                    method="lm",color="gray80",size=0.4,alpha=0.1,
                    inherit.aes = FALSE, se=FALSE)+
geom_smooth(aes(color=Sig_Trend, fill=Sig_Trend),method=lm,
            fullrange=TRUE, linetype=1, se=TRUE,alpha=0.3)+
    scale_color_manual(values=mycolors,drop=FALSE)+
    scale_fill_manual(values=myfills,drop=FALSE)+
    scale_y_continuous(expand=c(0.1,0.1))+
    scale_x_date(date_breaks = "2 year",date_labels = "%Y")+
        theme(panel.background = element_rect(color="black",fill="transparent"),
          panel.border = element_rect(color="black", fill="transparent"),
          axis.text.x = element_text(size=7, color="black"),
          axis.text.y = element_text(size=7, color="black"),
          axis.title.x = element_text(size=9, hjust=0.5, vjust=1.9),
          axis.title.y = element_text(angle = 90, vjust=1.2, size=10),
          title=element_text(size=13),
          legend.position = "none",
          legend.key.size = unit(1,"line"),
          legend.text = element_text(size=8),
          legend.title=element_text(size=14),
          legend.background = element_rect(fill=alpha("white",0.9),
                                           color="transparent"))+
    geom_hline(yintercept=0, linetype=2, color="gray30",alpha=0.8)+
    stat_poly_eq(formula = y~ x,eq.with.lhs = "italic(hat(y))~`=`~",
                 aes(label = paste(..eq.label.., ..rr.label..,
                                   sep = "~~~")), parse = TRUE)+
    labs(x="Year", y="Relative difference in pin height (mm)",
```

```
        title = wrapper(paste("C) Pin-level slopes (light gray lines) and
                              linear model trend (mean ± SE; shown in color,
                              if significant) of relative change in wetland
                              elevation (mm/year) at ",
                              siteName, " site within ",
                              refugeName, " NWR.",sep=""),
                        width=80))


#create facet plot of individual stations
SETallDatesPlot_noOutliers_facet<-SETallDatesPlot_noOutliers+
  facet_wrap(~Station_Name, drop=TRUE,ncol=1)+
  ggtitle(wrapper("B) Pin-level linear regression of change in elevation
                  by sampling date (mm/year) among SET stations.", width=46))+
    theme(strip.text=element_text(size=8),
          legend.position = "bottom",
          axis.title.y=element_text(size=12),
          title=element_text(size=10))

cat('\n\n#### Summary of ', siteName, '\n\n\\')

cat('               ')

#Intro paragraph
cat('\n\n',"Surface elevation table (SET) data were collected between ",
    site.sampling.info$`Start Year`,"-",
    site.sampling.info$`End Year`," at A) ",
    site.sampling.info$`SETs (N)`, " SET stations at ",
    siteName, " within the ",
    refugeName, " NWR. The estimated trend in change in surface
    elevation (mean \u00B1 SE) was ",
    round(site.mean.df$mean,2), " \u00B1 ",
    round(site.mean.df$SE,2)," mm/year. Slope equations for pin-level
    linear regression models represent mean trends (mm/year) and are
    shown below for B) individual stations and C) at the site level.",'\n\n',
    sep="")


library(ggpubr)
#combine trendMapSite and
plot1<-ggarrange(trendMapSite, SETallDatesPlot_noOutliers_facet,
                 heights=c(1,0.7), widths=c(1,0.75))

#print map
subchunkify(plot1, 6, 9)
#print(trendMapSite)

#plot Site
#print(SETallDatesPlot_noOutliers_Site)
subchunkify(SETallDatesSite_noOutliers, 3.7,9)


#add blank lines
```

```
cat("\n\\clearpage\n")

}
```

```
### Sea-level Rise and SET trend (adjusted comparison)

# download up-to-date slr trends from NOAA:

# path to the file
myFile = "./Data/SLR_trend_data/USStationsLinearSeaLevelTrends.csv"

# https://tidesandcurrents.noaa.gov/sltrends/data/USStationsLinearSeaLevelTrends.csv
if (!file.exists(myFile)) {
    download.file("https://tidesandcurrents.noaa.gov/sltrends/data/
                USStationsLinearSeaLevelTrends.csv",
        destfile = "./Data/SLR_trend_data/
                USStationsLinearSeaLevelTrends.csv")
}

# Read in SLR trend data ( NOTE: Column headers come in
# wonky:
#'X....95..CI..mm.yr.' = MSL 95% CI (Use this for figure 11 to add to bars)
#'MSL.Trend..ft.century.' = MSL feet per 100 yrs
#'MSL.Trend..ft.century.' = MSL feet per 100 yrs 95% CIs
slr.trend.data <- read.csv("./Data/SLR_trend_data/USStationsLinearSeaLevelTrends.csv")


# filter out station data without the required years (e.g.,
# up to 2021)
slr.trend.data.sub <- subset(slr.trend.data, Last.Year > 2015)

##################################### Section to pair NOAA stations with SET locations

# get NOAA station locations
slr.locations <- slr.trend.data.sub[, c("Station.ID", "Longitude",
    "Latitude")]

# get SET station locations
set.station.locations <- all.set.stations[, c("Refuge", "Site_Name",
    "Station_Name", "Longitude", "Latitude")]

paired.dist <- pointDistance(set.station.locations[, c("Longitude",
    "Latitude")], slr.locations[, c("Longitude", "Latitude")],
    lonlat = TRUE, allpairs = T)

pairs_closest <- apply(paired.dist, 1, which.min)

# get list of slr stations using index from pairs_closest
slr.closest <- slr.locations$Station.ID[pairs_closest]

# cbind with set.station.locations
set.station.locations.2 <- cbind(set.station.locations, slr.closest)

# change column name from NOAA_id to 'Station.ID'
```

```r
names(set.station.locations.2)[names(set.station.locations.2) ==
    "slr.closest"] <- "Station.ID"

# switch Station.ID to factor
set.station.locations.2$Station.ID <- as.factor(as.character(set.station.locations.2$Station.ID))

# redefine as new object
slr.stations <- set.station.locations.2

#####################################

# get list of unique NOAA tide stations to keep
noaa.station.keep <- unique(slr.stations$Station.ID)

# get water level data (mean annual water level)
save.monthly.sea.level <- list()
for (i in 1:length(noaa.station.keep)) {

    new.station <- noaa.station.keep[i]

    new.filename <- paste(new.station, "_", "NOAA_water_level_data_monthly.csv",
        sep = "")

