National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Rocky Mountain National Park
Wetland Ecological Integrity

2007–2017 Data Summary Report

Natural Resource Data Series NPS/ROMN/NRDS—2019/1220





ON THIS PAGE
Reed canary grass monoculture and historical equipment from ranching operations in the Kawuneeche Valley, Rocky Mountain National Park, 2017 (NPS/B. SCHWEIGER)

ON THE COVER
Rocky Mountain Network crew sample a wilderness fen near Haynach Lakes, Rocky Mountain National Park, 2008 (NPS/K. HAYNES)

Rocky Mountain National Park Wetland Ecological Integrity

2007–2017 Data Summary Report

Natural Resource Data Series NPS/ROMN/NRDS—2019/1220

Authors

E. William Schweiger[1]

Kirk Sherrill[1]

Kristin Long[1]

Mike Britten[1]

[1]National Park Service
Rocky Mountain Network
1201 Oakridge Dr.
Fort Collins, CO 80525

Editor

Sonya Daw

National Park Service
Inventory and Monitoring Division
1250 Siskiyou Blvd.
Ashland, OR 97520

April 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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

This report is available from the Rocky Mountain Inventory and Monitoring Network website and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Schweiger, E. W., K. Sherrill, K. Long, and M. Britten. 2019. Rocky Mountain National Park wetland ecological integrity: 2007–2017 data summary report. Natural Resource Data Series NPS/ROMN/NRDS—2019/1220. National Park Service, Fort Collins, Colorado.

NPS 121/151290, April 2019

Contents

Page

Figures....vi

Tables....xv

Appendices....xvii

Executive Summary....xviii

Acknowledgments....xix

List of Abbreviations....xx

1 Introduction....1

1.1 The National Park Service Inventory and Monitoring Program....1

1.2 Purpose of report....1

1.3 Rocky Mountain National Park....2

1.4 Rationale and justification for wetland monitoring....2

1.5 Monitoring objectives....3

1.5.1 Parkwide scale status....3

1.5.2 Site-specific status and temporal pattern....3

2 Methods....5

2.1 Sample design....5

2.2 Field methods....7

2.2.1 Vegetation....8

2.2.2 Hydrology....9

2.2.3 Soil and water chemistry....9

2.2.4 Human disturbance....10

2.2.5 Ungulate and beaver use....11

2.3 Analyses....12

2.3.1 ‘Best’ sample events....13

2.3.2 Status....13

2.3.3 Graphics and visualizations....13

Contents (continued)

Page

3 Results and Discussion 15

3.1 Overview 15

3.2 Data availability 15

3.2.1 Datasets 15

3.2.2 Protocol and publications 15

3.3 Wetland extent 16

3.3.1 Overview 16

3.3.2 Baseline wetland extent at the parkwide scale 16

3.4 Disturbance: human, ungulate, and beaver habitat use 19

3.4.1 Overview—human use 19

3.4.2 Human disturbance: baseline 20

3.4.3 Human disturbance: patterns across time at sentinel sites 30

3.4.4 Overview—ungulate and beaver habitat use 35

3.4.5 Ungulate and beaver habitat use: baseline 36

3.4.6 Ungulate and beaver habitat use: patterns across time at sentinel sites 45

3.5 Vegetation 46

3.5.1 Overview 46

3.5.2 Community composition summary 48

3.5.3 Baseline 67

3.5.4 Patterns across time at sentinel sites 87

3.6 Groundwater hydrology: depth to water from ground surface 93

3.6.1 Overview 93

3.6.2 Baseline 94

3.6.3 Patterns across time at sentinel sites 99

3.7 Woody vegetation 106

3.7.1 Overview 106

Contents (continued)

Page

3.7.2 Baseline 111

3.7.3 Patterns across time at sentinel sites 126

3.8 Soil Chemistry 130

3.8.1 Overview 130

3.8.2 Baseline 131

3.8.3 Patterns across time 138

3.9 *In situ* water chemistry 144

3.9.1 Overview 144

3.9.2 Baseline 145

3.9.3 In situ water chemistry: patterns across time at sentinel sites 154

4 Quality assurance and quality control: signal to noise 156

5 Conclusions and Future Directions 162

5.1 Management applications 162

5.2 Future directions 163

Literature Cited 165

Figures

Page

Figure 1. Rocky Mountain National Park wetland ecological integrity sites sampled in 2007–2017 6

Figure 2. Default wetland ecological integrity sample plot used by the Rocky Mountain Inventory and Monitoring Network 7

Figure 3. Rocky Mountain Network wetland crew sampling a wetland site on top of Terrah Tomah Mountain, 2008. 8

Figure 4. Crews sample vegetation in a 1 × 1 meter plot, Rocky Mountain National Park, 2008 8

Figure 5. Example of a soil core from which samples and peat depth are collected, Rocky Mountain National Park, 2008. 9

Figure 6. Rocky Mountain Network crews collect information for the Human Disturbance Index (HDI) in Moraine Park, Rocky Mountain National Park, 2008 11

Figure 7. Elk graze the alpine in Rocky Mountain National Park, 2016. 12

Figure 8. A relatively small isolated fen above the Kawuneeche Valley in Rocky Mountain National Park. 16

Figure 9. Example of historical human disturbance as estimated by the Human Disturbance index (HDI) 19

Figure 10. Example of human disturbances included in the Human Disturbance index (HDI), Moraine Park, Rocky Mountain National Park 20

Figure 11. Human Disturbance Index (HDI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 21

Figure 12. Baseline component metrics in the Human Disturbance Index (HDI) at wetland ecological integrity sites in Rocky Mountain National Park: (left) Hydrologic alteration, (center) Landscape disturbance, (right) Physical/chemical alteration 22

Figure 13. Baseline component metrics in the Human Disturbance Index (HDI) at wetland ecological integrity sites in Rocky Mountain National Park: (left) Landuse Wetland Index, (right) Landuse Buffer Index. 24

Figure 14. Map of the Human Disturbance Index (HDI) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box) 26

Figures (continued)

Page

Figure 15. Human Disturbance (HDI) for the population of (top) fens, (center) wet meadows, and (bottom) riparian wetland in Rocky Mountain National Park.....29

Figure 16. Human Disturbance Index (HDI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 30

Figure 17. Component metrics in the Human Disturbance Index (HDI): (left) Hydrologic alteration, (center) Landscape disturbance, (right) Physical/chemical alteration at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017.....32

Figure 18. Component metrics in the Human Disturbance Index (HDI): (left) Landuse in buffer, (right) Landuse in wetland at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017.....33

Figure 19. Example of change in human disturbance at Moraine Park sentinel site 505 in Rocky Mountain National Park in: (left) 2007, (center) 2009 and (right) 2015.....34

Figure 20. Riparian wetland in Endo Valley, Rocky Mountain National Park, 2008.....35

Figure 21. Baseline Ungulate Use Index (UUI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park.....36

Figure 22. Baseline Beaver Use Index (BUI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park.....37

Figure 23. Map of Ungulate Use Index (UUI) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows areas (interior of the red box).....39

Figure 24. Map of Beaver Use Index (BUI), beaver presence and current beaver habitat viability at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the park's central eastern side (Moraine and Horseshoe Park and Wild Basin; interior of the red box).....40

Figure 25. Ungulate Use index (UUI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 45

Figure 26. Beaver Use index (UUI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. 46

Figure 27. Understory wetland vegetation in Rocky Mountain National Park, 2009.....47

Figures (continued)

Page

Figure 28. Narcissus-flowered anemone (*Anemone narcissiflora* var. *zephyr)* in Rocky Mountain National Park, 2009 49

Figure 29. Highly invasive (I rank score 8; Morse et al. 2004) reed canary grass (*Phalaris arundinacea)* in the foreground of this image taken at a wetland in Kawuneeche Valley, Rocky Mountain National Park, 2017 58

Figure 30. Mean conservatism (Rocchio 2007a, b; cover weighted, index) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 69

Figure 31. Degree of invasion by wetland type at wetland ecological integrity sites in Rocky Mountain National Park: (left) cover weighted mean I-rank (Morse et al. (2004), (right) percent of assemblage as invasive taxa weighted mean I-rank..... 71

Figure 32. Wetland affinity (cover weighted, index) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 72

Figure 33. Native forb cover (averaged across all absolute cover values from sampled subplots in a site, square cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 74

Figure 34. Absolute (left; units are square cm) and relative (right; units are %) cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 75

Figure 35. Map of mean conservatism (Rocchio 2007a, b; cover weighted, index) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box)..... 77

Figure 36. Map of degree of invasion (cover weighted mean I-rank; index), in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park Meadows areas (interior of the red box)..... 78

Figure 37. Map of degree of invasion index 2 (percent of assemblage as invasive taxa weighted mean I-rank) in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box)..... 79

Figure 38. Map of wetland affinity (Tiner 2012; cover weighted, index) in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park areas (interior of the red box) 80

Figures (continued)

Page

Figure 39. Map of native forb cover (cm^2) in (left) Rocky Mountain National Park and (right) the Grand Lake area (interior of the red box) 81

Figure 40. Map of absolute cover (cm^2) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park areas (interior of the red box) 82

Figure 41. Map of relative cover (%) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) in (left) Rocky Mountain National Park and (right) upper Colorado River valley area (interior of the red box) 83

Figure 42. Mean conservatism (Rocchio 2007a, b; cover weighted, index; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park 85

Figure 43. Wetland affinity (Tiner 2012; cover weighted, index; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park 86

Figure 44. Mean conservatism (Rocchio 2007a, b; cover weighted, index) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 87

Figure 45. Degree of invasion: (left) cover weighted mean I-rank (Morse et al. 2004; index), (right) percent of assemblage as invasive taxa weighted mean I-rank by wetland type at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 89

Figure 46. Native forb cover (averaged across all absolute cover values from sampled subplots in a site, square cm) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 90

Figure 47. Wetland affinity (cover weighted, index) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 91

Figure 48. Absolute (left; units are square cm) and relative (right; units are %) cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) by wetland type at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 92

Figure 49. Rocky Mountain Network crewmember measuring depth to water from ground surface at an Alpine sentinel site in Rocky Mountain National Park, 2007 94

Figure 50. Depth to water from ground surface (DTW, cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 95

Figures (continued)

Page

Figure 51. Map of hand measured depth to water from ground surface (DTW, cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley area (interior of the red box) 96

Figure 52. Depth to water from ground surface (cm, DTW; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park 98

Figure 53. Depth to water from ground surface (cm, DTW) by wetland type at sentinel wetland ecological integrity sites in Rocky Mountain National Park, 2007 to 2017 99

Figure 54. Daily mean depth to water from ground surface (cm, DTW) at six wetland ecological integrity sites within the Moraine Park sentinel complex in Rocky Mountain National Park, 2007 to 2014 101

Figure 55. Daily mean depth to water from ground surface (cm, DTW) at three wetland ecological integrity sites within the Kawuneeche Valley sentinel complex in Rocky Mountain National Park, 2009 to 2014 102

Figure 56. Daily mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sites within the Big Meadows sentinel complex in Rocky Mountain National Park, 2008 to 2014 103

Figure 57. Daily mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sites within the Alpine sentinel complex in Rocky Mountain National Park, 2008 to 2014 104

Figure 58. Annual mean proportions of depth to water (DTW) logs in each sentinel complex with daily mean depth to water from ground surface below -40 cm (“dry”) or above -5 cm (“saturated”) at four wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2014 105

Figure 59. Maximum (dark blue bars) and minimum (orange bars) mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2014. 106

Figure 60. Network crews sample a Kawuneeche Valley site in 2008 in Rocky Mountain National Park 107

Figure 61. Network crews sample a site near Poudre Pass in 2007, Rocky Mountain National Park 107

Figures (continued)

Page

Figure 62. Mean proportion of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in five height classes by wetland type at wetland ecological integrity sites in Rocky Mountain National Park.....111

Figure 63. Mean stems per square meter of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in five height classes by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. 112

Figure 64. Damage on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch): (left) Ungulate browse on live stems (%), (center) Dead stems (%), (right) Dieback (%) at wetland ecological integrity sites in Rocky Mountain National Park 113

Figure 65. Map of the proportion of stems of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) across five height classes at wetland ecological integrity sites in Rocky Mountain National Park.....114

Figure 66. Map of total stems per square meter of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box).....116

Figure 67. Browse (%) on live stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley (interior of the red box) 117

Figure 68. Dead stems (%) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (a) Rocky Mountain National Park and (b) the lower Kawuneeche Valley (interior of the red box) 118

Figure 69. Dieback (%) on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley (interior of the red box) 119

Figure 70. Total stems per square meter (all x-axes) of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park.....124

Figures (continued)

Page

Figure 71. Browse (%) (all x-axes) on live stems of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park 125

Figure 72. Woody stems per square meter (log transformed) in five height classes of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch) for wetland ecological integrity plots in sentinel sites in Rocky Mountain National Park, 2007 to 2017 126

