

Wind Cave National Park: Riparian Condition Assessment, and Trend and Power Analysis

February 19, 2021

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ACRONYMS AND ABBREVIATIONS

BLM	Bureau of Land Management
COOP	Cooperative Observer Network
CusterSP	Custer State Park
DMA	Designated monitoring area
DS	Dominant species
GG	Greenline-to-greenline
GLM	Generalized linear model
MIM	Multiple Indicator Monitoring
NPS	National Park Service
USFS	United States Forest Service
WICA	Wind Cave National Park

1 Analysis Summary

Riparian monitoring data has been collected from three perennial streams within Wind Cave National Park (WICA) using the Bureau of Land Management's Multiple Indicator Monitoring (MIM) protocol (Burton, Smith, and Cowley, 2011). Designated monitoring areas were established on Beaver Creek, Highland Creek, and Cold Spring Creek (Figure 1-1). Data collection began in 2009 and repeated sampling efforts have been performed at irregular intervals since then (Table 1-1). Additional data collection efforts using the same protocol have been implemented in Custer State Park and neighboring National Forest lands.

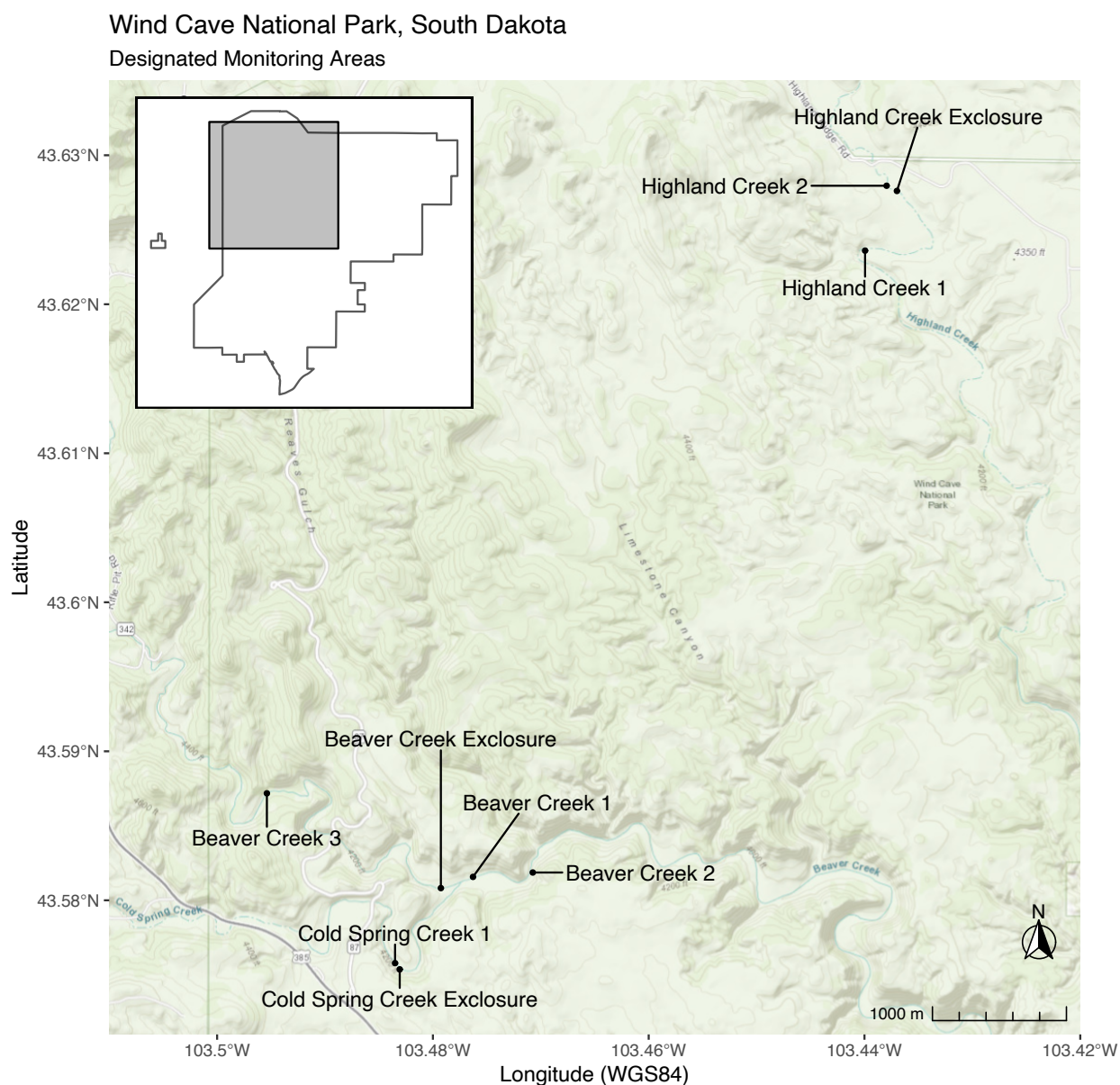


Figure 1-1: Locations of Wind Cave National Park designated monitoring areas (DMAs) on Beaver Creek, Highland Creek, and Cold Spring Creek.

Table 1-1: MIM data collection within Wind Cave National Park during 2009-2019.

Designated Monitoring Area	2009	2010	2012	2013	2014	2016	2017	2018	2019
Beaver Creek Exclosure		x	x	x				x	
Beaver Creek 1	x		x	x	x			x	
Beaver Creek 2	x		x	x					
Beaver Creek 3		x	x	x					
Cold Spring Creek Exclosure		x		x			x		
Cold Spring Creek 1		x		x	x		x		
Highland Creek Exclosure		x	x		x	x			x
Highland Creek 1	x		x	x		x			x
Highland Creek 2	x		x	x		x			x
Total	4	5	7	8	3	3	2	2	3

Section 2 summarizes riparian condition within each monitoring site for each year of data collection (Table 1-1). MIM indicators and metrics were computed using the raw data recorded in the provided Excel spreadsheets in accordance with the methods detailed in the BLM's MIM protocol. Rating value descriptors (Table 1-3) are also included for each of the four MIM metrics within each respective summary table. Characterization of the overall ecological condition of each stream based on all MIM indicators and metrics was not undertaken since previous efforts were based on professional judgement by WICA scientists.

Graphical and regression analysis methods were utilized to assess trends in each individual MIM indicator and metric (Section 3). Trends were quantified separately for each perennial stream and for DMAs inside versus outside fenced exclosures. Changes in riparian condition over time can be assessed visually by inspecting plots of the MIM indicators and metrics. For example, Figure 1-2 displays the average stubble height indicator within Beaver Creek non-exclosure DMAs during the period of 2009 to 2019. In this plot, each DMA is represented by a different plotting character. Some notable observations from the plot include: (1) DMA 2 tends to exhibit larger temporal variation than DMAs 1 and 3; (2) the most recent average stubble height in DMA 1 has increased considerably after having been lower than the other DMAs during 2009 to 2013; and (3) during years where each DMA was sampled, there is a considerable amount of spatial variability present despite DMAs being located in relatively close spatial proximity to each other (e.g., range of values in 2012). In addition to visually assessing how average stubble height has changed within each DMA over time, it is also useful to estimate quantitatively how heights have changed during the period of interest on a stream-wide basis. To do this, a regression model was fit using all of the average stubble height measurements from each non-exclosure DMA. As indicated by the positive slope of the blue regression line in Figure 1-2, it is estimated that average stubble height within Beaver Creek non-exclosure DMAs has been increasing during the period of 2009 to 2019.

A benefit of utilizing a statistical model is that we were able to also quantify several sources of uncertainty related to this estimate. First, the degree of uncertainty in the mean average stubble height at any given time is depicted visually by the width of the shaded blue confidence interval. Second, we were able to compute a 95% confidence interval for the slope coefficient, thus providing a range of plausible values for the trend. Confidence intervals contain information that is equivalent to some aspects of a hypothesis test. For example, if the confidence interval contains zero, we are unable to statistically conclude that the true trend in average stubble height differs from zero (i.e., no change in height over time). Note, this is equivalent to failing to reject the null hypothesis corresponding to a

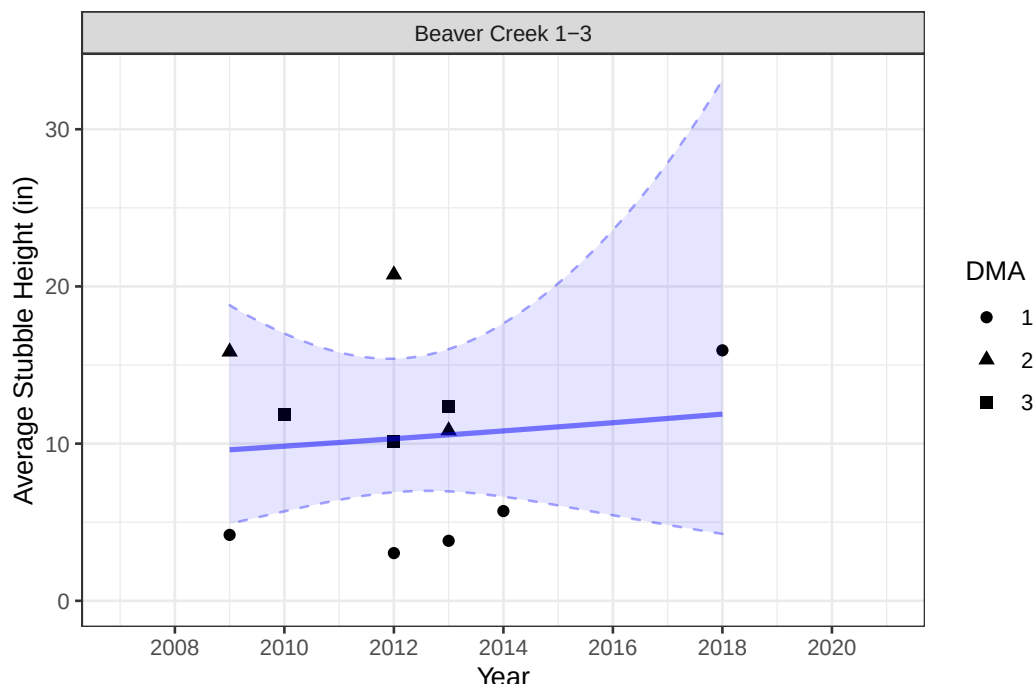


Figure 1-2: Estimated trend in the mean average stubble height for Beaver Creek non-exclosure DMAs during the period of 2009 to 2019.

two-sided test (at the 0.05 alpha level) that the trend effect equals zero. For non-exclosure DMAs on Beaver Creek, the trend coefficient was estimated to be 0.024 with 95% confidence interval $(-0.142, 0.189)$. Because this confidence interval contains 0, we fail to reject the null hypothesis that the true trend in average stubble height is zero. Regardless of a trend's statistical significance, it is recommended that readers consult the plot containing the indicator/metric values that the trend is based on. This is because biologically meaningful change could be occurring even though it is not able to be detected statistically. Additionally, comparisons between individual DMA observations and the stream-wide trend line provide useful context for a particular stream's results.

MIM indicators and metrics have been collected using the same protocol in both Custer State Park and neighboring National Forest lands. Graphical and regression analysis methods were utilized to assess trends in each of these neighboring areas compared to within WICA (Section 4). Interpretation of trends for these comparisons mirrors those presented in Section 3.

When designing or modifying a monitoring program, it is often of interest to know: "How many samples do we need to detect a trend?" One of the main objectives for the work presented here is to assist in the assessment of sample adequacy regarding the amount of data being collected on each stream. In this context, sample adequacy relates to the degree of certainty associated with the ability to see differences in an indicator/metric through time. Generally speaking, more data corresponds to more certainty, but the variability of the response mediates the magnitude of the sample effort needed to see differences. Responses with less variability will require fewer samples to detect a trend. In essence, the signal to noise ratio is higher for response variables with less variability through time. In order to provide some quantitative support for the consideration of potential sampling effort that may be implemented in the future, we developed a simulation-based power analysis.

Section 5 provides the details associated with the methods used to estimate the magnitude of trend detectable for a given level of statistical power under varying levels of sampling effort. In the context of this analysis, sampling effort only refers to the sampling interval associated with sampling all DMAs concurrently. Statistical power quantifies the probability of detecting a trend that exists and is generally preferred to be at least 80%. The estimated trend effect therefore represents the estimated minimum effect size that is detectable with 80% probability under the assumed sampling interval. The shorter the interval between sampling events, the smaller the detectable trend effect size will be. As an example of this simulation-based power analysis approach, Table 1-2 provides the estimated detectable trend, with 80% power, in average stubble height in non-exclosure Beaver Creek DMAs. The first three columns of the table correspond to the estimated trend effect detectable for the different sampling intervals. To put these trend effect sizes in context, the most recent estimate of average stubble in non-exclosure DMAs on Beaver Creek is provided (i.e., 11.88 inches, see Figure 1-2 for visualization). Additionally, the last three columns provide the respective changes from the latest estimate of average stubble height that would result assuming the estimated minimum detectable trend is applied over a period of 10 years (see Figure 1-3 for visualization of these changes over time).

The results in Table 1-2 correspond to the detectable trend effect size based on the variability of measurements collected on Beaver Creek to date. This is relevant since the magnitude of the trend effect corresponds to the signal part of the signal to noise concept. In cases where there exists noticeable variation (noise) among observations, both in space and/or time, more observations are needed to detect the underlying signal. When the number of samples is limited by either the number of sampled DMAs or the sampling interval, the magnitude of signal that is detectable with sufficient power increases. In the example above, the minimum magnitude of trend that is detectable assuming each Beaver Creek non-exclosure DMA is concurrently sampled each year is relatively large ($-7.18, +18.18$ inches). However, it is possible that the magnitude of detectable trend could be lower if additional DMAs could be sampled. One of the advantages of this type of power analysis is the ability to assess the change in the necessary sampling effort for different trend magnitudes. With respect to the ability to design efficient sampling plans, additional power analyses can be used to determine the minimum number of sampled DMAs necessary to detect trend of a given magnitude. In this way, the optimal sampling effort is estimated and additional resources are not used to increase sampling effort beyond what is specified.

An exploratory analysis aimed at identifying potential drivers of riparian condition is provided in Section 6. A combination of graphical and regression methods analysis were utilized to explore potential relationships concerning both weather and management related drivers. Interpretation of variable effects for these regressions mirror those presented in Section 3.

Table 1-2: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in average stubble height after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of average stubble height is provided along with the respective changes in average stubble height that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80			Latest Estimate (in.)	$\pm\Delta$ in Average Stubble Height (in.) After 10 years		
	Sampling Frequency:				Sampling Frequency:		
	3 yrs	2 yrs	1 yr		3 yrs	2 yrs	1 yr
Beaver Creek 1-3	0.139	0.118	0.093	11.88	(−8.93, +36.02)	(−8.22, +26.72)	(−7.18, +18.18)

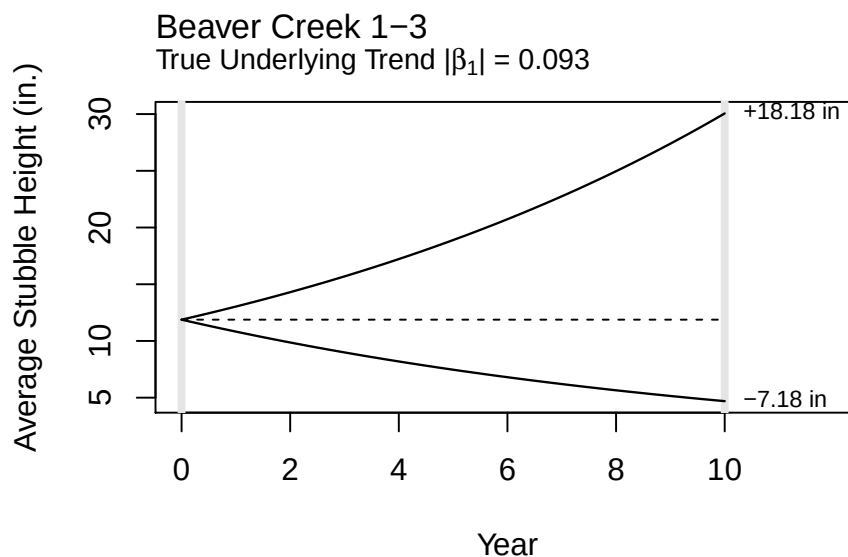


Figure 1-3: Visualization of the changes in average stubble height for Beaver Creek 1-3, assuming the estimated minimum detectable time trend is applied for a period of 10 years and sampling occurs every year.

Table 1-3: MIM metrics used in analysis of WICA riparian condition. Rating value ranges and descriptors are based on Table 3 of Burkhardt and Kovacs (2013).

	Metric	Values	Condition Descriptor
Wetland Rating		[0, 16)	very poor
		[16, 41)	poor
		[41, 61)	fair
		[61, 85)	good
		[85, 100]	very good
Greenline Stability Rating		[0, 3)	very low
		[3, 5)	low
		[5, 7)	mid
		[7, 9)	high
		[9, 10]	very high
Ecological Status Rating		[0, 16)	very early
		[16, 41)	early
		[41, 61)	mid
		[61, 85)	late
		[85, 100]	potential natural community
Plant Diversity Index		[0, 1)	very low
		[1, 3)	low
		[3, 5)	moderate
		[5, 6]	high
		>6	very high

2 Riparian Condition Assessment

2.1 MIM Database

Riparian monitoring data from each sampling event has been entered/imported into the Data Analysis Module Excel workbook provided by (Burton, Smith, and Cowley, 2011). Although it is reasonably easy to extract the computed metrics from the module's export worksheet, all metrics were instead derived using the raw data provided in both the header and DMA worksheets. This was done in an effort to maintain consistency across MIM files and for computational reproducibility.

2.1.1 Revised Metric Computations

To validate the metric computation code, rederived metric values were compared to those provided in Burkhart and Kovacs (2013) for Beaver Creek 1 in year 2009. Resulting from this comparison, the following inconsistencies were identified and corrected:

1. Metric values for percent covered bank and percent stable bank were not able to be computed from the raw data due to missing values in the streambank stability data columns (DMA worksheet, columns F through H). The Excel document computes values for both metrics using hand-entered values in DMA worksheet column X, which overrides the existing formula for computing the streambank stability class. It was assumed that the hand-entered values in column X are valid.
2. As defined in Burkhart and Kovacs (2013), the hydric herbaceous species indicator corresponds to the percent of plots containing hydric plant species. However, what is actually computed in the Data Analysis Module is the percent of recorded species codes that are hydric herbaceous. The two issues are: (1) using hydric versus hydric herbaceous species (note: hydric herbaceous is a subset of hydric), and (2) calculating the percent of plots versus the percent of recorded species. The second issue is also applicable to the woody species composition indicator. It was assumed that the definition in Burkhart and Kovacs (2013) was an error and hydric herbaceous plant species were used. Metric calculations were carried out in accordance with the 2011 MIM protocol.
3. The wetland rating differs due to the Data Analysis Module using the default region wetland rating values instead of the values specific to the Western Mountains, Valleys, and Coast (WM) region. Values specific to the Western Mountains, Valleys, and Coast (WM) region were used in the subsequent analyses.
4. The greenline ecological status rating differs due to the following reasons:
 - (a) Per Winward (2000), the calculated ecological status score should be adjusted if the stream should support a hydrophytic woody overstory component (i.e., the stream has a gradient greater than 0.5 percent and has water forces adequate to periodically cut banks and deposit bars), but doesn't. The referenced discussion on page 21 states:

"On streams with gradients of less than 0.5 percent, streambanks generally can be adequately protected by robust sedges, rushes, and grasses. Woody species are seldom naturally present on the greenline in these settings."

Accordingly, it was assumed that adjustments to the score are applied only if both the gradient was greater than 0.5 (header worksheet cell G18) and the stream is expected to contain hydric woody plants (header worksheet cell F13). Because the gradient is less than 0.5, the woody overstory adjustment was not applied. Note: the Data Analysis Module does not consider the stream gradient and therefore applied an adjustment because F13 = Y and no woody species were present.

- (b) The capability group (i.e., the expected percent of the greenline that should be represented by late seral community types) used differs. Per the header worksheet, a G18 cell value of 0.5 should correspond to "less than 0.5%." Combined with the presence of consolidated material substrate, the expected percent of late seral community types should be 98+% (Winward, 2000, Appendix A). Note: the Data Analysis module considers the gradient to be equal to 0.5 which results in an expected value of 90%.
- (c) The Data Analysis Module utilizes the sum of all 'Late' community type composition percentages and 50% of the sum of all 'Mid' community type composition percentages when computing the percent of late seral community types. The additional 'Mid' contributions are not detailed in Winward (2000) so were not included in the rederived metric values. Additionally, a cursory literature review did not return any reference to this approach.

2.1.2 Missing Data

Missing values were imputed with the previous year's value when determined to be reasonable. A complete list of all imputed values can be found in the Excel file [summary_of_changes.xlsx](#). Missing plant species data were provided by Stephanie Rockwood with NPS.

2.2 Stream Condition Status

2.2.1 Beaver Creek

Table 2-1: Key indicators of Beaver Creek Exclosure DMA condition.

	2010-09-29	2012-09-10	2013-09-18	2018-09-24
Avg. Stubble Ht. (in)	16.478	16.155	25.368	15.929
Dominate Species (DS)	POPR ¹	AGST2 ²	CAUT ³	POPR ¹
DS Avg. Stubble Ht. (in)	14.606	13.192	22.011	14.117
Streambank Cover	0.900	1.000	0.976	1.000
Streambank Alteration	0.014	0.057	0.082	0.000
Streambank Stability	0.786	0.867	0.723	1.000
Avg. GG Width (m)	2.611	2.443	–	1.732
Hydric Herbaceous Pct.	0.700	0.867	–	0.976
Pct. Woody Comp.	0.371	0.233	–	0.190
Plant Diversity Index	9.385 (very high)	13.255 (very high)	–	16.185 (very high)
Greenline Stability Rating	2.999 (low)	3.168 (low)	–	5.204 (mid)
Site Wetland Rating	59.284 (fair)	60.318 (fair)	–	73.667 (good)
Ecological Status Rating	0.027 (very early)	0.000 (very early)	–	0.317 (early)

¹ POPR: *Poa pratensis* - Kentucky bluegrass

² AGST2: *Agrostis stolonifera* - Creeping bentgrass

³ CAUT: *Carex utriculata* - Beaked sedge

Table 2-2: Key indicators of Beaver Creek 1 DMA condition.

	2009-08-11	2012-08-29	2013-09-03	2014-08-14	2018-09-01
Avg. Stubble Ht. (in)	4.194	3.035	3.818	5.709	15.934
Dominate Species (DS)	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹
DS Avg. Stubble Ht. (in)	3.870	2.656	3.136	5.232	10.161
Streambank Cover	0.038	0.025	0.225	0.785	1.000
Streambank Alteration	0.820	0.918	0.560	0.532	0.630
Streambank Stability	0.000	0.000	0.038	0.089	0.180
Avg. GG Width (m)	5.428	4.850	–	3.942	4.807
Hydric Herbaceous Pct.	0.912	0.875	–	0.975	0.978
Pct. Woody Comp.	0.038	0.025	–	0.112	0.109
Plant Diversity Index	12.609 (very high)	13.161 (very high)	–	24.578 (very high)	15.761 (very high)
Greenline Stability Rating	4.058 (low)	3.876 (low)	–	3.732 (low)	3.468 (low)
Site Wetland Rating	65.157 (good)	64.787 (good)	–	57.687 (fair)	63.859 (good)
Ecological Status Rating	0.256 (early)	0.255 (early)	–	0.225 (early)	0.157 (early)

¹ CANE2: *Carex nebrascensis* - Nebraska sedge**Table 2-3:** Key indicators of Beaver Creek 2 DMA condition.

	2009-08-12	2012-08-29	2013-09-03
Avg. Stubble Ht. (in)	15.841	20.746	10.829
Dominate Species (DS)	AGST2 ¹	AGST2 ¹	SCPA8 ²
DS Avg. Stubble Ht. (in)	16.070	18.286	11.015
Streambank Cover	0.950	0.732	0.951
Streambank Alteration	0.335	0.682	0.342
Streambank Stability	0.488	0.000	0.333
Avg. GG Width (m)	2.692	2.579	–
Hydric Herbaceous Pct.	0.875	0.982	–
Pct. Woody Comp.	0.175	0.070	–
Plant Diversity Index	14.659 (very high)	13.007 (very high)	–
Greenline Stability Rating	4.739 (low)	4.102 (low)	–
Site Wetland Rating	75.675 (good)	77.479 (good)	–
Ecological Status Rating	0.296 (early)	0.264 (early)	–

¹ AGST2: *Agrostis stolonifera* - Creeping bentgrass² SCPA8: *Scirpus pallidus* - Cloaked bulrush

Table 2-4: Key indicators of Beaver Creek 3 DMA condition.

	2010-08-12	2012-09-19	2013-09-04
Avg. Stubble Ht. (in)	11.836	10.109	12.331
Dominant Species (DS)	CAREX ¹	CAREX ¹	ELPA3 ²
DS Avg. Stubble Ht. (in)	15.103	15.136	9.862
Streambank Cover	0.862	0.750	0.888
Streambank Alteration	0.542	0.685	0.420
Streambank Stability	0.238	0.162	0.262
Avg. GG Width (m)	2.760	3.560	–
Hydric Herbaceous Pct.	0.888	0.775	–
Pct. Woody Comp.	0.100	0.150	–
Plant Diversity Index	14.707	18.912	–
	(very high)	(very high)	
Greenline Stability Rating	4.197	3.454	–
	(low)	(low)	
Site Wetland Rating	76.460	62.730	–
	(good)	(good)	
Ecological Status Rating	0.000	0.000	–
	(very early)	(very early)	

¹ CAREX: *Carex spp* - Sedge² ELPA3: *Eleocharis parvula* - Dwarf spikerush

2.2.2 Cold Spring Creek

Table 2-5: Key indicators of Cold Spring Creek Exclosure DMA condition.

	2010-09-08	2013-09-18	2017-09-06
Avg. Stubble Ht. (in)	16.054	9.393	14.934
Dominate Species (DS)	POPR ¹	CAHY4 ²	AGST2 ³
DS Avg. Stubble Ht. (in)	15.111	10.335	13.484
Streambank Cover	0.952	0.870	0.988
Streambank Alteration	0.045	0.182	0.085
Streambank Stability	0.742	0.662	0.775
Avg. GG Width (m)	3.275	1.911	1.229
Hydric Herbaceous Pct.	0.323	0.481	0.888
Pct. Woody Comp.	0.613	0.377	0.425
Plant Diversity Index	13.389	14.902	23.525
	(very high)	(very high)	(very high)
Greenline Stability Rating	4.133	4.519	4.989
	(low)	(low)	(mid)
Site Wetland Rating	52.042	55.761	69.331
	(fair)	(fair)	(good)
Ecological Status Rating	0.156	0.046	0.386
	(early)	(very early)	(early)

¹ POPR: *Poa pratensis* - Kentucky bluegrass

² CAHY4: *Carex hystericina* - Bottlebrush sedge

³ AGST2: *Agrostis stolonifera* - Creeping bentgrass

Table 2-6: Key indicators of Cold Spring Creek 1 DMA condition.

	2010-08-26	2013-09-17	2014-08-19	2017-09-05
Avg. Stubble Ht. (in)	9.741	5.606	5.109	4.916
Dominate Species (DS)	CANE2 ¹	CANE2 ¹	ELPA3 ²	ELPA3 ²
DS Avg. Stubble Ht. (in)	7.184	5.628	6.046	5.286
Streambank Cover	0.438	0.350	0.734	0.925
Streambank Alteration	0.790	0.952	0.900	0.738
Streambank Stability	0.075	0.075	0.329	0.525
Avg. GG Width (m)	4.969	4.134	3.650	2.150
Hydric Herbaceous Pct.	0.475	0.938	0.925	1.000
Pct. Woody Comp.	0.212	0.112	0.100	0.112
Plant Diversity Index	12.926	9.222	12.420	9.379
	(very high)	(very high)	(very high)	(very high)
Greenline Stability Rating	3.371	2.760	2.915	3.663
	(low)	(very low)	(very low)	(low)
Site Wetland Rating	57.397	63.324	59.637	80.578
	(fair)	(good)	(fair)	(good)
Ecological Status Rating	0.096	0.000	0.000	0.024
	(very early)	(very early)	(very early)	(very early)

¹ CANE2: *Carex nebrascensis* - Nebraska sedge² ELPA3: *Eleocharis parvula* - Dwarf spikerush

2.2.3 Highland Creek

Table 2-7: Key indicators of Highland Creek Exclosure DMA condition.

	2010-09-09	2012-09-12	2013-07-11	2014-09-03	2016-09-07	2019-09-26
Avg. Stubble Ht. (in)	20.045	5.425	22.746	17.919	19.602	19.082
Dominate Species (DS)	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹
DS Avg. Stubble Ht. (in)	22.160	4.444	21.870	20.189	20.624	19.648
Streambank Cover	1.000	0.450	0.988	1.000	1.000	1.000
Streambank Alteration	0.000	0.900	0.200	0.090	0.020	0.152
Streambank Stability	0.955	0.025	0.927	0.873	0.975	0.888
Avg. GG Width (m)	2.737	2.765	1.896	1.839	1.045	1.635
Hydric Herbaceous Pct.	0.886	0.950	1.000	0.962	0.975	0.925
Pct. Woody Comp.	0.364	0.350	0.110	0.225	0.125	0.362
Plant Diversity Index	17.668	14.086	27.015	21.559	22.089	23.890
	(very high)	(very high)	(very high)	(very high)	(very high)	(very high)
Greenline Stability Rating	4.484	4.047	6.075	4.070	5.719	5.110
	(low)	(low)	(mid)	(low)	(mid)	(mid)
Site Wetland Rating	67.062	55.583	87.154	59.841	83.031	70.594
	(good)	(fair)	(very good)	(fair)	(good)	(good)
Ecological Status Rating	0.004	0.000	0.661	0.112	0.486	0.392
	(very early)	(very early)	(late)	(very early)	(mid)	(early)

¹ CANE2: *Carex nebrascensis* - Nebraska sedge

Table 2-8: Key indicators of Highland Creek 1 DMA condition.

	2009-08-14	2012-08-30	2013-09-04	2016-09-17	2019-09-25
Avg. Stubble Ht. (in)	11.333	7.178	11.824	10.427	11.919
Dominate Species (DS)	AGST2 ¹	AGST2 ¹	ELPA3 ²	AGST2 ¹	AGST2 ¹
DS Avg. Stubble Ht. (in)	11.781	6.562	9.738	8.110	9.993
Streambank Cover	0.812	0.650	0.864	1.000	1.000
Streambank Alteration	0.565	0.628	0.494	0.165	0.491
Streambank Stability	0.262	0.150	0.210	0.961	0.800
Avg. GG Width (m)	2.651	2.820	–	1.998	2.623
Hydric Herbaceous Pct.	0.812	0.650	–	0.980	0.935
Pct. Woody Comp.	0.188	0.175	–	0.353	0.364
Plant Diversity Index	18.483 (very high)	19.078 (very high)	–	27.362 (very high)	18.815 (very high)
Greenline Stability Rating	4.220 (low)	3.681 (low)	–	4.158 (low)	3.082 (low)
Site Wetland Rating	67.931 (good)	59.726 (fair)	–	70.656 (good)	68.613 (good)
Ecological Status Rating	0.179 (early)	0.075 (very early)	–	0.391 (early)	0.073 (very early)

¹ AGST2: *Agrostis stolonifera* - Creeping bentgrass² ELPA3: *Eleocharis parvula* - Dwarf spikerush**Table 2-9:** Key indicators of Highland Creek 2 DMA condition.

	2009-08-20	2012-08-30	2013-09-04	2016-09-06	2019-09-24
Avg. Stubble Ht. (in)	4.699	4.099	6.408	6.756	7.326
Dominate Species (DS)	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹	CANE2 ¹
DS Avg. Stubble Ht. (in)	4.071	2.831	3.328	4.724	4.760
Streambank Cover	0.430	0.662	0.875	1.000	1.000
Streambank Alteration	0.620	0.458	0.350	0.392	0.302
Streambank Stability	0.165	0.200	0.250	0.562	0.633
Avg. GG Width (m)	2.510	2.491	–	2.422	2.431
Hydric Herbaceous Pct.	0.850	0.738	–	0.938	0.875
Pct. Woody Comp.	0.112	0.088	–	0.312	0.350
Plant Diversity Index	22.715 (very high)	15.217 (very high)	–	37.690 (very high)	18.514 (very high)
Greenline Stability Rating	4.478 (low)	3.906 (low)	–	4.311 (low)	3.585 (low)
Site Wetland Rating	66.528 (good)	64.796 (good)	–	65.482 (good)	58.011 (fair)
Ecological Status Rating	0.216 (early)	0.150 (very early)	–	0.235 (early)	0.208 (early)

¹ CANE2: *Carex nebrascensis* - Nebraska sedge

3 Trend Analysis

Trends in each riparian condition metric were quantified using regression analysis. Each metric can be characterized as being either (1) continuous and restricted to a closed interval (e.g., percent plots containing hydric herbaceous species) or (2) continuous and non-negative (e.g., average stubble height). Metrics characterized by (1) were modeled using a beta regression model (Ferrari and Cribari-Neto, 2004) and fit with the `betareg` R package (Cribari-Neto and Zeileis, 2010). Metrics characterized by (2) were modeled using a gamma generalized linear model (GLM).

3.1 Methods

3.1.1 Beta Regression

For each metric containing values in an interval (a, b) that is not the standard unit interval, values were first scaled to the $(0, 1)$ interval to match the support of the beta distribution. If the metric values $(y_i, i = 1, \dots, n)$ assumed the extreme values of 0 and/or 1, the transformation

$$(y \cdot (n - 1) + 0.5)/n,$$

was applied (Smithson and Verkuilen, 2006).

It is assumed that the response variable y_i is distributed according to a beta distribution parameterized by a mean μ_i and unknown precision ϕ : $y_i \sim \text{Beta}(\mu_i, \phi)$. The beta regression model is then defined as

$$g(\mu_i) = \mathbf{x}_i^\top \boldsymbol{\beta},$$

where $\boldsymbol{\beta}$ is a vector of unknown regression parameters, $\mathbf{x}_i^\top$ is the vector of covariates for the i th observation ($i = 1, \dots, n$), and $g(\cdot)$ is the link function. In this particular application, the link function used was the logit link:

$$g(\mu) = \text{logit}(\mu) = \log\{\mu/(1 - \mu)\}.$$

Trend was defined as the linear trend in time (years) on the logit scale:

$$\text{logit}(\mu_i) = \beta_0 + \beta_1 t_i, \tag{1}$$

where t_i is the i th year since 2009. The trend parameter β_1 corresponds to a multiplicative change in the odds of the metric for each unit increase in time. For example, consider the percent plots containing hydric herbaceous species metric. If $\hat{\beta}_1$ equals 0.05, the interpretation would be as follows: for every unit increase in time, the odds of percent plots containing hydric herbaceous species is estimated to increase by a factor of $\exp(0.05) = 1.051$.