    # download monthly Mean Sea Level (MSL) between 1 Jan 1980
    # and present
    download.file.input <- paste("https://api.tidesandcurrents.noaa.gov/api/prod/
                            datagetter?product=monthly_mean&application=
                            NOS.COOPS.TAC.WL&begin_date=19800101&end_date=
                            20210108&datum=NAVD&station=",
        new.station, "&time_zone=GMT&units=metric&format=CSV",
        sep = "")

    destination <- paste("./Data/SLR_trend_data/", new.station,
        "_", "NOAA_water_level_data_monthly.csv", sep = "")

    # dowload data
    download.file(download.file.input, destfile = destination)

    # read in downloaded data
    new.downloaded.data <- read.csv(destination)

    # add column for Station.ID
    new.downloaded.data$Station.ID <- new.station

    # compile
    save.monthly.sea.level <- rbind(save.monthly.sea.level, new.downloaded.data)
}

# save compiled MSL data (All files that are saved must have
# generic filepath)
write.csv(save.monthly.sea.level, file = "./Data/SLR_trend_data/ALL_NOAA_water_level_data_monthly.csv",
    row.names = FALSE)
#############################################
```

```
# read in monthly sea levels
monthly.sealevel <- read.csv("./Data/SLR_trend_data/ALL_NOAA_water_level_data_monthly.csv")

# aggregate to get annual mean sea.levels and plot by
# Station.ID
yearly.sealevel.mean <- aggregate(MSL ~ Year + Station.ID, data = monthly.sealevel,
    FUN = "mean")

# make Station.ID a factor
yearly.sealevel.mean$Station.ID <- as.factor(as.character(yearly.sealevel.mean$Station.ID))

# aggregate to get annual mean high water (mhw) sea.levels
# and plot by Station.ID
yearly.sealevel.mhw <- aggregate(MHW ~ Year + Station.ID, data = monthly.sealevel,
    FUN = "mean")

# make Station.ID a factor
yearly.sealevel.mhw$Station.ID <- as.factor(as.character(yearly.sealevel.mhw$Station.ID))

# aggregate to get annual mean low water (mlw) sea.levels and
# plot by Station.ID
yearly.sealevel.mlw <- aggregate(MLW ~ Year + Station.ID, data = monthly.sealevel,
    FUN = "mean")

# make Station.ID a factor
yearly.sealevel.mlw$Station.ID <- as.factor(as.character(yearly.sealevel.mlw$Station.ID))

# add these in with mean
yearly.sealevel.df <- merge(merge(yearly.sealevel.mhw, yearly.sealevel.mlw,
    by = c("Year", "Station.ID")), yearly.sealevel.mean, by = c("Year",
    "Station.ID"))

# add Lat Long coords
yearly.sealevel.merge <- merge(yearly.sealevel.df, slr.stations,
    by = "Station.ID", all.x = TRUE)

# change column headers for Latitude and Longitude
names(yearly.sealevel.merge)[names(yearly.sealevel.merge) ==
    "StationLat"] <- "Latitude"
names(yearly.sealevel.merge)[names(yearly.sealevel.merge) ==
    "StationLon"] <- "Longitude"
```

```
### Figure 8. NOAA sea-level trend estimates (mm/yr) among SET sites.
#NOAA station IDs are shown in white.

#now subset slr.trend data
slr.trend.data.sub<-subset(slr.trend.data, Station.ID %in% noaa.station.keep)

#add Refuge Column by merging with slr.stations.sub
slr.trend.data.merge<-merge(slr.trend.data.sub, unique(slr.stations),
                            by="Station.ID",all.x=TRUE)

#change colname
```

```
names(slr.trend.data.merge)[names(slr.trend.data.merge)=="MSL.Trends..mm.yr."]<-
  "Mean_SLR_Trend_mm_per_yr"

slr.trend.data.merge$Site_Name<-as.factor(slr.trend.data.merge$Site_Name)

#########################################################################
#If interested, I wanted to see a plot of just sea level rise among sites.

#simplify
slr.trend.data.simp<-unique(slr.trend.data.merge[,c("Station.ID",
                                                    "Mean_SLR_Trend_mm_per_yr",
                                                    "Site_Name")])

#sort from highest to lowest sea level rise
slr.trend.sort<-slr.trend.data.simp[order(slr.trend.data.simp$Mean_SLR_Trend_mm_per_yr,
                                          decreasing = FALSE),]

#levels(slr.trend.sort$Site_Name)

#reassign factor levels
slr.trend.sort$Site_Name<-factor(slr.trend.sort$Site_Name,
                                 levels=unique(slr.trend.sort$Site_Name))

#add label column
slr.trend.sort$myLabel<-as.character(slr.trend.sort$Station.ID)

#plot annual mean sea.level and trend (blue and red plot)
site_SLR_plot_1<-ggplot(data=slr.trend.sort, aes(x=Site_Name,
                                                 y=Mean_SLR_Trend_mm_per_yr))+
  geom_bar(stat="identity",fill="royalblue",alpha=0.6)+
    theme(#axis.text.x=element_text(angle=90),
      panel.background = element_rect(fill="white",color="black"),
      panel.grid=element_blank(),
      panel.border=element_rect(fill="transparent",color="black"))+
   coord_flip()+
   geom_text(aes(label = myLabel), hjust = 1.4, color="white",size=3) +
  labs(y="Mean Sea Level Rise Trend (mm/yr)", x="Site")

print(site_SLR_plot_1)
```

```
### Figure 9. Plot of benchmark-adjusted surface elevation (m) in
#comparison with NOAA sea-level estimates (m).