Figure 73. Total woody stems per square meter (log transformed) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch) for wetland ecological integrity plots in sentinel sites in Rocky Mountain National Park, 2007 to 2017 127

Figure 74. Damage indicators on Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch): (left) Browse on live stems (%), (center) Dead stems (%), and (right) Dieback (%) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017 129

Figure 75. Example of a gleyed wetland soil. Rocky Mountain National Park, 2008 130

Figure 76. Soil organic matter (at 40 cm depth, %) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 131

Figure 77. Depth of peat (cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. 132

Figure 78. Map of soil organic matter (at 40 cm depth, %) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the upper Colorado River area (interior of the red box) 134

Figure 79. Map of depth of peat (cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Kawuneeche Valley and western side of the Continental Divide area (interior of the red box) 135

Figure 80. Soil organic matter (at 40 cm depth, %; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park 137

Figure 81. Soil organic matter (at 40 cm depth, %) at the Moraine Park wetland ecological integrity sentinel site in Rocky Mountain National Park, 2007 to 2017 138

Figures (continued)

Page

Figure 82. Mean soil pH (s.u.) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park 143

Figure 83. Mean soil potassium (mg/kg) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park..... 143

Figure 84. Mean soil ammonium (mg/kg) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park..... 144

Figure 85. Collecting an in situ water sample, 2008, in Rocky Mountain National Park..... 145

Figure 86. Groundwater specific conductance (us/cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park 146

Figure 87. pH (s.u.) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park..... 147

Figure 88. Map of groundwater specific conductance (us/cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Moraine and Horseshoe Park area (interior of the red box)..... 149

Figure 89. Map of groundwater pH (s.u.) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Kawuneeche Valley and western side of the Continental Divide area (interior of the red box)..... 150

Figure 90. Groundwater specific conductance (us/cm; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park..... 152

Figure 91. Groundwater pH (s.u.; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park..... 153

Figure 92. Groundwater specific conductance (us/cm) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017..... 154

Figure 93. Groundwater pH (s.u.) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017..... 155

Figure B1. Aerial view of the Big Meadows sentinel site, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009. 186

Figure B2. One of several dams installed along the main drainage ditch during the Big Meadows wetland restoration project, circa 1990 187

Figures (continued)

Page

Figure B3. Aerial view of the Moraine Park wetland ecological integrity sentinel site in Rocky Mountain National Park. 189

Figure B4. Stead Ranch, circa 1970s. Historical human use of Moraine Park 190

Figure B5. Aerial view of the Alpine sentinel complex, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009. 192

Figure B6. Alpine wetland ecological integrity sentinel site in Rocky Mountain National Park, 2017 193

Figure B7. Photo of section of Trail Ridge road traversing tundra—part of B. Willard's study area (Willard and Marr 1970) 194

Figure B8. Aerial view of the Kawuneeche Valley complex sentinel site, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009 195

Figure B9. Never Summer Ranch, circa 1920s. 197

Tables

Page

Table 1. Human Disturbance Index component metrics for wetland monitoring in Rocky Mountain National Park 10

Table 2. Beaver and ungulate habitat use and habitat context field measures for wetland monitoring in Rocky Mountain National Park 11

Table 3. Design-based estimates of wetland extent in Rocky Mountain National Park, 2007–2009, using Rocky Mountain Network wetland ecological integrity data 18

Table 4. Error matrix for wetland types in evaluated wetland complexes, 2007–2009, using Rocky Mountain Network wetland ecological integrity data 18

Table 5. Baseline parkwide summary statistics for Human Disturbance Index (HDI) and its component metrics for the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park, 2007–2017.[a] 27

Table 6. Design-based proportion and total area in Ungulate Use Index (UUI) and Beaver Use Index (BUI) classes and a suite of beaver presence/absence and habitat viability indicators at wetland ecological integrity sites in Rocky Mountain National Park 42

Table 7. Rocky Mountain National Park species of concern at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017 50

Table 8. High conservation value species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA 2018 51

Table 9. Invasive species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA (2019) 55

Table 10. Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015) 59

Table 11. Summary statistics for depth to water from ground surface (DTW, cm) for all sample sites and the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park 97

Table 12. Species of Salicaceae (willow, aspen and cottonwood) and Betulaceae (alder and birch) important for ungulates and beaver at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017 109

Tables (continued)

Page

Table 13. Baseline parkwide scale summary statistics for woody stem density (m^2), proportion by height class, and absolute and relative cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park.....120

Table 14. Baseline parkwide summary statistics for ungulate browse (%), dead stems (%), and dieback (%) on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park.....123

Table 15. Baseline summary statistics for soil organic matter and depth of peat for all sample sites and the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park 136

Table 16. Summary of soil chemistry from 68 sample events at 39 wetland ecological integrity sites structured into two sampled periods (2009–2010; 2014–2015) at Rocky Mountain National Park.....139

Table 17. Baseline summary statistics for groundwater specific conductance (us/cm) for all sample sites and the population of fens, wet meadows, riparian wetland and all wetland in Rocky Mountain National Park.....151

Table 18. Signal to Noise for select wetland ecological integrity indicators.....156

Appendices

Page

Appendix A: Sample Sites 177

Appendix B: Sentinel Site Descriptions 186

Appendix C: Quality Assurance and Quality Control Overview 199

Appendix D: Remotely Sensed Estimates of Wetland Extent 202

Appendix E: Vegetation Metrics 205

Appendix F: Groundwater Depth Metrics 210

Executive Summary

Wetlands are important because they are biodiversity hotspots and support iconic wildlife. They also provide valuable "ecosystem services," such as flood attenuation and storage, aquifer discharge and recharge, sediment stabilization and sequestration, carbon storage, water quality enhancement, and nutrient cycling. Wetlands also provide important aesthetic values and are highly valued by visitors. The National Park Service (NPS) Rocky Mountain Inventory and Monitoring Network (hereafter, network) conducts long-term monitoring at wetlands in Rocky Mountain National Park as part of its natural resources vital signs monitoring program.

The purpose of this report is to describe and summarize wetland monitoring data and information collected under the network's wetland ecological integrity monitoring protocol so that NPS resource managers and superintendents and scientific and technical staff will understand and be able to access the data and information. We summarize and provide descriptive statistics of the data but do no formal analysis, statistical testing, or modeling, and we do not interpret the data. For example, we do not compare the condition of park wetlands to other wetlands in Colorado or to desired conditions, and we do not analyze changes in wetland conditions over time. Our goal is to fully describe the dataset and provide access to the data and information collected. Therefore, this report has not undergone a formal peer review, though the data collection and analysis methods it contains have been independently peer-reviewed by outside scientific experts reviewing the *Rocky Mountain Network Wetland Ecological Integrity Monitoring Protocol.* Detailed syntheses can be found in a peer reviewed paper focused on models of structural relationships among human disturbance, ungulates, beavers, and wetland response (Schweiger et al. 2016) and in future status and trend reports.

This report presents graphical and tabular summaries of data collected from wetlands at Rocky Mountain National Park (hereafter, the park) from 2007 to 2017. Monitoring included a sample of 154 fens, wet meadows and riparian wetlands conducted across the park from 2007 to 2009 and annual monitoring (2010–2017) at four "sentinel" wetlands. At each site, we collected data on vascular and nonvascular plant species composition, woody species (if present), stand structure (primarily cottonwood and willows), and damage and mortality of woody stems. We also collected field and laboratory soil chemistry samples, documented *in-situ* groundwater electrical conductivity and pH, and measured depth to water at a shallow groundwater well in the center of each plot. Finally, we documented human disturbance as well as beaver and ungulate use of habitat in and around each plot and in the wetland complex.

This report documents fully quality assured and quality checked 2007–2017 data in the network's Wetland Ecological Integrity (WEI) database. Results summarized here serve as important baselines for future modeling and assessment of status and trend in the condition of the park's wetlands. These assessments will be reported in forthcoming publications.

Acknowledgments

This report was prepared by Rocky Mountain Inventory and Monitoring Network (network) staff based on input and information from many people. Errors are the responsibility of network staff.

We would like to thank network staff who assisted with, or facilitated, Rocky Mountain National Park wetland monitoring since 2007, especially Katie (Driver) Haynes, who led the parkwide wetland survey from 2007 to 2009, and Donna Shorrock and Erin Borgman, who led annual monitoring at select wetland sentinel sites since 2010. Others who assisted in wetland monitoring fieldwork include Alexa Armstrong, Isabel Ashton, Melinda Barnes, Christy Cleaver, Erica Duda, Rebecca Evans, Thomas Faust, Evan Gohring, Brandon Gottung, Cullen McGovern, Kyle Motley, Theresa O'Halloran, Darin Rummel, Jaci Stanton, Scott Sveiven, Caitlin White, and Molly Wiebush. We also thank network data management staff who helped manage wetland data and information, including Laura Atkinson, Jennifer Burke, Brent Frakes, and Laura O'Gan.

We would like to especially thank Rocky Mountain National Park staff who provided guidance, direction, park housing for monitoring field crews, and logistical support, including Hanem Abouelezz, Stan Austin, Ben Bobowski, Jeff Connor, Ken Czarnowski, Scott Esser, Therese Johnson, Paul McLaughlin, Koren Nydick, and Judy Visty.

The Rocky Mountain Network Technical Committee laid the groundwork for long-term wetland ecological integrity monitoring in the park and all network parks and continues to provide vision and guidance for our long-term inventory and monitoring program. Thanks to the current and past members of the committee: Isabel Ashton, Mark Biel, Ben Bobowski, Fred Bunch, Tara Carolin, Jeff Connor, Ken Czarnowski, Marian Doane, Scott Esser, Chris Ford, Sallie Hejl, Therese Johnson, John Mack, Paul McLaughlin, Brendan Moynahan, Phyllis Pineda-Bovin, Jack Potter, Jason Smith, Melana Stichman, Kathy Tonnessen, Michael Stops, Terry Terrell, Judy Visty, Leigh Welling, Phil Wilson, and Rick Wilson.

We thank the many outside scientists and experts who have generously shared their knowledge of Rocky Mountain National Park wetlands with us, including David Cooper, Ed Gage, Derek Shook, and Jeremy Sultenfuss from Colorado State University; Jim Grace, Glenn Guntenspergen and Don Schoolmaster from USGS; and Joanna Lemly, Joe Rochhio, Renee Rondeau, and Joe Stevens from the Colorado Natural Heritage Program.

Thanks to Bruce Bingham and Michael Bozek, as Intermountain Region Inventory and Monitoring Coordinators, for providing sound advice, encouragement, and support for the Rocky Mountain Network's Inventory and Monitoring Program, including wetland monitoring in Rocky Mountain National Park.

List of Abbreviations

BUI	Beaver Use Index
CDF	cumulative distribution function
CNHP	Colorado Natural History Program
DTW	depth to water
EPA	Environmental Protection Agency
HDI	Human Disturbance Index
I&M	National Park Service Inventory and Monitoring Program
IRMA	NPS Integrated Resources Management Applications web portal
NPS	National Park Service
NRCS	Natural Resources Conservation Service
QAQC	quality assurance and quality control
USGS	US Geological Survey
UUI	Ungulate Use Index
WEI	NPS Rocky Mountain Network Wetland Ecological Integrity monitoring program

1 Introduction

1.1 The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory and Monitoring (I&M) Program (Fancy et al. 2009) is to develop and provide scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems (i.e., ecological integrity). As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, a primary role of the I&M Program is to collect, organize, and make available natural resource data and to contribute to the NPS institutional knowledge by facilitating the transformation of data into information through analysis, synthesis, and modeling of specific key vital signs.

The Rocky Mountain Inventory and Monitoring Network (hereafter, the network), its six partner parks in the region, and scientific collaborators identified 12 high-priority vital signs for focused, long-term monitoring. The vital signs include wet and dry deposition; weather and climate; water chemistry; surface water dynamics; freshwater communities; invasive/exotic aquatic biota; groundwater dynamics; wetland communities; invasive/exotic plants; vegetation composition, structure, and soils; focal species (beaver, elk, grizzly bear, and Great Sand Dunes National Park and Preserve endemic insects); and landscape dynamics (Britten et al. 2007).

Wetland Ecological Integrity (WEI) monitoring in Rocky Mountain National Park (hereafter, the park) addresses five of the network's 12 high priority vital signs (VS): wetland communities, groundwater dynamics, invasive/exotic plants, focal species—elk, and focal species—beaver. Two other high priority vital signs are indirectly linked with the WEI protocol, including landscape dynamics and weather and climate.

The WEI protocol (Schweiger et al. 2015) provides the rationale for the WEI design and field elements, summaries of analytical methods, an overview of data management, and an administrative plan for long-term implementation. The WEI protocol also includes a series of standard operating procedures (SOPs) that provide detailed instructions for executing field, data management, analytical, and administrative components of the protocol.