In many instances, trends can appear approximately linear due to the relatively short time frame over which measurements are available (e.g., 10-year period in Figure 3-1). An alternative approximation to the change in the mean response over time is to divide the change in the predicted mean response (Δ_{resp}) by the time span over which it occurred (Δ_{yr}). This can be considered analogous to fitting a standard linear regression model to the data. To this end, values for Δ_{resp} and Δ_{yr} have been included in each summary table. This approximation, however, is not valid for indicators/metrics where the fitted regression line is clearly non-linear.

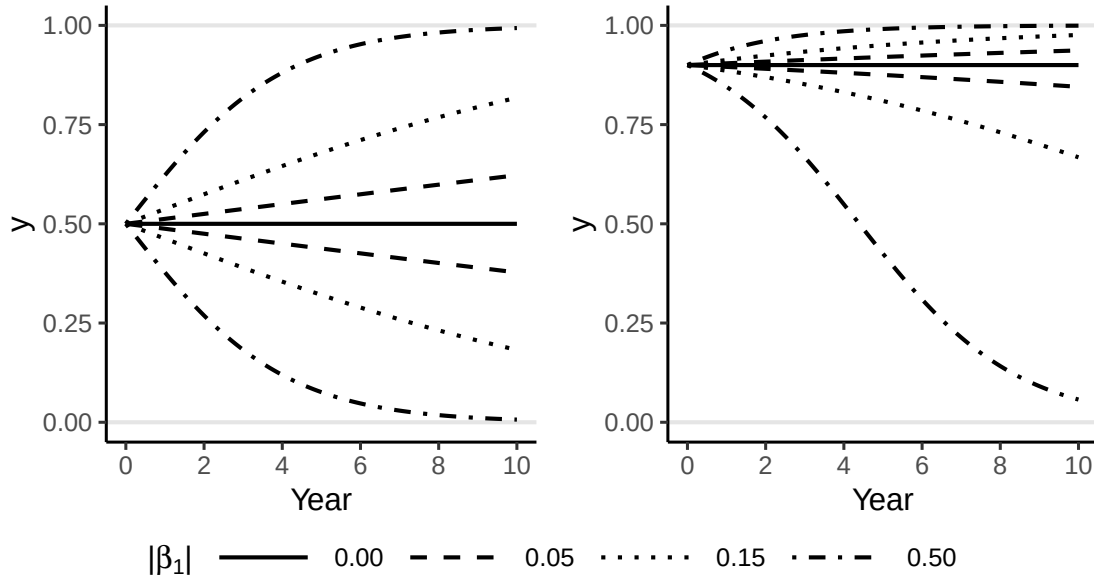


Figure 3-1: Predicted mean response for three different trend effect magnitudes (on link function scale), illustrating the non-linear function of year due to the logit transformation. Time zero mean response equal to 0.5 [left] versus 0.9 [right].

3.1.2 Gamma GLM

It is assumed that the response variable y_i is distributed according to a gamma distribution parameterized by a mean μ_i and dispersion parameter ϕ : $y_i \sim \text{Gamma}(\mu_i, \phi)$. The gamma GLM is then defined as

$$g(\mu_i) = \mathbf{x}_i^\top \boldsymbol{\beta},$$

where $\boldsymbol{\beta}$ is a vector of unknown regression parameters, $\mathbf{x}_i^\top$ is the vector of covariates for the i th observation ($i = 1, \dots, n$), and $g(\cdot)$ is the link function. In this particular application, the link function was the log link: $g(\mu) = \log(\mu)$.

Trend was defined as the linear trend in time (years) on the log scale:

$$\log(\mu_i) = \beta_0 + \beta_1 t_i, \quad (2)$$

where t_i is the i th year since 2009. The trend parameter β_1 corresponds to a multiplicative change of $\exp(\beta_1)$ in the metric's mean for every unit increase in time. For example, consider the average greenline-greenline width metric. If $\hat{\beta}_1$ equals 0.05, the interpretation would be as follows: for every unit increase in time, the mean average greenline-greenline width increases by a factor of $\exp(0.05) = 1.051$.

3.1.3 Additional Considerations

It is acknowledged that some degree of spatial and/or temporal autocorrelation likely exists between observations given the nature of the data. However, due to the limited amount of data within each DMA grouping, we did not attempt to model either type of autocorrelation within the fitted statistical models.

3.2 Results

3.2.1 Average Stubble Height

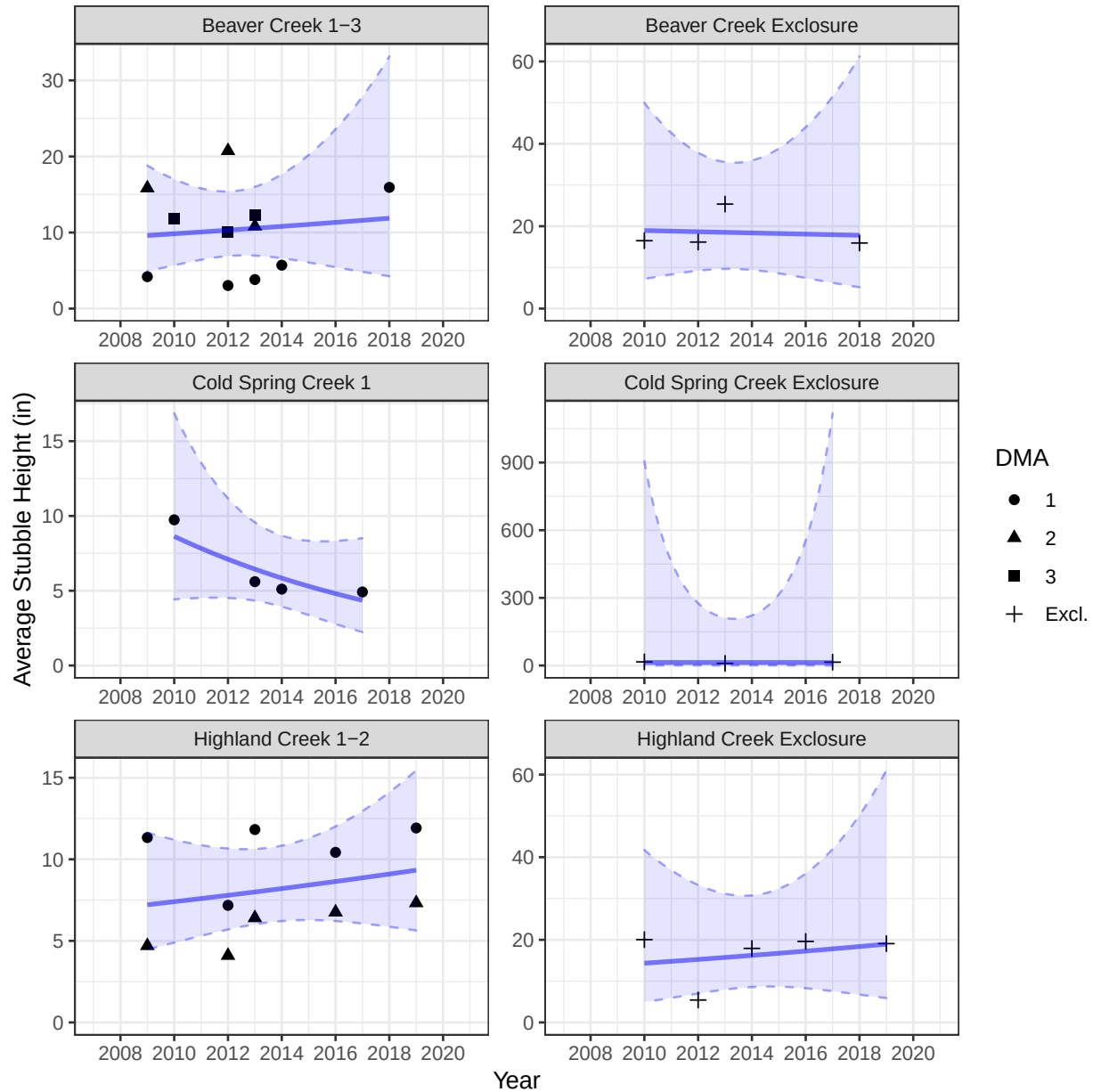


Figure 3-2: Average stubble height for each sampled DMA (black dots) within WICA. Estimated mean average stubble height as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 3-1: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean average stubble height from a gamma regression (log link) fit to each stream and exclosure type. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean average stubble height (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	11	0.024	0.073	(-0.142, 0.189)	1.024	2.3	9
Beaver Creek Exclosure	4	-0.008	0.051	(-0.229, 0.213)	0.992	-1.2	8
Cold Spring Creek 1	4	-0.098	0.036	(-0.253, 0.058)	0.907	-4.3	7
Cold Spring Creek Exclosure	3	-0.005	0.075	(-0.958, 0.948)	0.995	-0.5	7
Highland Creek 1-2	10	0.026	0.035	(-0.055, 0.107)	1.026	2.1	10
Highland Creek Exclosure	5	0.031	0.064	(-0.173, 0.235)	1.032	4.6	9

3.2.2 Average Greenline-Greenline Width

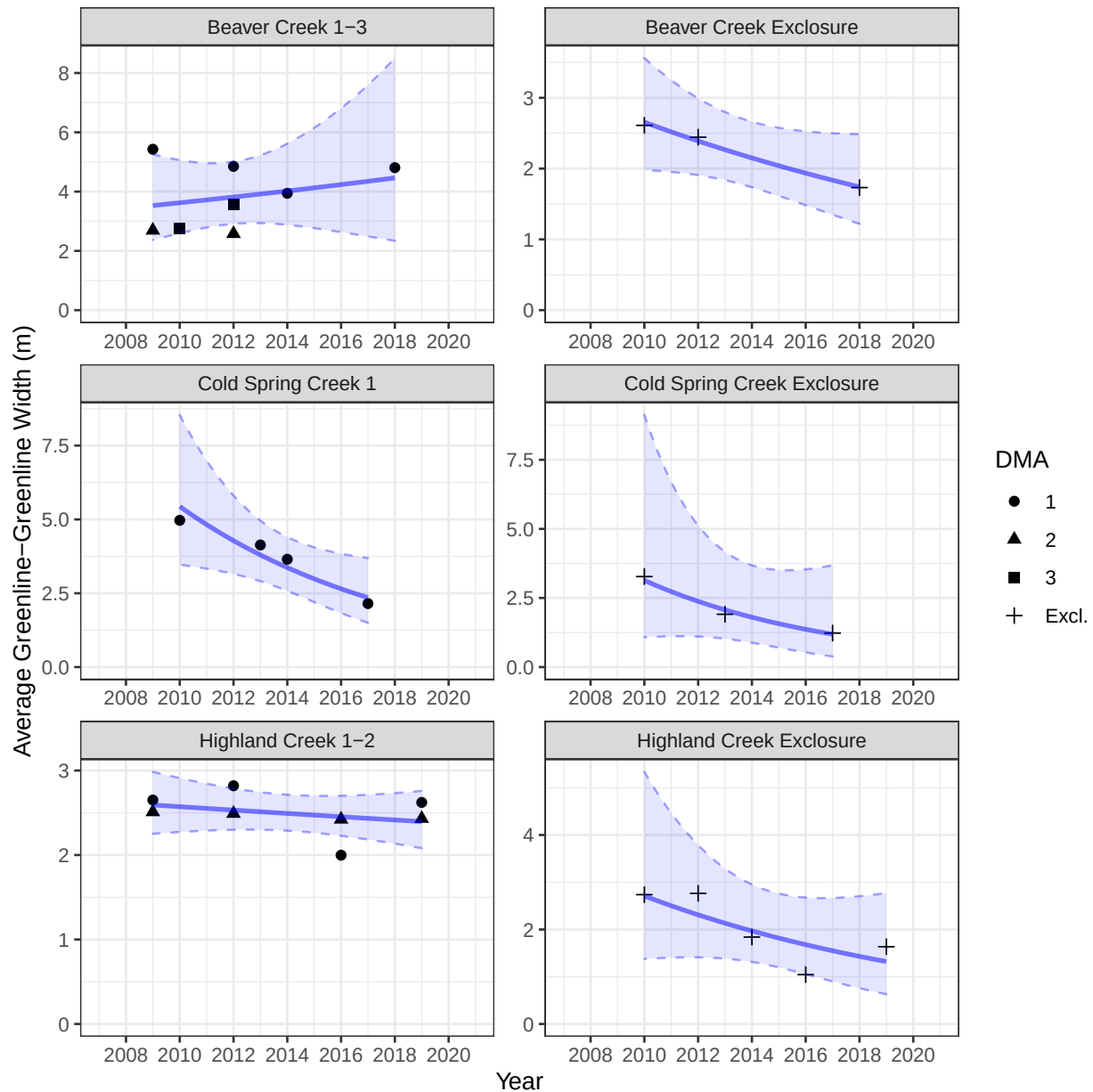


Figure 3-3: Average greenline-greenline width for each sampled DMA (black dots) within WICA. Estimated mean average greenline-greenline width as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 3-2: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean average greenline-greenline width from a gamma regression (log link) fit to each stream and exclosure type. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean average greenline-greenline width (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	0.026	0.040	(-0.072, 0.124)	1.026	0.9	9
Beaver Creek Exclosure	3	-0.053	0.005	(-0.114, 0.009)	0.949	-0.9	8
Cold Spring Creek 1	4	-0.120	0.024	(-0.225, -0.015)	0.887	-3.1	7
Cold Spring Creek Exclosure	3	-0.138	0.019	(-0.381, 0.104)	0.871	-1.9	7
Highland Creek 1-2	8	-0.008	0.009	(-0.030, 0.015)	0.992	-0.2	10
Highland Creek Exclosure	5	-0.080	0.041	(-0.209, 0.050)	0.923	-1.4	9

3.2.3 Dominant Species Average Stubble Height

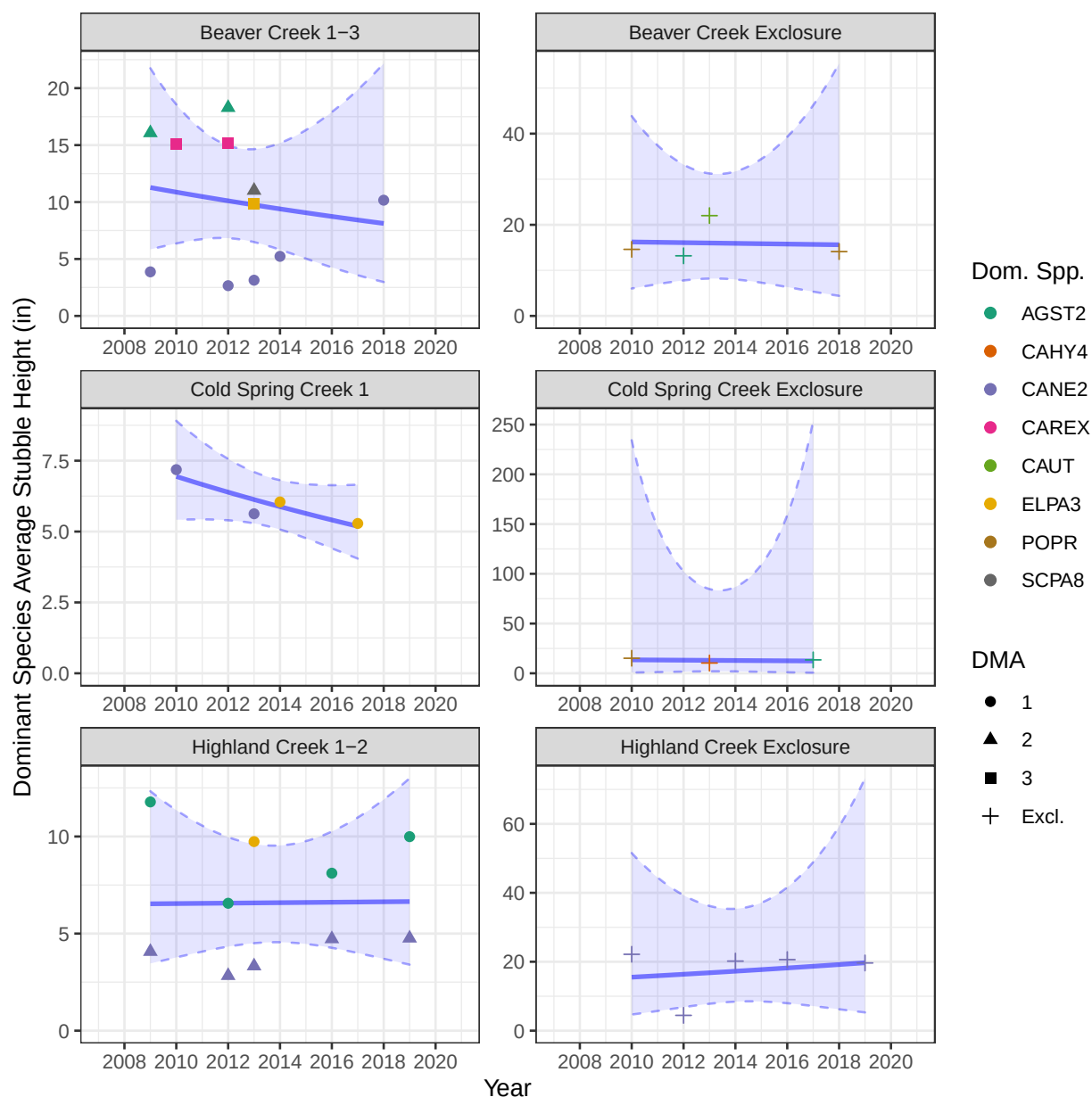


Figure 3-4: Dominant species average stubble height for each sampled DMA (black dots) within WICA. Estimated mean dominant species average stubble height as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Species abbreviations are as follows: AGST2 = *Agrostis stolonifera* (Creeping bentgrass); CAHY4 = *Carex hystericina* (Bottlebrush sedge); CANE2 = *Carex nebrascensis* (Nebraska sedge); CAREX = *Carex spp* (Sedge); CAUT = *Carex utriculata* (Beaked sedge); ELPA3 = *Eleocharis parvula* (Dwarf spikerush); POPR = *Poa pratensis* (Kentucky bluegrass); SCPA8 = *Scirpus pallidus* (Cloaked bulrush).

Table 3-3: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean average stubble height of the dominant species from a gamma regression (log link) fit to each stream and exclosure type. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean average stubble height of the dominant species (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	11	-0.036	0.071	(-0.198, 0.125)	0.964	-3.2	9
Beaver Creek Exclosure	4	-0.005	0.053	(-0.231, 0.222)	0.995	-0.6	8
Cold Spring Creek 1	4	-0.042	0.013	(-0.100, 0.016)	0.959	-1.8	7
Cold Spring Creek Exclosure	3	-0.012	0.051	(-0.661, 0.636)	0.988	-1.1	7
Highland Creek 1-2	10	0.002	0.047	(-0.106, 0.109)	1.002	0.1	10
Highland Creek Exclosure	5	0.026	0.072	(-0.203, 0.256)	1.027	4.2	9

3.2.4 Diversity Index

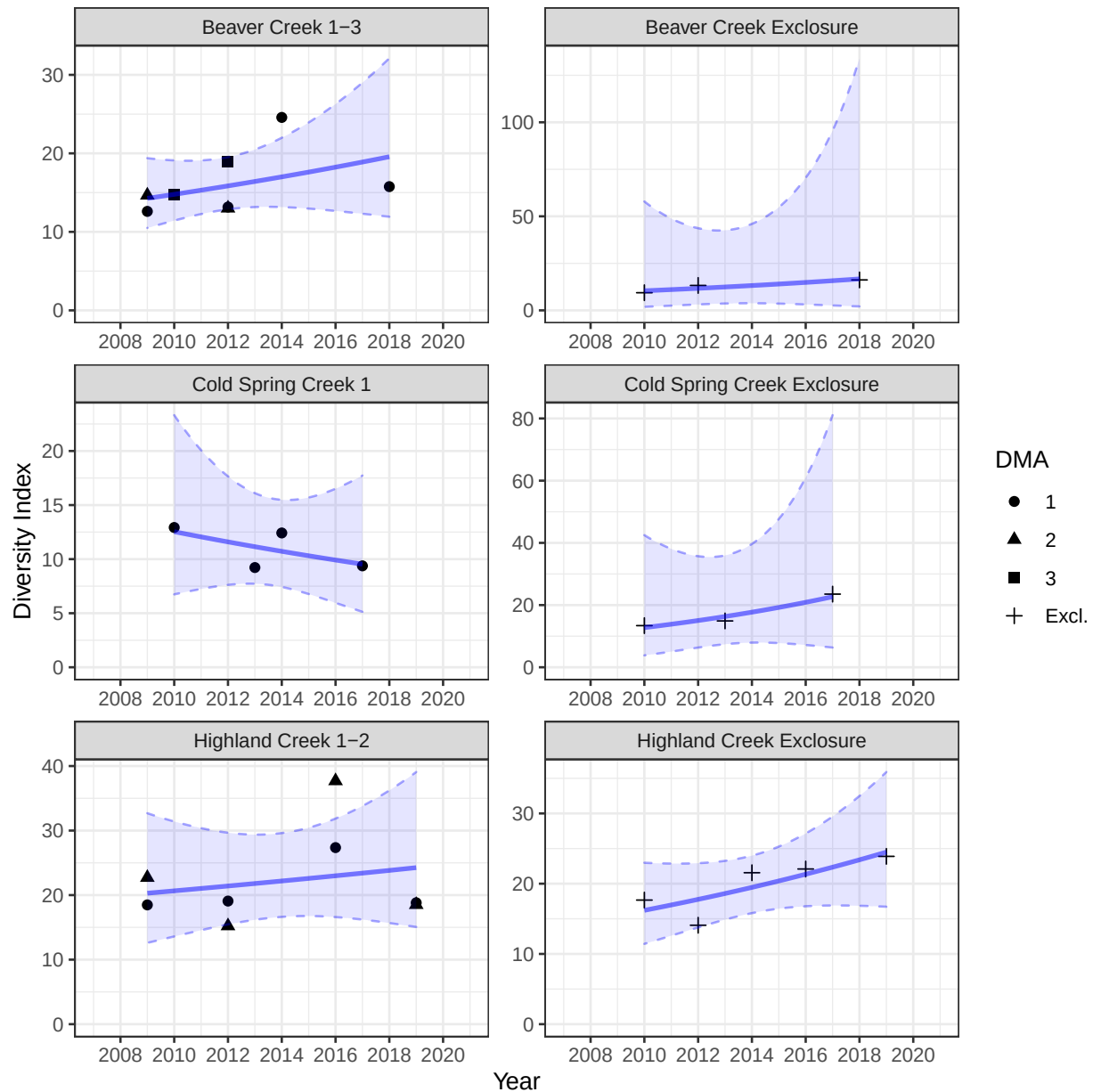


Figure 3-5: Diversity index for each sampled DMA (black dots) within WICA. Estimated mean diversity index as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 3-4: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in mean diversity index from a gamma regression (log link) fit to each stream and exclosure type. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean diversity index (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	0.035	0.031	(-0.040, 0.110)	1.036	5.3	9
Beaver Creek Exclosure	3	0.059	0.028	(-0.301, 0.420)	1.061	6.3	8
Cold Spring Creek 1	4	-0.039	0.034	(-0.183, 0.105)	0.962	-3.0	7
Cold Spring Creek Exclosure	3	0.082	0.022	(-0.191, 0.356)	1.086	9.9	7
Highland Creek 1-2	8	0.018	0.031	(-0.058, 0.094)	1.018	4.0	10
Highland Creek Exclosure	5	0.046	0.021	(-0.021, 0.113)	1.047	8.3	9

3.2.5 Streambank Cover

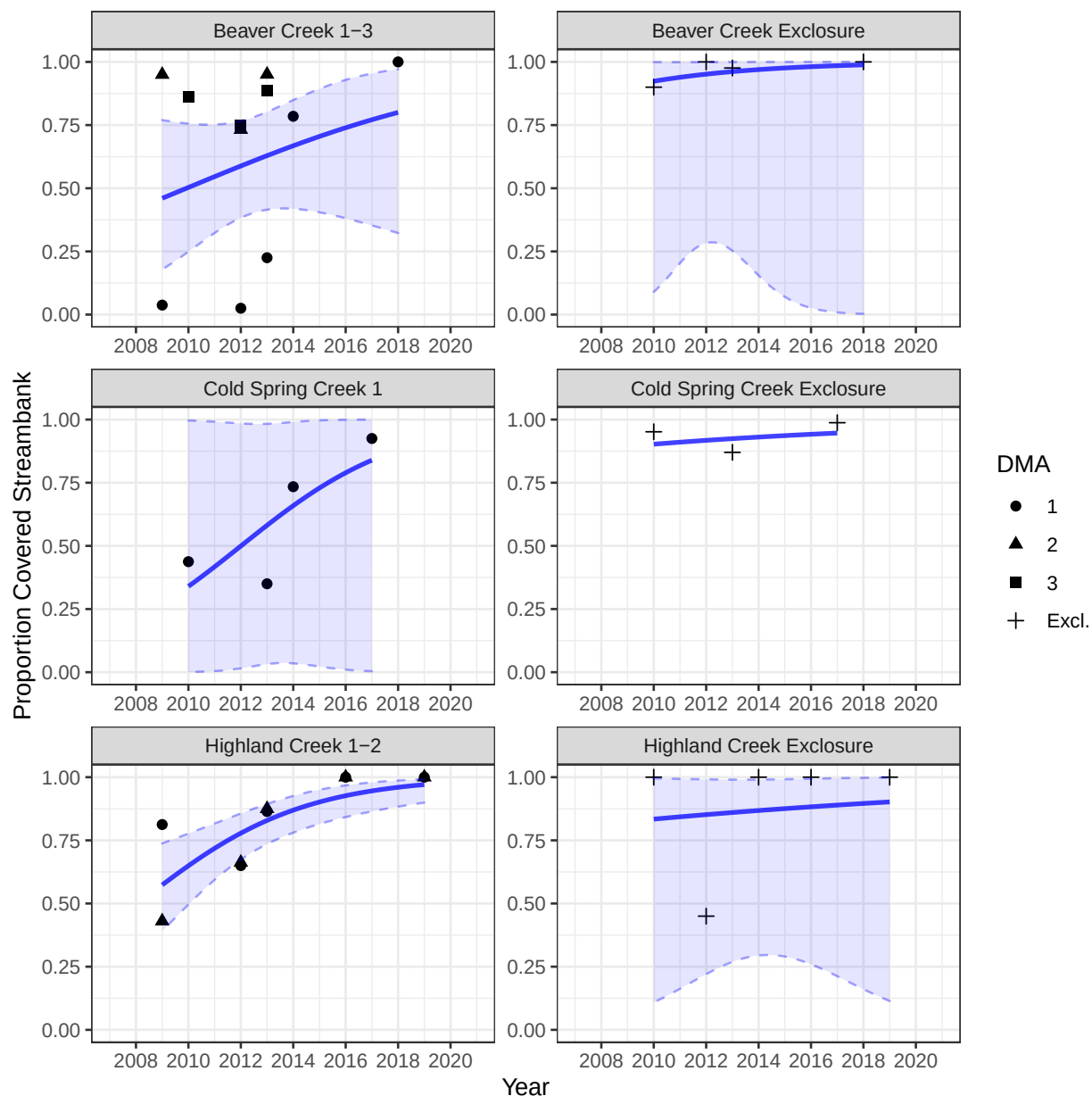


Figure 3-6: Percent plots containing covered streambank for each sampled DMA (black dots) within WICA. Estimated mean percent plots containing covered streambank as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: unable to compute a confidence interval for Cold Spring Creek Exclusion due to insufficient sample size.

Table 3-5: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing covered streambank from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing covered streambank (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: unable to compute a confidence interval for Cold Spring Creek Exclosure due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	11	0.172	0.147	(-0.167, 0.510)	1.187	0.34	9
Beaver Creek Exclosure	4	0.242	0.122	(-1.309, 1.794)	1.274	0.06	8
Cold Spring Creek 1	4	0.331	0.127	(-1.277, 1.938)	1.392	0.50	7
Cold Spring Creek Exclosure	3	0.093	0.118	–	1.097	0.04	7
Highland Creek 1-2	10	0.320	0.072	(0.149, 0.491)	1.377	0.40	10
Highland Creek Exclosure	5	0.067	0.149	(-0.572, 0.706)	1.070	0.07	9

3.2.6 Streambank Stability

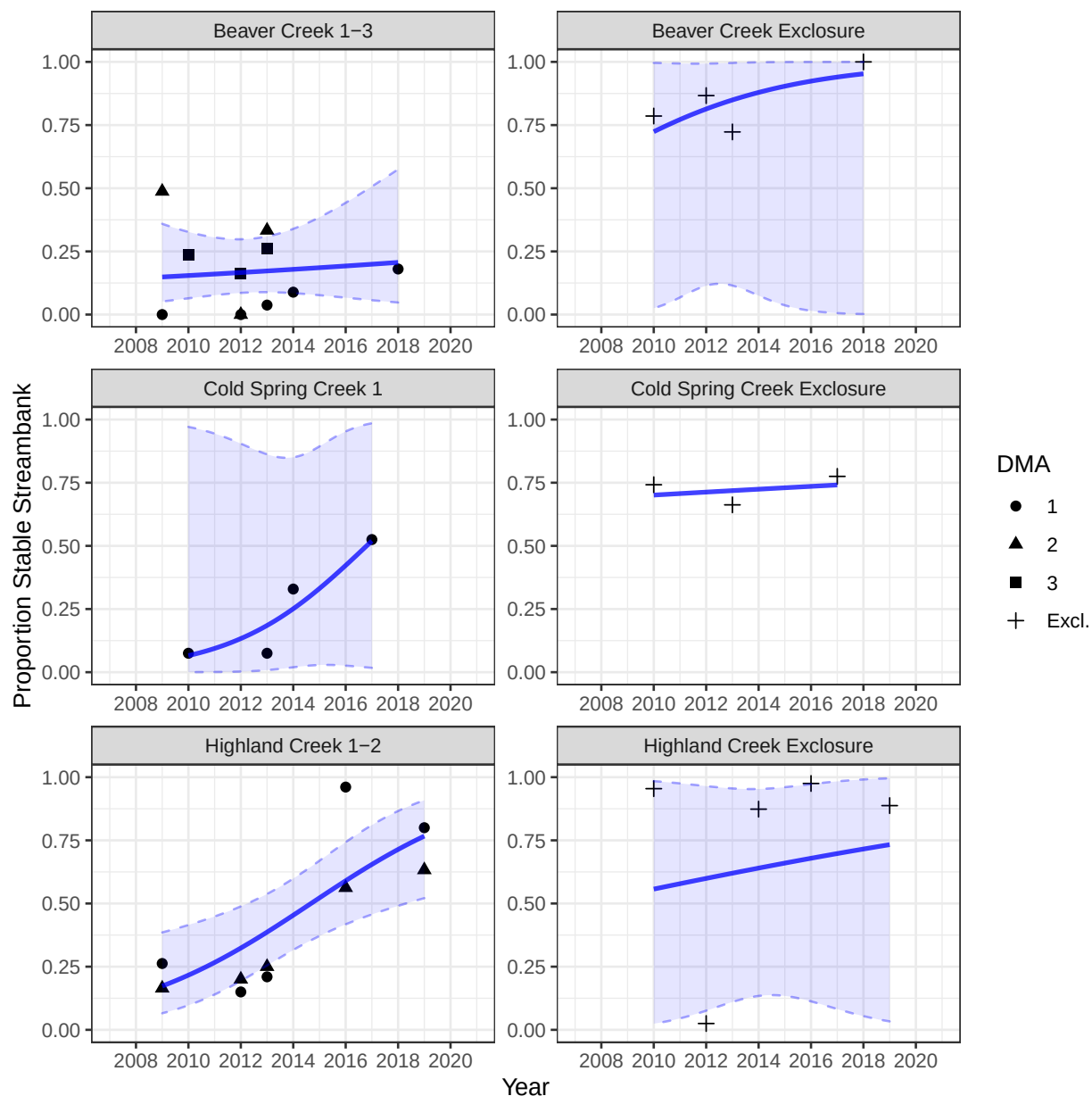


Figure 3-7: Percent plots containing stable streambank for each sampled DMA (black dots) within WICA. Estimated mean percent plots containing stable streambank as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: unable to compute a confidence interval for Cold Spring Creek Exclusion due to insufficient sample size.