#read in elevation data (from Reports: SET Stations.csv) -
#Will need this for Region 5, as well
SET.gnss.elev<-read.csv("./Data/SET Stations.csv", skip=3,
                        header=TRUE)

#modify Refuge Name
SET.gnss.elev$Refuge<-trimws(gsub("National Wildlife Refuge","",
                                  SET.gnss.elev$Refuge))
SET.gnss.elev$SiteName<-trimws(gsub("NWR","",SET.gnss.elev$SiteName))

#fix colnames
```

```
names(SET.gnss.elev)[names(SET.gnss.elev)=="StationElevation_m"]<-"StationElevation_mm"
names(SET.gnss.elev)[names(SET.gnss.elev)=="SiteName"]<-"Site_Name"
names(SET.gnss.elev)[names(SET.gnss.elev)=="StationName"]<-"Station_Name"

#get unique site-level trends
slr.trend.data.merge.2<-slr.trend.data.merge
slr.trend.data.merge.2$Station_Name<-NULL
slr.trend.data.merge.2$Longitude.y<-NULL
slr.trend.data.merge.2$Latitude.y<-NULL

slr.trend.data.merge.2<-unique(slr.trend.data.merge.2)

#merge with slr.trend.data.merge
site.elev.merge<-merge(SET.gnss.elev, slr.trend.data.merge.2,
                       \by=c("Refuge","Site_Name"),all.x=TRUE)

#only keep "Accepted" data
site.elev.keep.df<-unique(subset(site.elev.merge,
                                 DataProcessingLevel=="Accepted"))

#relaxed inclusion of all data (comment this line out to only use Accepted, as stated above)
site.elev.keep.df<-unique(site.elev.merge)

#remove NAs where no SLR data occur
site.elev.keep.df.2<-subset(site.elev.keep.df,
                            ! is.na(site.elev.keep.df$Station.ID))
##############################################################################################
#get table of mean SET measurements (i.e., vertical offset, mean pin height, pin length)

#vertical offset (Will need this info from Region 5, potentially?)
vertical.offset.state<-data.frame("State"=c("NC","SC","FL"),
                                  "Vertical_Offset_mm"=c(398,396,388))

#merge with all Refuges to create data.frame
vertical.offset.refuge<-merge(unique(all.set.refuges[,c("State","Refuge")]),
                              vertical.offset.state, by="State",all.x=TRUE)

#get mean pin height
mean.station.trends<-all.set.stations[,c("State","Refuge","Site_Name",
                                         "Station_Name","Latitude",
                                         "Longitude","mean","SE")]

#now build data.frame with all needed data
mean.station.merge<-merge(mean.station.trends, vertical.offset.state,
                          by=c("State"),all.x=TRUE)

#pin data
pin.data<-unique(raw.set.data[,c("Refuge","Site_Name","Station_Name",
                                 "EventDate","PipeDirectionAzimuth",
                                 "PinPosition","PinLength_mm",
                                 "PinHeight_mm","DataProcessingLevelCode")])

#fix Refuge
```

```
pin.data$Refuge<-gsub(" National Wildlife Refuge","",pin.data$Refuge)

#include only accepted
pin.data.accepted<-subset(pin.data, DataProcessingLevelCode=="A")

#include All pin data (comment this out if truly desiring only "Accepted" data)
pin.data.accepted<-pin.data

#add vertical offset column
pin.data.accepted.1<-merge(pin.data.accepted, vertical.offset.refuge,
                           by=c("Refuge"),all.x=TRUE)

#now add elevation (gnss)
pin.data.accepted.2<-merge(pin.data.accepted.1, site.elev.keep.df.2,
                           by=c("Refuge","Station_Name"),
                           all.x=TRUE)

#compute trends of True_Pin_Height_mm
#for each pin measurement, add this equation: Sediment Surface with
#respect to top of SET mark = Vertical Offset (A) - (Pin Length (C) -
#Pin Measurement (B)) (from Cain and Hansell 2016)

#NOTE for
#Fix "StationElevation_m" should be: "StationElevation_mm"
names(pin.data.accepted.2)[names(pin.data.accepted.2)=="StationElevation_m"]<-"StationElevation_mm"

#use ifelse to compute True_Pin_Height_mm, and return NA if missing values
pin.data.accepted.2$True_Pin_Height_mm<-ifelse(is.na(pin.data.accepted.2$PinHeight_mm),
       NA,
       {pin.data.accepted.2$StationElevation_mm +
           (pin.data.accepted.2$Vertical_Offset_mm -
              (pin.data.accepted.2$PinLength_mm -
                 pin.data.accepted.2$PinHeight_mm))}
       )

#remove any rows where True_Pin_Height_mm is NA
pin.height.computed<-subset(pin.data.accepted.2,
                            !is.na(pin.data.accepted.2$True_Pin_Height_mm))

#get range of computed pin heights
#range(pin.height.computed$True_Pin_Height_mm)

#make True_Pin_Height_m column
pin.height.computed$True_Pin_Height_m<-pin.height.computed$True_Pin_Height_mm/1000

#make Year column
pin.height.computed$Year<-lubridate::year(as.Date(pin.height.computed$EventDate,
                                                  tryFormats = c( "%m/%d/%Y")))

#aggregate to get mean pin height per yr
yearly.elevation.mean<-aggregate(True_Pin_Height_m~Year+Refuge+Station_Name,
                                 data=pin.height.computed, FUN="mean")
colnames(yearly.elevation.mean)<-c("Year","Refuge","Station_Name",
```

```
                                    "Mean_True_Pin_Height_m")

yearly.elevation.sd<-aggregate(True_Pin_Height_m~Year+Refuge+Station_Name,
                               data=pin.height.computed, FUN="sd")
colnames(yearly.elevation.sd)<-c("Year","Refuge","Station_Name",
                                 "SD_True_Pin_Height_m")

yearly.elevation.df<-merge(yearly.elevation.mean, yearly.elevation.sd,
                           by=c("Year","Refuge","Station_Name"))


#stack data, and create factor for sea level and surface elev (m)
slr.df<-unique(yearly.sealevel.merge[,c("Refuge","Year","Station.ID",
                                        "MSL","MHW","MLW")])

#unique(slr.df$Refuge)

#add Type column
slr.df$Type<-"Mean_Sea_Level_m"

#rename columns
colnames(slr.df)<-c("Refuge","Year","Station.ID","Mean","Upper",
                    "Lower","Type")

#make refuge station.ID df
station.id.df<-unique(slr.df[,c("Refuge","Station.ID")])

#now Elevation
elev.df<-yearly.elevation.df[,c("Refuge","Station_Name","Year",
                                "Mean_True_Pin_Height_m",
                                "SD_True_Pin_Height_m")]