1.2 Purpose of report

This report presents summaries of WEI monitoring data collected by the network and our partners from 2007 to 2017. We do no formal analysis, statistical tests or modeling and do not interpret the data (e.g., we do not compare wetland conditions relative to some reference or desired condition). Rather this report is a relatively simple, largely graphical and tabular presentation of select data summaries. Detailed syntheses can be found in a peer reviewed paper focused on models of structural relationships among human disturbance, ungulates, beavers, and wetland response (Schweiger et al. 2016), as well as in future status and trend reports. The summaries in this report serve as an important baseline for future status and trend syntheses. This is especially relevant for the large sample of sites taken in 2007–2009.

1.3 Rocky Mountain National Park

Rocky Mountain National Park, established on January 26, 1915, is a ~415,000 acre park that straddles the Continental Divide in central Colorado. Most of the park, just miles from the largest urban area in the Rocky Mountain region, is designated wilderness, giving many Coloradoans and other visitors an opportunity for solitude and wilderness recreation. Its complex topography and wide range of elevation also result in remarkable biological diversity. Several river systems originate in the park, including the Colorado River and the Cache la Poudre River, the first and only designated wild and scenic river in Colorado. The park's main purpose, according to its foundation document (NPS 2013), is to "preserve the high-elevation ecosystems and wilderness character of the southern Rocky Mountains within its borders and to provide the freest recreational use of and access to the park's scenic beauties, wildlife, natural features and processes, and cultural objects."

Important (NPS 2013) habitats include diverse wetland, alpine tundra, montane habitats (especially ponderosa pine and upland shrub communities), lodgepole pine, and aspen woodlands. Important species include elk, bighorn sheep, mule deer, moose (a recent arrival), beaver, black bear, wolves, mountain lion, pine marten, river otter, greenback cutthroat trout, Colorado River cutthroat trout, nonnative fish (and other nonnative aquatic species), boreal toad, several raptor species, white-tailed ptarmigan, songbirds, butterflies, capshell snail, exotic invasive plants, and several rare and high conservation value plants and vegetation communities. Important ecological processes include fire; herbivory (especially by elk and moose) and effects on aspen and willow communities, stream hydrology, other herbivores such as beaver and ptarmigan; exotic plant animal invasion; and erosion.

Important (NPS 2013) natural resource issues include access to wild places, high-elevation ecosystems, increased recreation, temperature increases, changes in water availability, air quality degradation, invasion by exotic plants, reduced alpine/increased subalpine, riparian habitat restoration, wilderness character, headwaters of the Continental Divide, ability to experience a wide variety of recreational opportunities, and human footprints on the landscape.

1.4 Rationale and justification for wetland monitoring

Wetland is one of the most important resources in the park. Along with alpine tundra it is likely the most recognizable resource in the park—largely because of its importance to elk (*Cervus elaphus*), which are perhaps the signature large mammal species in the park. It is also critical habitat for beaver (*Castor canadensis*)—a keystone species currently at very low numbers in the park—and moose (*Alces alces shirasi*), which can have a pronounced effect on wetlands and have a growing population in the park.

There were several reasons behind the choice to conduct long-term wetland monitoring in the Rocky Mountain National Park. Though wetlands compose a small percentage of the landscape in the park, they are an important component of the ecosystem (NPS 2007, Schweiger et al. 2015). Wetlands are widely recognized for the numerous important ecological functions they provide (Naiman et al. 1993, Cooper and Sanderson 1997, Stohlgren et al. 1997, Mitsch and Gosselink 2007). The park supports a variety of wetland types, from fens to important riparian wetland valley bottoms. Some of the valuable ecological functions that wetlands in the park provide include wildlife support, flood attenuation and storage, aquifer discharge and recharge, sediment stabilization and

sequestration, carbon storage, water quality enhancement, and nutrient cycling (Mitsch and Gosselink 2007, Sutula et al. 2006). However, wetlands are among the most significantly altered ecosystems in North America due to changes in hydrology from flow regulation, pumping and fill placement, overgrazing by domestic and native ungulates, atmospheric deposition, and exotic species invasion (Patten 1998, Bedford and Godwin 2003, Zedler and Kercher 2005). Wetland resources are considered especially vulnerable to climate change due to their relationship to ground and surface water dynamics (Larson 1995, Baron et al. 2000, Burkett and Kusler 2000, Voldseth et al. 2009).

1.5 Monitoring objectives

The general goals for long-term ecological monitoring of park wetlands focus on documenting the status and trend in extent and condition, helping to understand the causes of changes—especially where change is relatable to human disturbance—and assisting in the application of WEI results and relevant auxiliary information to park management. While not an objective per se, WEI monitoring in the park does serve to add to the general ecological knowledge regarding wetlands in the park.

We only include objectives below that are addressed in this data report—see Schweiger et al. (2015) for a complete set of objectives and more detail. We modify some objectives to better fit how they are presented in this report. Note that we retain the numbering of objectives as established in the WEI protocol.

1.5.1 Parkwide scale status

This report summarizes data from the 2007–2009 survey of park wetlands. These summaries are "population" in scale in that they use methods that provide statistically valid estimates for the entirety of three wetland types in the park—fens, wet meadows, and riparian wetland. Parkwide scale summaries are ideal estimates of parkwide baseline conditions in the park. "Status" includes estimates for a single well defined period of time.

1. Determine status in wetland area:
    a. Using remotely sensed data
    b. Using 2007–2009 survey data
2. Determine status in a suite of indicators:
    a. Human and natural disturbances (i.e., beaver, ungulates)
    b. Soil chemistry
    c. *In situ* water chemistry
    d. Depth to groundwater
    e. Vegetation community composition and metrics of community attributes

1.5.2 Site-specific status and temporal pattern

We estimate site-specific status across all sampled sites and for specific sentinel sites. Analyses or visualizations of these data are specific to the sites included (i.e., specific sites in a sentinel complex). We do not estimate trend models in this report but do present simple graphics as time series that support future treatment with more complex models and interpretation.

3. Determine status for all sample sites in a suite of indicators (as in objective 2a-e)

4. Determine temporal pattern for sentinel sites in a suite of indicators (as in objective 2a-e)

2 Methods

The following present brief summaries of how and why sites were selected, how data were collected in the field or harvested from auxiliary sources, and how data were analyzed and interpreted. For a more complete treatment, see the Rocky Mountain Network's wetland ecological integrity (WEI) monitoring protocol (Schweiger et al. 2015) and the appendices to this report.

2.1 Sample design

WEI monitoring at Rocky Mountain National Park includes three sample design types: 1) a parkwide random "survey" of 93 fen, riparian wetland, and wet meadow sites conducted every 5–10 years, 2) annual "sentinel" site monitoring at 26 sites in four wetland complexes, and 3) episodic sampling at 35 subjectively selected "gradient" sites every 5–10 years (Figure 1). The complete site list is in Appendix A. Appendix B presents detailed overviews of each of the four sentinel complexes.

The survey allows us to describe the parkwide status of Rocky Mountain National Park wetlands without statistical bias, whereas annual sentinel site monitoring allows us to estimate trends specifically at these important wetlands. Repeat surveys will allow us to document parkwide wetland condition changes over the long term. For select analyses we use all sites (survey, sentinel and gradient) in models to better understand patterns across sites and the structural connections among our indicators. Importantly these all-site summaries apply to the sampled sites only. They are useful because they may better capture important extreme conditions, such as wetlands with high levels of human disturbance. We present both (all) site level and parkwide survey based summaries in this report.

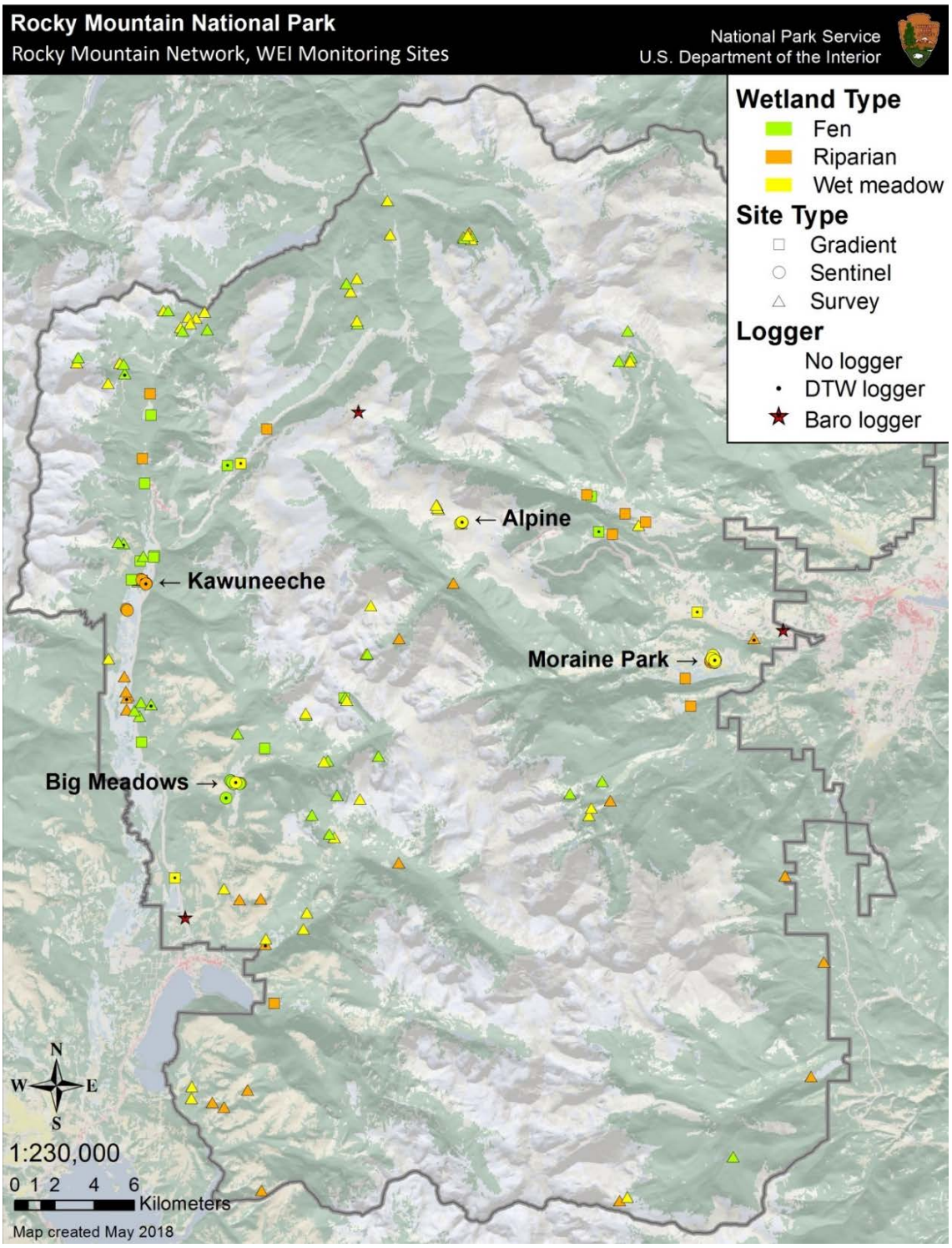


Figure 1. Rocky Mountain National Park wetland ecological integrity sites sampled in 2007–2017. Point symbology is based on wetland type and sample design. Sites that have had depth to water (DTW) loggers are indicated with a dot inside the site symbol. Sites that have had a barometric pressure logger are represented by a red star. The four sentinel site complexes are labeled. These sites are mapped at a more detailed scale in Appendix B. Note that at this scale, several sites overlap and this map should be used with caution.

2.2 Field methods

All field methods are described in Schweiger et al. (2015) and only briefly summarized here. The WEI protocol includes a broad spectrum of indicators to help evaluate the ecological integrity of wetlands in the park. Appendix C presents a brief overview of the quality assurance methods we apply to WEI data. Most data were collected from 10 m^2 plots with two scales (1 m^2 and 4 m^2) of nested subplots arranged systematically around the groundwater monitoring well (Figure 2, Figure 3). This plot design adequately samples multiple wetland drivers and responses in the park (Schweiger et al. 2015).

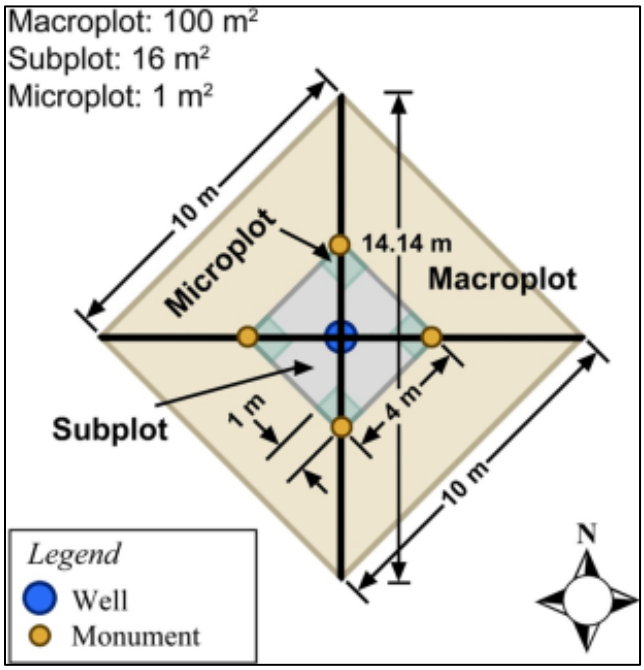


Figure 2. Default wetland ecological integrity sample plot used by the Rocky Mountain Inventory and Monitoring Network. Plots are always oriented with North at the top of the plot. Rebar is capped with a standard Rocky Mountain Network monument cap. The center of the plot is a groundwater well (except in most gradient sites).