Table 3-6: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing stable streambank from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing stable streambank (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: unable to compute a confidence interval for Cold Spring Creek Exclosure due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	11	0.044	0.114	(-0.218, 0.307)	1.045	0.06	9
Beaver Creek Exclosure	4	0.255	0.114	(-1.188, 1.699)	1.291	0.23	8
Cold Spring Creek 1	4	0.390	0.096	(-0.833, 1.614)	1.478	0.45	7
Cold Spring Creek Exclosure	3	0.028	0.042	–	1.029	0.04	7
Highland Creek 1-2	10	0.275	0.079	(0.089, 0.462)	1.317	0.59	10
Highland Creek Exclosure	5	0.087	0.173	(-0.657, 0.831)	1.091	0.18	9

3.2.7 Percent Hydric Herbaceous

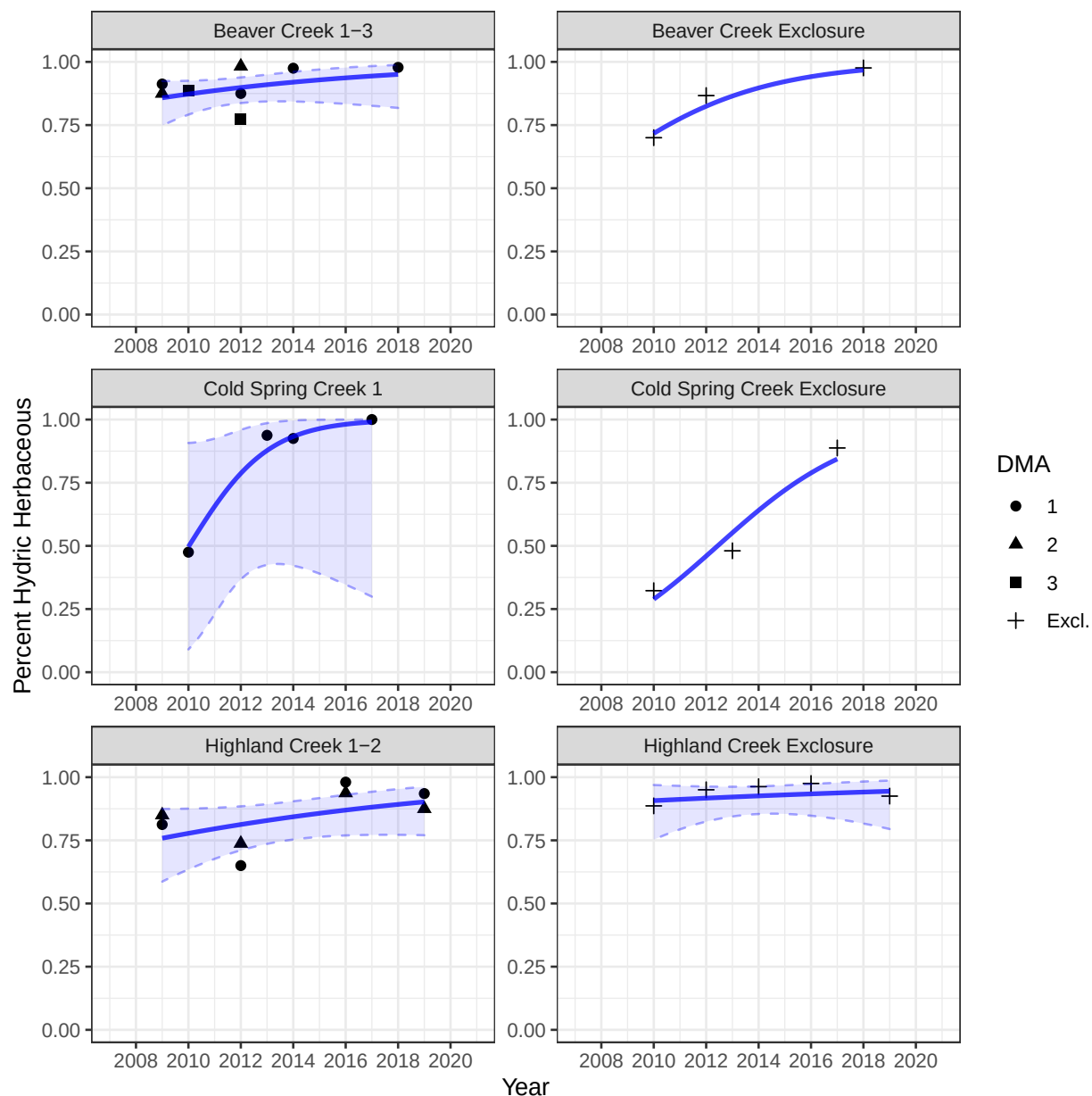


Figure 3-8: Percent plots containing hydric herbaceous species for each sampled DMA (black dots) within WICA. Estimated mean percent plots containing hydric herbaceous species as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

Table 3-7: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing hydric herbaceous species from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing hydric herbaceous species (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	0.129	0.079	(-0.074, 0.331)	1.137	0.09	9
Beaver Creek Exclosure	3	0.308	0.044	–	1.361	0.25	8
Cold Spring Creek 1	4	0.661	0.074	(-0.281, 1.602)	1.936	0.49	7
Cold Spring Creek Exclosure	3	0.369	0.054	–	1.447	0.55	7
Highland Creek 1-2	8	0.108	0.055	(-0.034, 0.250)	1.114	0.14	10
Highland Creek Exclosure	5	0.061	0.056	(-0.179, 0.301)	1.063	0.04	9

3.2.8 Percent Woody Composition

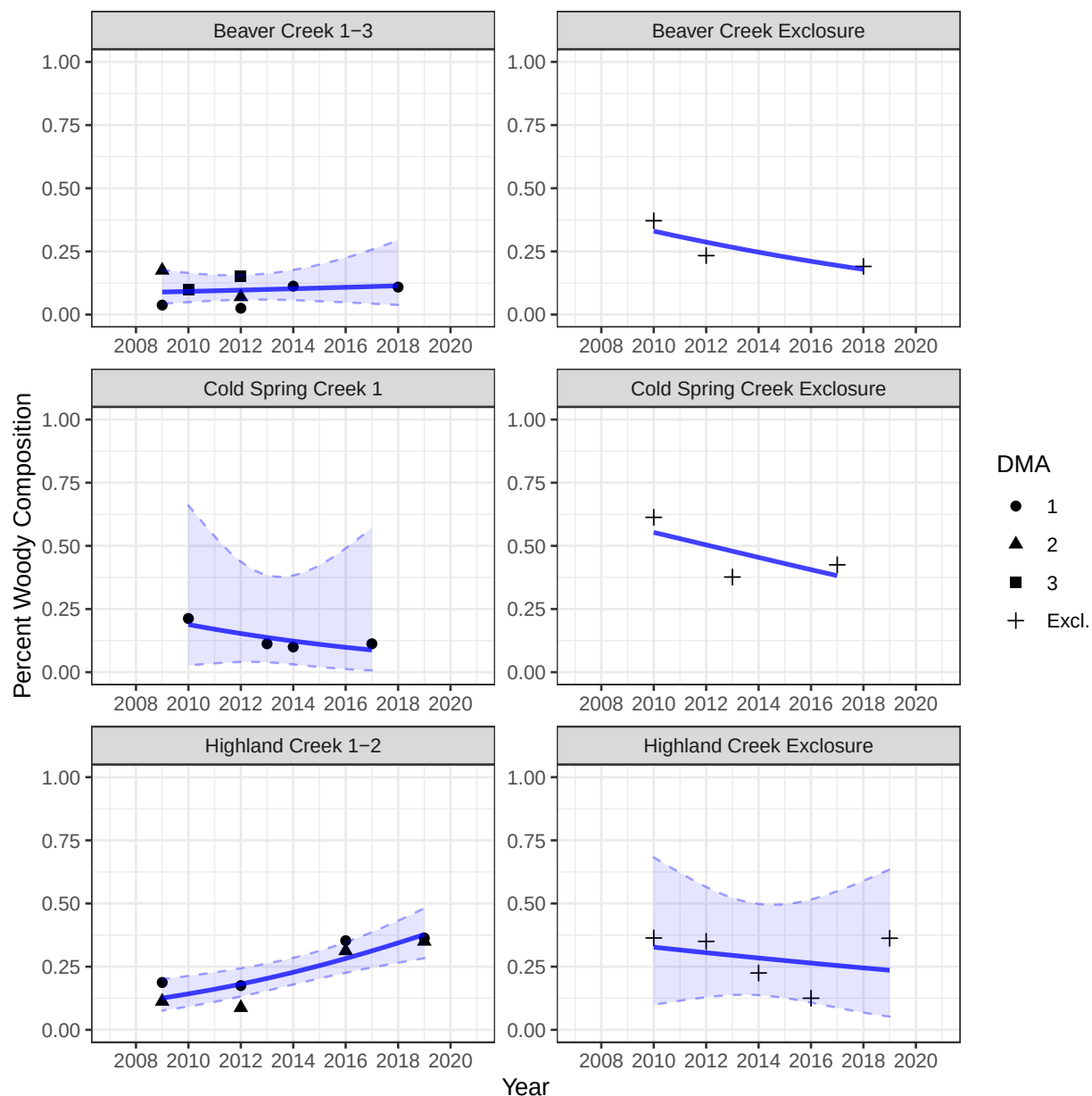


Figure 3-9: Percent plots containing woody plants for each sampled DMA (black dots) within WICA. Estimated mean percent plots containing woody plants as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

Table 3-8: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing woody plants from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing woody plants (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	0.030	0.070	(-0.149, 0.210)	1.031	0.02	9
Beaver Creek Exclosure	3	-0.102	0.036	–	0.903	-0.15	8
Cold Spring Creek 1	4	-0.126	0.044	(-0.679, 0.427)	0.882	-0.10	7
Cold Spring Creek Exclosure	3	-0.099	0.060	–	0.906	-0.17	7
Highland Creek 1-2	8	0.144	0.031	(0.065, 0.223)	1.155	0.25	10
Highland Creek Exclosure	5	-0.050	0.068	(-0.343, 0.242)	0.951	-0.09	9

3.2.9 Streambank Alteration

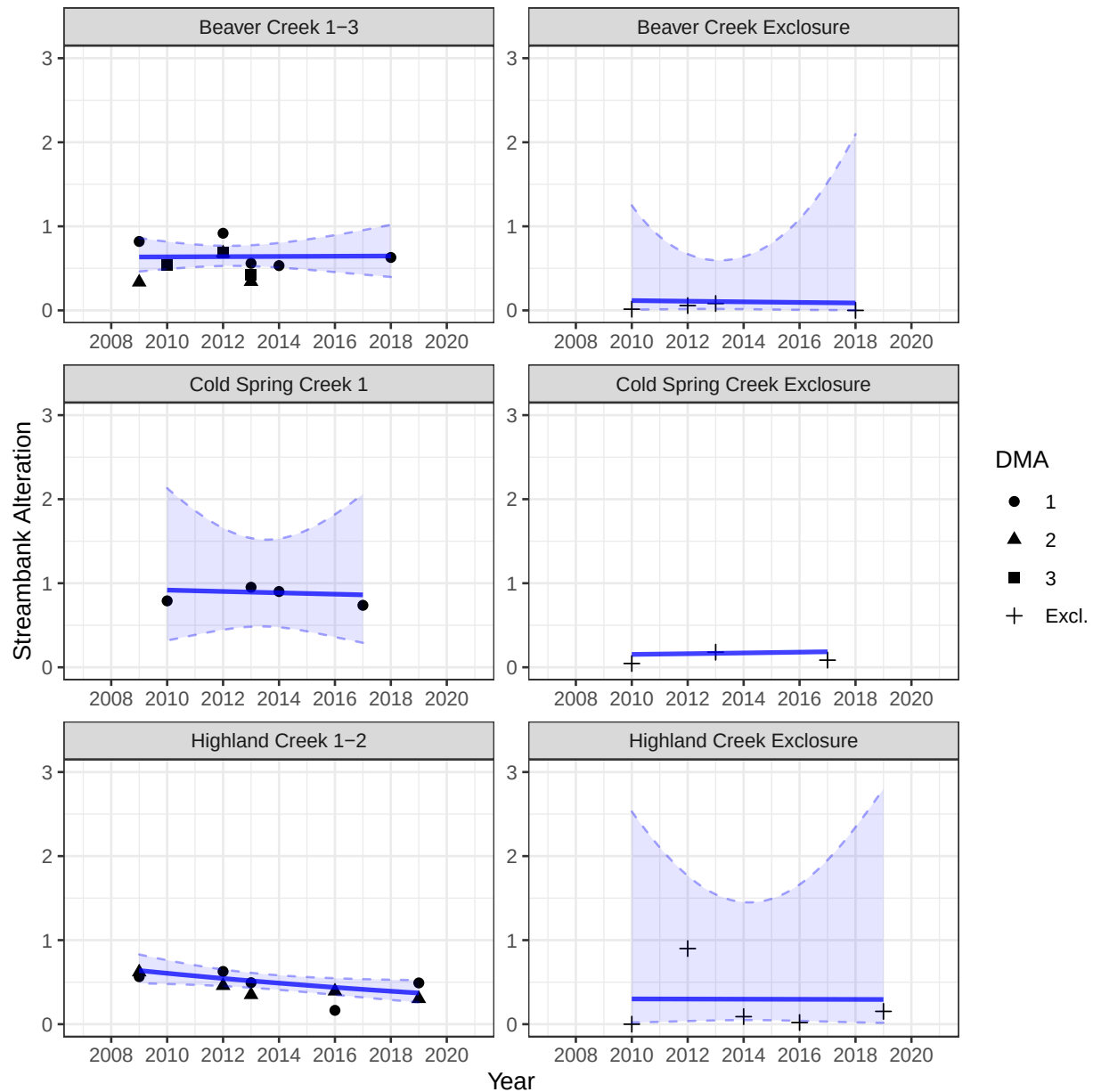


Figure 3-10: Streambank alteration (i.e., mean number of lines in each monitoring frame that intersect streambank alteration) for each sampled DMA (black dots) within WICA. Estimated mean number of lines intersecting streambank alteration as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence interval for Cold Spring Creek Exclosure unable to be computed due to insufficient sample size.

Table 3-9: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean number of lines intersecting streambank alteration from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean number of lines intersecting streambank alteration (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence interval for Cold Spring Creek Exclosure unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	11	0.002	0.038	(-0.085, 0.090)	1.002	0.01	9
Beaver Creek Exclosure	4	-0.036	0.050	(-0.672, 0.600)	0.965	-0.03	8
Cold Spring Creek 1	4	-0.011	0.022	(-0.291, 0.269)	0.989	-0.06	7
Cold Spring Creek Exclosure	3	0.028	0.062	–	1.028	0.03	7
Highland Creek 1-2	10	-0.060	0.024	(-0.117, -0.004)	0.942	-0.27	10
Highland Creek Exclosure	5	-0.003	0.114	(-0.494, 0.489)	0.997	-0.01	9

3.2.10 Modified Winward Greenline Stability Rating

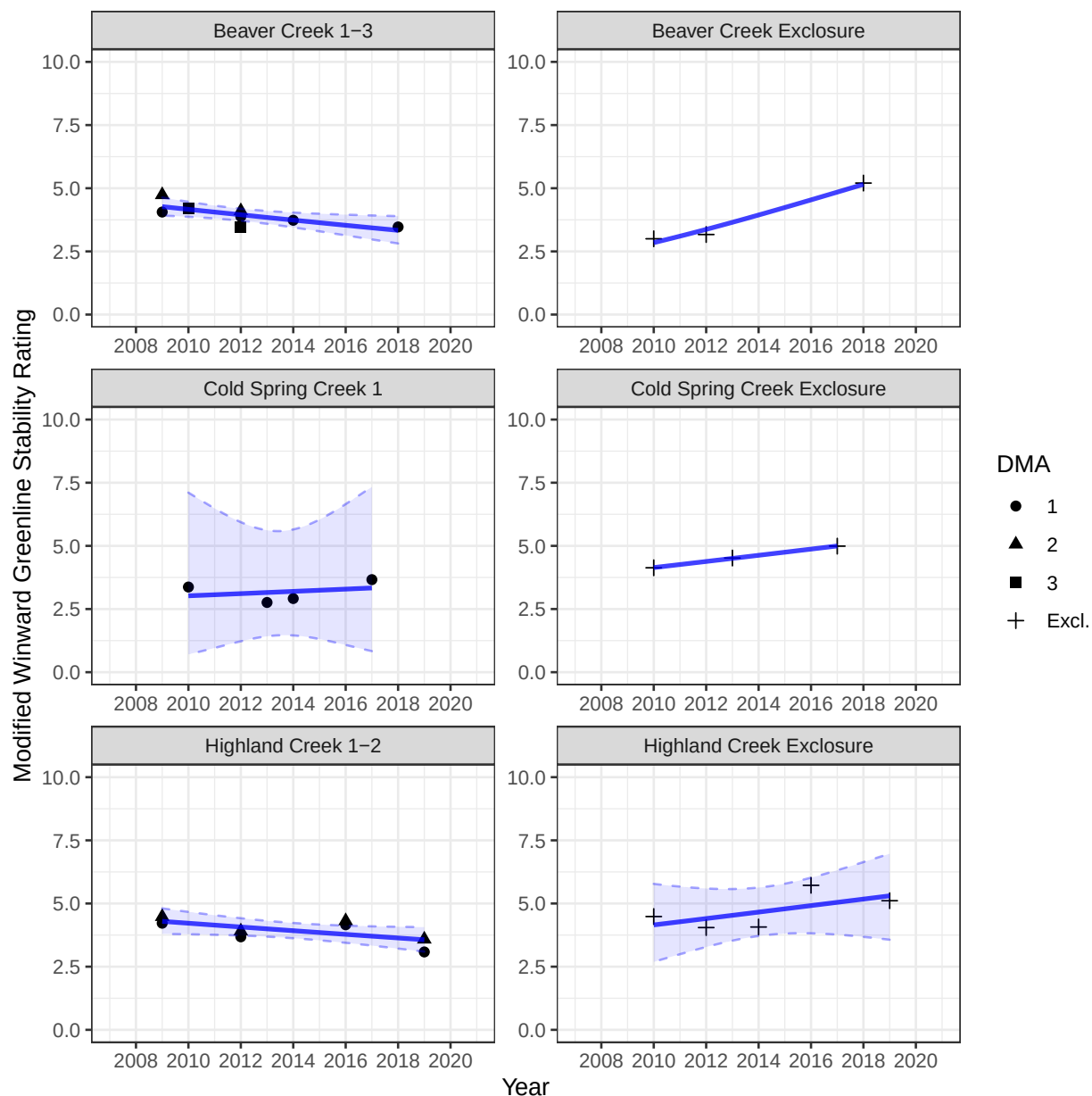


Figure 3-11: Modified Winward greenline stability rating for each sampled DMA (black dots) within WICA. Estimated mean modified Winward greenline stability rating as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

Table 3-10: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean stability rating from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean stability rating (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	-0.044	0.014	(-0.081, -0.008)	0.957	-0.94	9
Beaver Creek Exclosure	3	0.123	0.011	–	1.131	2.31	8
Cold Spring Creek 1	4	0.020	0.031	(-0.379, 0.420)	1.021	0.31	7
Cold Spring Creek Exclosure	3	0.049	0.001	–	1.051	0.85	7
Highland Creek 1-2	8	-0.031	0.013	(-0.064, 0.003)	0.970	-0.73	10
Highland Creek Exclosure	5	0.052	0.029	(-0.073, 0.176)	1.053	1.15	9

3.2.11 Wetland Rating

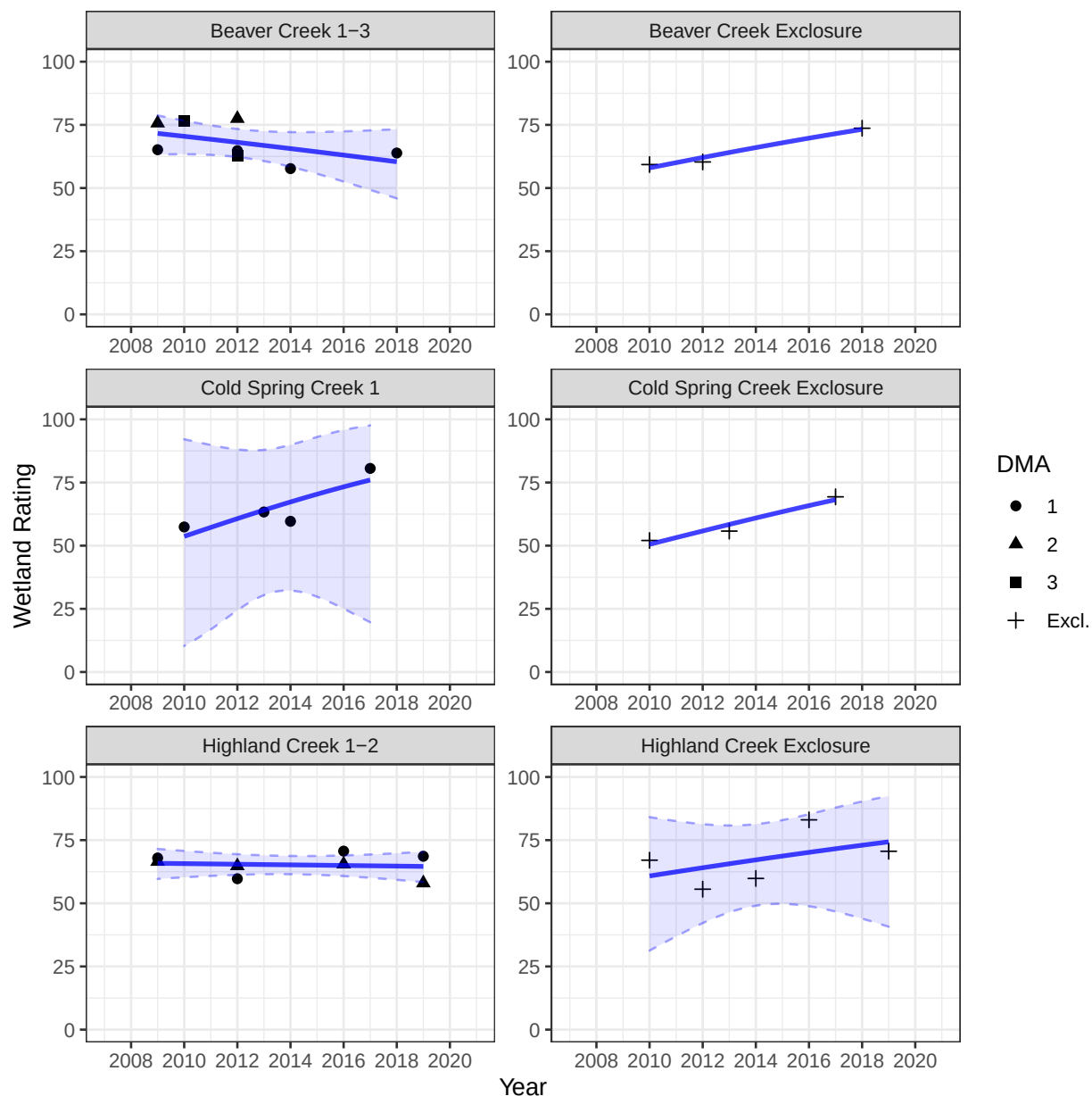


Figure 3-12: Wetland rating for each sampled DMA (black dots) within WICA. Estimated mean wetland rating as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

Table 3-11: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean wetland rating from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean wetland rating (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	-0.056	0.035	(-0.146, 0.034)	0.946	-11.22	9
Beaver Creek Exclosure	3	0.085	0.010	–	1.089	15.24	8
Cold Spring Creek 1	4	0.144	0.045	(-0.425, 0.712)	1.154	22.32	7
Cold Spring Creek Exclosure	3	0.106	0.016	–	1.112	17.65	7
Highland Creek 1-2	8	-0.005	0.016	(-0.047, 0.037)	0.995	-1.22	10
Highland Creek Exclosure	5	0.069	0.057	(-0.174, 0.313)	1.072	13.51	9

3.2.12 Ecological Status

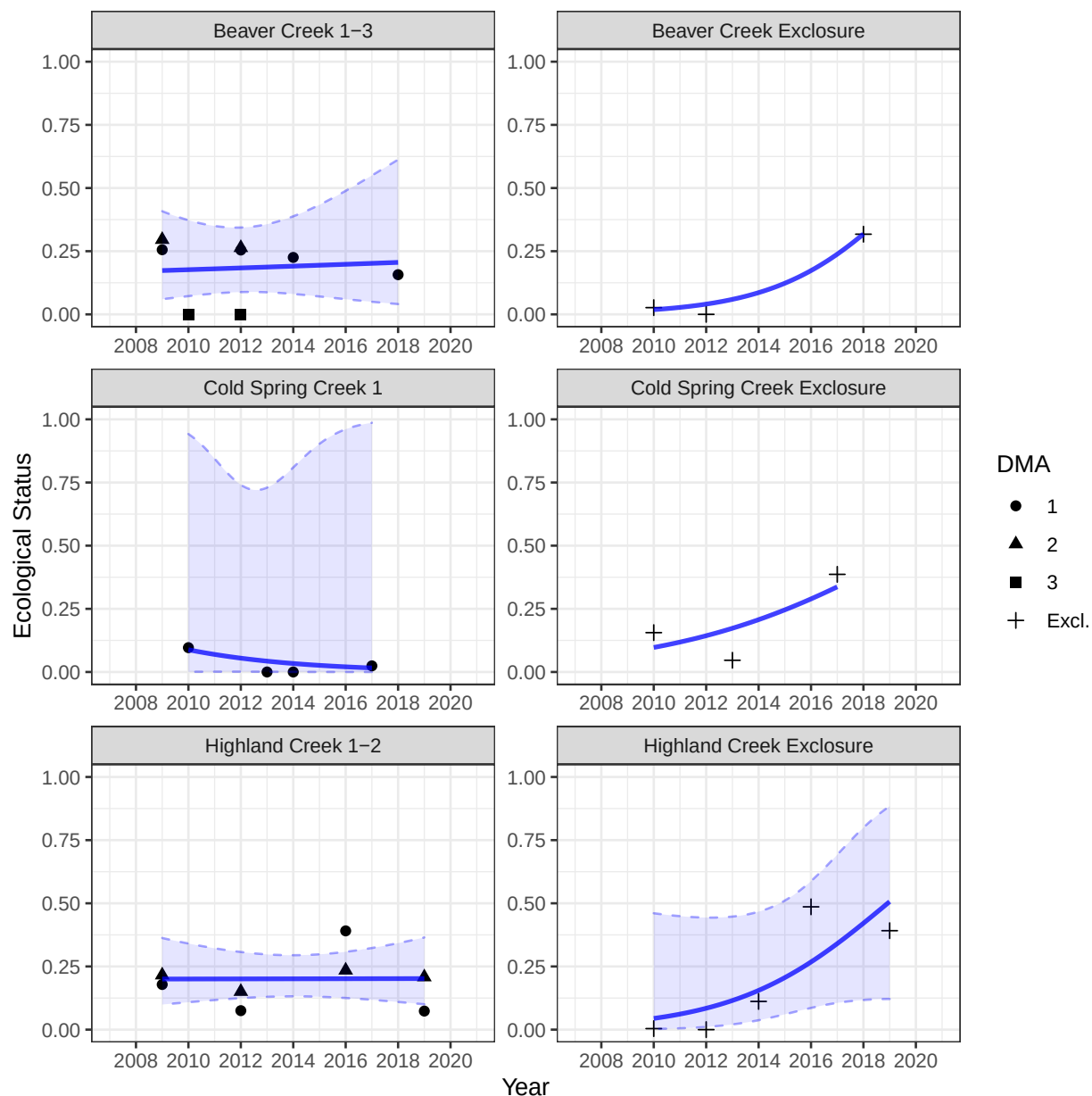


Figure 3-13: Ecological status for each sampled DMA (black dots) within WICA. Estimated mean ecological status as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

Table 3-12: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean ecological status from a beta regression (logit link) fit to each monitored stream and exclosure type within WICA. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean ecological status (Δ_{resp}) over the course of Δ_{yr} number of years is also provided. Note: confidence intervals for Beaver Creek Exclosure and Cold Spring Creek Exclosure were unable to be computed due to insufficient sample size.

DMA	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
Beaver Creek 1-3	8	0.023	0.105	(-0.248, 0.294)	1.024	0.03	9
Beaver Creek Exclosure	3	0.400	0.078	–	1.492	0.30	8
Cold Spring Creek 1	4	-0.255	0.121	(-1.795, 1.285)	0.775	-0.07	7
Cold Spring Creek Exclosure	3	0.222	0.125	–	1.248	0.24	7
Highland Creek 1-2	8	0.001	0.050	(-0.128, 0.130)	1.001	0.00	10
Highland Creek Exclosure	5	0.344	0.105	(-0.107, 0.795)	1.411	0.46	9

3.3 Discussion

In all but a few instances, we are unable to statistically conclude that true trend in the MIM indicators within each perennial stream differs from zero. This is primarily due to the limited number of observations informing each regression fit. Additionally, the relatively short time period and presence of within-year variability (i.e., spatial variability) also contribute to the low statistical power of detecting trends in the MIM indicators/metrics. However, plots of the observed indicator/metric values and the fitted regression lines can still provide useful relative characterizations of condition within each perennial stream over time and compared to individual DMAs.

4 Inside versus Outside WICA Comparison

4.1 Methods

Differences in riparian condition within WICA compared to outside the Park were explored using regression models. Areas outside of WICA included Custer State Park (CusterSP) and neighboring U. S. Forest Service lands (USFS). See Table 4-1 for a detailed list of DMAs outside of WICA used in the analysis. Regression models were fit to each riparian condition metric for each area of interest following the methodology detailed in Section 3.1.

Table 4-1: MIM sampling events outside Wind Cave National Park during 2009-2019.

Designated Monitoring Area	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19
Flynn Creek ¹	–	–	–	–	–	–	–	–	–	–	1	–
Highland Creek Exclosure ¹	–	–	–	–	–	1	–	–	–	–	–	–
Highland Creek Outside Exclosure ¹	–	–	–	–	–	1	–	–	–	–	–	–
Kourthaus Creek ¹	–	–	–	–	–	–	–	–	–	–	1	–
NF Lame Johnny Creek ¹	–	–	–	–	–	1	–	–	–	–	–	–
Parker Creek ¹	–	–	–	–	–	–	–	–	–	–	1	–
Flynn Creek ²	–	1	–	–	1	–	–	–	–	–	–	–
Ladyfinger Gulch ²	–	1	–	–	1	–	–	–	–	–	–	–
Pole Cabin Creek ²	–	1	–	–	1	–	–	–	–	–	–	–
Redfern Slate Creek ²	–	1	–	–	1	–	–	–	–	–	–	–
Bald Horse Middle Victoria ³	1	–	–	–	–	–	–	1	–	–	–	–
Beaver Creek Riparian ³	–	–	–	2	–	1	–	–	–	–	2	–
Deer Creek ³	–	–	–	–	1	–	–	2	–	–	2	–
Deerfield Heely ³	1	–	–	–	–	–	1	–	–	–	–	–
Dugout Gulch ³	–	–	–	1	2	–	–	–	–	–	–	–
Guidinger ³	1	–	–	1	–	–	2	–	–	–	–	–
Little Beaver Creek ³	–	–	–	–	2	–	–	2	–	–	–	–
Middle Fork Redwater Creek ³	–	–	–	–	–	1	–	–	–	1	–	–
North Fork Redwater Creek ³	–	–	–	–	2	–	–	–	–	2	–	–
Palmer Gulch Upper Bear ³	1	–	–	–	–	–	–	1	–	–	–	–
Pole Cabin Gulch ³	–	–	1	1	2	–	–	–	1	–	–	–
Redfern Slate Creek ³	1	–	–	–	1	–	–	–	–	–	–	–
Slate Prairie Mystic ³	1	–	–	–	–	–	1	–	–	–	–	–
Slate Prairie Whitetail ³	1	–	–	–	1	–	–	–	–	–	–	–
South Fork Miller Creek ³	–	–	–	–	–	2	–	–	2	–	–	2
Tent Canyon ³	–	–	–	2	–	1	2	2	1	–	–	–
Tigerville Mini ³	1	–	–	–	1	–	–	–	–	–	–	–

¹ Located in Custer State Park

² Located on neighboring USFS land, collected by Norbeck Society

³ Located on neighboring USFS land, collected by USFS

4.2 Results

4.2.1 Average Stubble Height

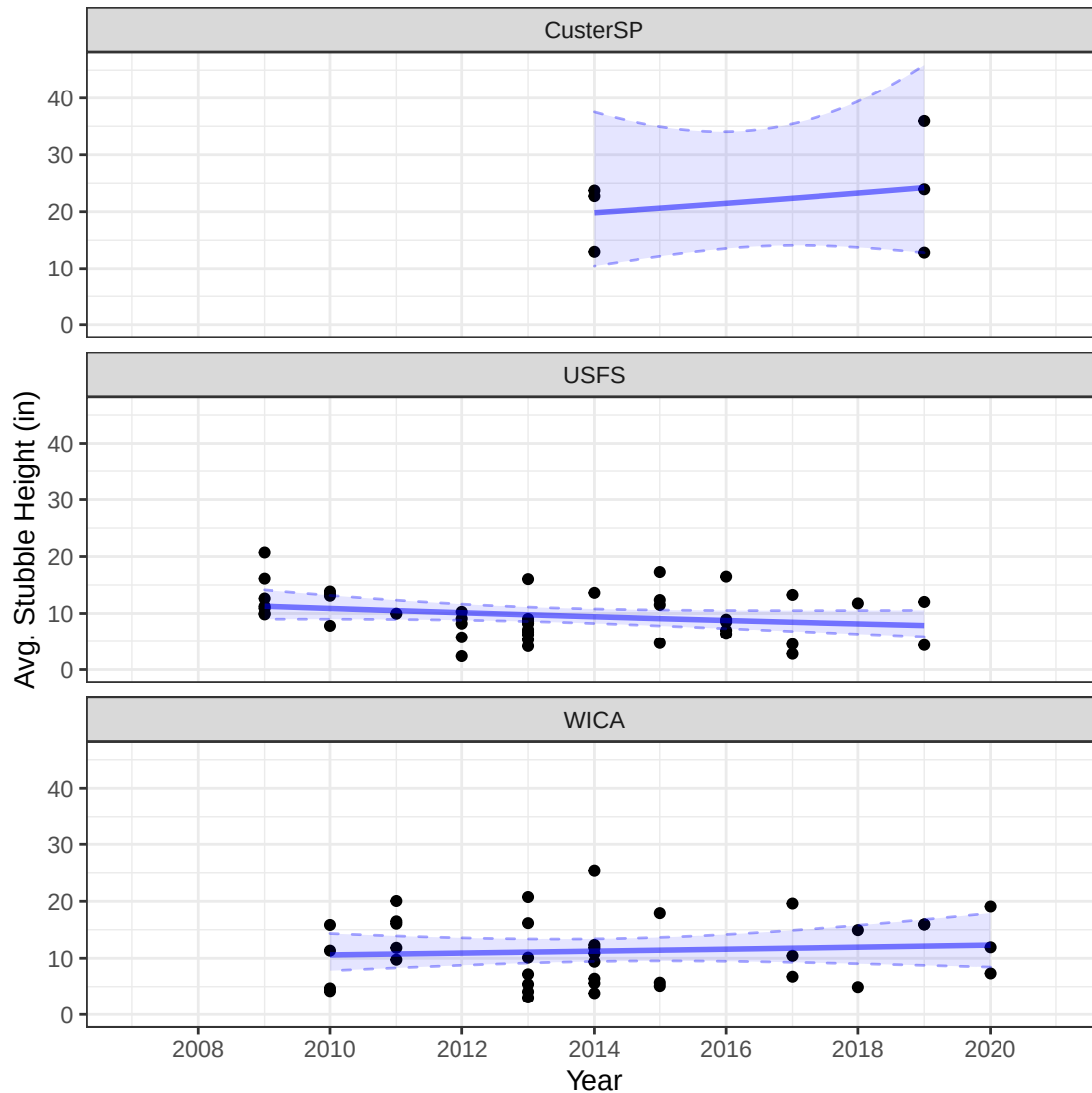


Figure 4-1: Average stubble height for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean average stubble height as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-2: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean average stubble height from a gamma regression (log link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean average stubble height (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	0.040	0.065	(-0.140, 0.221)	1.041	4.4	5
USFS	43	-0.036	0.022	(-0.081, 0.009)	0.965	-3.4	10
WICA	37	0.015	0.029	(-0.043, 0.073)	1.015	1.7	10