#add upper and lower columns
elev.df$Upper<-elev.df$Mean_True_Pin_Height_m+elev.df$SD_True_Pin_Height_m
elev.df$Lower<-elev.df$Mean_True_Pin_Height_m-elev.df$SD_True_Pin_Height_m

#now remove SD column
elev.df$SD_True_Pin_Height_m<-NULL

#rename columns
colnames(elev.df)<-c("Refuge","Station_Name","Year","Mean", "Upper", "Lower")

#now add Type column
elev.df$Type<-"Surface_Elevation_m"

#row bind slr and elev
combined.df<-dplyr::bind_rows(slr.df, elev.df)

#fix NAs in Station.ID
combined.df.2<-merge(combined.df, station.id.df, by=c("Refuge"), all.x=TRUE)
#rename columns
names(combined.df.2)[names(combined.df.2)=="Station.ID.y"]<-"Station.ID"
#remove column
```

```
combined.df.2$Station.ID.x<-NULL

#make Type a factor
combined.df.2$Type<-as.factor(combined.df.2$Type)

myColors<-c("royalblue","goldenrod2")

#make Refuge a factor
combined.df.2$Refuge<-as.factor(combined.df.2$Refuge)

#plot annual mean sea.level and trend (blue and red plot)
sea.level.plot<-ggplot(data=combined.df.2, aes(x=Year, y=Mean))+
  geom_hline(yintercept=0, color="gray80")+
  geom_line(data=subset(combined.df.2,Type=="Mean_Sea_Level_m"),
            aes(x=Year, y=Mean,group=Station.ID),
            color="royalblue",alpha=0.2,inherit.aes = FALSE)+
geom_line(data=subset(combined.df.2,Type=="Surface_Elevation_m"),
          aes(x=Year, y=Mean,group=Station_Name),color="goldenrod2",
          alpha=0.2,inherit.aes = FALSE)+
  geom_smooth(aes(color=Type,fill=Type), method="lm", se=TRUE)+
  scale_color_manual(values=myColors)+
  scale_fill_manual(values=myColors)+
  xlim(2010,2020)+
  labs(x="Year", y="Mean elevation (m)")+
  theme(
    panel.background = element_rect(fill="white",color="black"),
    panel.grid.major.x=element_blank(),
    panel.grid.minor.y=element_line(color="gray80", linetype=2, size=0.5),
    panel.grid.major.y=element_line(color="gray80", linetype=2, size=0.5),
    panel.border=element_rect(fill="transparent",color="black"),
    legend.position=c(0.2,0.75),
    legend.background = element_rect(fill=alpha("white",0.6),color="black")
  )

print(sea.level.plot)
```

```
### Figure 10. Plot of refuge-level benchmark-adjusted surface elevation (m)
#in comparison with NOAA sea-level estimates (m)*.
#*Note Mackay Island missing SLR NOAA station (Station.ID = 8638660) data between 2010 and 2020.

#remove Sites with out elevation
combined.df.3<-subset(combined.df.2, Type=="Surface_Elevation_m")
keepList<-unique(combined.df.3$Refuge)

combined.df.4<-subset(combined.df.2, Refuge %in% keepList)

#plot annual mean sea.level and trend
sea.level.plot<-ggplot(data=combined.df.4, aes(x=Year, y=Mean))+
  geom_hline(yintercept=0, color="gray80")+
  geom_line(data=subset(combined.df.4,Type=="Mean_Sea_Level_m"),
            aes(x=Year, y=Mean, group=Refuge),color="royalblue",
            alpha=0.3,inherit.aes = FALSE)+
  geom_line(data=subset(combined.df.4,Type=="Surface_Elevation_m"),
            aes(x=Year, y=Mean,group=Station_Name),color="goldenrod2",
```

```
            alpha=0.3,inherit.aes = FALSE)+
  geom_smooth(aes(color=Type, fill=Type), method="lm", se=TRUE, fullrange=TRUE)+
  scale_color_manual(values=myColors)+
  scale_fill_manual(values=myColors)+
  #scale_x_continuous(limits=c(1980,NA))+
  #coord_cartesian(xlim=c(2010,2020))+
  xlim(2010,2020)+
  labs(x="Year", y="Mean elevation (m)")+
  theme(
    panel.background = element_rect(fill="white",color="black"),
    panel.grid.major.x=element_blank(),
    panel.grid.minor.y=element_line(color="gray80", linetype=2, size=0.5),
    panel.grid.major.y=element_line(color="gray80", linetype=2, size=0.5),
    panel.border=element_rect(fill="transparent",color="black"),
    #legend.position=c(0.9,0.1),
    legend.position="top"
    #legend.background = element_rect(fill=alpha("white",0.6),color="black")
  )
#sea.level.plot

#now facet plots by Refuge
sea.level.plot.facet<-sea.level.plot+facet_wrap(~Refuge, ncol=5)
sea.level.plot.facet
```

```
### Figure 11. Comparison of mean and 95% CI trends (mm/year)
### in surface elevation table (yellow) and NOAA sea-level rise
### (blue).

# get trends for SET elev and slr

# annual trend for SET
SET.trends <- mean.station.trends

# now get site-level means
SET.site.means <- summaryFunction(dataIn = SET.trends, factor = "Site_Name",
    response = "mean")

# merge with SET.trends covs
SET.site.means.merge <- merge(SET.site.means, unique(SET.trends[,
    c("State", "Refuge", "Site_Name")]), by = "Site_Name", all.x = TRUE)

# add in Station.ID (NOAA)
SET.site.means.merge.2 <- merge(SET.site.means.merge, unique(slr.trend.data.merge.2[,
    c("Site_Name", "Station.ID")]), by = "Site_Name", all.x = TRUE)

SET.site.means.merge.3 <- SET.site.means.merge.2[, c("Refuge",
    "Site_Name", "Station.ID", "mean", "upr", "lwr")]

# compute 95%CI
SET.site.means.merge.3$"95%CI" <- SET.site.means.merge.3$upr -
    SET.site.means.merge.3$mean

# remove upper and lower columns
SET.site.means.merge.3$upr <- NULL
```

```
SET.site.means.merge.3$lwr <- NULL

# add Type column
SET.site.means.merge.3$Type <- "Mean_Marsh_elev_trend_mm_per_yr"

names(SET.site.means.merge.3)[4] <- "Trend"