At all plots, we collect vascular and nonvascular plant species composition, woody species stand structure (primarily willows), and we document damage to and mortality of woody stems. (Figure 3, Figure 4). We also collect soil chemistry samples, measure *in situ* groundwater specific conductivity and pH, and measure depth to water at a groundwater well in the center of the plot. Finally, we document human disturbance, ungulate use, and beaver presence and degree of habitat modifications in and around each plot and in the surrounding wetland complex.



Figure 3. Rocky Mountain Network wetland crew sampling a wetland site on top of Terrah Tomah Mountain, 2008. NPS/KATIE HAYNES

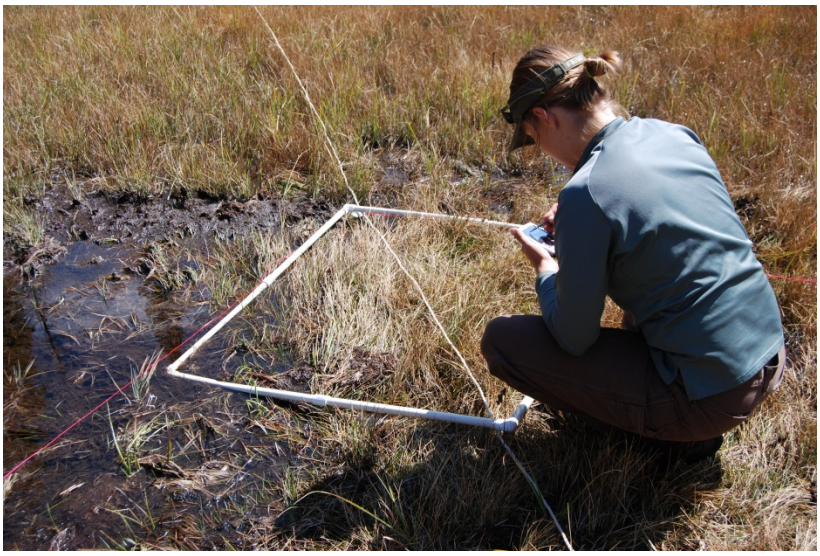


Figure 4. Crews sample vegetation in a 1 × 1 meter plot, Rocky Mountain National Park, 2008. NPS/B. SCHWEIGER

2.2.1 Vegetation

Plant species composition was quantified within six nested subplots in each site (Figure 4). All vascular and nonvascular taxa in each plot were identified to species and the canopy cover visually estimated for each taxon (Mueller-Dombois and Ellenberg 1974). Cover was averaged across all subplots before inclusion in models. In 2017 we switched plant species nomenclature to USDA (2019), transitioning from 10 years using Weber and Wittman (2001). We include five measures of ground cover in the visual estimates: bare ground, water, litter, basal area, and nonvascular taxa.

Woody stand structure was estimated by enumerating stems by taxa and age/size class within each subplot. Damage to and mortality of woody stems (Potter and Conkling 2015) was evaluated, followed by estimating the percent of stems that were dead, the percentage of live stems with browse (limited to evidence typical of ungulate foraging), and the percentage of live stems with dieback (from sources other than browse).

2.2.2 Hydrology

Groundwater monitoring wells at each site were hand-augured and cased with slotted PVC pipe to a depth adequate for measuring depth to the water table (usually 1 to 2 m). Continuous depth to water (DTW) was recorded ever hour year-round at 12 wells in sentinel sites with submersed pressure transducers. We also manually measured DTW at each visit using an electronic tape with an accuracy of +/- 2.0 mm. Most of these instantaneous DTW readings occurred at peak growing season when water stress on vegetation was likely highest. At a subset of sites we used data loggers to collect continuous ground water depths.

2.2.3 Soil and water chemistry

A composite soil sample was taken from the well bore or a soil pit at 0 to 20 cm and analyzed in a lab for 23 parameters, including pH, conductance, cation exchange capacity, nutrient concentrations, and several ions or salts (e.g., P, Mg, Mn, Al, Ca). A second sample was taken at around 40 cm and analyzed for percent organic matter. Field measures of soil at each site included a general characterization of soil layers and total peat thickness in the top 80 cm of the soil profile (Figure 5). Soil samples are taken every 5–10 years. Groundwater specific conductivity and pH were measured *in situ* from the well at the time of each sample event using a hand held sonde.



Figure 5. Example of a soil core from which samples and peat depth are collected, Rocky Mountain National Park, 2008. NPS/B. SCHWEIGER

2.2.4 Human disturbance

Human disturbance in and around each wetland site and complex was documented (Table 1, Figure 6). These field methods were rapidly employed measures modified from Faber-Langendoen et al. (2006), Rocchio (2007a, b), and Mack (2007) and were mostly categorical measures. Several measures were also evaluated in the office using a GIS (in some cases GIS data will be more precise and accurate).

Table 1. Human Disturbance Index component metrics for wetland monitoring in Rocky Mountain National Park. "GIS" indicates that the measure includes data from both field and GIS-based data sources.

Metric category	Component metric
Alterations within buffers and landscape context	Average Buffer Width (GIS)
	Land Use in 100 m Buffer
	Percentage of Unfragmented Landscape within 1 km (GIS)
	Riparian Corridor Continuity
Hydrological alterations	Hydrological Alterations
	Upstream Surface Water Retention (GIS)
	Upstream/Onsite Water Diversions/Additions (GIS)
	Floodplain Interaction
Physical/chemical disturbances	Substrate/Soil Disturbance
	Onsite Land Use
	Bank Stability
	Algal Blooms
	Invasive Dominance
	Sediment/Turbidity
	Toxics/Heavy Metals

These data were synthesized into a semi-quantitative Human Disturbance Index (HDI). The HDI provides an independent estimate of wetland condition against which vegetation attributes and other WEI responses are assessed to determine relationships with changes in human disturbance regimes across the park and over time.



Figure 6. Rocky Mountain Network crews collect information for the Human Disturbance Index (HDI) in Moraine Park, Rocky Mountain National Park, 2008. Examples of human caused soil disturbance in the foreground (here from the park's restoration of the site) and visitor services (trail stock, background) potentially impacting the site are evident in the photo. NPS/B. SCHWEIGER

2.2.5 Ungulate and beaver use

Characterization of 'natural' disturbance gradients in and around each wetland site is another key part of the WEI protocol. Crews estimated a series of categorical or presence/absence indicators of beaver and ungulates (Figure 7) as summarized in Table 2. Several measures were also evaluated in the office using a GIS.

Table 2. Beaver and ungulate habitat use and habitat context field measures for wetland monitoring in Rocky Mountain National Park. See Schweiger et al. (2015) for details.

Indicator	Values
Beaver Use	10: Site/Complex has dams, lodges, beaver chewed stems, beaver slides/runways, beaver tracks. More than one feature(s) and more than once.
	7: Site/Complex has dam, lodge, beaver chewed stem, beaver slide/runway, beaver spoor track. More than one feature.
	3: Site/Complex has dam, lodge, beaver chewed stem, beaver slide/runway, beaver spoor track. One feature only.
	0: Site/Complex has no evidence of beaver use
Beaver Present at Time of Sample	Site/Complex has current beaver activity: animal(s), dam(s), lodge(s), beaver chewed stem(s), beaver slide(s)/runway(s), beaver track(s). Currently used dams and lodges will have recently cut (green or not dried out stem) woody material. They will also likely have associated tracks and runways.
Beaver Habitat Potential	Site/Complex has habitat that would support beaver

Table 2 (continued). Beaver and ungulate habitat use and habitat context field measures for wetland monitoring in Rocky Mountain National Park. See Schweiger et al. (2015) for details.

Indicator	Values
Beaver Historical Use Relevant	Site/Complex has beaver features that still have an obvious impact on site's hydrology (i.e., old dam still creating habitat) and/or vegetation (most woody stems are beaver chewed and this is an obvious control on woody density)
Ungulate Use	10: Site/Complex has evidence of native ungulate (see, smell, hear), tracks, feces, browse, or beds. More than one feature(s) and more than once. 7: Site/Complex has evidence of native ungulate (see, smell, hear), track, feces, browse, or beds. More than one feature. 3: Site/Complex has evidence of native ungulate (see, smell, hear), track, feces, browse, bed. One feature only. 0: Site/Complex has no evidence of native ungulate use



Figure 7. Elk graze the alpine in Rocky Mountain National Park, 2016. NPS photo

2.3 Analyses

In this data summary report we do not include extensive interpretation. Our analyses include design-based and traditional status estimation and various graphical/tabular visualizations of field, lab, and derived data.

2.3.1 'Best' sample events

For sites with replicate samples, values for site and parkwide scale baseline summaries are derived from the sample event at the site where we believe vegetation phenology was optimal for plant identification purposes and the crew consisted of the best trained botanists. These events are referred to in this document as the 'best' sample events. 'Best' sample events occurred at all site types (sentinel, gradient, and survey). Other sample events from sites with replicates were used in estimates of precision and in sentinel sites for plotting an indicator across time.

2.3.2 Status

We define status as a 'snap shot' evaluation of a WEI response over a well-defined and relatively concise range in time (Olsen et al. 1999). Status is estimated using a variety of tools for all WEI variables at both parkwide and site scales.

For most WEI indicators, site scale status results are estimated as means and their variance. For parkwide scale estimates, we only use best event data from survey sites and design-based analyses. Design-based analyses are well specified and are the foundation of long-established analyses used in socioeconomics, politics, medicine and other fields. While beyond our scope here, in summary, design-based analyses use the inclusion probabilities (or sampling weights) from the design to extrapolate results or provide inference to unsampled elements of the target population (Horvitz and Thompson 1952, Overton and Stehman 1996, Stevens 1997). Results from design-based analyses apply (with the precision given in a confidence interval or standard error about an estimate) to all fen, wet meadow, and riparian wetland in the park in 2007–2009. We present parkwide scale estimates in tables and with a variety of graphics. Parkwide scale status estimates provide baselines for future assessment.

2.3.3 Graphics and visualizations

We use five graphical formats to present data summaries.

First, we use box plots that show distributions of data across wetland type. These are usually for site scale status estimates across all best sample events. They include a median value and a 'box' that spans the 75th and 25th percentiles (or the interquartile range). Whiskers outside the boxes span a distance of 1.5* the interquartile range. We show all individual data points (those within and outside the whiskers are considered as outliers and extreme points, respectively).

Second, we use bar charts for count data as a visualization of site scale status estimates. Bar charts include whiskers for estimates of variance (usually a standard deviation).

Third, to show data spatially, we use maps of site scale values across space. These 'bubble' plots show variation in data values with color. When data fall into classes, we occasionally use pie charts as the point symbols.

Fourth, for parkwide estimates, we plot the cumulative distribution function (CDF) of values from lowest to highest. Values in CDFs are derived from design-based methods and estimate the value for a population (i.e., all the fen in the park) with known certainty. Estimates of this certainty are plotted on the CDF as a 95% confidence interval generated from a local neighborhood variance estimate

(Stevens 1997). CDFs are ideal ways to visualize the role of assessment points. Assessment points may be placed along the x-axis at a value where an ecological threshold or management decision point occurs. The percentage of wetland area and its known confidence above or below this assessment point may then be read off the x-axis. Assessments of this nature will be presented in future reports.

Finally, we use scatter plots across time for sentinel site data. These are usually symbolized by wetland type. Where the distribution of data allows it, we fit LOWESS (LOcally WEighted Scatter-plot Smoother) models to these to show qualitative patterns across time (Cleveland et al. 1998). This is a weighted, nonparametric sliding-window average that calculates a line of best fit (not a trend estimate) and a 95% confidence interval. Fitted points and their standard errors (used in the confidence interval) are estimated with respect to the whole curve rather than a particular data point.

3 Results and Discussion

3.1 Overview

The following sections present key results organized by response measure (i.e., disturbance, soil, vegetation) and wetland type. We include results at the parkwide scale, across all sites, and a more detailed treatment of the four sentinel complexes in Rocky Mountain National Park.

3.2 Data availability

This *Rocky Mountain National Park Wetland Ecological Integrity 2007–2017 Data Summary Report* and its corresponding data package are available on the NPS Integrated Resource Management Applications (IRMA) web portal: https://irma.nps.gov/DataStore/Reference/Profile/2253671.