4.2.2 Average Greenline-Greenline Width

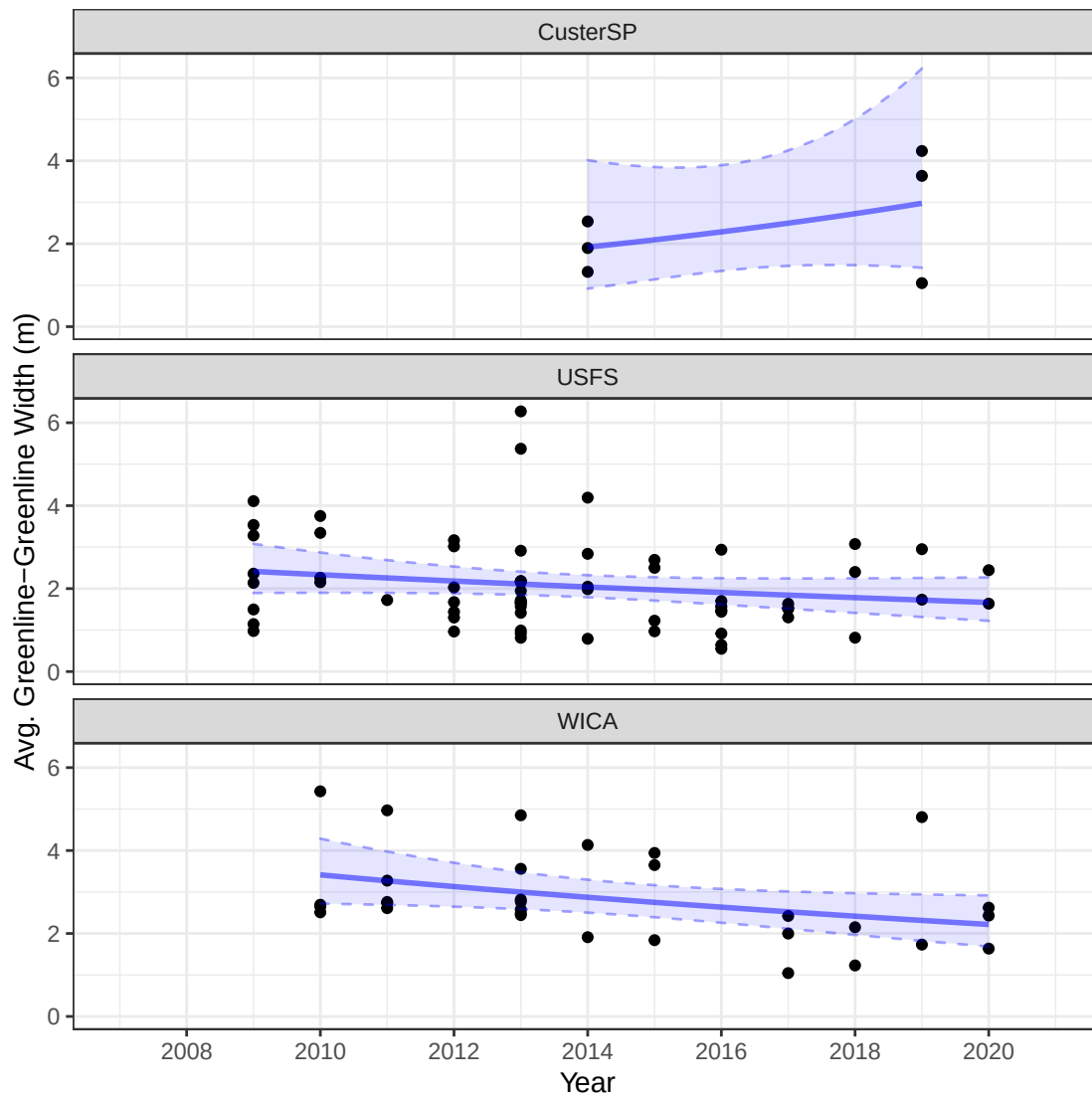


Figure 4-2: Average greenline-greenline width for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean average greenline-greenline width as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-3: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean average greenline-greenline width from a gamma regression (log link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean average greenline-greenline width (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	0.088	0.075	(-0.121, 0.297)	1.092	1.1	5
USFS	64	-0.034	0.022	(-0.078, 0.011)	0.967	-0.7	11
WICA	31	-0.043	0.021	(-0.085, -0.001)	0.958	-1.2	10

4.2.3 Dominant Species Average Stubble Height

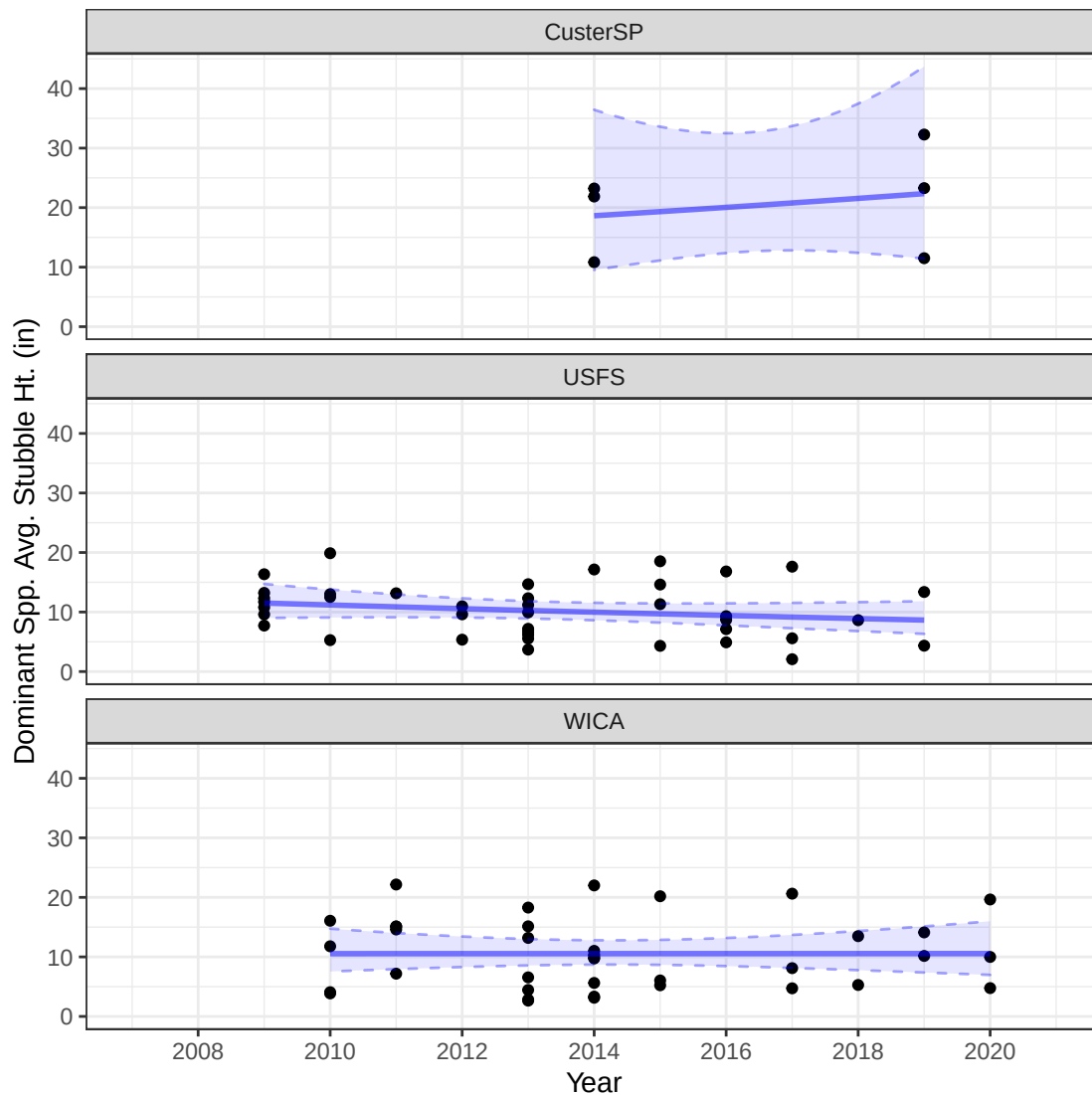


Figure 4-3: Dominant species average stubble height for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean dominant species average stubble height as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-4: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the mean dominant species average stubble height from a gamma regression (log link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean dominant species average stubble height (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	0.036	0.068	(-0.153, 0.226)	1.037	3.7	5
USFS	41	-0.029	0.024	(-0.077, 0.019)	0.972	-2.9	10
WICA	37	0.000	0.032	(-0.064, 0.064)	1.000	0.0	10

4.2.4 Diversity Index

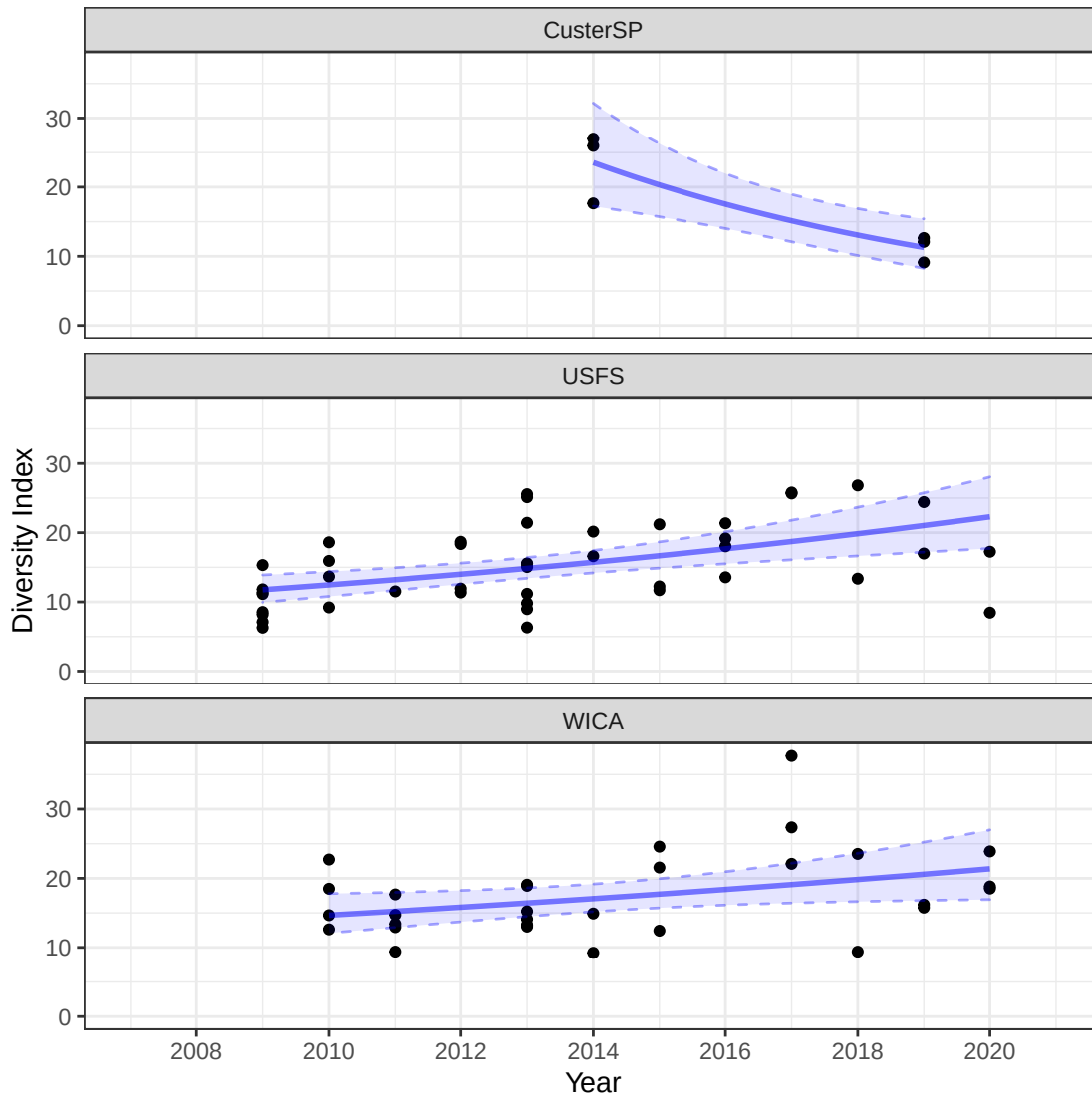


Figure 4-4: Diversity index for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean diversity index as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-5: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in mean diversity index from a gamma regression (log link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean diversity index (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.147	0.032	(-0.235, -0.059)	0.863	-12.3	5
USFS	44	0.058	0.015	(0.027, 0.089)	1.060	10.5	11
WICA	31	0.038	0.017	(0.002, 0.073)	1.038	6.7	10

4.2.5 Streambank Cover

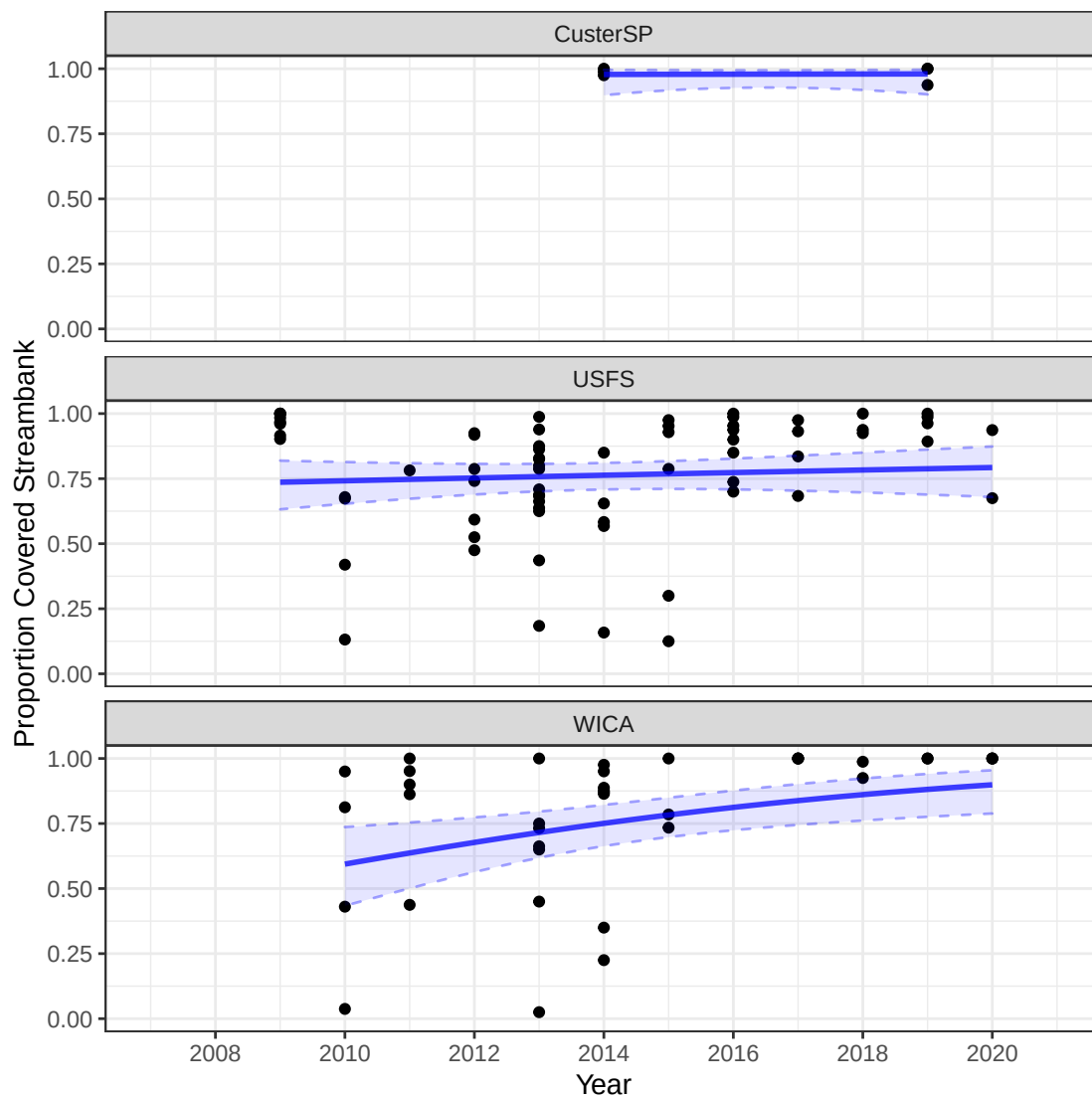


Figure 4-5: Percent plots containing covered streambank for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean percent plots containing covered streambank as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-6: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing covered streambank from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing covered streambank (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	0.019	0.129	(-0.392, 0.430)	1.019	0.00	5
USFS	68	0.029	0.042	(-0.055, 0.112)	1.029	0.06	11
WICA	37	0.180	0.061	(0.056, 0.305)	1.198	0.30	10

4.2.6 Streambank Stability

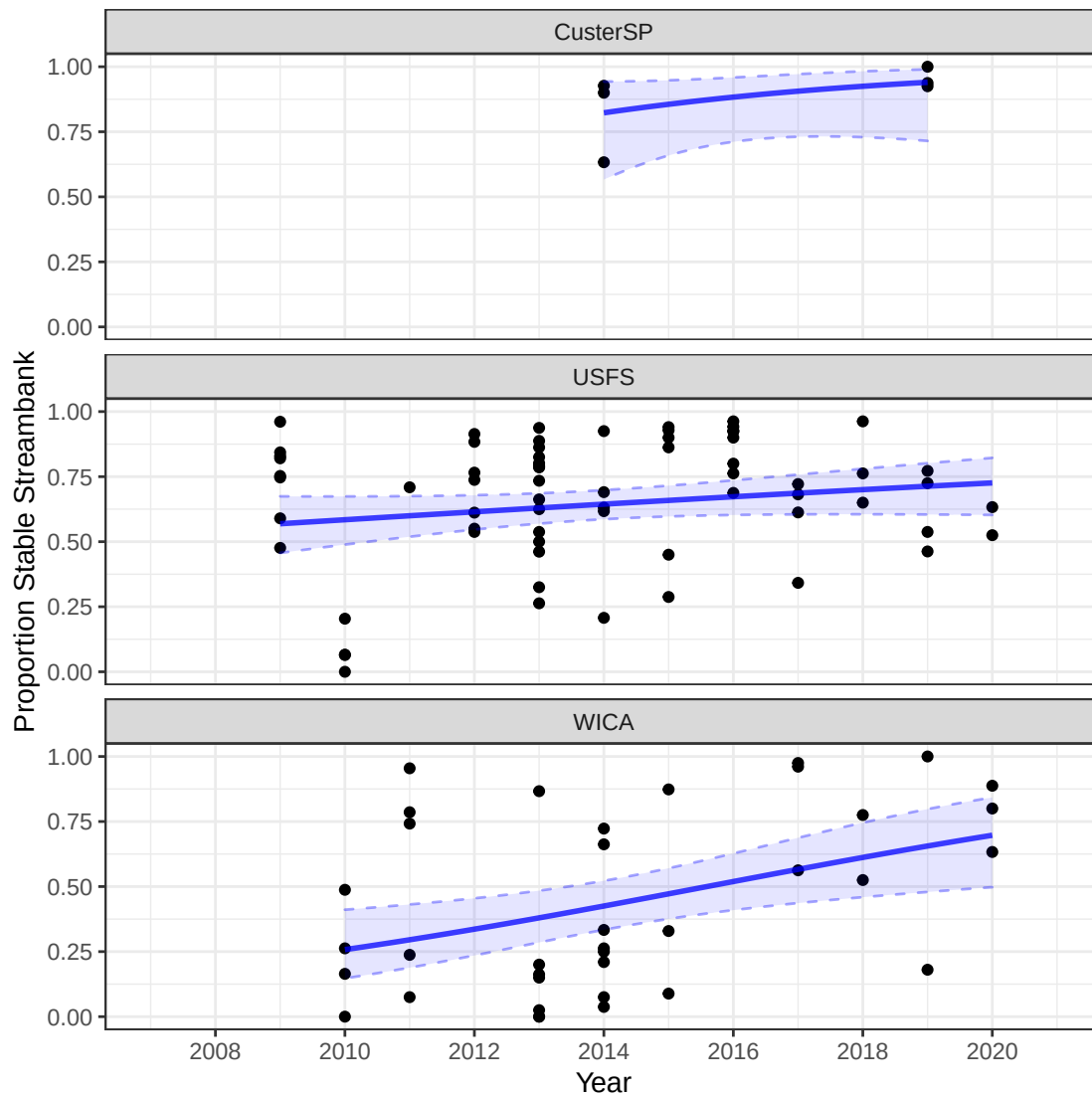


Figure 4-6: Percent plots containing stable streambank for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean percent plots containing stable streambank as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-7: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing stable streambank from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing stable streambank (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	0.244	0.132	(-0.176, 0.663)	1.276	0.12	5
USFS	68	0.063	0.040	(-0.017, 0.143)	1.065	0.16	11
WICA	37	0.189	0.066	(0.056, 0.322)	1.208	0.44	10

4.2.7 Percent Hydric Herbaceous

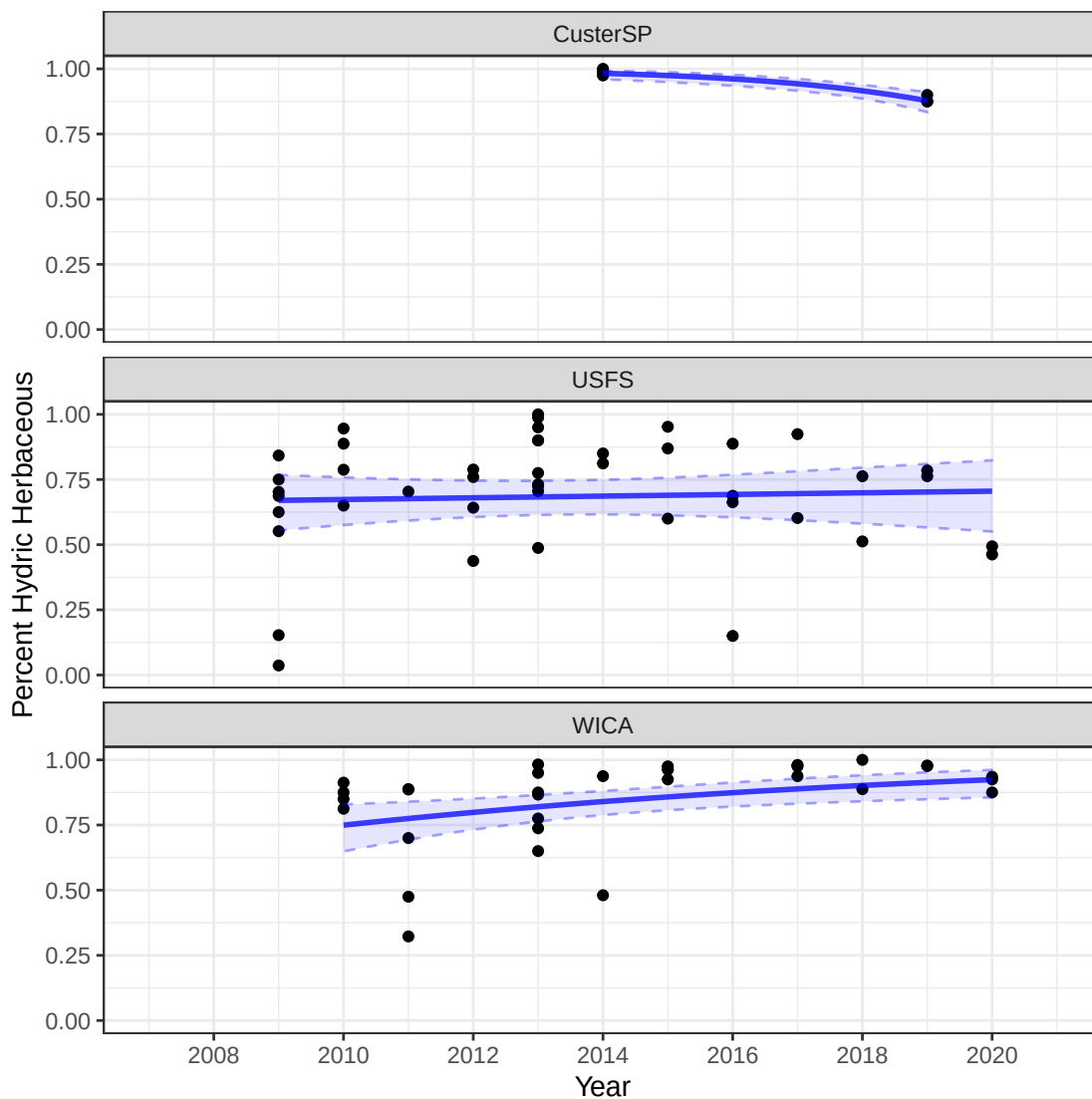


Figure 4-7: Percent plots containing hydric herbaceous species for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean percent plots containing hydric herbaceous species as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-8: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing hydric herbaceous species from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing hydric herbaceous (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.415	0.059	(-0.604, -0.226)	0.660	-0.11	5
USFS	44	0.015	0.044	(-0.074, 0.104)	1.015	0.04	11
WICA	31	0.140	0.047	(0.043, 0.237)	1.150	0.17	10

4.2.8 Percent Woody Composition

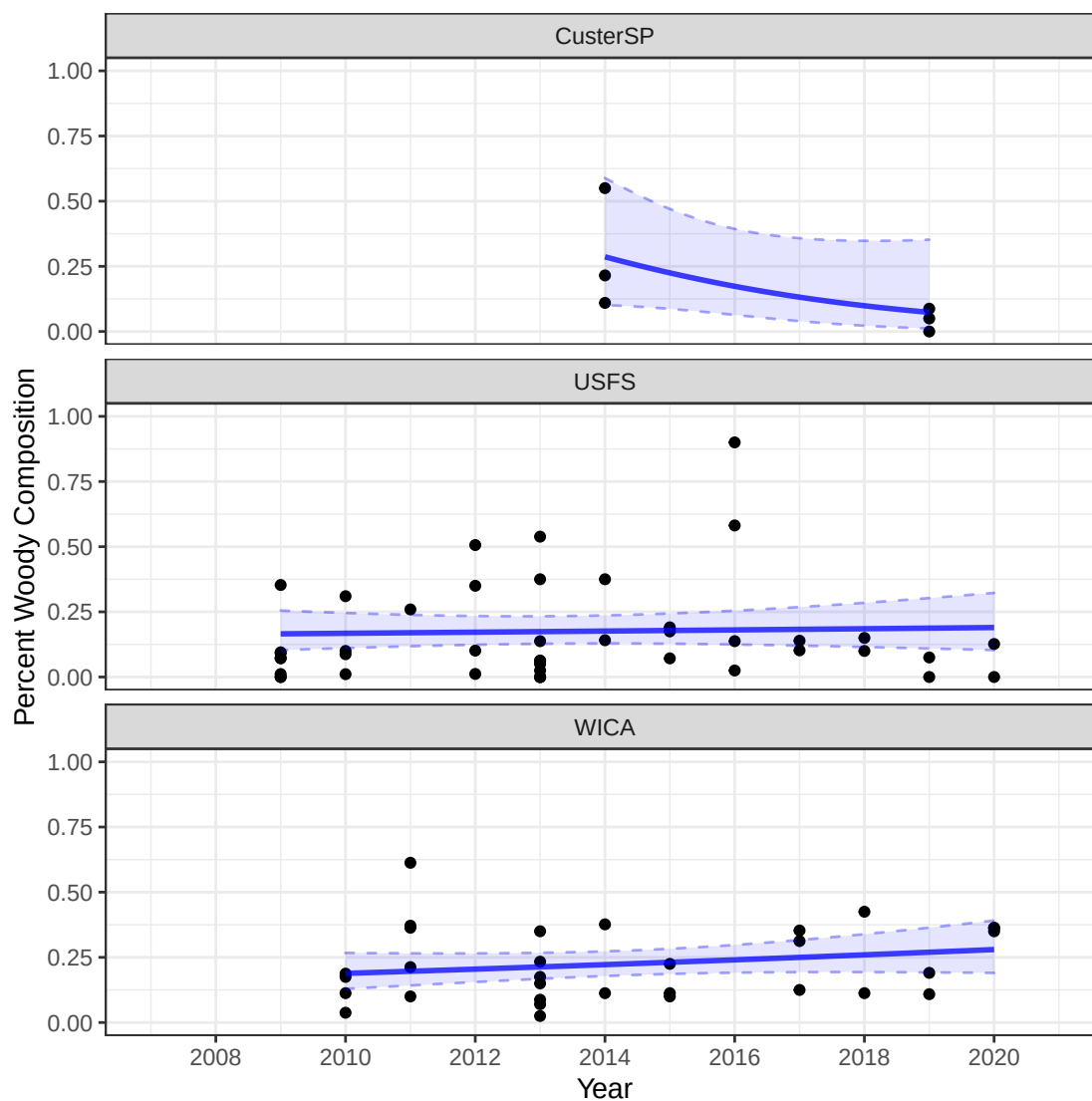


Figure 4-8: Percent plots containing woody plants for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean percent plots containing woody plants as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-9: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean percent plots containing woody plants from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean percent plots containing woody plants (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.324	0.139	(-0.767, 0.118)	0.723	-0.21	5
USFS	44	0.015	0.046	(-0.077, 0.107)	1.015	0.02	11
WICA	31	0.051	0.038	(-0.027, 0.130)	1.053	0.09	10

4.2.9 Streambank Alteration

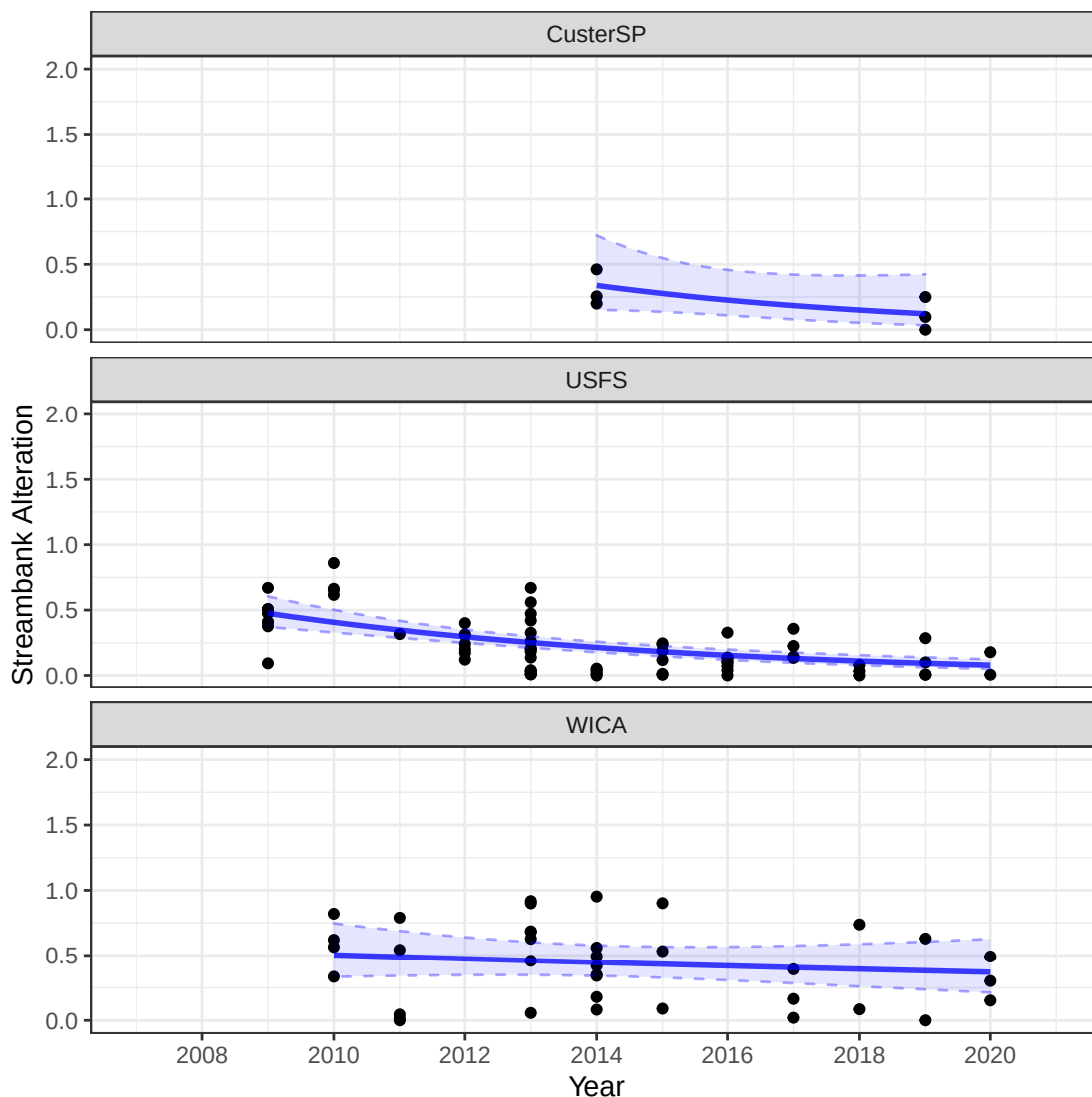


Figure 4-9: Streambank alteration (i.e., mean number of lines in each monitoring frame that intersect streambank alteration) for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean number of lines intersecting streambank alteration as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-10: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean number of lines intersecting streambank alteration from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean number of lines intersecting streambank alteration (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.213	0.094	(-0.514, 0.087)	0.808	-0.22	5
USFS	68	-0.171	0.028	(-0.227, -0.115)	0.843	-0.40	11
WICA	37	-0.034	0.042	(-0.119, 0.051)	0.967	-0.13	10