# get SLR trends
SLR.trends <- slr.trend.data.merge.2

slr.trends.covs <- SLR.trends[, c("Refuge", "Site_Name", "Station.ID")]

# Mean trend
mean.trend <- data.frame(slr.trends.covs, SLR.trends$Mean_SLR_Trend_mm_per_yr,
    SLR.trends$X....95..CI..mm.yr.)
# mean.trend$`95% CI`<-SLR.trends$`95% CI (mm/yr)`
mean.trend$Type <- "Mean_SLR_trend_mm/yr"

names(mean.trend)[4] <- "Trend"
names(mean.trend)[5] <- "95%CI"

# now rowbind SLR and SET trends
slr.set.trends <- rbind(mean.trend, SET.site.means.merge.3)

# compute difference (SET trend - SLR trend) and use this to
# sort data for plotting

# first, merge SET and SLR trends
slr.set.merge <- merge(mean.trend, SET.site.means.merge.3, by = c("Site_Name"),
    all = TRUE)

# create Diff column
slr.set.merge$Diff <- ifelse(slr.set.merge$Trend.y > 0, {
    slr.set.merge$Trend.y - slr.set.merge$Trend.x
}, {
    slr.set.merge$Trend.y + slr.set.merge$Trend.x - 5
})

# now sort by Diff
slr.set.order <- slr.set.merge[order(slr.set.merge$Diff, decreasing = TRUE),
    ]

# levels(slr.set.trends$Site_Name)

# now reorder factor levels using slr.set.order
slr.set.trends$Site_Name <- as.factor(slr.set.trends$Site_Name)
# levels(slr.set.trends$Site_Name)

slr.set.trends$Site_Name <- factor(slr.set.trends$Site_Name,
    levels = unique(as.character(slr.set.order$Site_Name)))

# levels(slr.set.trends$Site_Name)
```

```r
# plot annual mean sea.level and trend
trend.plot.new <- ggplot(data = slr.set.trends, aes(x = Site_Name,
    y = Trend)) + geom_hline(yintercept = 0, color = "gray80") +
    geom_point(aes(color = Type), size = 3, alpha = 0.8) + geom_errorbar(aes(ymin = Trend -
    `95%CI`, ymax = Trend + `95%CI`, color = Type), width = 0.3,
    alpha = 0.8) + scale_fill_manual(values = c("goldenrod2",
    "royalblue")) + scale_color_manual(values = c("goldenrod2",
    "royalblue")) + labs(x = "Site", y = "Trend (mm/yr)", fill = "mm/year") +
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5,
        hjust = 1), panel.background = element_rect(fill = "white",
        color = "black"), panel.grid.major.x = element_blank(),
        panel.grid.minor.y = element_line(color = alpha("gray80",
            0.5), linetype = 2, size = 0.5), panel.grid.major.y = element_line(color = alpha("gray80",
            0.5), linetype = 2, size = 0.5), panel.border = element_rect(fill = "transparent",
            color = "black"), legend.position = c(0.75, 0.85),
        legend.background = element_rect(fill = alpha("white",
            0.6), color = "black"))
trend.plot.new
```

```r
### Marker Horizon (MH) Analysis

#### Table 4. Summary of marker horizon data from 11 sites among
#### National Wildlife Refuges

mh.data <- mh.data.formatted

# remove 'Savanha' from analyes due to questionable data for
# now.
mh.data <- subset(mh.data, Site_Name != "Savannah")

# unique(mh.data$Site_Name)

# remove DataProcessingLevelDate column
mh.data$DataProcessingLevelDate1 <- NULL
mh.data$DataProcessingLevelLabel <- NULL
mh.data$DataProcessingLevelNote <- NULL

mh.data <- unique(mh.data)

# may need to remove initial date of establishment, let's see

# make sure column header is Refuge
names(mh.data)[names(mh.data) == "RefugeName"] <- "Refuge"

# make Year an integer
mh.data$Year <- as.integer(as.character(mh.data$Year))

mh.data.table.1 <- unique(mh.data[, c("State", "Refuge", "Site_Name")])

# remove NAs
mh.data.table.1 <- mh.data.table.1[complete.cases(mh.data.table.1),
    ]

# get freqency of SET stations per refuge
```

```
sub.mh.data <- unique(mh.data[, c("State", "Refuge", "Site_Name",
    "Station_Name")])
count.stations <- table(sub.mh.data$Site_Name, sub.mh.data$Station_Name)
count.stations.total <- rowSums(count.stations)
count.stations.total.1 <- data.frame(Site_Name = names(count.stations.total),
    N = as.data.frame(count.stations.total))

# get years sampled (start and end), and get number of
# MarkerHorizonIDs
sub.mh.data.years.1 <- unique(mh.data[, c("Site_Name", "Year",
    "MarkerHorizonID", "MarkerHorizonLabel", "CoreObservationNumber")])

# sub.mh.data.years<-subset(sub.mh.data.years.1,
# CoreObservationNumber != 0) removed to ensure we include
# the initial observation when feldspar is laid and depth=0mm
sub.mh.data.years <- sub.mh.data.years.1

# get refugeList
siteList <- unique(sort(as.character(sub.mh.data.years$Site_Name)))

# loop over refugeList to get range of years per refuge
range.years <- list()
for (i in 1:length(siteList)) {
    # subset set.data for 1 refuge
    new.mh.data <- subset(sub.mh.data.years, Site_Name == siteList[i])
    # get Refuge
    siteName <- as.character(unique(new.mh.data$Site_Name))
    # get starting year
    startYear <- min(new.mh.data$Year)
    # get ending year
    endYear <- max(new.mh.data$Year)
    # get total years
    nYears <- endYear - startYear + 1
    # get n unique observers (set.data recorders)
    nCores <- length(unique(new.mh.data$MarkerHorizonID))

    range.years.1 <- data.frame(Site_Name = siteName, startYear = startYear,
        endYear = endYear, nYears = nYears, nCores = nCores)
    range.years <- rbind(range.years, range.years.1)

}

# combine with SummaryTable.1
mh.data.table.2 <- na.omit(merge(mh.data.table.1, count.stations.total.1,
    by = "Site_Name", all.x = TRUE))