3.2.1 Datasets

The data package includes links to the MS Access relational databases (.accdb) and MS Excel tabular summaries (.xlsx) for the Wetland Ecological Integrity (WEI) components:

Vegetation, disturbance, well measurements – raw data:
https://irma.nps.gov/DataStore/Reference/Profile/2253648

Soils:
https://irma.nps.gov/DataStore/Reference/Profile/2253673

Instructions for viewing depth to water continuous data on the Aquarius Web portal are here:
https://irma.nps.gov/DataStore/Reference/Profile/2253641

Additionally, two higher level data summaries are available as formatted tables:

1. Complete list of vegetation taxa (Rocky Mountain Network - NPS 2019a):
    a. Rocky Mountain NP WEI Species Table 2007-2017_20180515_StandAlone.xlsx
    b. https://irma.nps.gov/DataStore/Reference/Profile/2259528
2. Complete list of vegetation metrics (Rocky Mountain Network - NPS 2019b):
    a. Rocky Mountain NP WEI Metric Summary 20180523_StandAlone.xlsx
    b. https://irma.nps.gov/DataStore/Reference/Profile/2259529

The data and information summarized in this report and data package may have application to specific questions and issues regarding the park's wetlands and associated resources. Please contact Rocky Mountain Network staff, especially the network Ecologist leading wetland monitoring, for assistance in interpreting and applying network wetland data to specific questions or issues.

3.2.2 Protocol and publications

The *Rocky Mountain Network Wetland Ecological Integrity Monitoring Protocol* is on IRMA (https://irma.nps.gov/DataStore/Reference/Profile/2222993) along with other publications relevant to Rocky Mountain National Park wetlands. Network staff can also provide these documents.

3.3 Wetland extent

3.3.1 Overview

Area is often used as an indicator of the condition of wetland across a landscape. Many functions are more secure when wetlands are large or well buffered from disturbance. Vegetation remains more intact or diverse, and hydrologic services, like water storage and purification, are more enabled in larger wetlands. However, small isolated wetlands in Rocky Mountain National Park may also be intact and have high integrity, especially fens embedded in forests on the park's west side (Figure 8).



Figure 8. A relatively small isolated fen above the Kawuneeche Valley in Rocky Mountain National Park. NPS/B. SCHWEIGER 2008

3.3.2 Baseline wetland extent at the parkwide scale

We used the properties of the survey design to generate design-based estimates of parkwide extent by wetland type. These results are based on a site level evaluation (focused on vegetation, soil and a general evaluation of hydrology) of the extent of wetland extrapolated via design-based analysis to the entire park.

Alternative traditional map-based parkwide scale summaries are given in Appendix D. These estimates are based on existing remotely sensed data, including 1) National Wetland Inventory (NWI; USFWS 1991) data based on circa 1970 1:80k imagery hand digitized using Cowardin wetland types, and 2) NPS Vegetation Mapping ("VegMap") program data based on 1:12k, 2001 imagery hand digitized with park specific map units (Salas et al. 2005). These data and their summary are quite different from our field data design-based estimates but they provide a connection to historical/traditional estimates of wetland extent.

Table 3 gives all parkwide extent estimates. Of the three types, fen was the least extensive, with roughly equal areas of meadow and riparian wetland. Fens were also smaller on average, with a mean patch size roughly half that of the other two types. The lower and upper 95% confidence bounds on

these estimates are larger than we would like. Across all three types, these bounds suggest that wetland area might range from a low of about 400 ha up to about 8300 ha. We expect to improve these estimates when we resurvey WEI sites. Surprisingly, parkwide total wetland area in the park in 2007–2009 of about 4100 hectares is very similar to the NWI remotely sensed data from the 1970s (Appendix D). We think this is largely coincidence, but it is interesting, nonetheless.

Our data may be further examined via the error matrix or types of habitat found at each site other than the expected wetland type (Table 4). This suggests types most readily confused as well as the types that might be transitional from one to another. Other than the target habitat type, upland was the most common patch type in fens and riparian wetland (i.e., upland was commonly confused with or included in these wetland complexes). Riparian wetland was the least confused type, while wet meadow and fens were often confused for one another.

Table 3. Design-based estimates of wetland extent in Rocky Mountain National Park, 2007–2009, using Rocky Mountain Network wetland ecological integrity data. Total area and mean patch size by wetland type are given in hectares, with the standard error and 95% upper and lower confidence bounds.

	Parkwide wetland extent						
Wetland type	**Response**	**N**	**Estimate (ha)**	**SE**	**LCB**	**UCB**	**Percent of park area**
Fen	Total Area	33	914.55	461.81	9.42	1819.68	0.85
Fen	Mean Patch Size	33	0.21	0.09	0.04	0.39	–
Meadow	Total Area	40	1571.87	603.54	388.95	2754.79	1.46
Meadow	Mean Patch Size	40	0.37	0.13	0.12	0.62	–
Riparian wetland	Total Area	20	1654.44	1059.69	0.00	3731.39	1.53
Riparian wetland	Mean Patch Size	20	0.39	0.25	0.00	0.88	–
Total Area	N/A	–	**4140.9**	–	**400**	**8300**	**3.84**

Table 4. Error matrix for wetland types in evaluated wetland complexes, 2007–2009, using Rocky Mountain Network wetland ecological integrity data. Mean (and standard deviation; SD) percent area (over the 100 m^2 around each site) of each wetland type, upland, water, or other cover. Data are organized by the expected type for the complex, with the type predicted by the design in green.

Wetland type	**Metric**	**Fen %**	**Riparian wetland %**	**Wet Meadow %**	**Upland %**	**Water %**	**Other %**
Expected fen	Mean	40.30[a]	3.90	22.79	25.29	3.31	4.41
	SD	44.35[a]	15.17	37.23	37.47	16.43	19.56
Expected riparian wetland	Mean	0.70	37.42[a]	2.89	55.58	1.92	2.57
	SD	7.64	42.24[a]	14.55	43.76	11.33	13.44
Expected wet meadow	Mean	22.28	4.95	22.01[a]	44.81	2.14	3.81
	SD	37.50	19.44	35.19[a]	43.42	12.54	17.75

[a] Proportion of sites matching the type predicted by the design (also in green font).

3.4 Disturbance: human, ungulate, and beaver habitat use

We present human disturbance, and ungulate and beaver wetland use indicators in the following sections. First, we present baseline data across all sites (including spatially) and at the parkwide scale from our representative survey. We then report site-specific data from 2007 to 2017.

3.4.1 Overview—human use

Estimating both human and 'natural' disturbance across time and space and the response in wetland condition to these drivers is in many ways the core purpose of WEI monitoring. Wetlands are highly sensitive to anthropogenic and other disturbances. In general road-zone effects have been especially well documented (Boarman and Sazaki 2006, Palomino and Carrascal 2007, Wilbert et al. 2008, Parris and Schneider 2008, Eigenbrod et al. 2009). There is also evidence for impacts from both urban and exurban development (Odell and Knight 2001, Hansen et al. 2005, McDonald et al. 2009), energy development (BLM 1999, Wilbert et al. 2008, Nasen 2009, Lovich and Ennen 2011, Naugle 2011), and agriculture (Davis et al. 1993, de Jong et al. 2008).

More specifically for Rocky Mountain National Park, humans have directly and indirectly affected wetlands since before the park was established and during its early operations (Figure 9). Direct human alterations of hydrologic processes in the park include small scale features such as water supply reservoirs and drainage ditches, and, more significantly, large scale diversions that influence around 44% of the park's area.



Figure 9. Example of historical human disturbance as estimated by the Human Disturbance index (HDI). Road operations in Moraine Park, Rocky Mountain National Park, circa 1920. NPS/Rocky Mountain National Park

Other disturbances have directly removed or degraded wetland vegetation, soils, and buffer areas. For example, the park historically contained several commercial operations, including a golf course and ski area that caused local disturbances (i.e., cutting ski runs) and also larger scale effects from

supporting facilities. During the late 1800s and early 1900s, the park and private landowners planted Eurasian pasture grass species, especially in wetlands, to support trail stock and ranching operations.

Historical disturbances can have persistent impacts that interact with and add to the effects of current park operations and visitor support services (Figure 10). The park has always had high visitation, with approximately 3 million visitors each year since 1970 (NPS 2015) and more than 4 million in 2015, ranking the park third in visitation within the NPS.

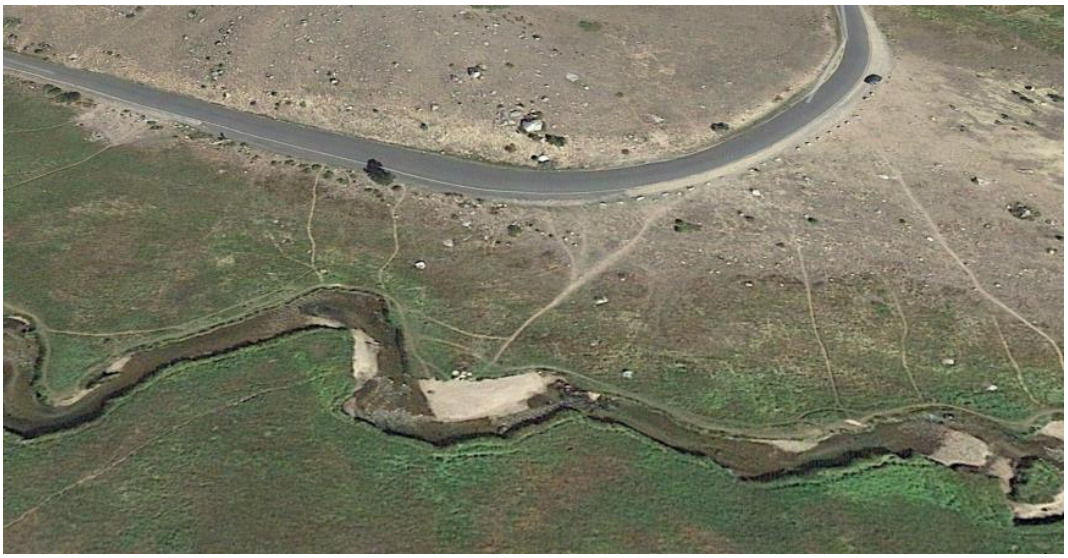


Figure 10. Example of human disturbances included in the Human Disturbance index (HDI), Moraine Park, Rocky Mountain National Park. Image shows riparian wetland adjacent to a road corridor with heavy social trails used by park visitors to access the Big Thompson River through the wetland. The Moraine Park sentinel wetland is just to the right of this image. NPS/Rocky Mountain National Park 2016.

3.4.2 Human disturbance: baseline

3.4.2.1 Site scale

Figure 11 shows HDI across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time, and patterns across these sites may best capture the range in condition. We infer status results to a parkwide scale in section 3.4.2.2 below. HDI is the primary metric for this important vital sign. Our results suggest that riparian wetland sites had higher median levels of human disturbance and slightly more variation than the other two wetland types. Riparian wetland sites are often in valley bottoms where front country visitor services are located and where historical human use was also concentrated.

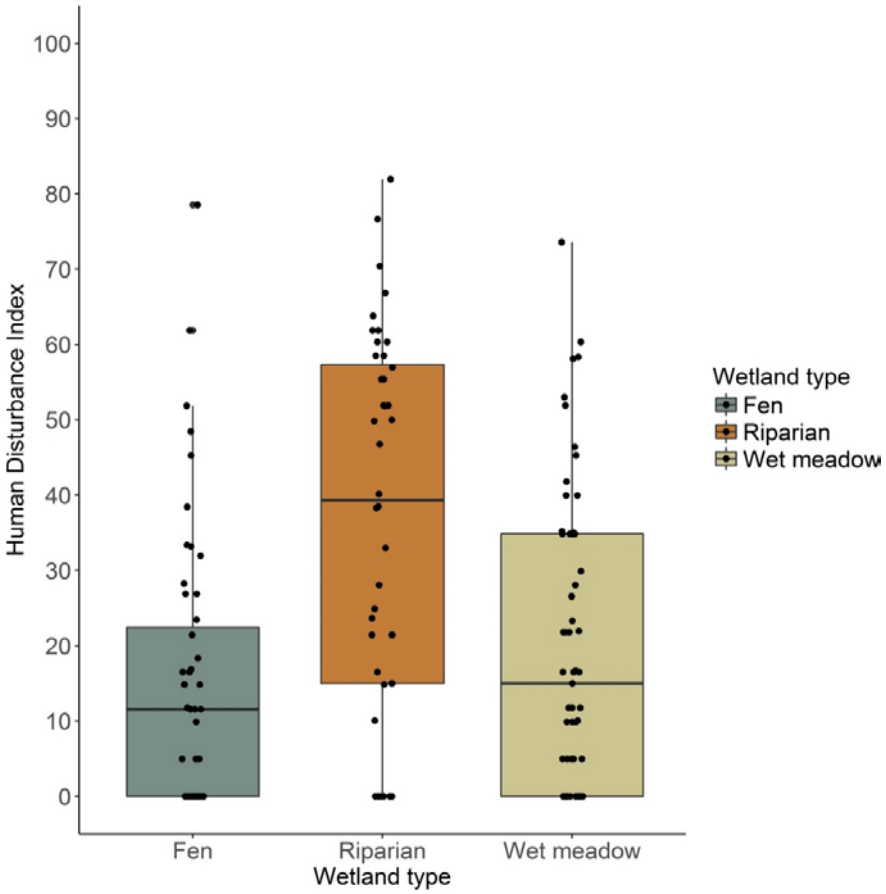


Figure 11. Human Disturbance Index (HDI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. HDI ranges from 0 (no measured human disturbance) to 100 (maximum human disturbance) and is constructed from a suite of landscape, hydrologic and physical disturbance submetrics. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Figure 12 shows the three summarized component metrics of HDI by wetland type across best events at all sites (see also Table 1 and Schweiger et al. 2015). Patterns are similar to HDI. They suggest that the most important relative influence on WEI fen sites is landscape disturbance. Fen sites are often remote with the only human stress coming at broad scales such as water diversions in their watershed.