4.2.10 Modified Winward Greenline Stability Rating

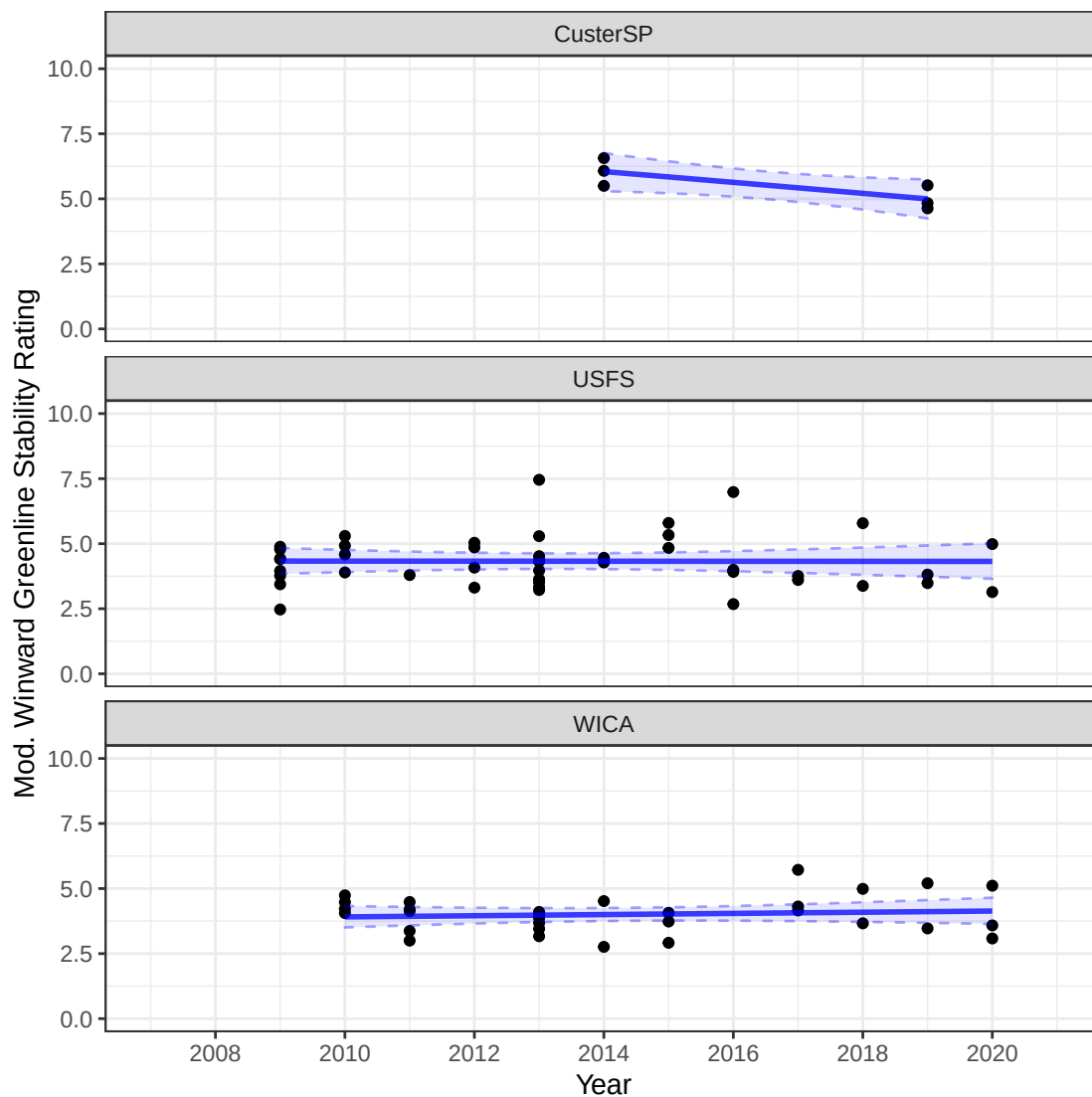


Figure 4-10: Modified Winward greenline stability rating for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean modified Winward greenline stability rating as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-11: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean stability rating from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean stability rating (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.085	0.027	(-0.172, 0.001)	0.918	-1.05	5
USFS	44	-0.000	0.019	(-0.038, 0.037)	1.000	-0.01	11
WICA	31	0.009	0.016	(-0.023, 0.041)	1.009	0.23	10

4.2.11 Wetland Rating

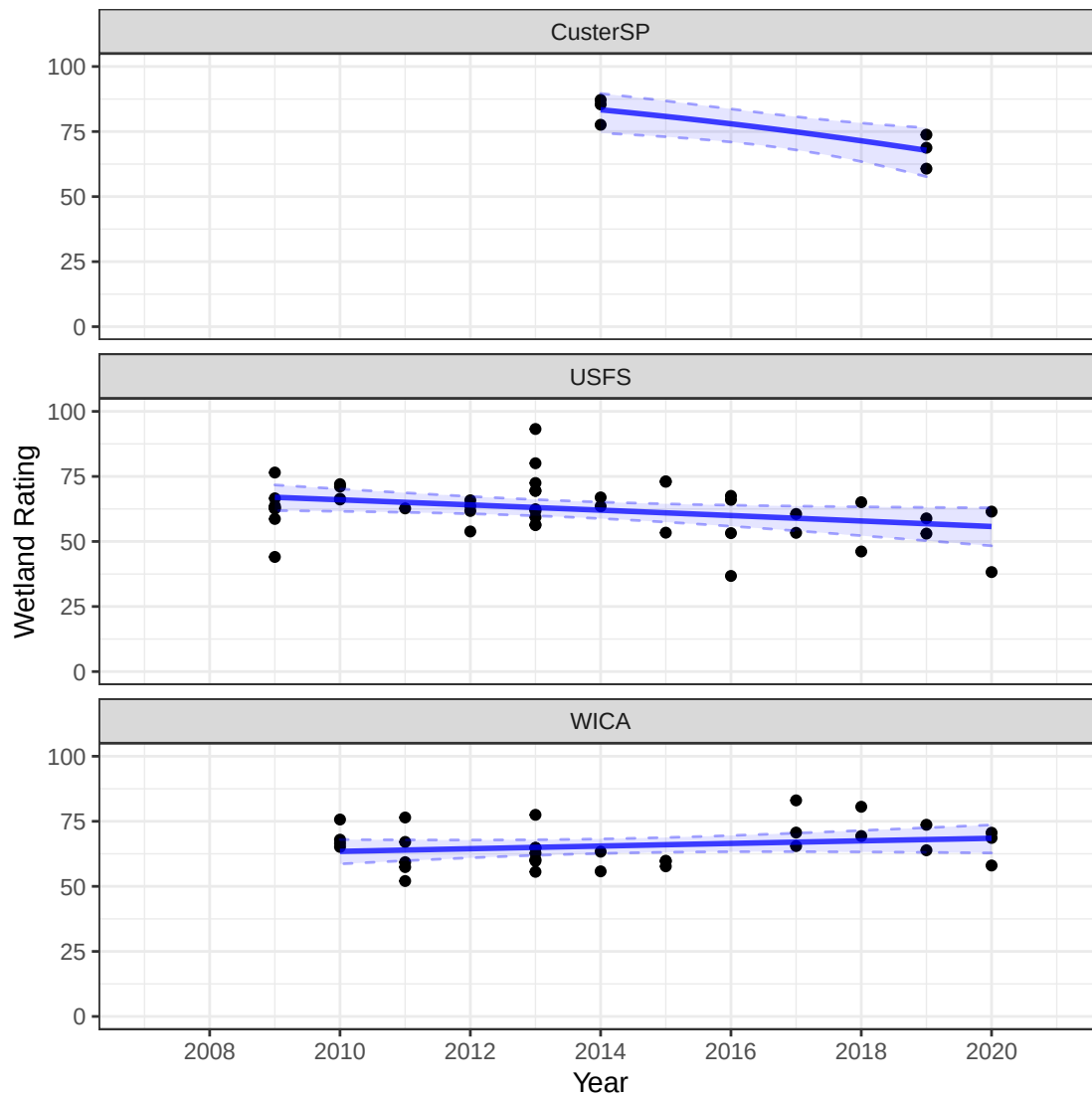


Figure 4-11: Wetland rating for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean wetland rating as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-12: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean wetland rating from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean wetland rating (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.174	0.044	(-0.313, -0.034)	0.841	-15.59	5
USFS	44	-0.043	0.020	(-0.084, -0.003)	0.958	-11.23	11
WICA	31	0.022	0.019	(-0.015, 0.060)	1.023	5.04	10

4.2.12 Ecological Status

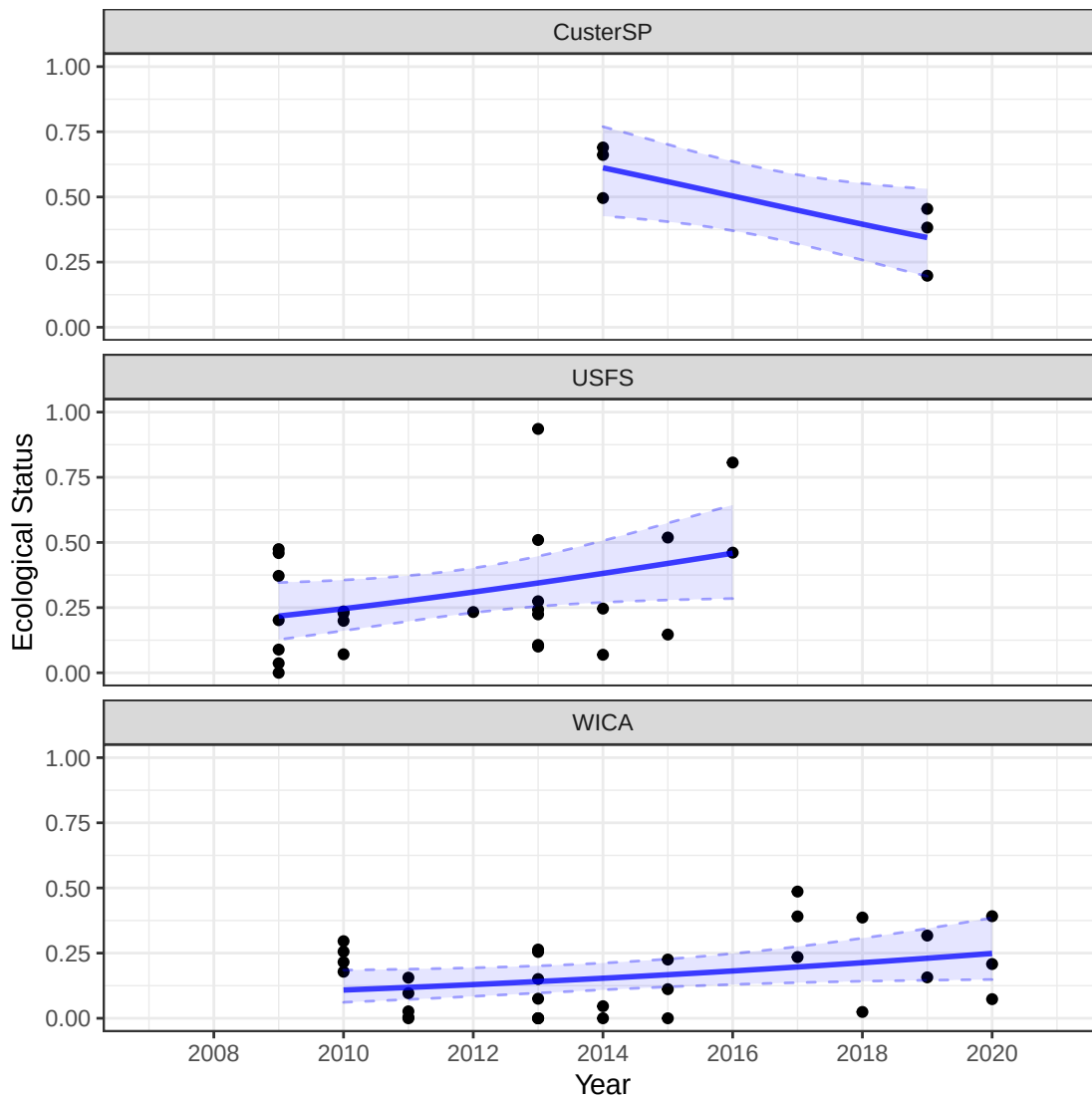


Figure 4-12: Ecological status for each sampled DMA (black dots) within Custer State Park, neighboring USFS land, and WICA. Estimated mean ecological status as a function of year plotted in blue with 95% confidence interval shaded in light blue and bound by dashed lines.

Table 4-13: Summary of the estimated multiplicative trend (i.e., $\exp(\hat{\beta}_1)$) in the odds of mean ecological status from a beta regression (logit link) fit to sampled sites within each designated area. If the 95% confidence interval (95% CI) for the trend effect contains the value of 0, this is equivalent to failing to reject the null hypothesis of no trend at the 5% significance level for a two-sided test (i.e., $H_0: \beta_1 = 0$ versus $H_1: \beta_1 \neq 0$). The change in the predicted mean ecological status (Δ_{resp}) over the course of Δ_{yr} number of years is also provided.

Area	n	$\hat{\beta}_1$	SE ($\hat{\beta}_1$)	95% CI for $\hat{\beta}_1$	$\exp(\hat{\beta}_1)$	Δ_{resp}	Δ_{yr}
CusterSP	6	-0.220	0.068	(-0.435, -0.004)	0.803	-0.27	5
USFS	25	0.159	0.079	(-0.004, 0.322)	1.173	0.24	7
WICA	31	0.100	0.049	(-0.000, 0.201)	1.105	0.14	10

4.3 Discussion

When interpreting trends within each area of interest and making comparisons across areas, consideration should be given to both the statistical significance of the estimated trend and the period over which it was computed. This is particularly pertinent to any comparison involving Custer State Park because: (1) there are a limited number of DMAs informing the trend estimate, (2) there are only two years with sample measurements, and (3) the time period over which trend is computed is approximately half the duration of the other two areas. In addition to comparing estimated trend effects, it is also useful to compare both the relative magnitude of MIM indicator/metric values and the within-year variability. The first provides information regarding the relative condition of each area and the second provides useful context for how variable DMAs are spatially within the area of interest within a given year.

5 Power Analysis

5.1 Methods

Power analyses are a function of the following five parameters: (1) power - the probability of rejecting the null hypothesis when it is false; (2) sample size; (3) type I error rate - the probability of rejecting the null hypothesis given that it is true; (4) effect size; and (5) variance of the metric. Increasing the value of the sample size, type I error rate, or effect size, while holding the remaining parameters constant, will result in increased power. Decreasing the variance, while holding the remaining parameters constant, will also result in increased power. If values are provided for four of the parameters, it is possible to solve for the remaining parameter value.

The magnitude of a linear trend in time (link function scale) detectable with 80% power for varying levels of sampling effort was estimated using a combination of Monte Carlo simulation (Gelman and Hill, 2006) and optimization. The type I error rate was set equal to 0.05 and the variance of each metric was estimated from the observed data using the estimated dispersion parameter $\hat{\phi}$ from each regression fit in Section 3.2. Sample size varied according to sampling frequency and it was assumed that every DMA within a stream is sampled concurrently.

To estimate power for a given trend effect size, ten thousand hypothetical time series were simulated according to the defined per year trend, on the link function scale, for a period of 10 years. Simulated variation from the conditional mean value was equal to the estimated residual variation from the regression analyses (i.e., the parameter $\hat{\phi}$, which is visually represented by the light blue shaded intervals in the conditional distribution figures provided in Section 7.1). Regressions were fit to each simulated time series in accordance to the methods detailed in Section 3.1. Power was estimated by computing the proportion of the ten thousand regressions that corresponded to a rejected null hypothesis of $H_0 : \beta_1 = 0$ in favor of $H_1 : \beta_1 \neq 0$. Optimization via the `optim()` function in R was used to solve for the approximate trend effect size yielding 80% power.

For metrics fit with gamma GLMs, the minimum detectable trend effect size was estimated assuming sampling frequencies of every 1, 2, and 3 years. For metrics fit with beta regression models, estimates were only computed for sampling frequencies of every 1 and 2 years. This was due to computational reasons related to the small sample size associated with sampling every 3 years ($n = 4$ observations per DMA) and the large amount of variation present in the data for many of the metrics.

Accompanying each estimated trend effect size are the changes (Δ) in the conditional mean, on the response scale, assuming the yearly trend effect size is applied over a period of 10 years. The changes are relative to the estimated metric mean value for the latest year of data collection. For example, consider the estimated trend effect size for average stubble height within Beaver Creek 1-3, assuming sampling occurs every year (Table 5-1). The latest estimate of the mean average stubble height is 11.88 inches, and a trend effect of $|\beta_1| = 0.093$ applied over 10 years corresponds to either an increase of 18.18 inches, or a decrease of 7.18 inches in the mean of average stubble height (Figure 1-3). It should be noted that when making comparisons across stream groups within the Δ columns of the Section 5.2 tables, each Δ pair is a function of both the estimated β_1 value and the latest estimate. That is to say, even if two stream groups had similar estimates for β_1 , their Δ pair values may noticeably differ if the latest estimates are sufficiently different. This is due to the fact that the linear trend on the link function scale is non-linear on the response scale (see Section 3.1 for additional discussion). Additionally, for metrics fit with a beta regression model, it is important

to remember that changes on the response scale are less noticeable when near the response scale boundaries of 0 or 1 (see Figure 3-1).

5.2 Results

5.2.1 Average Stubble Height

Table 5-1: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in average stubble height after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of average stubble height is provided along with the respective changes height that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80			Latest Estimate (in.)	$\pm\Delta$ in Average Stubble Height (in.) After 10 years		
	Sampling Frequency:				Sampling Frequency:		
	3 yrs	2 yrs	1 yr		3 yrs	2 yrs	1 yr
Beaver Creek 1-3	0.139	0.118	0.093	11.88	(-8.93, +36.02)	(-8.22, +26.72)	(-7.18, +18.18)
Beaver Creek Exclosure	0.244	0.136	0.090	17.80	(-16.25, +186.70)	(-13.22, +51.40)	(-10.58, +26.10)
Cold Spring Creek 1	0.137	0.080	0.053	4.36	(-3.25, +12.83)	(-2.41, +5.39)	(-1.80, +3.08)
Cold Spring Creek Exclosure	0.282	0.167	0.118	13.22	(-12.43, +207.87)	(-10.72, +56.87)	(-9.16, +29.82)
Highland Creek 1-2	0.122	0.100	0.075	9.33	(-6.57, +22.19)	(-5.89, +15.96)	(-4.94, +10.49)
Highland Creek Exclosure	0.334	0.198	0.133	18.95	(-18.28, +516.88)	(-16.32, +117.72)	(-13.96, +53.00)

5.2.2 Average Greenline-Greenline Width

Table 5-2: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in average greenline-greenline width after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of average greenline-greenline width is provided along with the respective changes in width that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80			Latest Estimate (m)	$\pm\Delta$ in Average Greenline-Greenline Width (m) After 10 years		
	Sampling Frequency:				Sampling Frequency:		
	3 yrs	2 yrs	1 yr		3 yrs	2 yrs	1 yr
Beaver Creek 1-3	0.076	0.066	0.050	4.46	(−2.37, +5.05)	(−2.15, +4.14)	(−1.76, +2.90)
Beaver Creek Exclosure	0.022	0.013	0.009	1.74	(−0.34, +0.43)	(−0.21, +0.24)	(−0.14, +0.16)
Cold Spring Creek 1	0.092	0.055	0.037	2.35	(−1.42, +3.55)	(−0.99, +1.71)	(−0.72, +1.04)
Cold Spring Creek Exclosure	0.071	0.042	0.029	1.19	(−0.60, +1.23)	(−0.41, +0.63)	(−0.30, +0.39)
Highland Creek 1-2	0.031	0.026	0.020	2.40	(−0.65, +0.88)	(−0.55, +0.71)	(−0.43, +0.52)
Highland Creek Exclosure	0.214	0.127	0.085	1.32	(−1.17, +9.88)	(−0.95, +3.38)	(−0.76, +1.78)

5.2.3 Dominant Species Average Stubble Height

Table 5-3: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in dominant species average stubble height after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of dominant species average stubble height is provided along with the respective changes in height that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80			Latest Estimate (in.)	$\pm\Delta$ in Dominant Spp. Avg. Stubble Ht. (in.) After 10 years		
	Sampling Frequency:				Sampling Frequency:		
	3 yrs	2 yrs	1 yr		3 yrs	2 yrs	1 yr
Beaver Creek 1-3	0.137	0.118	0.091	8.12	(−6.05, +23.75)	(−5.63, +18.32)	(−4.84, +11.99)
Beaver Creek Exclosure	0.250	0.138	0.093	15.62	(−14.33, +173.91)	(−11.68, +46.28)	(−9.43, +23.78)
Cold Spring Creek 1	0.051	0.030	0.020	5.19	(−2.09, +3.49)	(−1.36, +1.84)	(−0.95, +1.16)
Cold Spring Creek Exclosure	0.191	0.113	0.078	12.39	(−10.56, +71.33)	(−8.38, +25.94)	(−6.70, +14.59)
Highland Creek 1-2	0.159	0.131	0.100	6.65	(−5.30, +26.10)	(−4.86, +18.05)	(−4.20, +11.44)
Highland Creek Exclosure	0.385	0.221	0.150	19.70	(−19.28, +906.17)	(−17.53, +159.49)	(−15.29, +68.29)

5.2.4 Diversity Index

Table 5-4: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in diversity index after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of diversity index is provided along with the respective changes in index that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80			Latest Estimate	$\pm\Delta$ in Diversity Index After 10 years		
	Sampling Frequency:				Sampling Frequency:		
	3 yrs	2 yrs	1 yr		3 yrs	2 yrs	1 yr
Beaver Creek 1-3	0.058	0.049	0.038	19.57	(−8.57, +15.26)	(−7.60, +12.43)	(−6.20, +9.07)
Beaver Creek Exclosure	0.128	0.075	0.050	16.73	(−12.06, +43.17)	(−8.81, +18.62)	(−6.59, +10.87)
Cold Spring Creek 1	0.126	0.075	0.050	9.54	(−6.84, +24.18)	(−5.04, +10.68)	(−3.75, +6.19)
Cold Spring Creek Exclosure	0.081	0.048	0.032	22.68	(−12.58, +28.25)	(−8.65, +13.97)	(−6.22, +8.57)
Highland Creek 1-2	0.105	0.087	0.067	24.26	(−15.78, +45.18)	(−14.14, +33.91)	(−11.78, +22.92)
Highland Creek Exclosure	0.110	0.066	0.044	24.50	(−16.30, +48.73)	(−11.86, +23.01)	(−8.70, +13.50)

5.2.5 Streambank Cover

Table 5-5: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in streambank cover after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of streambank cover is provided along with the respective changes in cover that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Percent Covered Streambank After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.370	0.228	0.80	(−0.71, +0.19)	(−0.51, +0.18)
Beaver Creek Exclosure	0.112	0.073	0.99	(−0.02, +0.01)	(−0.01, +0.01)
Cold Spring Creek 1	0.313	0.170	0.84	(−0.65, +0.15)	(−0.35, +0.13)
Cold Spring Creek Exclosure	0.152	0.094	0.95	(−0.15, +0.04)	(−0.07, +0.03)
Highland Creek 1-2	0.140	0.104	0.97	(−0.08, +0.02)	(−0.05, +0.02)
Highland Creek Exclosure	NA	0.431	0.90	NA	(−0.79, +0.10)

5.2.6 Streambank Stability

Table 5-6: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in streambank stability after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of streambank stability is provided along with the respective changes in stability that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Percent Stable Streambank After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.174	0.132	0.21	(−0.16, +0.39)	(−0.14, +0.29)
Beaver Creek Exclosure	0.207	0.121	0.95	(−0.23, +0.04)	(−0.10, +0.03)
Cold Spring Creek 1	0.175	0.104	0.52	(−0.36, +0.34)	(−0.24, +0.23)
Cold Spring Creek Exclosure	0.083	0.054	0.74	(−0.19, +0.13)	(−0.12, +0.09)
Highland Creek 1-2	0.208	0.152	0.77	(−0.48, +0.20)	(−0.35, +0.17)
Highland Creek Exclosure	NA	NA	0.73	NA	NA

5.2.7 Percent Hydric Herbaceous

Table 5-7: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in percent hydric herbaceous species after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of percent hydric herbaceous species is provided along with the respective changes in percent plots that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Percent Hydric Herbaceous After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.074	0.056	0.95	(−0.05, +0.03)	(−0.03, +0.02)
Beaver Creek Exclosure	0.052	0.035	0.97	(−0.02, +0.01)	(−0.01, +0.01)
Cold Spring Creek 1	0.082	0.053	0.99	(−0.01, +0.01)	(−0.01, +0.00)
Cold Spring Creek Exclosure	0.096	0.062	0.84	(−0.17, +0.09)	(−0.10, +0.07)
Highland Creek 1-2	NA	0.087	0.90	NA	(−0.11, +0.05)
Highland Creek Exclosure	0.091	0.059	0.94	(−0.07, +0.03)	(−0.04, +0.02)

5.2.8 Percent Woody Composition

Table 5-8: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in percent woody composition after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of percent woody composition is provided along with the respective changes in percent plots that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Percent Woody Composition After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.071	0.056	0.11	(−0.05, +0.09)	(−0.05, +0.07)
Beaver Creek Exclosure	0.075	0.050	0.18	(−0.09, +0.14)	(−0.06, +0.09)
Cold Spring Creek 1	0.063	0.042	0.09	(−0.04, +0.07)	(−0.03, +0.04)
Cold Spring Creek Exclosure	0.134	0.085	0.38	(−0.24, +0.32)	(−0.17, +0.21)
Highland Creek 1-2	0.068	0.052	0.38	(−0.14, +0.17)	(−0.11, +0.13)
Highland Creek Exclosure	0.220	0.129	0.24	(−0.20, +0.50)	(−0.16, +0.29)

5.2.9 Streambank Alteration

Table 5-9: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in streambank alteration after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of streambank alteration is provided along with the respective changes in alteration that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Streambank Alteration After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.041	0.032	0.13	(−0.04, +0.05)	(−0.03, +0.04)
Beaver Creek Exclosure	0.036	0.023	0.02	(−0.01, +0.01)	(−0.00, +0.00)
Cold Spring Creek 1	0.036	0.024	0.17	(−0.05, +0.06)	(−0.03, +0.04)
Cold Spring Creek Exclosure	0.049	0.032	0.04	(−0.01, +0.02)	(−0.01, +0.01)
Highland Creek 1-2	0.039	0.030	0.07	(−0.02, +0.03)	(−0.02, +0.02)
Highland Creek Exclosure	0.246	0.142	0.06	(−0.05, +0.36)	(−0.04, +0.15)

5.2.10 Modified Winward Greenline Stability Rating

Table 5-10: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in modified Winward greenline stability rating after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of modified Winward greenline stability rating is provided along with the respective changes in rating that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Mod. Winward Greenline Stability Rating After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.021	0.017	0.33	(−0.05, +0.05)	(−0.04, +0.04)
Beaver Creek Exclosure	0.030	0.018	0.52	(−0.07, +0.07)	(−0.05, +0.05)
Cold Spring Creek 1	0.063	0.042	0.33	(−0.12, +0.15)	(−0.09, +0.10)
Cold Spring Creek Exclosure	0.002	0.001	0.50	(−0.00, +0.00)	(−0.00, +0.00)
Highland Creek 1-2	0.034	0.027	0.36	(−0.07, +0.08)	(−0.06, +0.06)
Highland Creek Exclosure	0.090	0.058	0.53	(−0.21, +0.20)	(−0.14, +0.14)

5.2.11 Wetland Rating

Table 5-11: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in wetland rating after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of wetland rating is provided along with the respective changes in rating that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Wetland Rating After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.053	0.041	0.60	(−0.13, +0.12)	(−0.10, +0.09)
Beaver Creek Exclosure	0.023	0.015	0.73	(−0.05, +0.04)	(−0.03, +0.03)
Cold Spring Creek 1	0.092	0.059	0.76	(−0.20, +0.13)	(−0.12, +0.09)
Cold Spring Creek Exclosure	0.033	0.022	0.68	(−0.07, +0.07)	(−0.05, +0.04)
Highland Creek 1-2	0.042	0.033	0.65	(−0.10, +0.09)	(−0.08, +0.07)
Highland Creek Exclosure	0.180	0.111	0.74	(−0.42, +0.20)	(−0.26, +0.15)

5.2.12 Ecological Status

Table 5-12: Estimated minimum detectable time trend (i.e., $|\beta_1|$) in ecological status after a period of 10 years with power equal to 0.80 for varying sampling frequencies. Each DMA's latest estimate of ecological status is provided along with the respective changes in status that would result assuming the estimated minimum detectable trend is applied over 10 years.

DMA	Est. Detectable $ \beta_1 $ w/ Power = 0.80		Latest Estimate	$\pm\Delta$ in Ecological Status After 10 years	
	Sampling Frequency:			Sampling Frequency:	
	2 yrs	1 yr		2 yrs	1 yr
Beaver Creek 1-3	0.155	0.117	0.21	(−0.15, +0.34)	(−0.13, +0.25)
Beaver Creek Exclosure	0.105	0.067	0.32	(−0.18, +0.25)	(−0.13, +0.16)
Cold Spring Creek 1	0.115	0.073	0.02	(−0.01, +0.03)	(−0.01, +0.02)
Cold Spring Creek Exclosure	0.276	0.151	0.34	(−0.31, +0.55)	(−0.24, +0.36)
Highland Creek 1-2	0.119	0.089	0.20	(−0.13, +0.25)	(−0.11, +0.18)
Highland Creek Exclosure	0.307	0.167	0.51	(−0.46, +0.45)	(−0.34, +0.34)

5.3 Discussion

The two primary parameters influencing the results of this power analysis are the estimated variance of the metrics and the sample size. Metrics with larger estimates of variability (i.e., blue intervals in the Section 7.1 figures) are associated with larger minimum detectable trend effect sizes. Sample size also has a noticeable impact on the detectable effect sizes such that increased sampling frequency generally results in smaller detectable effect sizes. It should be noted that additional sampling sites were not considered in this analysis but increasing sample size by sampling more DMAs (for a given sampling interval) would have a similar effect in lowering the detectable effect size. The general recommendation from the analysis is to maximize the sample size, either by decreasing the sampling interval or increasing the number of DMAs sampled within each stream.

6 Drivers of Riparian Condition

6.1 Weather Data

Weather data was obtained from *The Climate Analyzer* (www.climateanalyzer.us) for two weather stations: (1) Cooperative Observer Network (COOP) station located near the visitor center, and (2) Remote Automatic Weather Station (RAWS) located atop Elk Mountain. The distance separating the two stations is approximately 875 feet (266.6 m) and they differ in elevation by approximately 30 feet (9.2 m). Although both stations are relatively close in spatial proximity, weather observations at each can sometimes differ substantially (for example, see Figure 6-1 for differences in April monthly precipitation totals). Per Wu, Hubbard, and You (2005), discrepancy between station observations is a common occurrence. Based on discussions with WICA scientists, it was determined that weather observations from the RAWS station are unreliable and were therefore excluded from the analysis. Additionally, all Highland Creek DMAs were excluded from the analysis because weather observed at the COOP station is unlikely to be representative of the weather observed approximately 5 miles away.

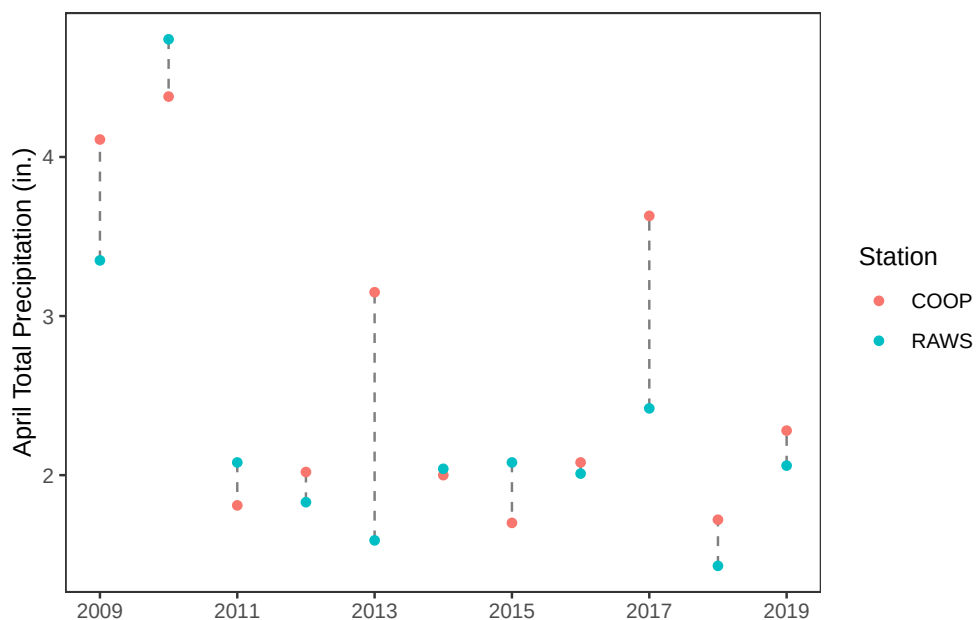


Figure 6-1: April monthly precipitation totals (inches) for the COOP and RAWS weather stations in WICA. Dashed lines depict magnitude of discrepancy between observed totals.

Sampling at each DMA occurred during the months of August or September, which was assumed to be at the culmination of the growing season. Potential covariates were therefore restricted to those involving the months prior to and including September. The start of the growing season was assumed to be April based on a notable increase in precipitation during this month and average monthly low temperatures beginning to exceed the frost point.

After an initial exploration of potential temperature and precipitation variables (many of which are highly correlated), it was determined that the growing season can be characterized by two periods:

(1) the months of April to June which are generally the wettest of the year, and (2) the months of July to September which are generally the warmest of the year. Additionally, how wet the spring was and how dry the summer was both represent limiting factors assumed to affect plant growth during the growing season. Based on these observations, covariates for total precipitation observed during the months of April to June and the average Keetch-Byram drought index during the months of July to September were included in the proceeding regression analyses.

6.2 Management Data

Estimated population counts for both elk and bison within WICA were provided by Isabel Ashton. The median of the yearly population interval estimates was utilized in the proceeding analyses (Figure 6-2).

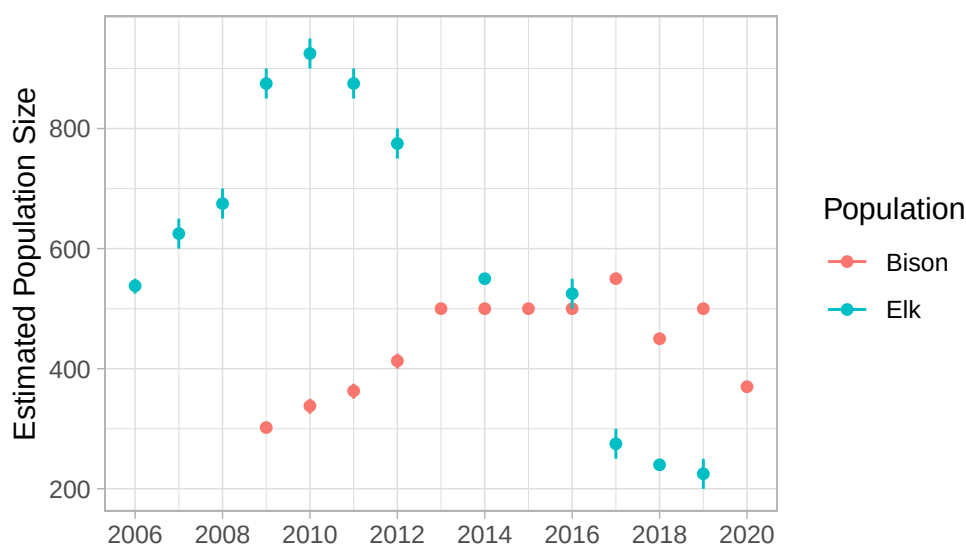


Figure 6-2: Yearly estimated elk and bison population counts within WICA are presented. Median estimated population counts are plotted as black circles with uncertainty interval (if available) represented by a vertical bar.

6.3 Methods

Potential drivers of riparian condition were explored through a combination of graphical and regression methods. Regression models were fit for each riparian condition metric following the methodology detailed in Section 3.1.