# now combine with range.years
mh.data.table.3 <- merge(mh.data.table.2, range.years, by = "Site_Name")

# get Site order sorted North to South
siteLat <- aggregate(Latitude ~ Site_Name, data = mh.data, FUN = "mean")
siteOrder <- siteLat[order(siteLat$Latitude, decreasing = TRUE),
    ]
```

```
siteOrderList <- unique(siteOrder$Site_Name)
# length(refugeOrderList)

# Now sort table by Latitude (reorder Refuge factor) create
# data.frame with NWRs ordered from North to South
SiteOrder.df <- data.frame(Site = siteOrderList, orderNum = seq(1:length(siteOrderList)))

# rename column headers
colnames(mh.data.table.3) <- c("Site", "State", "Refuge", "Num_Marker_Horizons",
    "Start_Year", "End_Year", "Num_Years", "Num_Cores")

# reorder columns
mh.data.table.4 <- mh.data.table.3[, c("Site", "State", "Refuge",
    "Num_Marker_Horizons", "Num_Cores", "Num_Years", "Start_Year",
    "End_Year")]

# create integer column of order for NWRs
mh.data.table.order <- merge(mh.data.table.4, SiteOrder.df, by = c("Site"),
    all.x = TRUE)
mh.data.table.order <- mh.data.table.order[order(mh.data.table.order$orderNum,
    mh.data.table.order$Refuge), ]
mh.data.table.5 <- mh.data.table.order
mh.data.table.5$orderNum <- NULL

# remove row.names from table
row.names(mh.data.table.5) <- NULL

# rename column headers
colnames(mh.data.table.5) <- c("Site", "State", "NWR", "Marker Horizons (N)",
    "Core Samples (N)", "Num. Years", "Start Year", "End Year")

panderOptions("table.alignment.default", function(df) ifelse(sapply(df,
    is.numeric), "right", "left"))
panderOptions("table.split.table", Inf)

pander(mh.data.table.5)
```

```
# test computeTrends
computeTrendsMH(dataIn = mh.data)
```

```
#### Figure 12. Mean annual trend (mean $\pm$ SE) of marsh
#### accretion (mm/year) from marker horizon data among 17
#### sites.

# plot Marker horizon data (box plot)

# get sorted Refuge levels
mh.refuge.order <- all.mh.refuges[order(all.mh.refuges$mean,
    decreasing = TRUE), ]
mh.refuge.order$Refuge <- factor(mh.refuge.order$Refuge,
    levels = unique(as.character(mh.refuge.order$Refuge)))

# sort by mean
mh.site.order <- all.mh.sites[order(all.mh.sites$mean,
```

```
    decreasing = TRUE), ]

mh.site.order$Refuge <- factor(mh.site.order$Refuge, levels = unique(mh.refuge.order$Refuge[order(mh.re
    decreasing = TRUE)]), ordered = TRUE)

# order by Site_Name
mh.site.order$Site_Name <- factor(mh.site.order$Site_Name, levels = mh.site.order$Site_Name[order(mh.si
    decreasing = FALSE)], ordered = TRUE)

# remove plots with problematic data: Blackbeard Island, Wolf
# Island, Pinckney Island, Wassaw, and Waccamaw
removeSiteList <- c("Blackbeard Island", "Wolf Island",
    "Pinckney Island", "Wassaw", "Waccamaw")

mh.site.order.reduced <- subset(mh.site.order,
    !(Site_Name %in% removeSiteList))

# point plot with errorbars (cannot make boxplots due to lack
# of multiple sites within each refuge)
mh.site.trend.plot <- ggplot(data = mh.site.order.reduced, aes(x = Site_Name,
    y = mean)) + geom_point(aes(color = mean), alpha = 0.9, size = 2) +
    geom_errorbar(aes(ymin = mean - SE, ymax = mean + SE, color = mean),
        width = 0, show.legend = FALSE) + geom_hline(yintercept = 0,
    linetype = 2, color = alpha("lightgray", 0.8)) + scale_fill_gradientn(colors = viridis(100)) +
    scale_color_gradientn(colors = viridis(100)) + theme(panel.background = element_rect(fill = "white"
    panel.border = element_rect(fill = "transparent", color = "black"),
    axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1),
    legend.position = c(0.08, 0.22), legend.background = element_rect(fill = "white",
        colour = "transparent")) + labs(y = "Trend (mm/year)",
    x = "Site", color = "Trend")

print(mh.site.trend.plot)
```

```
#### Figure 13. Mean Station-level trend (mean $\pm$ SE) in marsh accretion (mm/year) from marker horiz

#sort by mean
mh.station.order<-all.mh.stations[order(c(all.mh.stations$mean),decreasing=TRUE),]

#order mh.station levels
mh.station.order$Station_Name<-factor(mh.station.order$Station_Name, levels=rev(unique(as.character(mh.s

#order mh.station Site levels
mh.station.order$Site_Name<-factor(mh.station.order$Site_Name,
                                   levels=rev(unique(as.character(mh.station.order$Site_Name))))

#order by Refuge
mh.station.order$Refuge<-factor(mh.station.order$Refuge,
                                levels=unique(as.character(mh.refuge.order$Refuge)))

#sort by mean
mh.station.order<-all.mh.stations[order(c(all.mh.stations$mean),
                                        decreasing=TRUE),]

#get sorted Refuge levels
```

```
mh.refuge.order<-all.mh.refuges[order(all.mh.refuges$mean,decreasing=TRUE),]
mh.refuge.order$Refuge<-factor(mh.refuge.order$Refuge,
                               levels=unique(as.character(mh.refuge.order$Refuge)))

#sort by mean
mh.station.order<-all.mh.stations[order(all.mh.stations$mean,decreasing=TRUE),]

#site.order$Site_Name<-all.set.sites[order(all.set.sites$Refuge,
#all.set.sites$mean,decreasing=FALSE),]
mh.station.order$Refuge<- factor(mh.station.order$Refuge,
                                 levels=unique(mh.refuge.order$Refuge),
                                 ordered=TRUE)

#order by Site_Name
mh.station.order$Station_Name<-factor(mh.station.order$Station_Name, levels=unique(mh.station.order$Sta
                                      ordered=TRUE)