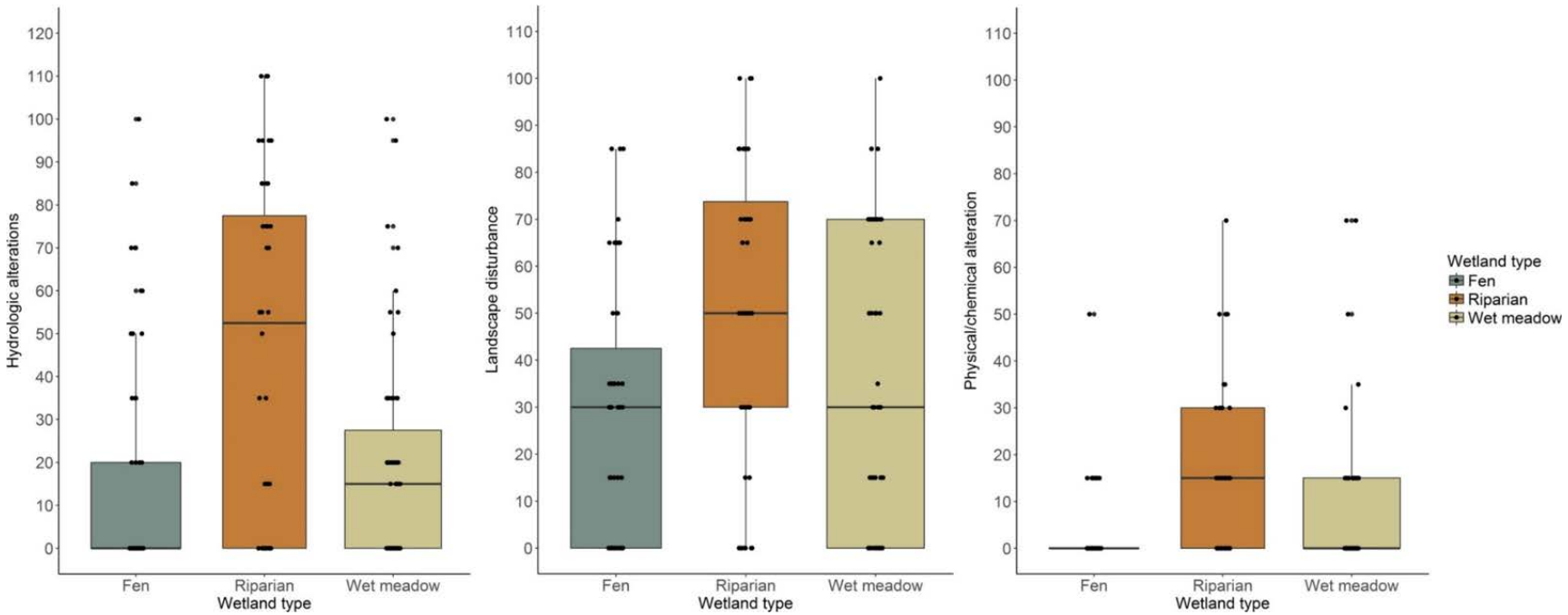


Figure 12. Baseline component metrics in the Human Disturbance Index (HDI) at wetland ecological integrity sites in Rocky Mountain National Park: (left) Hydrologic alteration, (center) Landscape disturbance, (right) Physical/chemical alteration. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). The dark horizontal line inside each box represents the median (if not visible this means the median is the same as the relevant quartile value). The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier. Some points overlap in select panels. The legend in the right graph applies to all panels.

Figure 13 presents two scales (wetland and its 100 m buffer) of another important disturbance indicator, composite human land use. This integrated metric ranges from 100, indicating natural land use in and around a wetland, to 0, suggesting an entirely anthropogenic matrix. Riparian wetland sites had more human disturbance, including recreation services, roads, and trails, than the other two types of wetland. Fens generally were more isolated, often with no human land use in or near them. We include this indicator as it was important in modeling relationships among wetland indicators and various stressors in Schweiger et al. (2016) and uses an intuitive continuous measurement scale we believe is more useful for resource management applications. It is also used by network wetland monitoring partners, including the USEPA (2015), and thus supports comparisons with partner data from outside the park.

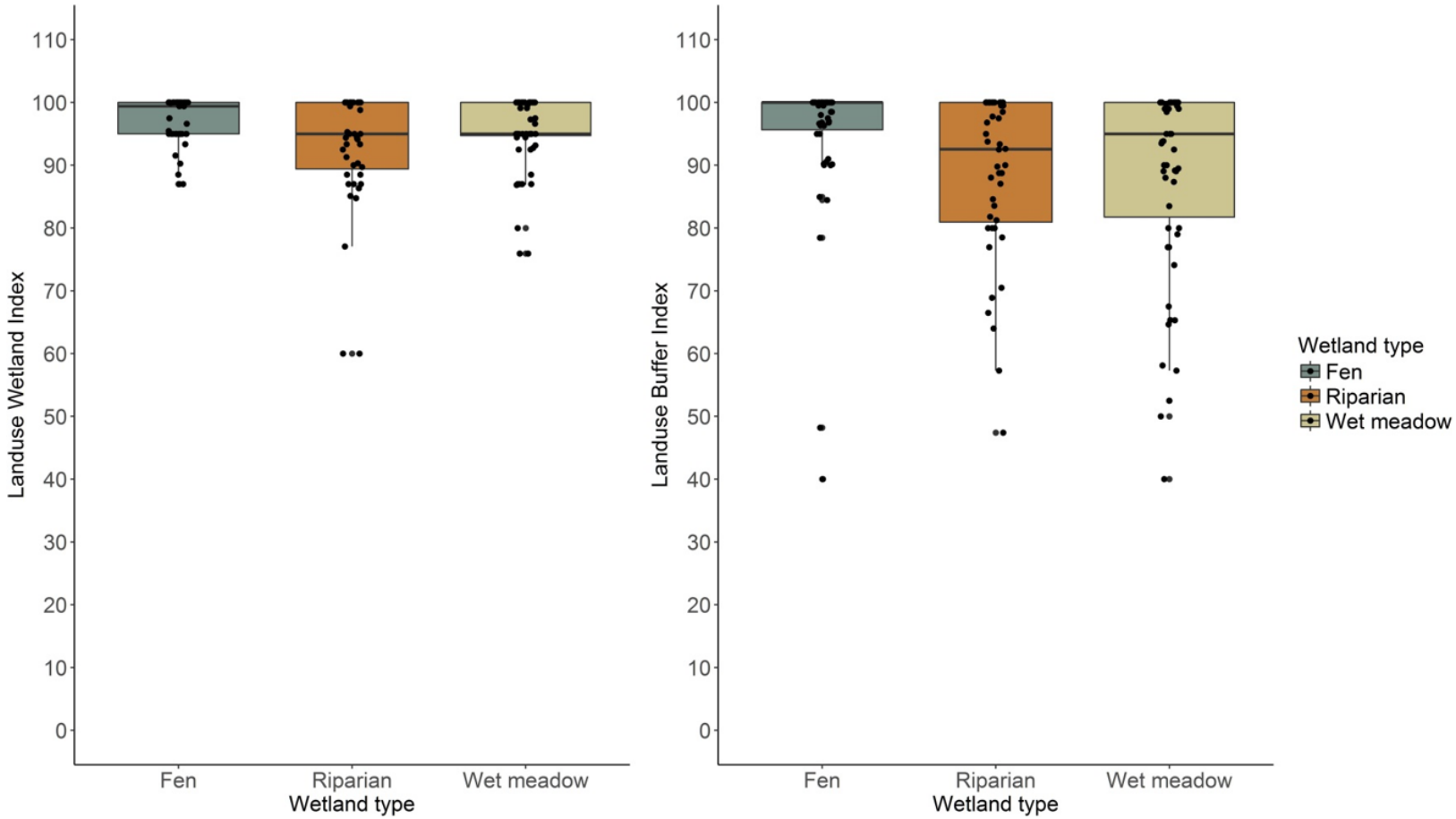


Figure 13. Baseline component metrics in the Human Disturbance Index (HDI) at wetland ecological integrity sites in Rocky Mountain National Park: (left) Landuse Wetland Index, (right) Landuse Buffer Index. Higher index values indicate less anthropogenic land use. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). The dark horizontal line inside each box represents the median (if not visible this means the median is the same as the relevant quartile value). The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier. Some points overlap in select panels. The legend in the right graph applies to both panels.

3.4.2.1.1 Spatial pattern

Figure 14 shows the spatial distribution of HDI at best events across all sites. These results largely reflect patterns noted above, with front country low elevation sites (especially riparian) more disturbed. This is most apparent for the Moraine Park and Kawuneeche Valley sentinel complexes. However, it also shows some interesting (and useful) outliers of more disturbed sites at higher elevations along Trail Ridge Road and along the Grand Ditch to the west of the Kawuneeche Valley.

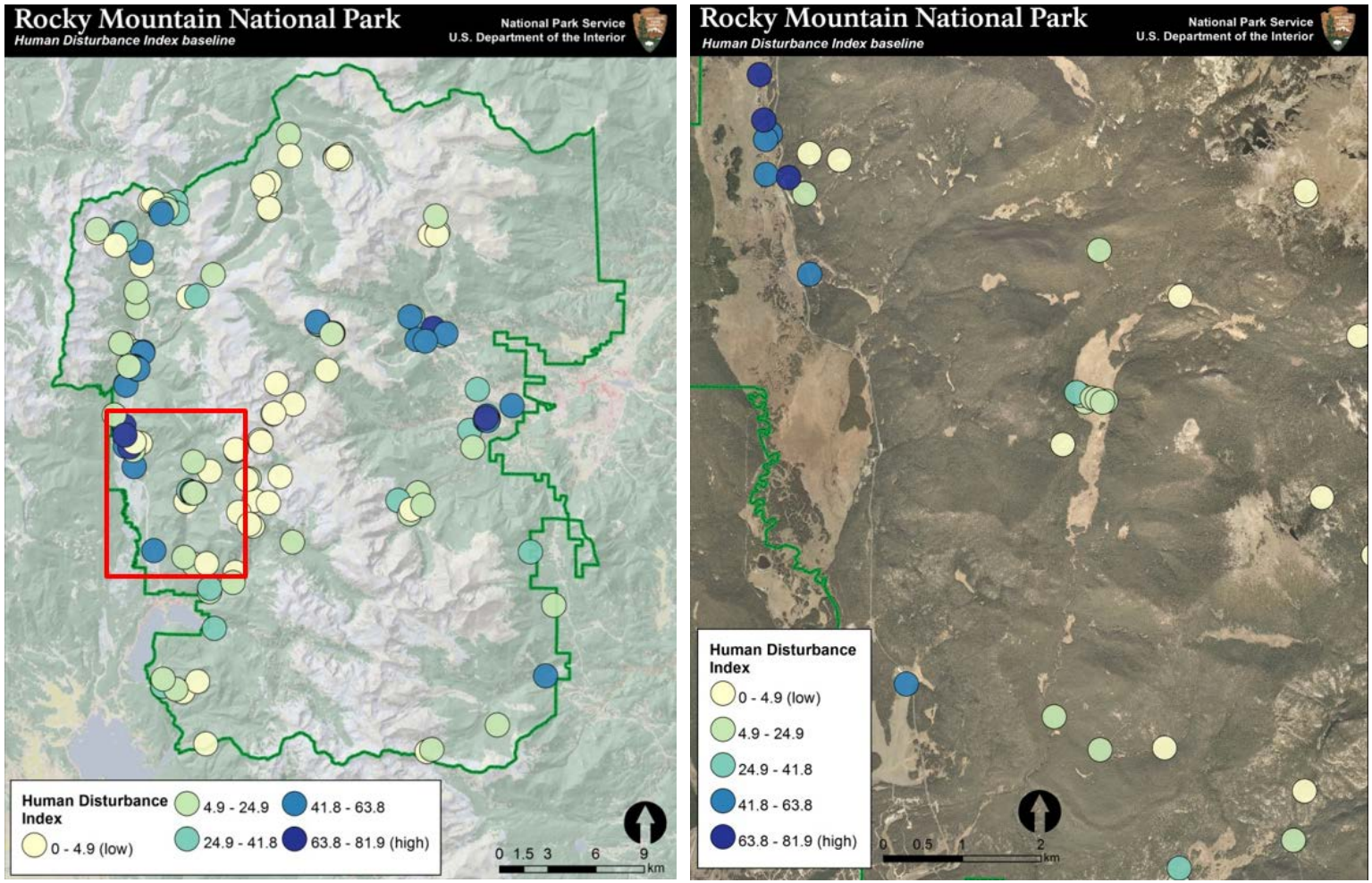


Figure 14. Map of the Human Disturbance Index (HDI) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box). The map on the right is an example of finer scale patterning. HDI ranges from 0 (no measured human disturbance) to 100 (maximum human disturbance) and is constructed from a suite of landscape, hydrologic, and physical disturbance submetrics. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker blue indicates sites with higher HDI and increasingly lighter shades of green to light yellow indicate less HDI. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.4.2.2 Parkwide scale

Table 5 presents design-based parkwide estimates from the 'best' survey sites for HDI and its component metrics across wetland type. There is a marked difference in HDI by wetland type across the park, with the populations of fens less disturbed than wet meadow and especially riparian wetland. This follows from the general tendency for riparian wetland to be located nearer stream corridors where roads, trails and other forms of current and legacy anthropogenic disturbance often exists. Moreover, fens are typically located in more complex topography, reducing the amount of infrastructure around them.