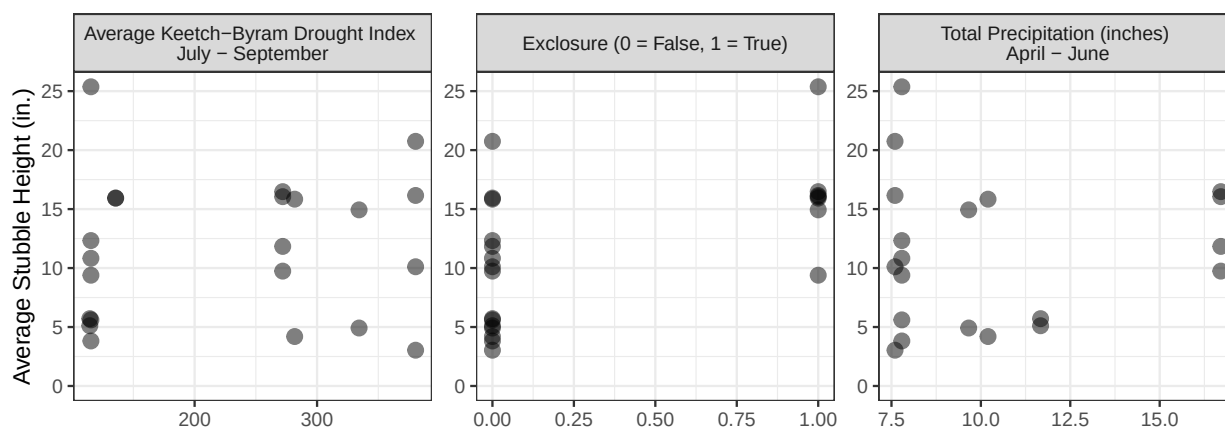
Two separate regression models were fit for each riparian condition metric. The first model (M_1) was fit to all DMAs (i.e., exclosure and non-exclosure) to investigate both weather and management drivers of riparian condition while accounting for differences over time and among streams. The second model (M_2) was fit using only non-exclosure DMAs to investigate the effect of elk and bison population counts on riparian condition for both less-used and heavily-used DMAs (as defined in Table 1, (Burkhart and Kovacs, 2013)). The covariates used in each model are detailed in Table 6-1.

Table 6-1: Covariates used in the regression analyses exploring drivers of riparian condition.

Parameter	Model	Description
avg_kbdi_mo789	M ₁	Average daily Keetch-Byram drought index during July-September
precip_in_mo456	M ₁	Total precipitation observed during April-June
excl	M ₁	Whether DMA is an exclosure
stream	M ₁	Stream that DMA is located on
yr	M ₁	Year sampled
bison	M ₂	Estimated bison population count within WICA
elk	M ₂	Estimated elk population count within WICA
heavy_use	M ₂	Indicator of heavy-use at DMA

6.4 Results

6.4.1 Average Stubble Height

**Figure 6-3:** Scatterplots of DMA average stubble height versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.**Table 6-2:** Parameter estimates from the fitted gamma regression model (log link) exploring potential drivers of DMA average stubble height within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.0366	0.6936	2.94	0.0116
avg_kbdi_mo789	0.0009	0.0012	0.80	0.4375
exclTRUE	0.7164	0.2497	2.87	0.0132
precip_in_mo456	0.0013	0.0414	0.03	0.9761
streamCold Spring Creek	-0.1627	0.5083	-0.32	0.7540
streamBeaver Creek:yr	-0.0006	0.1041	-0.01	0.9952
streamCold Spring Creek:yr	-0.0574	0.0809	-0.71	0.4900

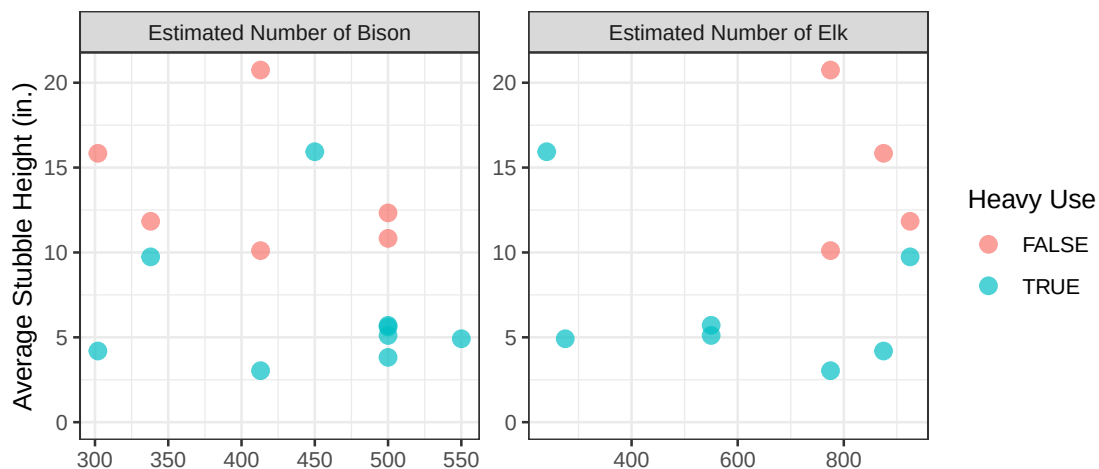


Figure 6-4: Scatterplots of non-exclosure DMA average stubble height versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-3: Parameter estimates from the fitted gamma regression model (log link) exploring potential management drivers of non-exclosure DMA average stubble height within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	5.9625	2.0548	2.90	0.0273
elk:heavy_useFALSE	-0.0028	0.0021	-1.36	0.2218
elk:heavy_useTRUE	-0.0022	0.0011	-1.98	0.0948
heavy_useFALSE:bison	-0.0025	0.0037	-0.69	0.5155
heavy_useTRUE:bison	-0.0063	0.0034	-1.88	0.1093

6.4.2 Average Greenline-Greenline Width

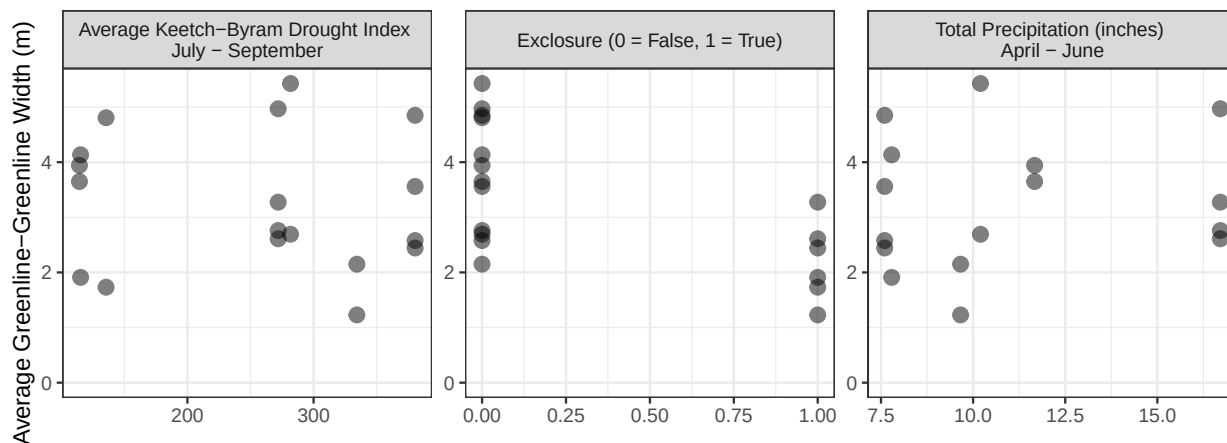


Figure 6-5: Scatterplots of DMA average greenline-greenline width versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-4: Parameter estimates from the fitted gamma regression model (log link) exploring potential drivers of DMA average greenline-greenline width within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	1.5404	0.3923	3.93	0.0035
avg_kbdi_mo789	-0.0003	0.0007	-0.46	0.6560
exclTRUE	-0.4781	0.1442	-3.31	0.0090
precip_in_mo456	-0.0081	0.0216	-0.37	0.7175
streamCold Spring Creek	0.4418	0.2645	1.67	0.1292
streamBeaver Creek:yr	-0.0108	0.0566	-0.19	0.8534
streamCold Spring Creek:yr	-0.1324	0.0416	-3.18	0.0112

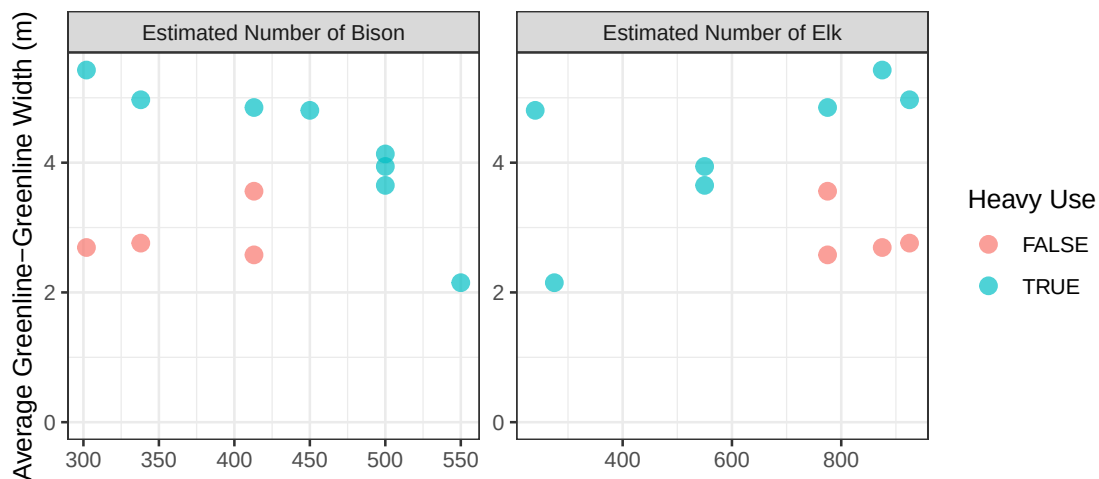


Figure 6-6: Scatterplots of DMA average greenline-greenline width versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-5: Parameter estimates from the fitted gamma regression model (log link) exploring potential management drivers of non-exclosure DMA average greenline-greenline width within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.7474	0.8824	3.11	0.0208
elk:heavy_useFALSE	-0.0016	0.0009	-1.84	0.1159
elk:heavy_useTRUE	-0.0001	0.0005	-0.19	0.8579
heavy_useFALSE:bison	-0.0009	0.0016	-0.55	0.6014
heavy_useTRUE:bison	-0.0029	0.0014	-2.01	0.0911

6.4.3 Dominant Species Average Stubble Height

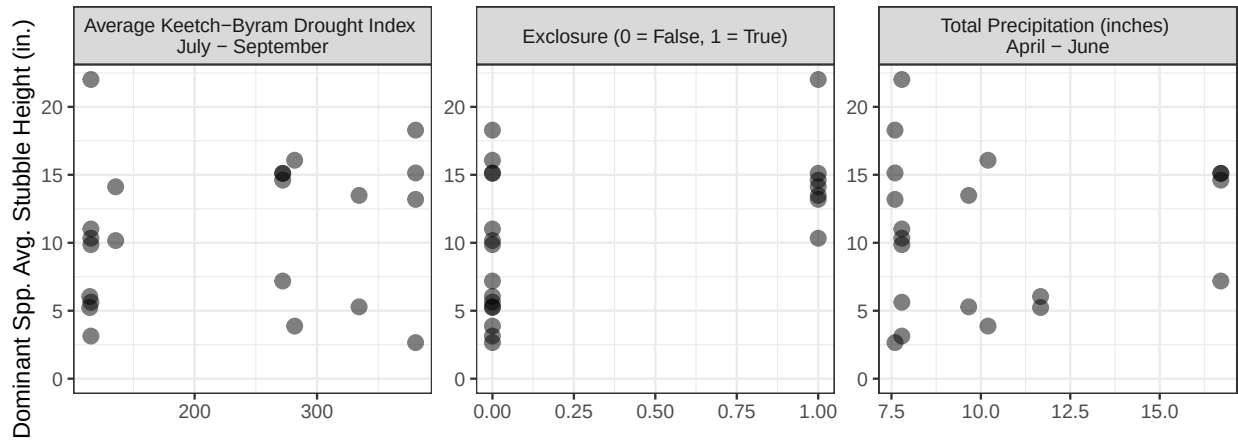


Figure 6-7: Scatterplots of DMA dominant species average stubble height versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-6: Parameter estimates from the fitted gamma regression model (log link) exploring potential drivers of DMA dominant species average stubble height within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.1397	0.6861	3.12	0.0081
avg_kbdi_mo789	0.0009	0.0011	0.77	0.4556
exclTRUE	0.6264	0.2470	2.54	0.0248
precip_in_mo456	0.0016	0.0409	0.04	0.9703
streamCold Spring Creek	-0.3537	0.5028	-0.70	0.4941
streamBeaver Creek:yr	-0.0380	0.1029	-0.37	0.7180
streamCold Spring Creek:yr	-0.0333	0.0800	-0.42	0.6839

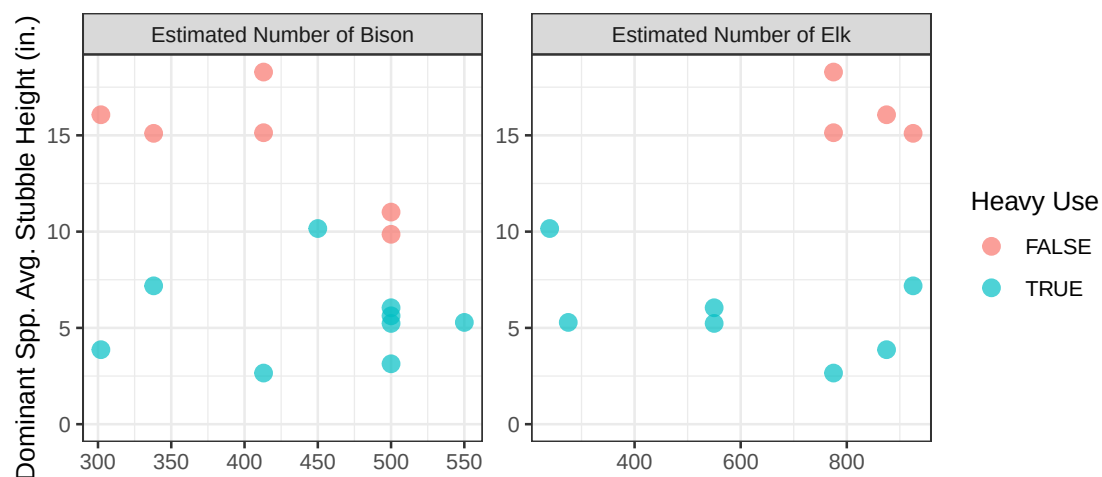


Figure 6-8: Scatterplots of DMA dominant species average stubble height versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-7: Parameter estimates from the fitted gamma regression model (log link) exploring potential management drivers of non-exclosure DMA dominant species average stubble height within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	3.8307	1.5175	2.52	0.0450
elk:heavy_useFALSE	-0.0010	0.0015	-0.65	0.5370
elk:heavy_useTRUE	-0.0014	0.0008	-1.70	0.1410
heavy_useFALSE:bison	-0.0006	0.0027	-0.22	0.8369
heavy_useTRUE:bison	-0.0029	0.0025	-1.16	0.2887

6.4.4 Diversity Index

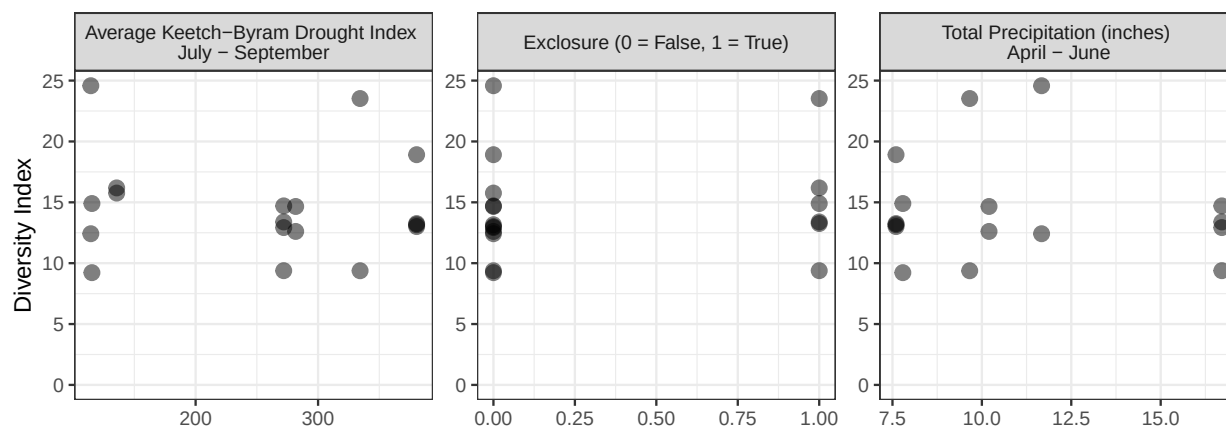


Figure 6-9: Scatterplots of DMA diversity index versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-8: Parameter estimates from the fitted gamma regression model (log link) exploring potential drivers of DMA diversity index within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.4161	0.4732	5.11	0.0006
avg_kbdi_mo789	-0.0002	0.0009	-0.25	0.8057
exclTRUE	0.1007	0.1740	0.58	0.5771
precip_in_mo456	0.0100	0.0261	0.38	0.7105
streamCold Spring Creek	-0.1067	0.3191	-0.33	0.7458
streamBeaver Creek:yr	0.1031	0.0683	1.51	0.1654
streamCold Spring Creek:yr	0.0420	0.0502	0.84	0.4247

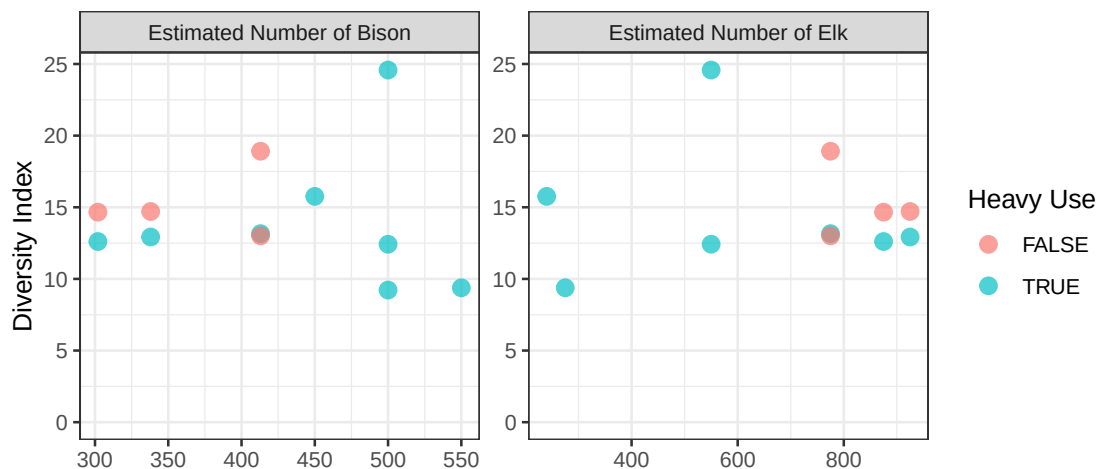


Figure 6-10: Scatterplots of DMA diversity index versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-9: Parameter estimates from the fitted gamma regression model (log link) exploring potential management drivers of non-exclosure DMA diversity index within WICA.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	2.1475	1.5190	1.41	0.2072
elk:heavy_useFALSE	0.0002	0.0015	0.13	0.9015
elk:heavy_useTRUE	0.0002	0.0008	0.20	0.8502
heavy_useFALSE:bison	0.0011	0.0027	0.42	0.6905
heavy_useTRUE:bison	0.0010	0.0025	0.39	0.7121

6.4.5 Streambank Cover

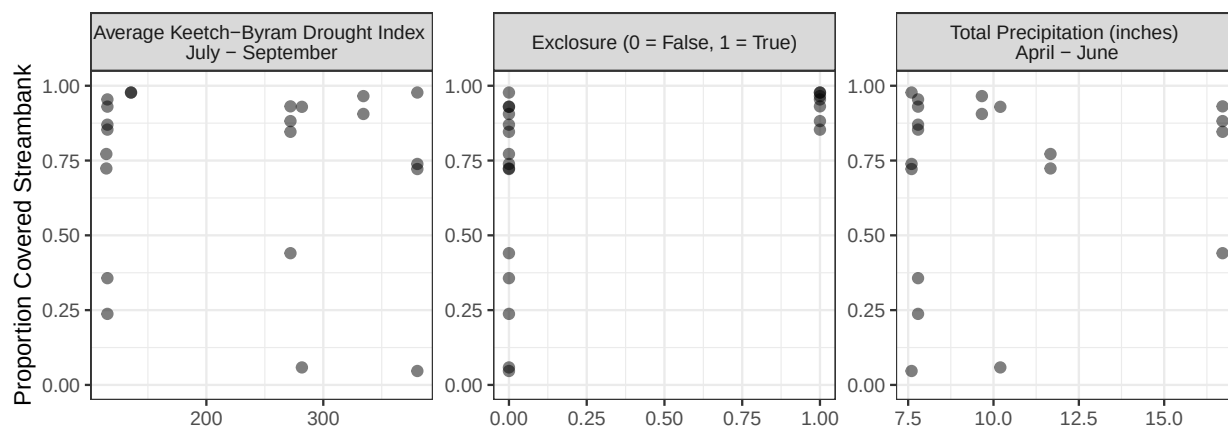


Figure 6-11: Scatterplots of DMA streambank cover versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-10: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA streambank cover within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-0.9405	1.4076	-0.67	0.5167
avg_kbdi_mo789	-0.0010	0.0024	-0.41	0.6874
exclTRUE	1.3012	0.5319	2.45	0.0308
precip_in_mo456	0.1060	0.0852	1.24	0.2373
streamCold Spring Creek	-0.8905	1.0375	-0.86	0.4076
streamBeaver Creek:yr	0.1908	0.2110	0.90	0.3837
streamCold Spring Creek:yr	0.2609	0.1680	1.55	0.1463

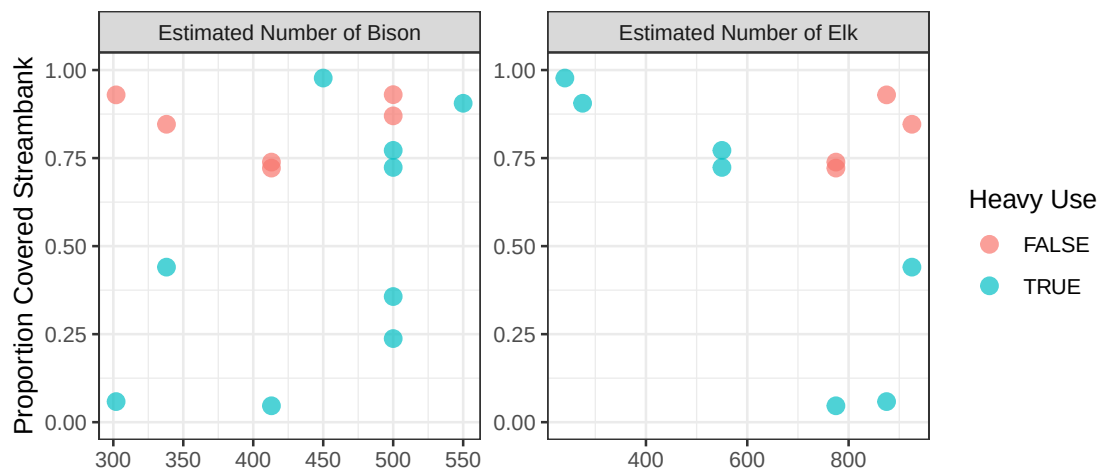


Figure 6-12: Scatterplots of DMA streambank cover versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-11: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA streambank cover within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	3.7715	3.7740	1.00	0.3635
elk:heavy_useFALSE	0.0008	0.0036	0.22	0.8354
elk:heavy_useTRUE	-0.0067	0.0022	-3.07	0.0277
heavy_useFALSE:bison	-0.0085	0.0063	-1.35	0.2338
heavy_useTRUE:bison	0.0009	0.0060	0.15	0.8859

6.4.6 Streambank Stability

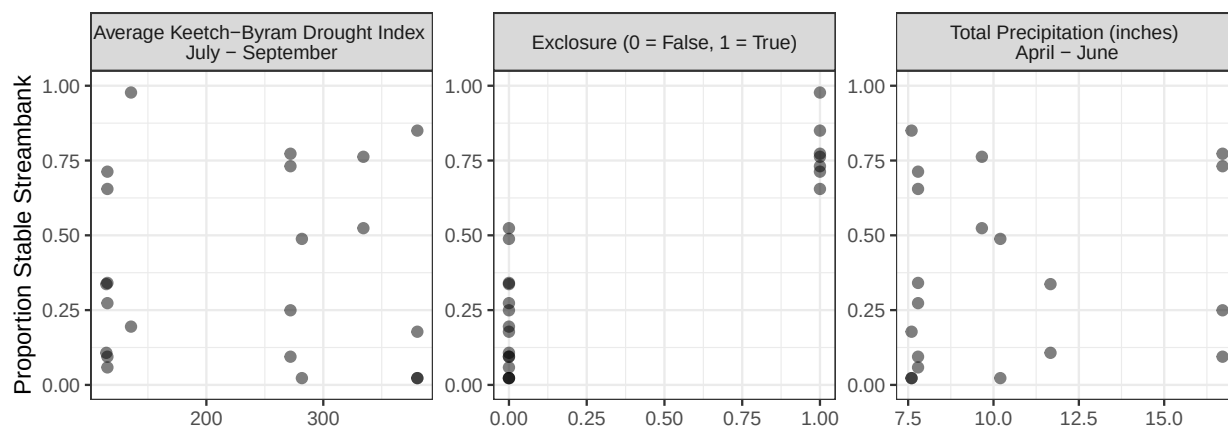


Figure 6-13: Scatterplots of DMA streambank stability versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-12: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA streambank stability within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-2.2026	1.0364	-2.13	0.0550
avg_kbdi_mo789	-0.0009	0.0017	-0.50	0.6250
exclTRUE	2.4689	0.3758	6.57	0.0000
precip_in_mo456	0.0806	0.0604	1.33	0.2069
streamCold Spring Creek	-0.9914	0.7580	-1.31	0.2154
streamBeaver Creek:yr	0.0182	0.1570	0.12	0.9098
streamCold Spring Creek:yr	0.2784	0.1193	2.33	0.0378

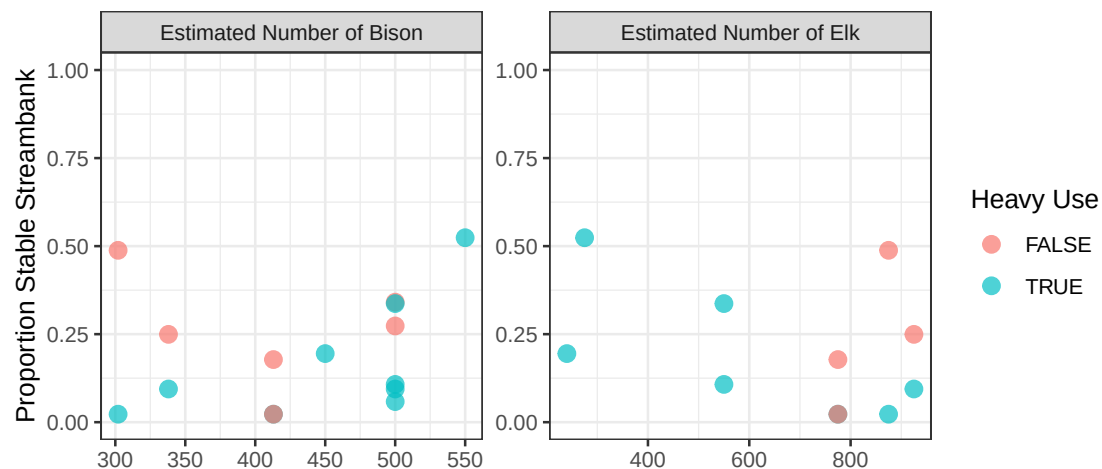


Figure 6-14: Scatterplots of DMA streambank stability versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-13: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA streambank stability within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-3.3798	2.6187	-1.29	0.2533
elk:heavy_useFALSE	0.0070	0.0027	2.55	0.0514
elk:heavy_useTRUE	-0.0021	0.0014	-1.50	0.1938
heavy_useFALSE:bison	-0.0106	0.0051	-2.08	0.0916
heavy_useTRUE:bison	0.0066	0.0045	1.48	0.2001

6.4.7 Percent Hydric Herbaceous

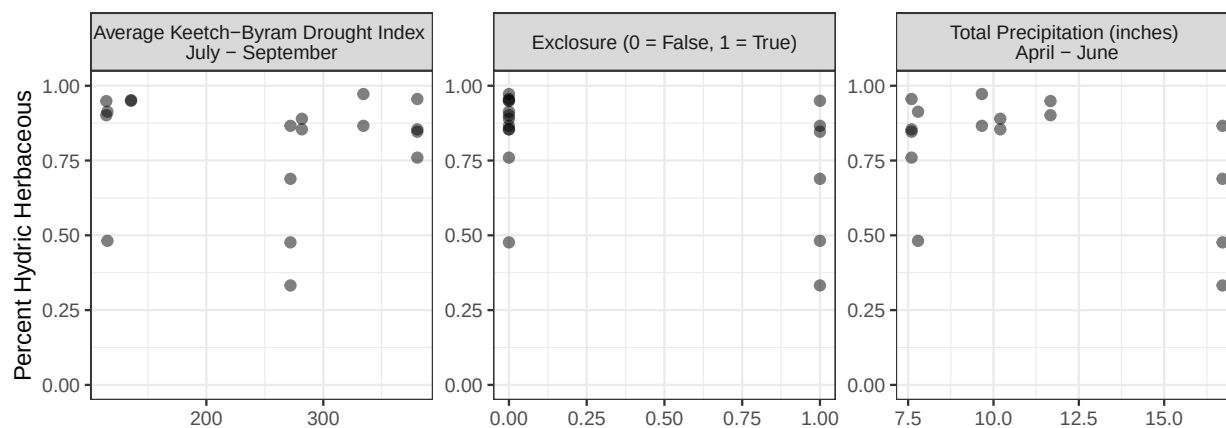


Figure 6-15: Scatterplots of DMA percent hydric herbaceous species versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-14: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA percent hydric herbaceous species within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	2.1074	0.6444	3.27	0.0113
avg_kbdi_mo789	-0.0007	0.0014	-0.52	0.6197
exclTRUE	-1.0731	0.2286	-4.69	0.0016
precip_in_mo456	-0.0118	0.0362	-0.33	0.7531
streamCold Spring Creek	-2.0011	0.4051	-4.94	0.0011
streamBeaver Creek:yr	0.1551	0.1148	1.35	0.2135
streamCold Spring Creek:yr	0.4031	0.0774	5.21	0.0008

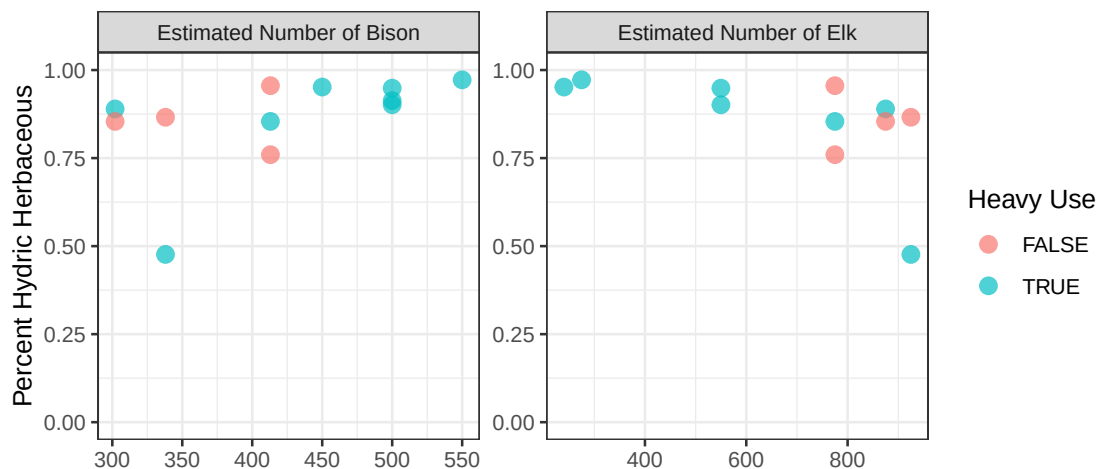


Figure 6-16: Scatterplots of DMA percent hydric herbaceous species versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-15: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA percent hydric herbaceous species within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	4.5567	3.3219	1.37	0.2285
elk:heavy_useFALSE	-0.0028	0.0031	-0.91	0.4057
elk:heavy_useTRUE	-0.0036	0.0019	-1.87	0.1203
heavy_useFALSE:bison	-0.0011	0.0054	-0.20	0.8480
heavy_useTRUE:bison	-0.0010	0.0052	-0.19	0.8539

6.4.8 Percent Woody Composition

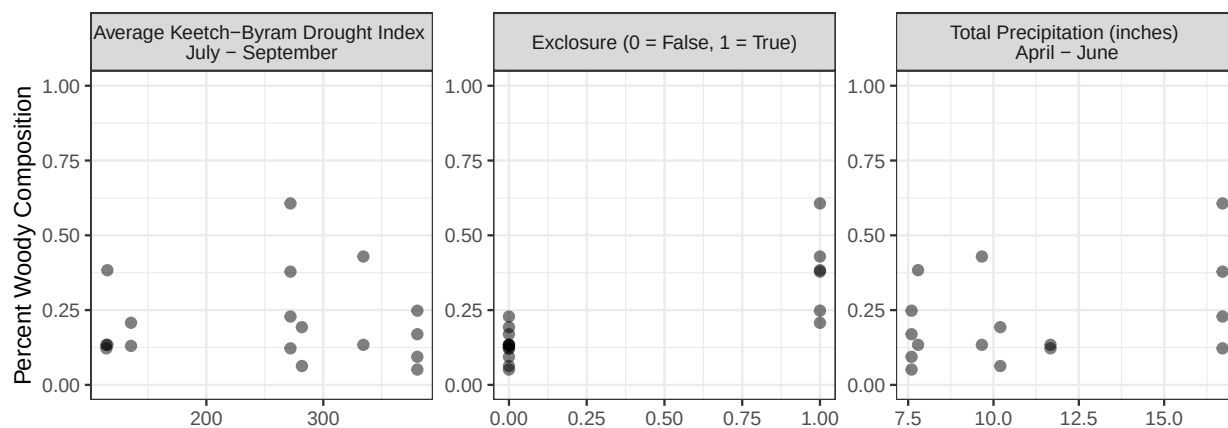


Figure 6-17: Scatterplots of DMA percent woody composition versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-16: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA percent woody composition within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-2.9629	0.4477	-6.62	0.0002
avg_kbdi_mo789	0.0005	0.0009	0.61	0.5590
exclTRUE	1.3797	0.1495	9.23	0.0000
precip_in_mo456	0.0589	0.0242	2.43	0.0409
streamCold Spring Creek	0.7785	0.2796	2.78	0.0238
streamBeaver Creek:yr	0.0241	0.0778	0.31	0.7644
streamCold Spring Creek:yr	-0.0426	0.0438	-0.97	0.3590