#remove plots with problematic data: Blackbeard Island, Wolf Island, Pinckney Island, Wassaw,
#and Waccamaw
removeSiteList<-c("Blackbeard Island", "Wolf Island", "Pinckney Island", "Wassaw", "Waccamaw")

mh.station.order.reduced<-subset(mh.station.order, ! (Site_Name  %in% removeSiteList))


mh.station.trend.plot<-ggplot(data=mh.station.order.reduced,
                              aes(x=Station_Name, y=mean))+
  #geom_bar(stat="identity",aes(fill=mean),alpha=0.9)+
  geom_point(aes(color=mean),alpha=0.9,size=2)+
  geom_errorbar(aes(ymin=mean-SE, ymax=mean+SE, color=mean),
                width=0, show.legend=FALSE)+
  geom_hline(yintercept = 0, linetype=2, color=alpha("lightgray",0.8))+
  scale_fill_gradientn(colors=viridis(100))+
  scale_color_gradientn(colors=viridis(100))+
theme(panel.background = element_rect(fill="white"),
        panel.border=element_rect(fill="transparent",color="black"),
        axis.text.x=element_text(angle=90,  vjust=0.5, hjust=1, size=5),
        legend.position = c(0.8,0.8),
        legend.background = element_rect(fill = "white", colour = "transparent"))+
\  labs(y="Trend (mm/year)", x="SET Station Name", color="Trend")

print(mh.station.trend.plot)
```

```
### Surface Elevation Table (SET) and Marker Horizon (MH)
### comparison

# combine mh.data.formatted and set.data.noOutliers
mh.data.comb <- mh.data
names(mh.data.comb)[names(mh.data.comb) ==
    "DepthToBenchmark_mm"] <- "value"
names(mh.data.comb)[names(mh.data.comb) ==
    "new.date"] <- "Date"

mh.data.comb.sub <- mh.data.comb[, c("State", "Refuge",
    "Station_Name", "Site_Name", "MarkerHorizonID",
```

```
    "Core_Notes", "Date", "Year", "Latitude", "Longitude",
    "value")]

# remove plots with problematic data: Blackbeard Island, Wolf
# Island, Pinckney Island, Wassaw, and Waccamaw
removeSiteList <- c("Blackbeard Island", "Wolf Island",
    "Pinckney Island", "Wassaw", "Waccamaw")

mh.data.comb.sub <- subset(mh.data.comb.sub,
    !(Site_Name %in% removeSiteList))


# remove all Os from DateEstablished
mh.data.comb.sub.2 <- subset(mh.data.comb.sub, Core_Notes !=
    "Established_feldspar")

# create Station_Year column
mh.data.comb.sub.2$Station_Date_Year <- paste(mh.data.comb.sub.2$Station_Name,
    mh.data.comb.sub.2$Date, mh.data.comb.sub.2$Year, sep = "_")

# get mean MH depth (mm) for each year and station
mh.station.summary <- summaryFunction(dataIn = mh.data.comb.sub.2,
    factor = "Station_Date_Year", response = "value")

# add Data_Type column
mh.station.summary$Data_Type <- "Marker_Horizon"

# separate Station_Date_Year
mh.covs <- read.table(text = as.character(mh.station.summary$Station_Date_Year),
    sep = "_")
colnames(mh.covs) <- c("Station_Name", "Date", "Year")

# add to summary
mh.station.summary.2 <- cbind(mh.covs, mh.station.summary)

# create Station_Year column
mh.station.summary.2$Station_Year <- paste(mh.station.summary.2$Station_Name,
    mh.station.summary.2$Year, sep = "_")

# get unique list of Stations in mh.data.comb.sub
mh.station.year <- unique(mh.station.summary.2$Station_Year)

# now get SET station-level elevations (average pins and
# arms, first)

# now simplify set data
set.data.comb <- set.data.SETomit[, c("State", "Refuge",
    "Site_Name", "Station_Name", "Date", "Year", "Latitude",
    "Longitude", "Position_Name", "variable", "value")]



# create Station_Date_Year column
```

```
set.data.comb$Station_Date_Year <- paste(set.data.comb$Station_Name,
    set.data.comb$Date, set.data.comb$Year, sep = "_")

# get summary
set.station.summary <- summaryFunction(dataIn = set.data.comb,
    factor = "Station_Date_Year", response = "value")

# remove first deltas (means), where mean pin value = 0
set.station.summary.2 <- subset(set.station.summary, mean !=
    0)

# or leave zeros in
set.station.summary.2 <- set.station.summary

# get covs
set.covs <- read.table(text = as.character(set.station.summary.2$Station_Date_Year),
    sep = "_")
colnames(set.covs) <- c("Station_Name", "Date", "Year")

# combine with summary
set.station.summary.3 <- cbind(set.covs,
    set.station.summary.2)

# add Data_Type column
set.station.summary.3$Data_Type <- "SET"

# make Station_Year column
set.station.summary.3$Station_Year <- paste(set.station.summary.3$Station_Name,
    set.station.summary.3$Year, sep = "_")

# subset set data by mh.stations
set.station.summary.sub <- subset(set.station.summary.3,
    Station_Year %in% mh.station.year)

# combine mh and set data
mh.set.comb <- rbind(mh.station.summary.2,
    set.station.summary.sub)

# convert Date back to as.Date
mh.set.comb$Date <- as.Date(mh.set.comb$Date,
    format = "%Y-%m-%d")

# create Station.Type factor
mh.set.comb$Station_Type <- paste(mh.set.comb$Station_Name,
    mh.set.comb$Data_Type, sep = "_")
mh.set.comb$Station_Type <- as.factor(mh.set.comb$Station_Type)

# make Data_Type a factor
mh.set.comb$Data_Type <- as.factor(mh.set.comb$Data_Type)


SET_MH_allDatesPlot <- ggplot(data = mh.set.comb,
    aes(x = Date, y = mean,
```