Table 5. Baseline parkwide summary statistics for Human Disturbance Index (HDI) and its component metrics for the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park, 2007–2017.[a]

Metric	Wetland type	Mean	SE	LCB	UCB
HDI	Fen	11.79	3.62	4.68	18.89
	Meadow	10.48	3.15	4.31	16.65
	Riparian wetland	21.96	11.99	0.00	45.46
	All	12.13	2.98	6.28	17.98
Hydrologic alteration	Fen	6.51	3.6.0	0.00	13.56
	Meadow	8.26	3.21	1.97	14.55
	Riparian wetland	24.2	16.87	0.00	57.26
	All	9.28	3.71	2.02	16.55
Landscape disturbance	Fen	27.08	6.99	13.39	40.78
	Meadow	21.82	6.41	9.26	34.38
	Riparian wetland	36.41	17.01	3.06	69.75
	All	25.19	5.21	14.98	35.4
Physical/chemical alteration	Fen	1.92	1.71	0.00	5.27
	Meadow	1.44	1.26	0.00	3.9
	Riparian wetland	5.22	2.86	0.00	10.84
	All	2.00	1.09	0.00	4.15
Landuse Wetland Index	Fen	96.68	1.00	94.72	98.64
	Meadow	96.48	0.87	94.78	98.18
	Riparian wetland	97.18	1.84	93.57	100.8
	All	96.62	0.50	95.64	97.61

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Table 5 (continued). Baseline parkwide summary statistics for Human Disturbance Index (HDI) and its component metrics for the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park, 2007–2017.[a]

Metric	Wetland type	Mean	SE	LCB	UCB
Landuse Buffer Index	Fen	96.64	1.57	93.56	99.72
	Meadow	93.76	2.81	88.24	99.27
	Riparian wetland	93.1	4.93	83.43	102.77
	All	94.71	1.81	91.17	98.25

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Figure 15 shows the cumulative distribution function (CDF) of HDI across wetland type. We only present select CDFs—others are available on request. The left y-axis shows the percent of the wetland in the park and the right y-axis gives the estimated area of wetland. The 95% confidence intervals (dotted lines) around the percent values (heavy line) are also shown. A CDF describes the 'value so far' of cumulative HDI from the lowest to highest score, moving from left to right. For example, compared across wetland type, the lower slope of the CDF for riparian wetland indicates this type had more area with higher human disturbance. However it is also clear that our confidence in the estimate is rather wide due to both lower sample size and higher levels of variation in HDI in riparian wetland. As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

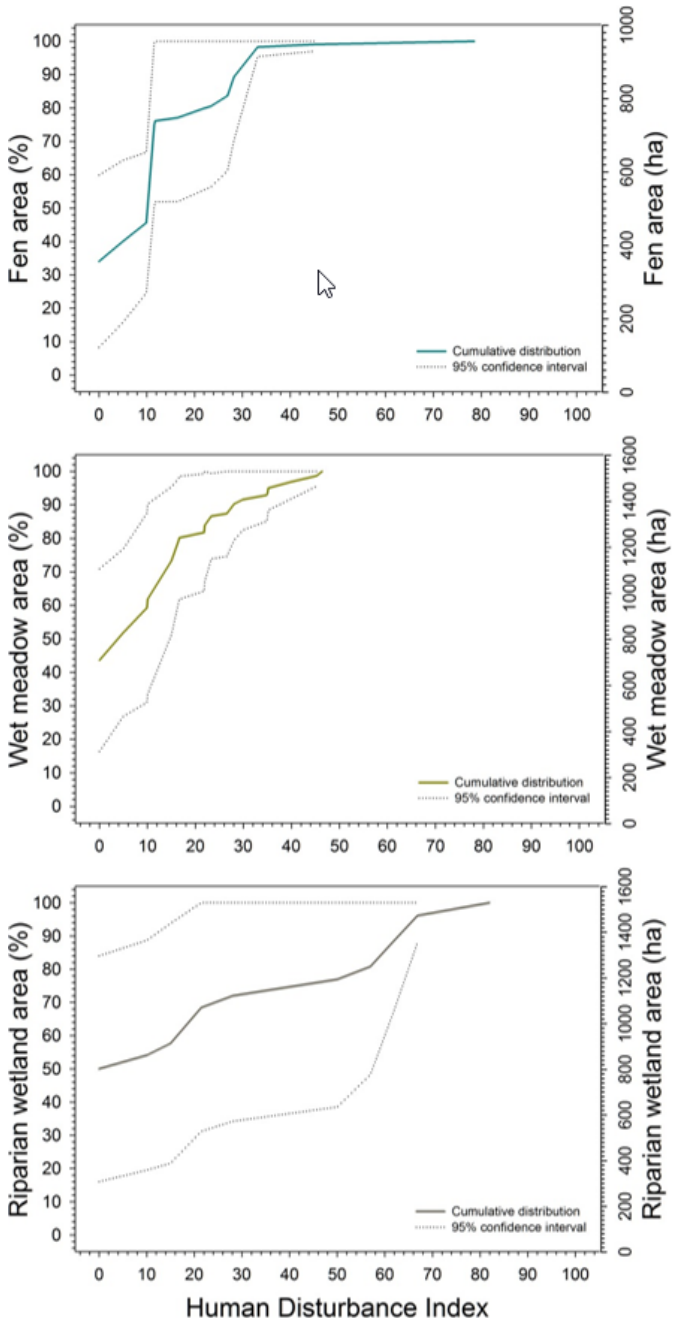


Figure 15. Human Disturbance (HDI) for the population of (top) fens, (center) wet meadows, and (bottom) riparian wetland in Rocky Mountain National Park. HDI ranges from 0 (no measured human disturbance) to 100 (maximum human disturbance) and is constructed from a suite of landscape, hydrologic and physical disturbance sub metrics. Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

3.4.3 Human disturbance: patterns across time at sentinel sites

Patterns across time at each of the four sentinel complexes in HDI and HDI component metrics are complex and will take careful modeling and assessment to better understand. General patterns in HDI revealed by Figure 16 include higher levels of HDI at the Kawuneeche Valley and Moraine Park sites, low to intermediate HDI levels at Big Meadows and generally low HDI levels at Alpine. There is some suggestion of declining levels in Kawuneeche Valley, increasing levels at Alpine, and perhaps increasing levels in Moraine Park during the golf course restoration in 2007–2009.

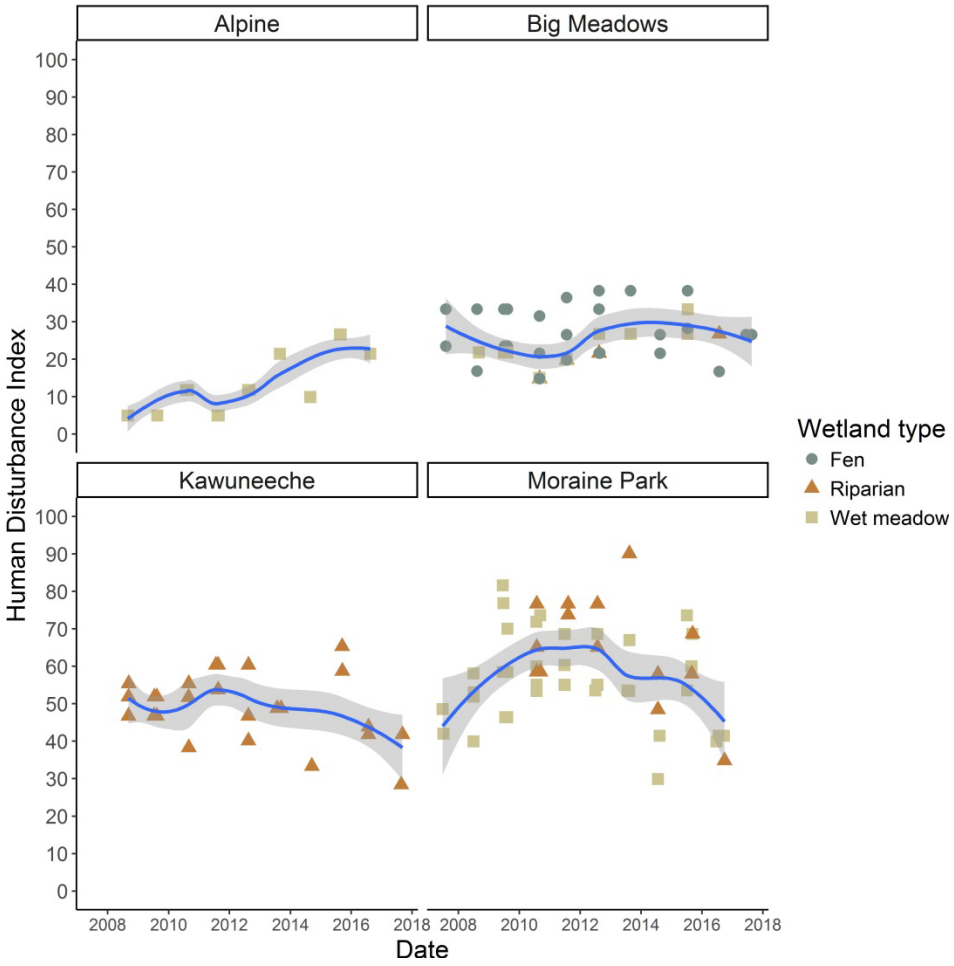


Figure 16. Human Disturbance Index (HDI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. HDI ranges from 0 (no measured human disturbance) to 100 (maximum human disturbance) and is constructed from a suite of landscape, hydrologic, and physical disturbance submetrics. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Data collection at Alpine and Kawuneeche began in 2009 and was missed in 2017 at the Alpine site.

Patterns across time at each of the four sentinel complexes in HDI component metrics are shown in Figure 17 and Figure 18. Figure 19 gives a photographic time series of site 505 in Moraine Park.

These require more complex analyses to fully interpret. However they largely mirror the overall HDI values at the sites. Of the three metrics, hydrologic alteration and landscape disturbance appeared to be both higher in HDI levels and more variable. These patterns were also seen in the modeling in Schweiger et al. (2016).