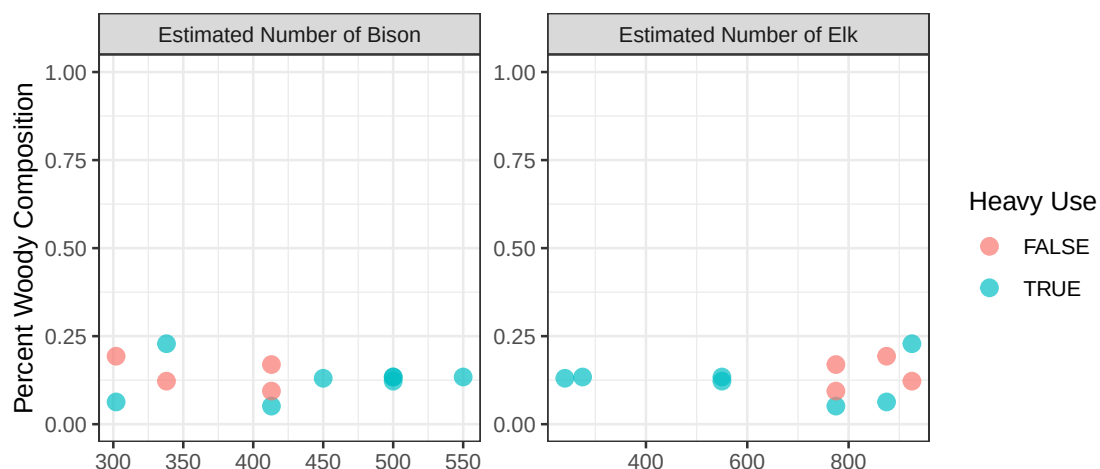


Figure 6-18: Scatterplots of DMA percent woody composition versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-17: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA percent woody composition within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1.7195	1.8718	-0.92	0.4004
elk:heavy_useFALSE	0.0007	0.0018	0.37	0.7259
elk:heavy_useTRUE	-0.0004	0.0010	-0.44	0.6813
heavy_useFALSE:bison	-0.0017	0.0033	-0.51	0.6296
heavy_useTRUE:bison	0.0000	0.0031	0.00	0.9991

6.4.9 Streambank Alteration

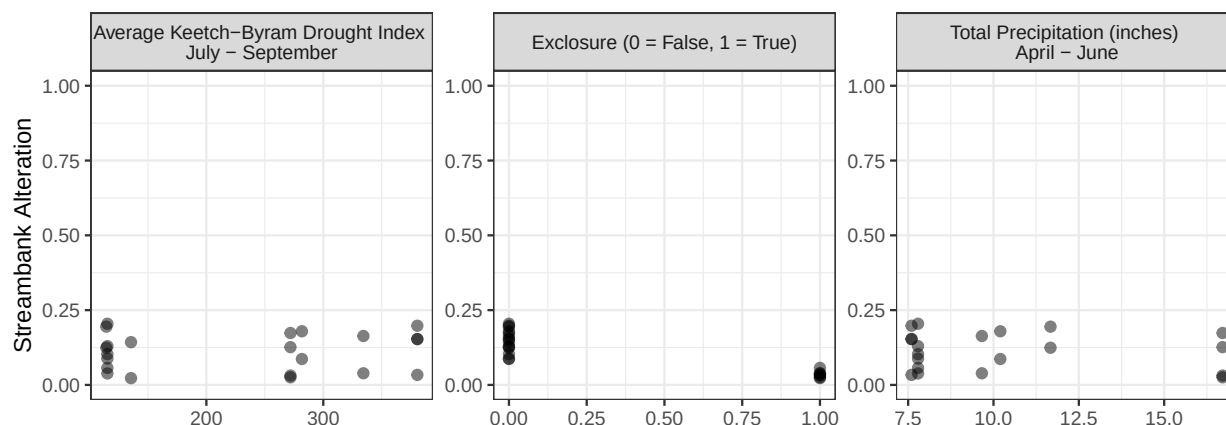


Figure 6-19: Scatterplots of DMA streambank alteration versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-18: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA streambank alteration within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1.7218	0.3038	-5.67	0.0001
avg_kbdi_mo789	0.0008	0.0005	1.65	0.1246
exclTRUE	-1.5490	0.1575	-9.84	0.0000
precip_in_mo456	-0.0346	0.0199	-1.74	0.1073
streamCold Spring Creek	0.6321	0.2360	2.68	0.0201
streamBeaver Creek:yr	-0.0097	0.0444	-0.22	0.8310
streamCold Spring Creek:yr	-0.0425	0.0369	-1.15	0.2726

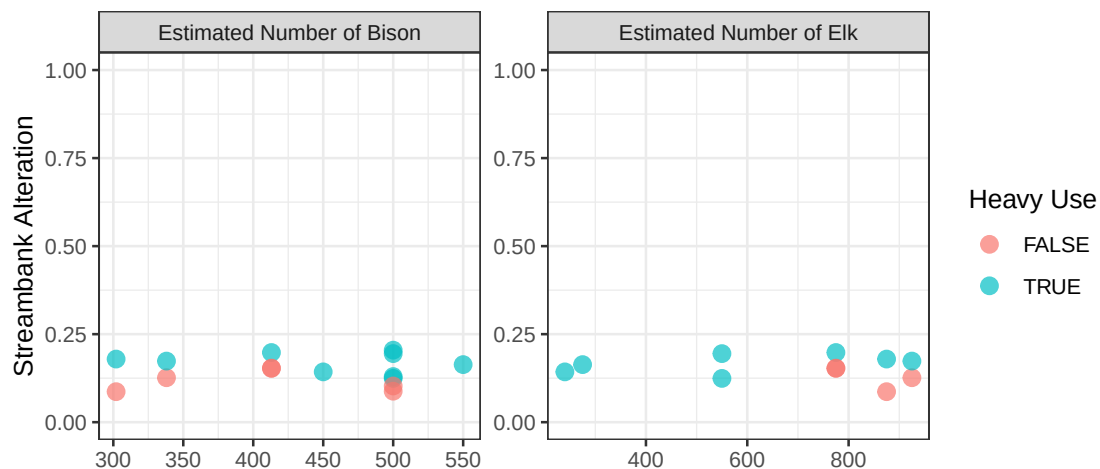


Figure 6-20: Scatterplots of DMA streambank alteration versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-19: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA streambank alteration within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-2.2131	0.6695	-3.31	0.0213
elk:heavy_useFALSE	-0.0011	0.0007	-1.54	0.1849
elk:heavy_useTRUE	0.0005	0.0004	1.46	0.2034
heavy_useFALSE:bison	0.0033	0.0013	2.61	0.0479
heavy_useTRUE:bison	0.0007	0.0011	0.60	0.5734

6.4.10 Modified Winward Greenline Stability Rating

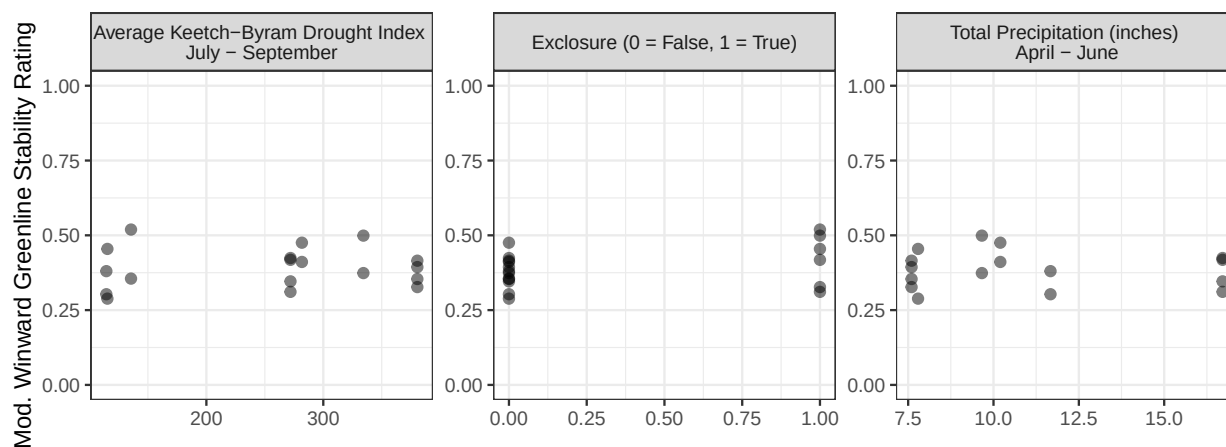


Figure 6-21: Scatterplots of DMA modified Winward greenline stability rating versus the three co-variates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-20: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA modified Winward greenline stability rating within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-0.4412	0.3570	-1.24	0.2515
avg_kbdi_mo789	0.0004	0.0007	0.63	0.5478
exclTRUE	0.0924	0.1310	0.71	0.5007
precip_in_mo456	-0.0056	0.0197	-0.29	0.7829
streamCold Spring Creek	-0.1968	0.2415	-0.81	0.4387
streamBeaver Creek:yr	-0.0508	0.0520	-0.98	0.3575
streamCold Spring Creek:yr	0.0204	0.0379	0.54	0.6053

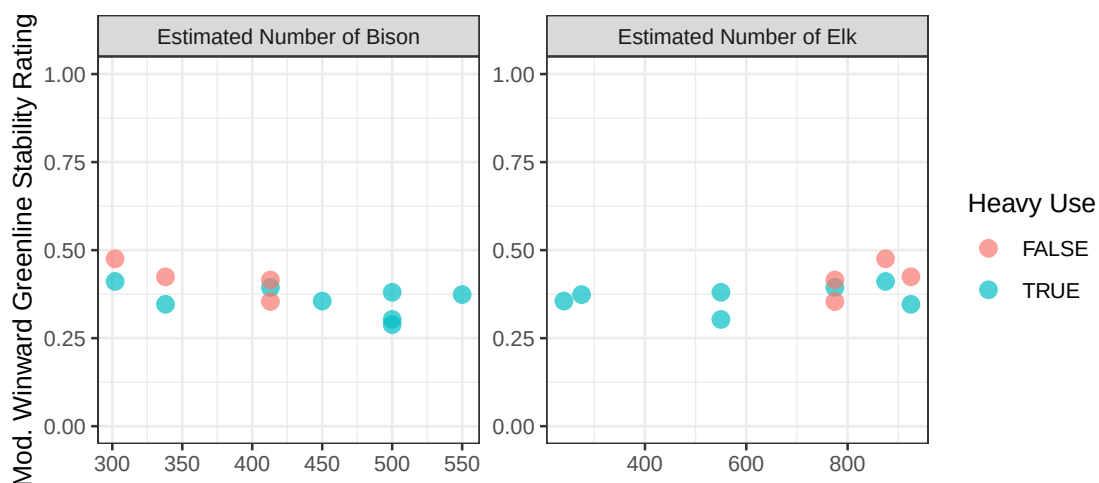


Figure 6-22: Scatterplots of DMA modified Winward greenline stability rating versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-21: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA modified Winward greenline stability rating within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-0.0011	0.5619	-0.00	0.9986
elk:heavy_useFALSE	0.0006	0.0006	1.01	0.3585
elk:heavy_useTRUE	-0.0002	0.0003	-0.49	0.6426
heavy_useFALSE:bison	-0.0022	0.0010	-2.23	0.0765
heavy_useTRUE:bison	-0.0010	0.0009	-1.13	0.3082

6.4.11 Wetland Rating

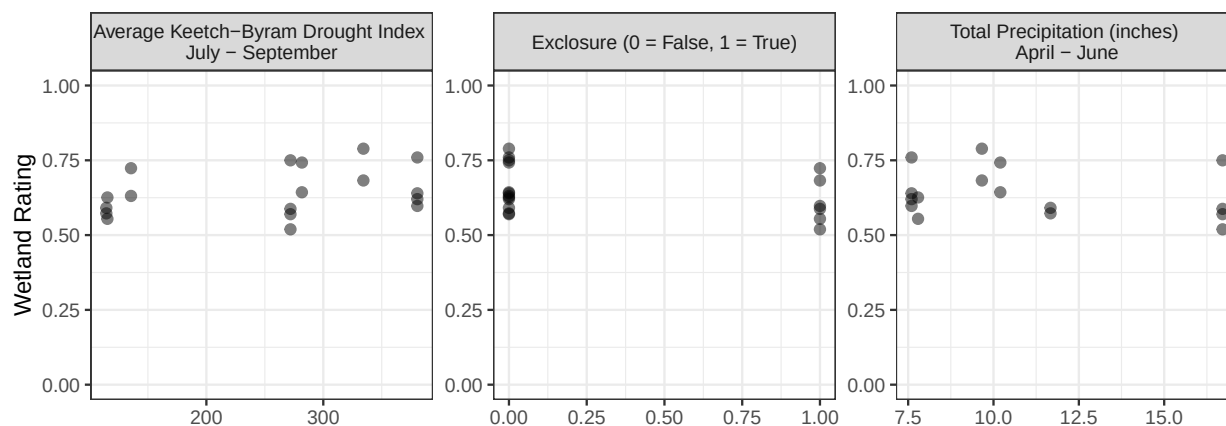


Figure 6-23: Scatterplots of DMA wetland rating versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-22: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA wetland rating within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.4488	0.2783	1.61	0.1455
avg_kbdi_mo789	0.0012	0.0005	2.38	0.0447
exclTRUE	-0.3460	0.1012	-3.42	0.0091
precip_in_mo456	0.0063	0.0152	0.42	0.6876
streamCold Spring Creek	-0.6429	0.1855	-3.47	0.0085
streamBeaver Creek:yr	-0.0750	0.0403	-1.86	0.0996
streamCold Spring Creek:yr	0.1115	0.0301	3.70	0.0060

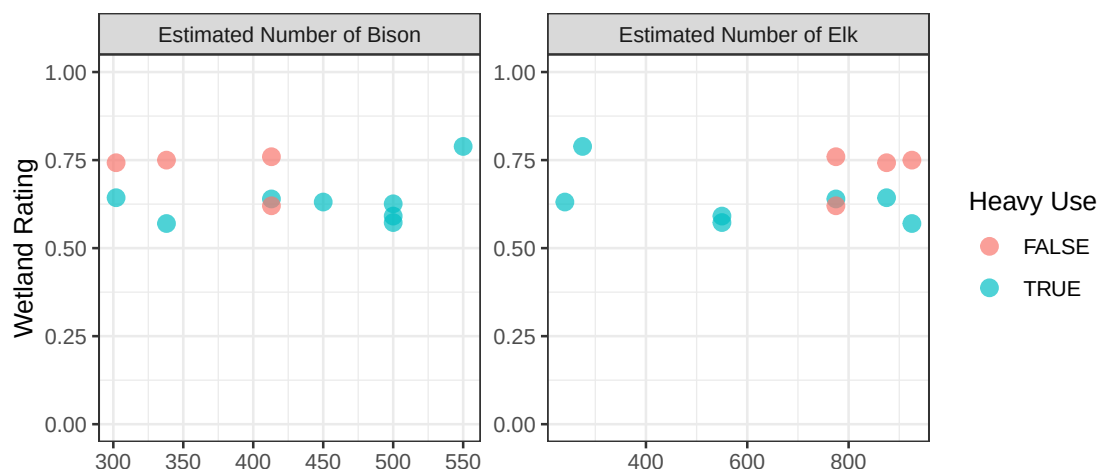


Figure 6-24: Scatterplots of DMA wetland rating versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-23: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA wetland rating within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.9527	1.1817	0.81	0.4568
elk:heavy_useFALSE	0.0007	0.0012	0.60	0.5761
elk:heavy_useTRUE	-0.0006	0.0006	-0.98	0.3713
heavy_useFALSE:bison	-0.0017	0.0022	-0.79	0.4674
heavy_useTRUE:bison	-0.0000	0.0019	-0.02	0.9849

6.4.12 Ecological Status

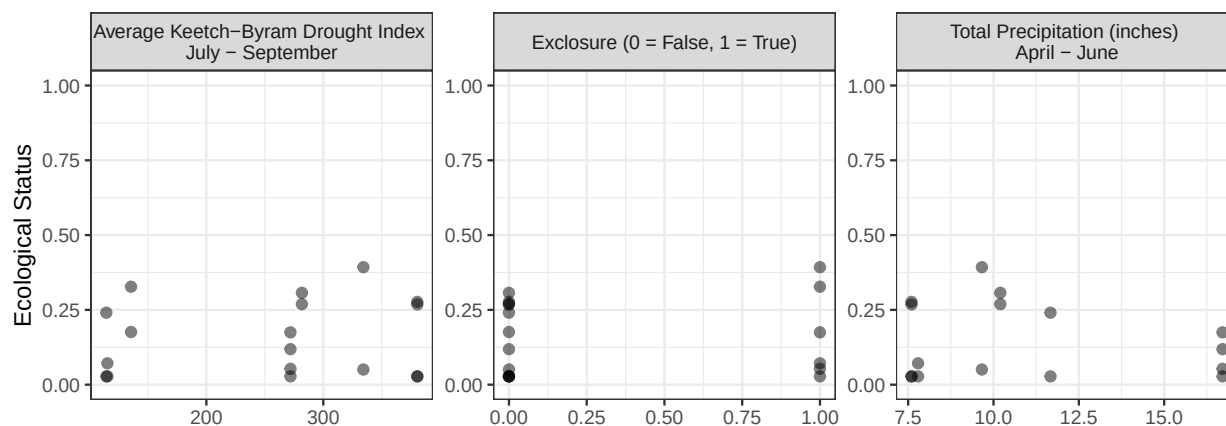


Figure 6-25: Scatterplots of DMA ecological status versus the three covariates representing potential drivers of riparian condition in WICA during 2009-2019.

Table 6-24: Parameter estimates from the fitted beta regression model (logit link) exploring potential drivers of DMA ecological status within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1.7317	1.2732	-1.36	0.2109
avg_kbdi_mo789	0.0017	0.0025	0.68	0.5164
exclTRUE	-0.0324	0.4674	-0.07	0.9465
precip_in_mo456	-0.0242	0.0707	-0.34	0.7410
streamCold Spring Creek	-0.1050	0.8546	-0.12	0.9052
streamBeaver Creek:yr	-0.1047	0.1857	-0.56	0.5883
streamCold Spring Creek:yr	-0.0262	0.1354	-0.19	0.8516

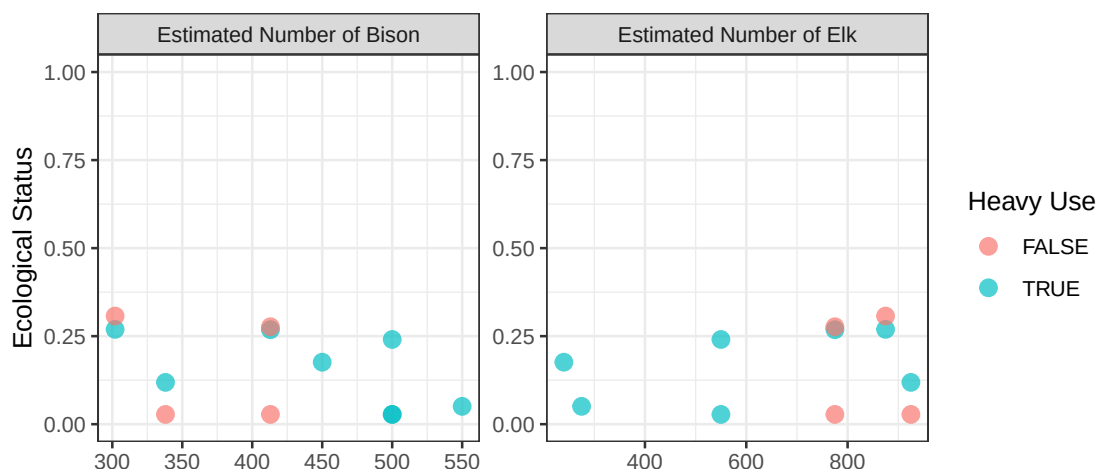


Figure 6-26: Scatterplots of DMA ecological status versus park-wide estimated bison and elk population counts within WICA during 2009-2019. Heavy use DMAs include Beaver Creek 1 and Cold Spring Creek 1.

Table 6-25: Parameter estimates from the fitted beta regression model (logit link) exploring potential management drivers of non-exclosure DMA ecological status within WICA.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	2.7466	3.1473	0.87	0.4227
elk:heavy_useFALSE	-0.0027	0.0033	-0.82	0.4479
elk:heavy_useTRUE	-0.0013	0.0017	-0.78	0.4699
heavy_useFALSE:bison	-0.0064	0.0060	-1.07	0.3342
heavy_useTRUE:bison	-0.0082	0.0053	-1.55	0.1822

6.5 Discussion

For model M_1 , the enclosure covariate was the primary parameter found to be statistically different from zero for a majority of metrics. These differences also tend to be readily apparent and corroborated by graphical comparisons of enclosure versus non-exclosure values. Due to the limited amount of data available to fit the regressions ($n \leq 22$), each of the estimated parameters should be viewed as exploratory while keeping the following in mind: (1) the true underlying process driving riparian condition is likely a complex process. A limited number of variables were included in the analysis due to data availability. Therefore if estimated effects don't match a priori expectations (particularly in the sign of the relationship), this may be due to what is known as omitted variable bias. When this occurs, the model can attribute the effect of missing variables to those that were included, resulting in biased estimates; (2) the variables representing potential drivers have been aggregated to some degree (e.g., weather variables averaged or summed over several months). The time scale that is pertinent for the relevant ecological processes that are driving condition may be mismatched, resulting in incorrect inferences or the absence of any effects; (3) limited data makes it hard to detect underlying signals, particularly when the signal to noise ratio is low. (4) relationships may be non-linear and limited data prevents the use of more sophisticated regression methods better equipped to model

such non-linearities; (5) processes could have lagged effects wherein conditions one year influence those in subsequent years. Results are therefore meant to be exploratory in nature and used to guide the identification of potential drivers that may be worth exploring further once additional data can be assembled. An additional note regarding interpretation is that all relationships can only be regarded as associations, despite the fact that 'drivers' tends to imply causation.

For M_2 , there was a single estimated parameter found to be statistically different from zero: elk population count within heavy use DMAs for the streambank cover indicator. It is estimated that increased elk population counts within heavy use DMAs is associated with decreased streambank cover. The plot of this relationship in Figure 6-12 corroborates this estimated relationship. Similar to the M_1 model, all results should be treated as exploratory in nature (see previous paragraph for potential caveats of the estimated effects). Of particular importance is that several relationships are based on extremely limited data (e.g., $n = 4$ for heavy use estimates).

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7 Appendix

7.1 Conditional Response Distributions

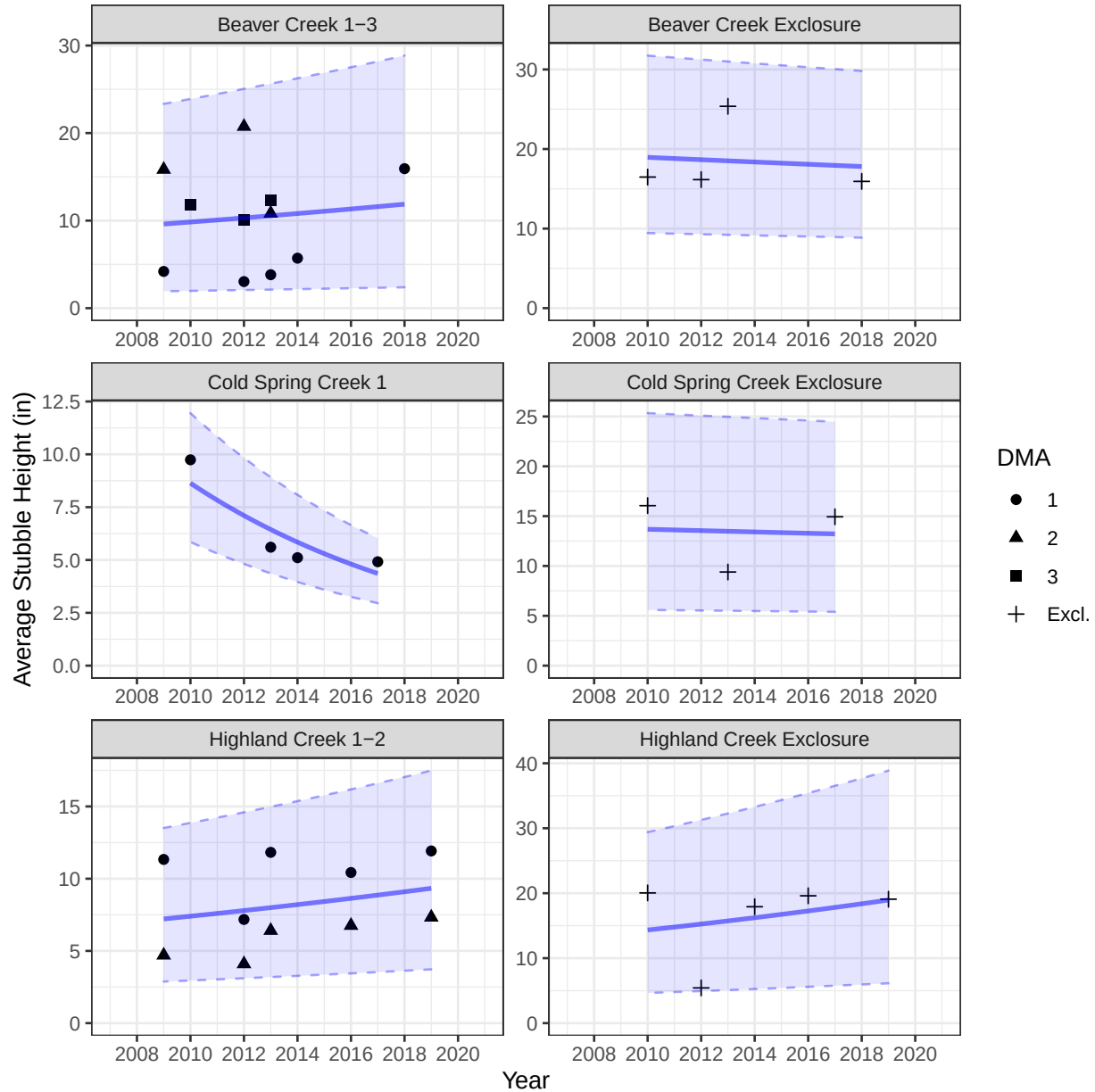


Figure 7-1: Average stubble height for each sampled DMA (black dots) within WICA. Conditional mean of average stubble height as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines.

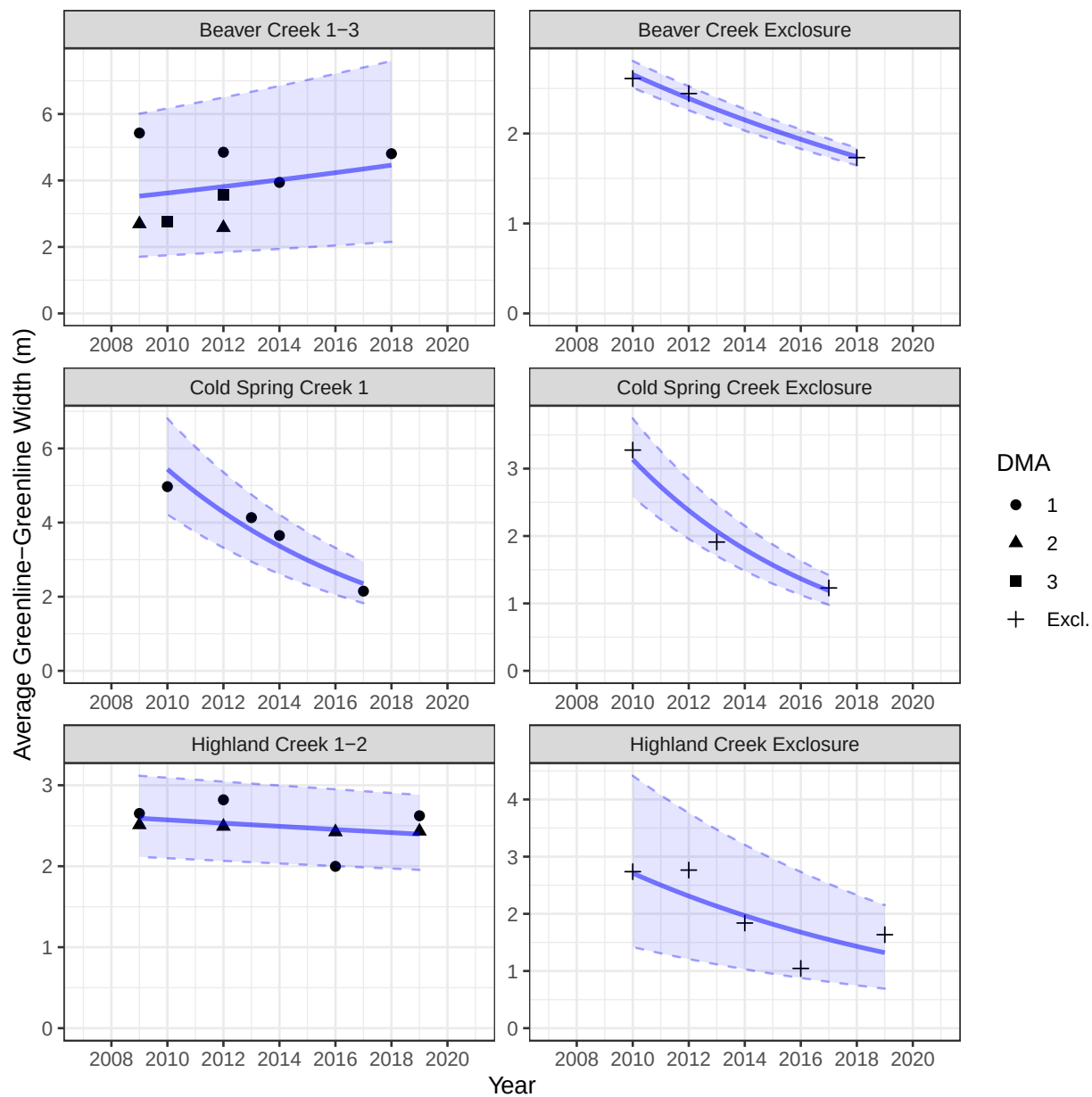


Figure 7-2: Average greenline-greenline width for each sampled DMA (black dots) within WICA. Conditional mean of average greenline-greenline width as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines.

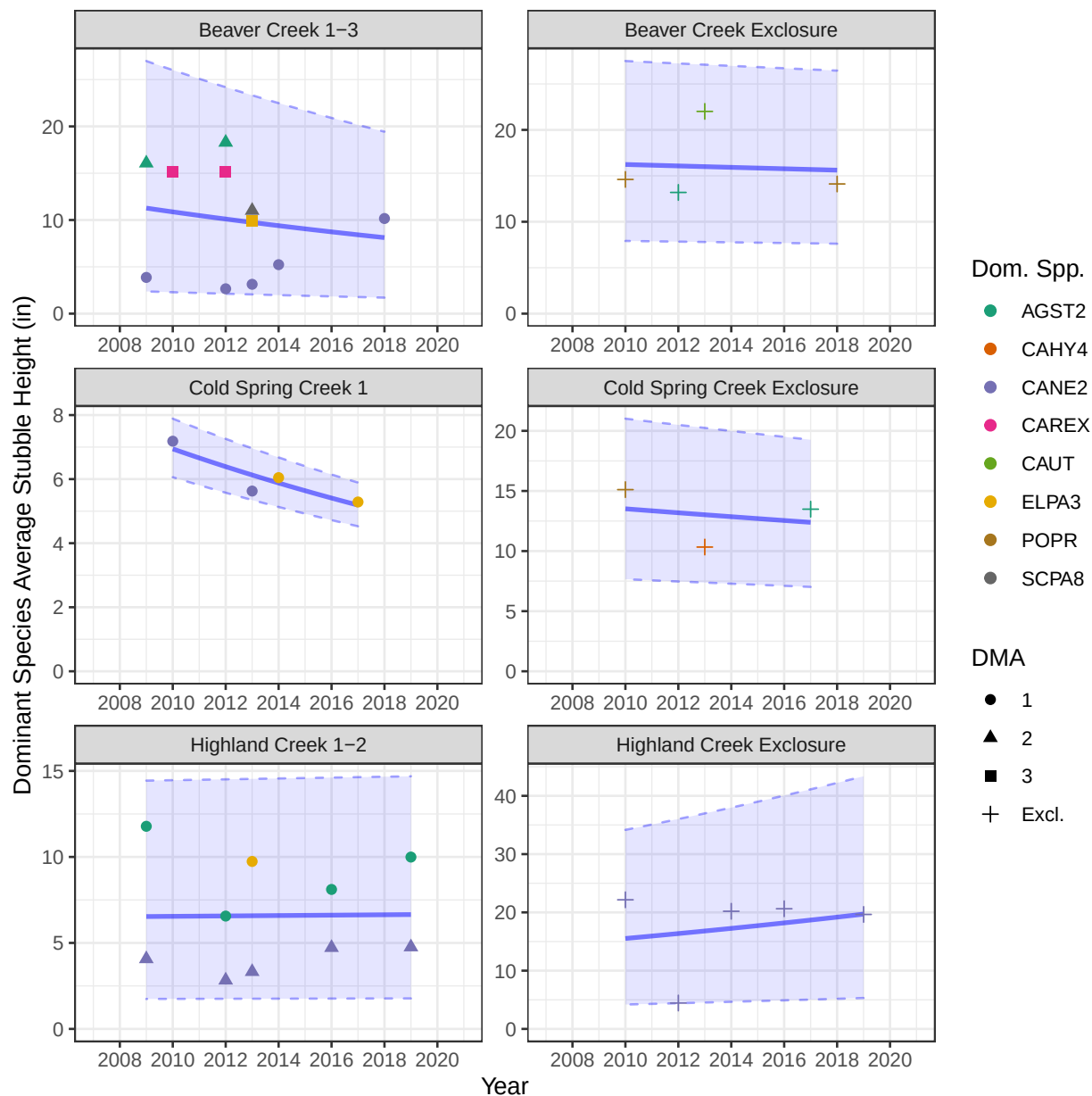


Figure 7-3: Average dominant species stubble height for each sampled DMA (black dots) within WICA. Conditional mean of average dominant species stubble height as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines.