```
        group = Station_Type)) +
    geom_hline(yintercept = 0,
        linetype = 2, color = "gray30",
        alpha = 0.6) + geom_errorbar(aes(ymin = mean -
    SE, ymax = mean + SE,
    color = Data_Type), alpha = 0.5) +
    geom_point(aes(color = Data_Type),
        size = 1, shape = 16,
        alpha = 0.5) + geom_path(aes(color = Data_Type),
    alpha = 0.5) + scale_color_manual(values = c("red",
    "royalblue")) + scale_y_continuous(expand = c(0.1,
    0.1)) + scale_x_date(date_breaks = "1 year",
    date_labels = "%Y") +
    theme(panel.background = element_rect(color = "black",
        fill = "transparent"),
        panel.border = element_rect(color = "black",
            fill = "transparent"),
        axis.text.x = element_text(size = 12,
            color = "black"),
        axis.text.y = element_text(size = 12,
            color = "black"),
        axis.title.x = element_text(size = 14,
            hjust = 0.5, vjust = 1.9),
        axis.title.y = element_text(angle = 90,
            vjust = 1.2, size = 14),
        legend.position = c(0.88,
            0.2), legend.key.size = unit(1,
            "line")) + labs(x = "Year",
    y = "Relative change in elevation (mm)")

# print(SET_MH_allDatesPlot)
```

```
#### Figure 14. Plot of relative changes (mean $\pm$ SE) in
#### elevation (mm) for station-level accretion (red) and SET
#### (light blue) data for each station.

# figure here showing computed SET-MH values indicating
# sub-surface influence on accretion/subsidence patterns.

SET_MH_allDatesPlot.2 <- ggplot(data = mh.set.comb.reduced, aes(x = Date,
    y = mean, group = Station_Type)) + geom_hline(yintercept = 0,
    linetype = 2, color = "gray30", alpha = 0.6) + geom_errorbar(aes(ymin = mean -
    SE, ymax = mean + SE, color = Data_Type), alpha = 0.5) +
    geom_point(aes(color = Data_Type), size = 1, shape = 16,
        alpha = 0.5) + geom_path(aes(color = Data_Type), alpha = 0.5) +
    scale_color_manual(values = c("red", "royalblue")) + scale_y_continuous(expand = c(0.1,
    0.1)) + scale_x_date(date_breaks = "3 year", date_labels = "%Y") +
    theme(panel.background = element_rect(color = "black", fill = "transparent"),
        panel.border = element_rect(color = "black", fill = "transparent"),
        axis.text.x = element_text(size = 9, color = "black"),
        axis.text.y = element_text(size = 9, color = "black"),
        axis.title.x = element_text(size = 14, hjust = 0.5, vjust = 1.9),
        axis.title.y = element_text(angle = 90, vjust = 1.2,
            size = 14), legend.position = "top", legend.key.size = unit(1,
```

```
            "line")) + labs(x = "Year", y = "Relative change in elevation (mm)")

SET_MH_allDatesPlot_facet <- SET_MH_allDatesPlot.2 + facet_wrap(~Station_Name,
    ncol = 5)

print(SET_MH_allDatesPlot_facet)
```

```
# compute new trends for reduced SET data
set.data.SETomit$Station_Year <- paste(set.data.SETomit$Station_Name,
    set.data.SETomit$Year, sep = "_")

# subset to include only corresponding mh data
set.data.SETomit.sub <- subset(set.data.SETomit, Station_Year %in%
    mh.station.year)

# use computeTrendsSET function on reduced SET data (NOTE,
# this will overwrite previously generated set trend
# estimates that were computed earlier)
computeTrendsSET(set.data.SETomit.sub)
```

```
#### Figure 15. Plot of mean accretion rate (mm/year) - mean
#### change in SET elevation (mm/year) to evaluate contributions
#### of sub-surface processes to overall wetland elevation
#### change*.

# *SET and MH data (trends of elevation change) can be
# compared to investigate the contribution of surface or
# subsurface processes to marsh elevation change.  3
# heuristic rules include: 1) If accretion is greater than
# elevation: shallow subsidence (subsurface effect) 2) If
# accretion is equal to elevation: surface processes dominate
# (with no subsurface influence) 3) If accretion is less than
# elevation: shallow expansion (subsurface effect)

# compute accretion rate - SET elevation change (mm/yr)

# fix names of 'mean' columns
names(all.mh.sites)[names(all.mh.sites) == "mean"] <- "mean_MH"
names(all.set.sites)[names(all.set.sites) == "mean"] <- "mean_SET"

# combine mh and SET trend data
all.mh.set.compare <- merge(all.mh.sites[, c("State", "Refuge",
    "Site_Name", "mean_MH")], all.set.sites[, c("State", "Refuge",
    "Site_Name", "mean_SET")], by = c("State", "Refuge", "Site_Name"),
    all.x = TRUE)

# compute Accretion - SET
all.mh.set.compare$MH_SET_diff <- all.mh.set.compare$mean_MH -
    all.mh.set.compare$mean_SET

# create categorical variable to color by
all.mh.set.compare$Sub_surface_effect <- ifelse(all.mh.set.compare$MH_SET_diff >
    0, "Shallow subsidence", ifelse(all.mh.set.compare$MH_SET_diff ==
    0, "No sub-surface effect", ifelse(all.mh.set.compare$MH_SET_diff <
```

```
    0, "Shallow expansion", "NA")))

# remove Sites where differences were not computed
all.mh.set.compare.2 <- subset(all.mh.set.compare, !is.na(MH_SET_diff))

# now plot

# order by difference
all.mh.set.compare.order <- all.mh.set.compare.2[order(all.mh.set.compare.2$MH_SET_diff,
    decreasing = TRUE), ]

# order by Site_Name
all.mh.set.compare.order$Site_Name <- factor(all.mh.set.compare.order$Site_Name,
    levels = all.mh.set.compare.order$Site_Name, ordered = TRUE)

mh.set.site.compare.plot <- ggplot(data = all.mh.set.compare.order,
    aes(x = Site_Name, y = MH_SET_diff)) + geom_bar(stat = "identity",
    aes(fill = MH_SET_diff), alpha = 0.9) + geom_hline(yintercept = 0,
    linetype = 2, color = alpha("lightgray", 0.8)) + scale_fill_gradientn(colors = viridis(100)) +
    scale_color_gradientn(colors = viridis(100)) + theme(panel.background = element_rect(fill = "white"
    panel.border = element_rect(fill = "transparent", color = "black"),
    axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1,
        size = 9), legend.position = c(0.8, 0.8), legend.background = element_rect(fill = "white",
        colour = "transparent")) + labs(y = "Sub-surface effects (MH - SET; mm/year)",
    x = "Site Name", fill = "Trend Comparison", color = NULL)

mh.set.site.compare.plot

# END CODE
```