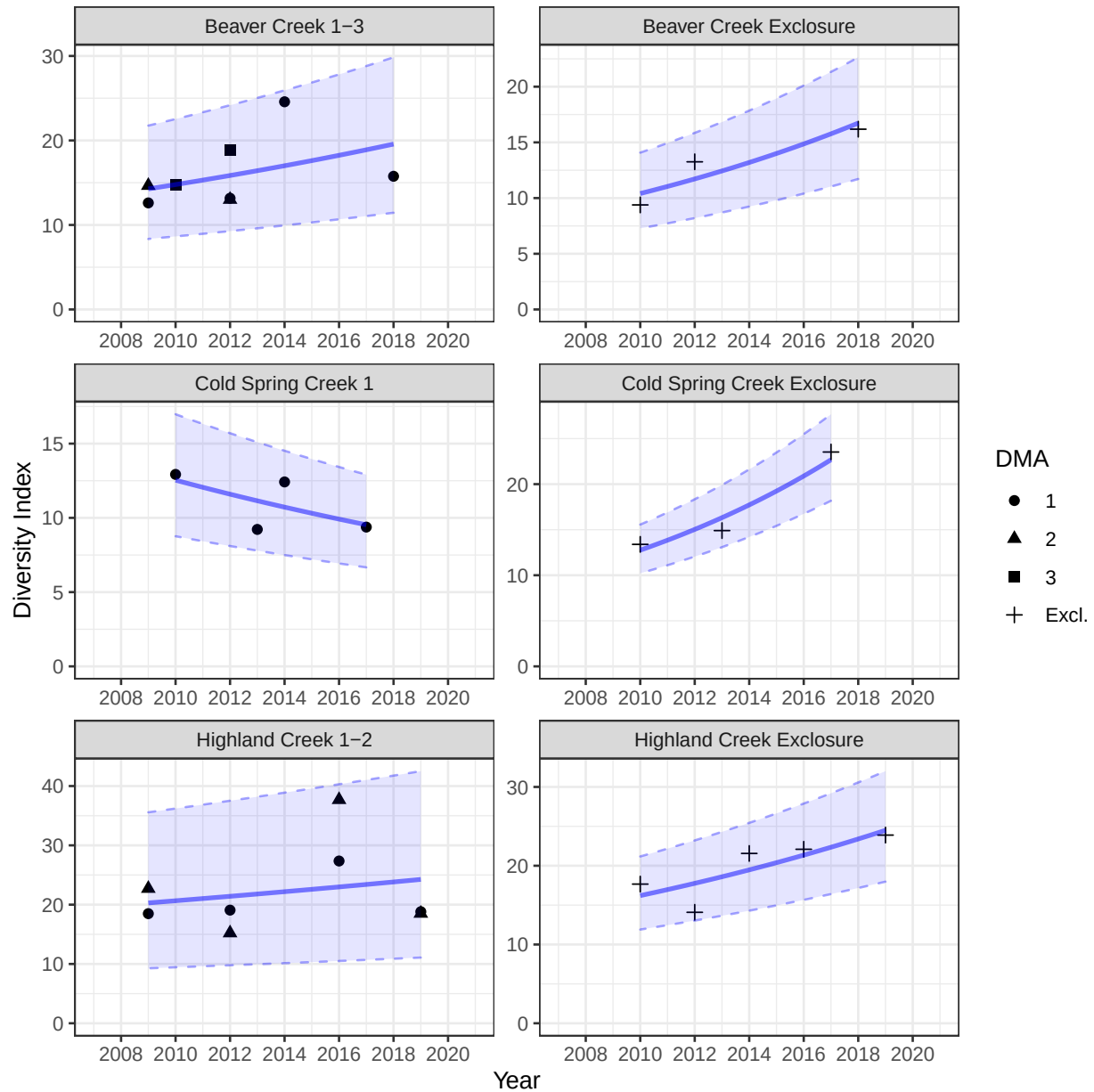


Figure 7-4: Plant diversity index for each sampled DMA (black dots) within WICA. Conditional mean of plant diversity index as a function of year plotted in blue with 95% interval of the conditional gamma distribution of the response shaded in light blue and bound by dashed lines.

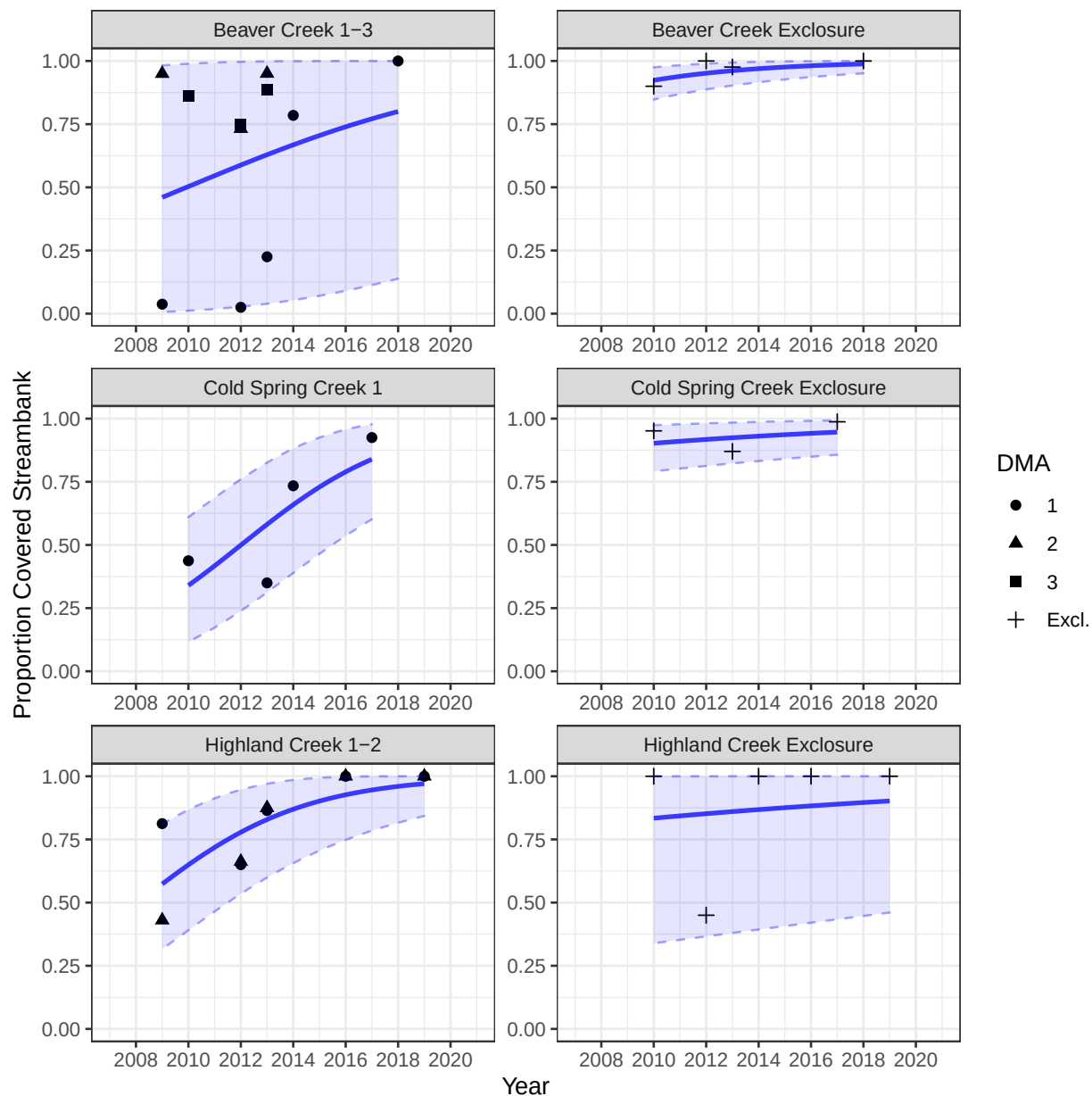


Figure 7-5: Percent plots containing covered streambank for each sampled DMA (black dots) within WICA. Conditional mean of percent plots containing covered streambank as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

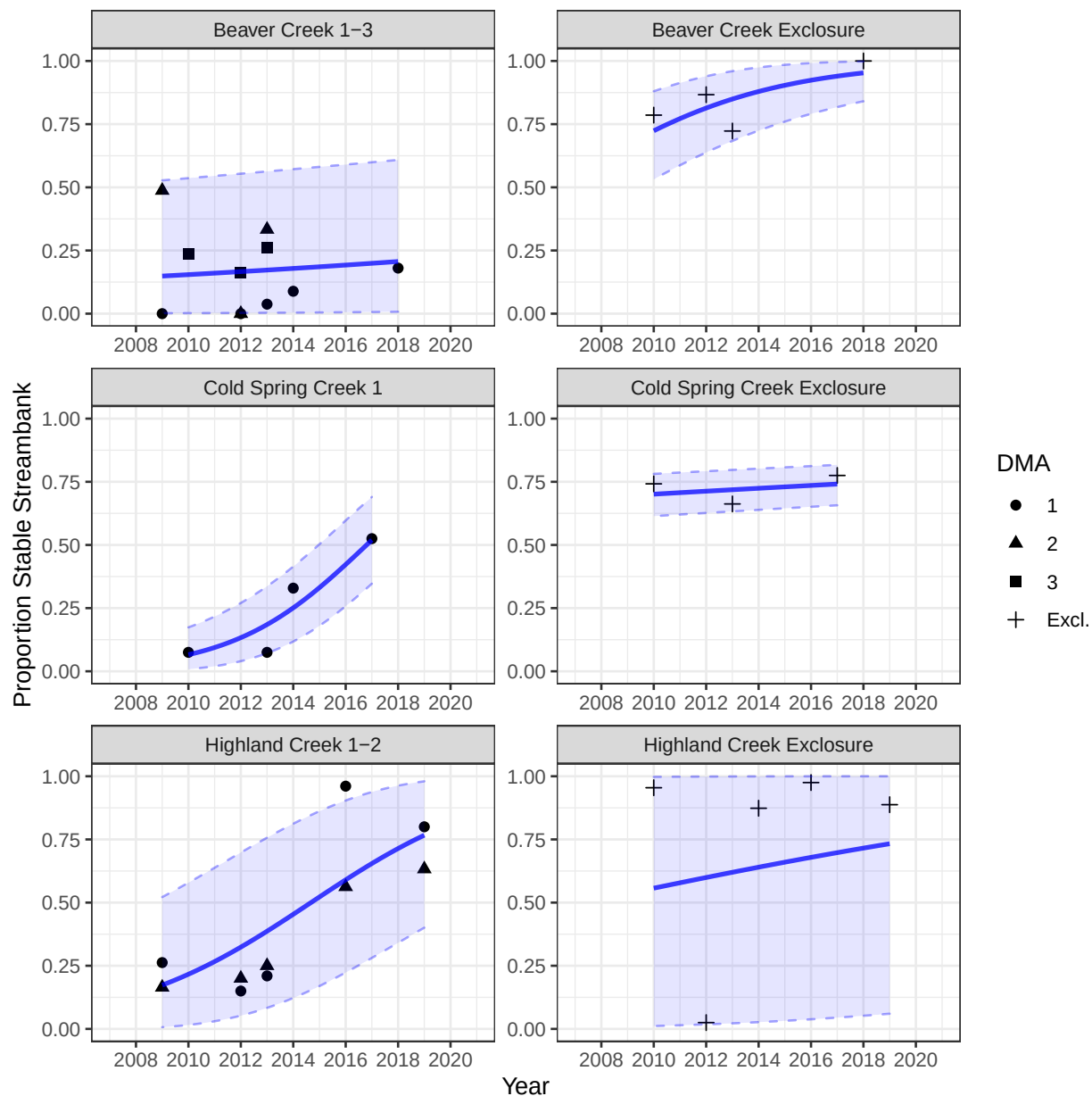


Figure 7-6: Percent plots containing stable streambank for each sampled DMA (black dots) within WICA. Conditional mean of percent plots containing stable streambank as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

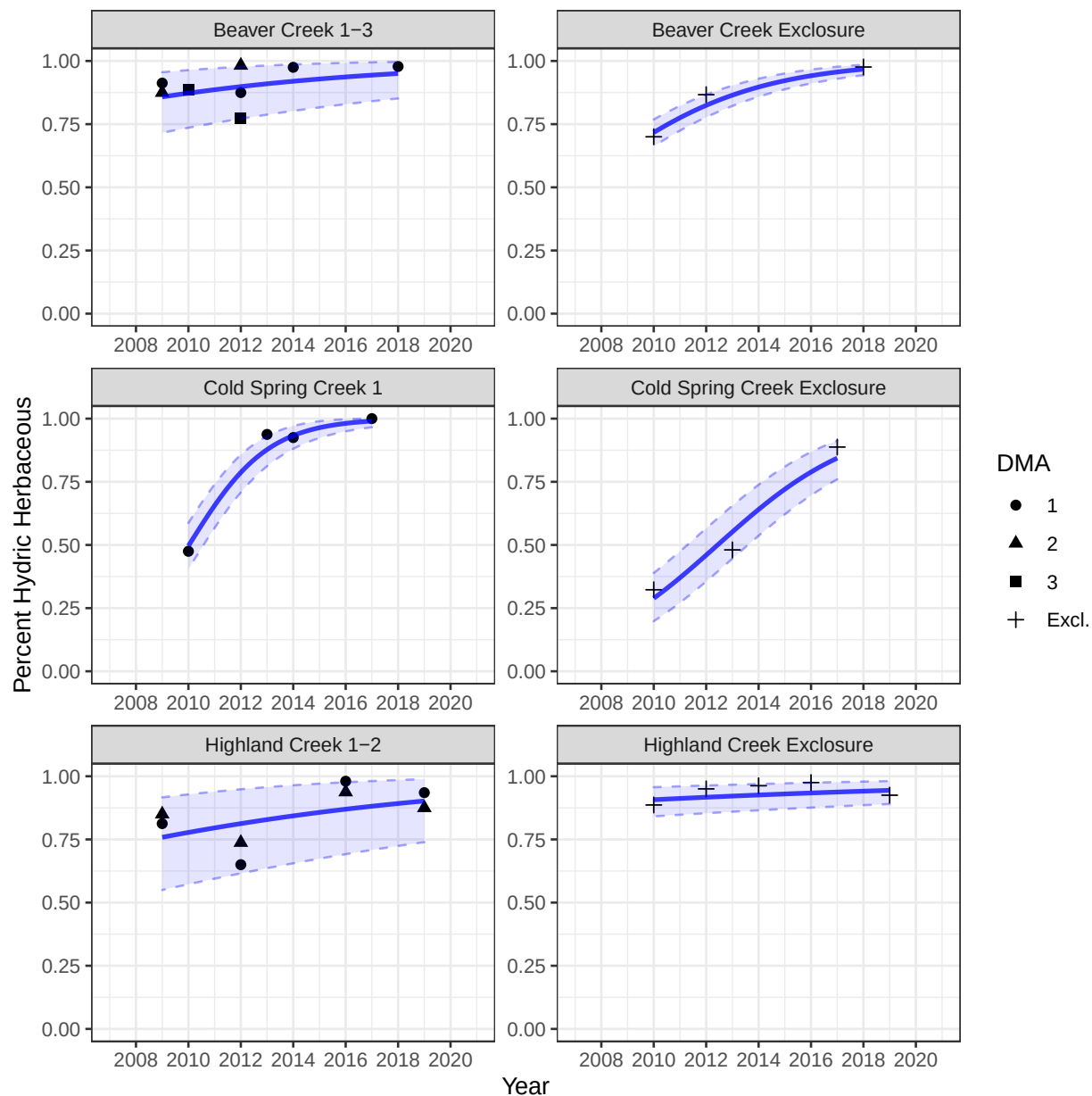


Figure 7-7: Percent plots containing hydric herbaceous species for each sampled DMA (black dots) within WICA. Conditional mean of percent plots containing hydric herbaceous species as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

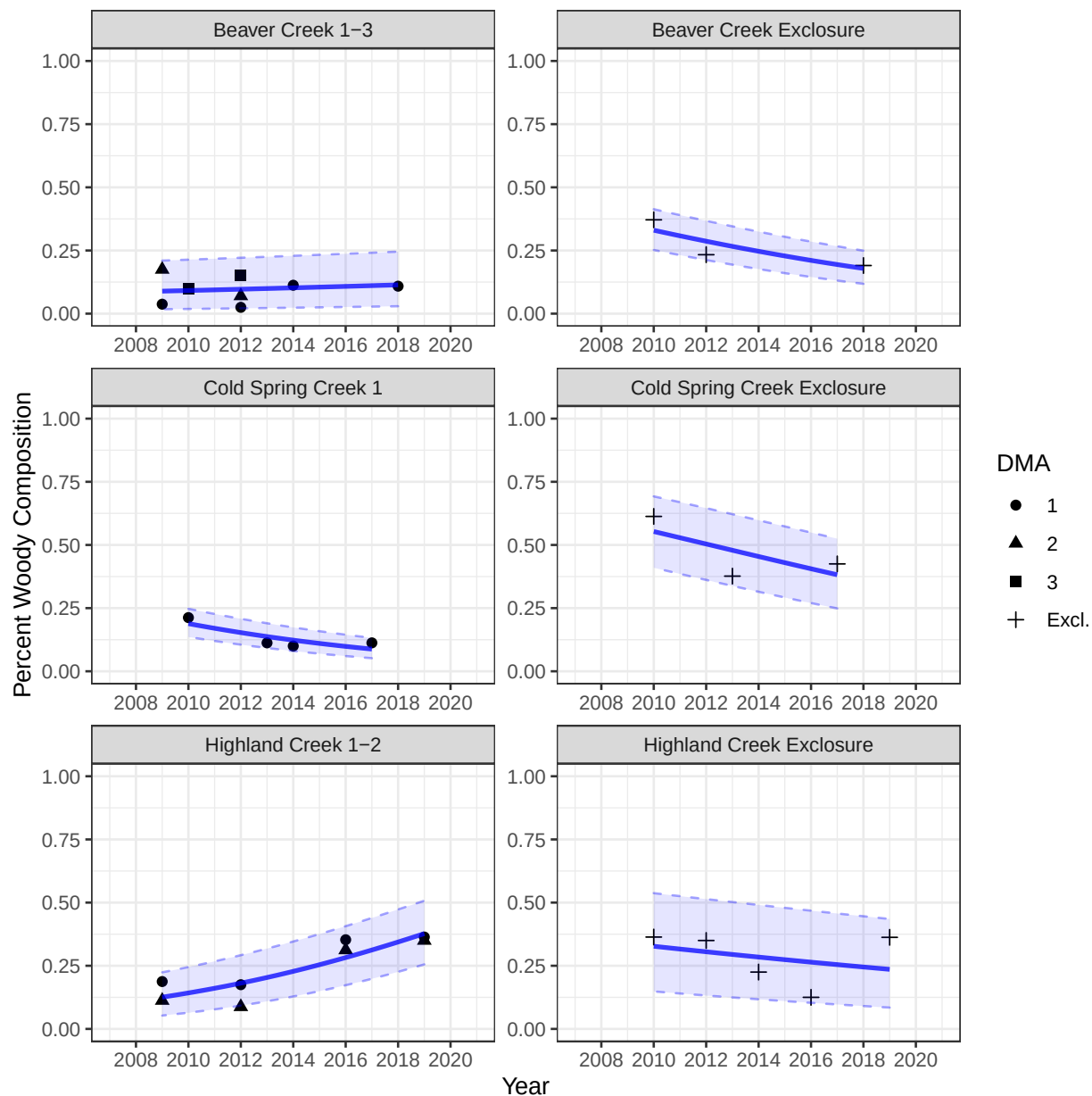


Figure 7-8: Percent plots containing woody plants for each sampled DMA (black dots) within WICA. Conditional mean of percent plots containing woody plants as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

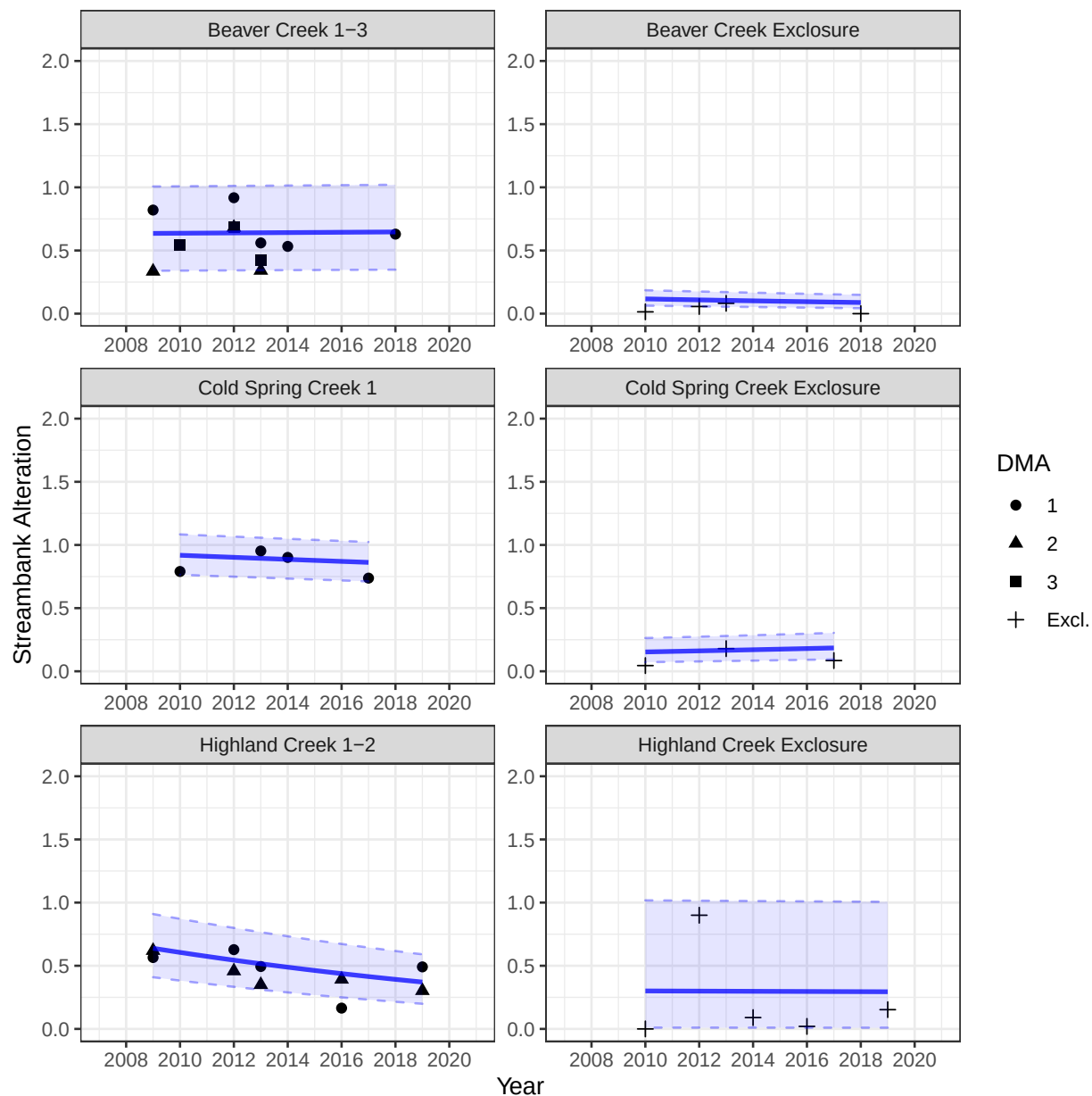


Figure 7-9: Average number of lines intersecting streambank alteration for each sampled DMA (black dots) within WICA. Conditional mean of average number of lines intersecting streambank alteration as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

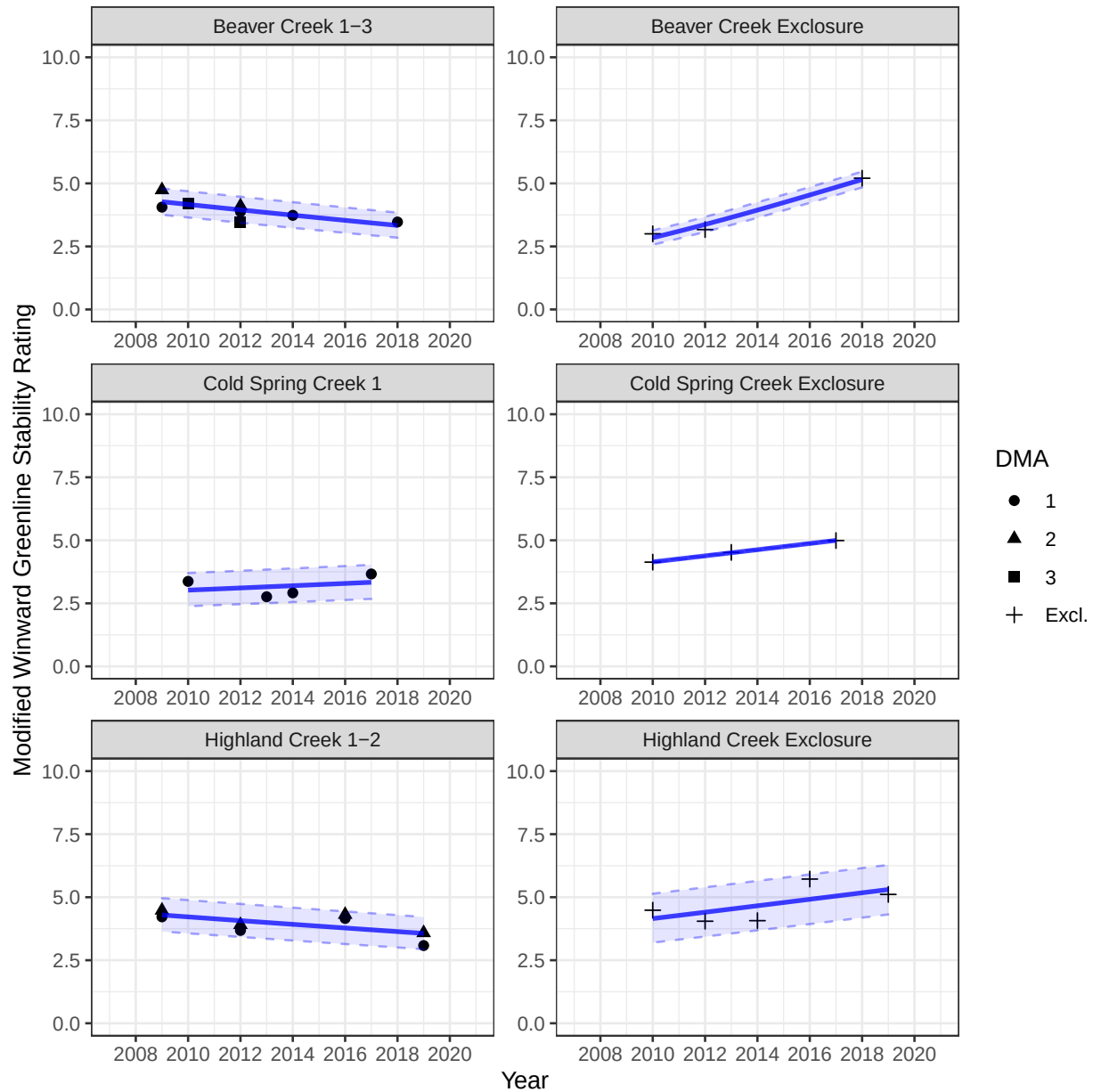


Figure 7-10: Modified Winward greenline stability rating for each sampled DMA (black dots) within WICA. Conditional mean of modified Winward greenline stability rating as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

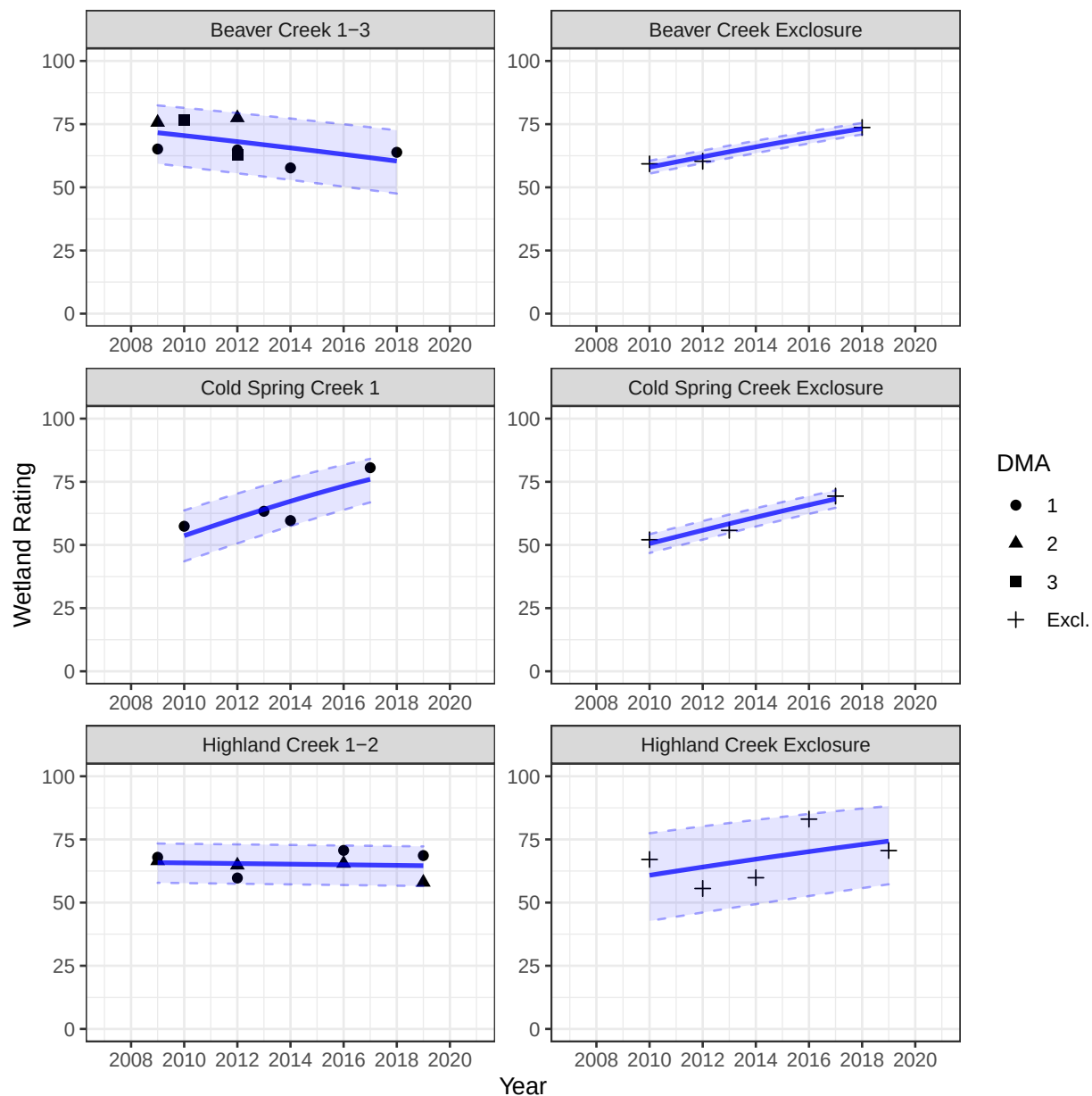


Figure 7-11: Wetland rating for each sampled DMA (black dots) within WICA. Conditional mean of wetland rating as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.

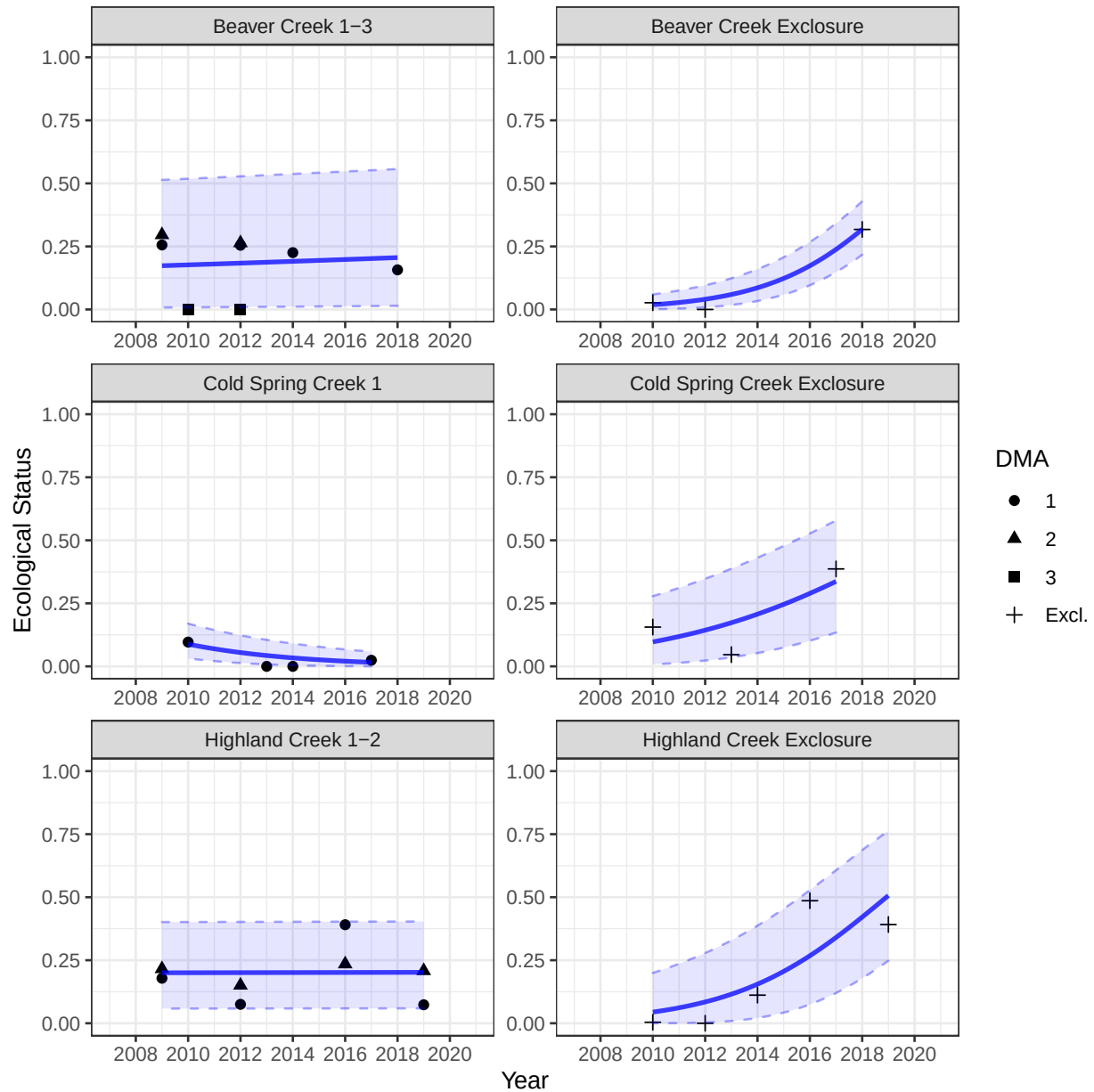


Figure 7-12: Ecological status for each sampled DMA (black dots) within WICA. Conditional mean of ecological status as a function of year plotted in blue with 95% interval of the conditional beta distribution of the response shaded in light blue and bound by dashed lines.