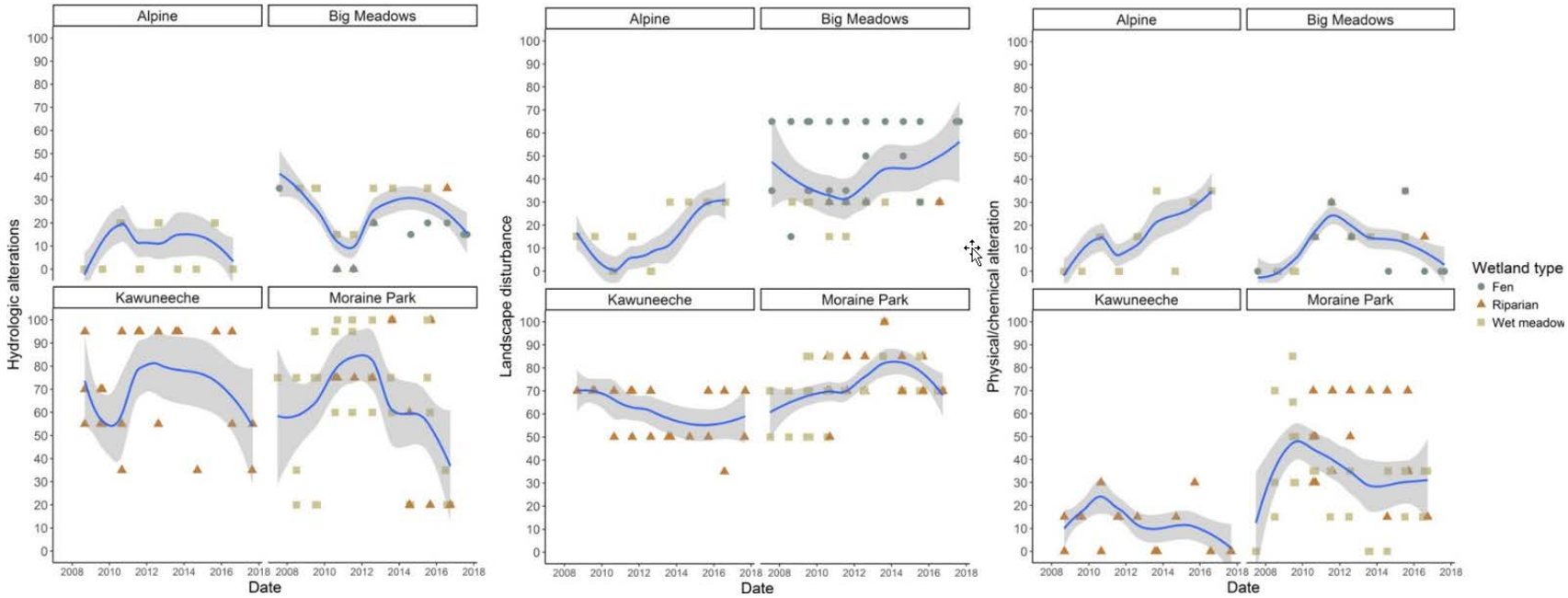


Figure 17. Component metrics in the Human Disturbance Index (HDI): (left) Hydrologic alteration, (center) Landscape disturbance, (right) Physical/chemical alteration at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Metric details are provided in main text. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). The legend in the right graph applies to all panels. Point symbology is based on wetland type with light blue circles for fens, brow triangles for wet meadows and light tan squares for riparian wetland. Some points overlap in select panels. Data collection at Alpine and Kawuneeche began in 2009 and was missed in 2017 at the Alpine site.

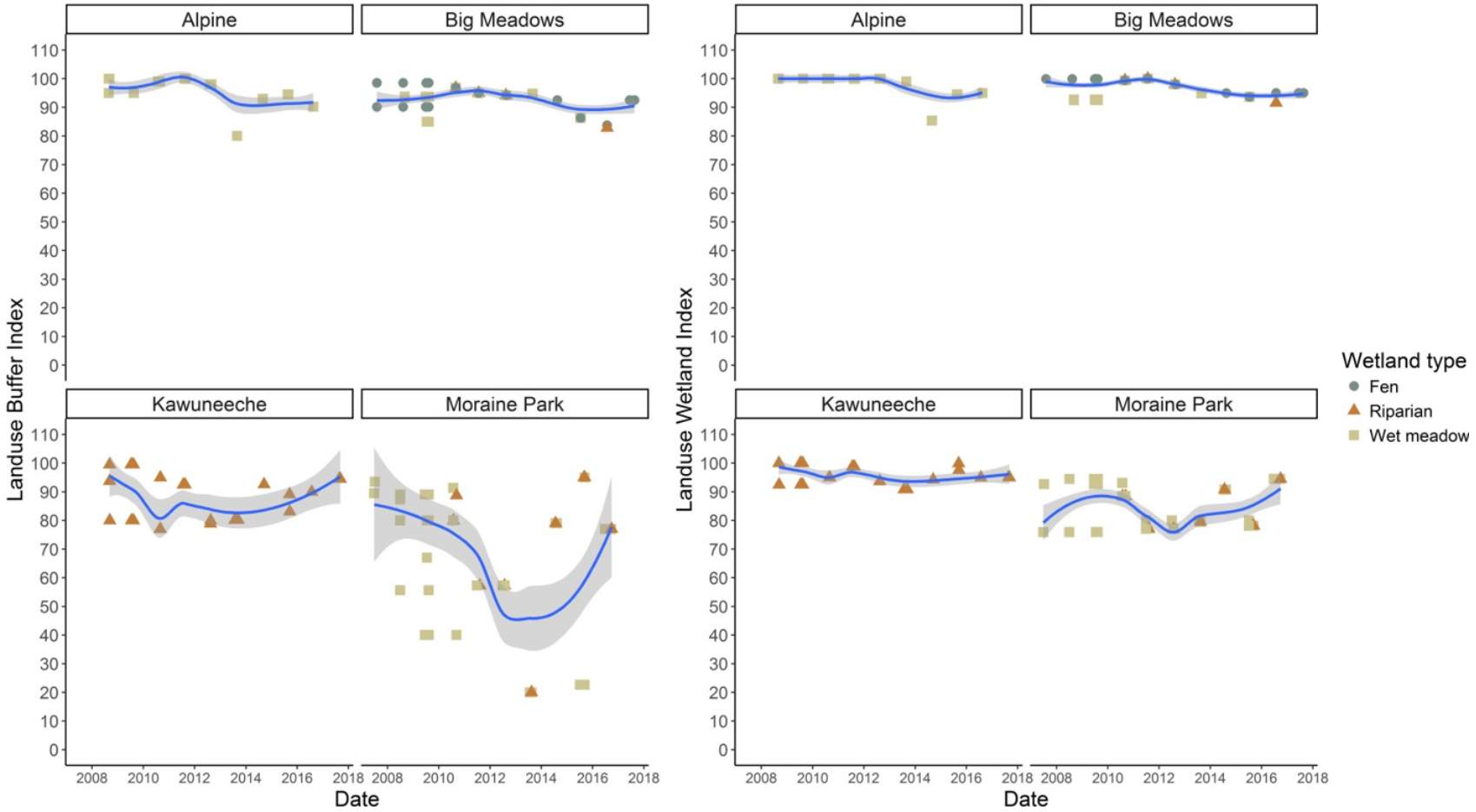


Figure 18. Component metrics in the Human Disturbance Index (HDI): (left) Landuse in buffer, (right) Landuse in wetland at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Metric details are provided in main text. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). The legend in the right graph applies to all panels. Some points overlap in select panels. Data collection at Alpine and Kawuneeche began in 2009 and was missed in 2017 at the Alpine site.



Figure 19. Example of change in human disturbance at Moraine Park sentinel site 505 in Rocky Mountain National Park in: (left) 2007, (center) 2009 and (right) 2015. General shifts in HDI and its component metrics are also seen in the data and LOWESS fits in Figure 16 and Figure 17. Note that some of the disturbance in the site is due to the park's active restoration efforts from 2007 to 2009.

3.4.4 Overview—ungulate and beaver habitat use

Large ungulates, including elk and nonnative moose, and beaver play important roles in wetland condition in Rocky Mountain National Park. Trapping nearly extirpated beaver by the 1940s (Packard 1947). Populations marginally recovered by the 1980s (Stevens and Christianson 1980). However, by the mid-1990s they were outcompeted by elk, and, more recently, by moose such that by 2015 there were likely only a few beaver resident in the park. Peak elk numbers in the early 2000s were at or above the carrying capacity of the winter range, as independently estimated by Hobbs et al. (1982) and Lubow et al. (2002). Moose were introduced to Colorado in 1978 (Bergman et al. 2013, CPW 2013), and these large wetland dependent herbivores were first observed in the park in the summer of 1980 (NPS 2007, Dungan et al. 2010). Moose numbers and range continued to increase through 2015 (J. Dungan, personal communication, 2015). While it is not clear if the effect of elk or moose on beaver and wetland condition is density dependent, research has shown that even at lower numbers, elk and moose do degrade wetlands and can outcompete beaver (Singer et al. 2002, Baker et al. 2012).

Ecosystem engineering by beaver has been a key driver of hydrologic regimes in many Rocky Mountain National Park wetlands (Figure 20; Westbrook et al. 2006, 2011). Yet beaver have not been a functional part of the park's wetlands since the mid-1990s (Singer et al. 1998, 2002, Baker et al. 2012) when elk exceeded their carrying capacity (Hobbs et al. 1982, Lubow et al. 2002, Coughenour 2002) and moose began to increase. The functional loss of beavers creates a detrimental positive feedback, with fewer beaver dams resulting in altered hydrologic regimes that no longer support recruitment of willows and other woody species that beavers use for forage and dam building materials.



Figure 20. Riparian wetland in Endo Valley, Rocky Mountain National Park, 2008. Site had intact willow stands and a diverse understory with many native forbs and high conservation value species and active beaver. NPS/B Schweiger

3.4.5 Ungulate and beaver habitat use: baseline

3.4.5.1 Site scale

Ungulate and beaver indicators are categorical or presence/absence in structure and require a different visualization than continuous data, such as the HDI. Figure 21 shows a histogram of the Ungulate Use Index (UUI) across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. There were no zero use sites across all three wetland types in the park. In other words, the 2007–2009 baseline for UUI suggests that all wetland sites in the park had at least some ungulate use.

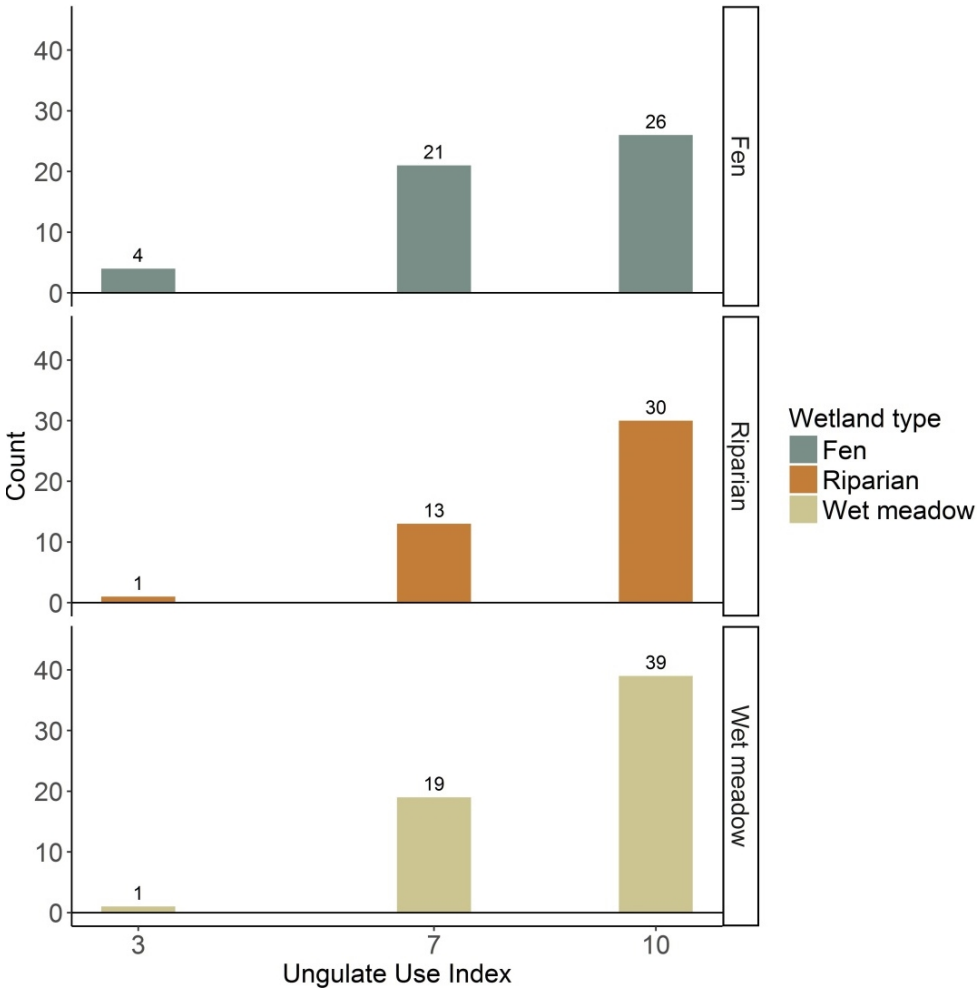


Figure 21. Baseline Ungulate Use Index (UUI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. UUI ranges from 0 (no ungulate use) to 10 (maximum ungulate use). Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). There were no zero (0) UUI sites in the baseline data set and this bin is not shown. Spacing between bars reflects the unequal distance between each class (i.e., medium use scores of 7 are closer to maximum use scores of 10 than the low use score of 3). Results are applicable to the sampled sites only. Y-axis is the count of sites in each class. There are 51 fen, 44 riparian wetland and 59 wet meadow sites.

Figure 22 gives a histogram of the Beaver Use Index (BUI) across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. In marked contrast with UUI, BUI suggests there are very few wetland sites in the park with beaver use. As discussed in the introduction above, beaver in the park are functionally absent. Essentially, only a few riparian wetland sites had beaver use in 2007–2009. Two sites, upper Endo Valley and Wild Basin, had both beaver use and actual beaver presence (see Figure 20).

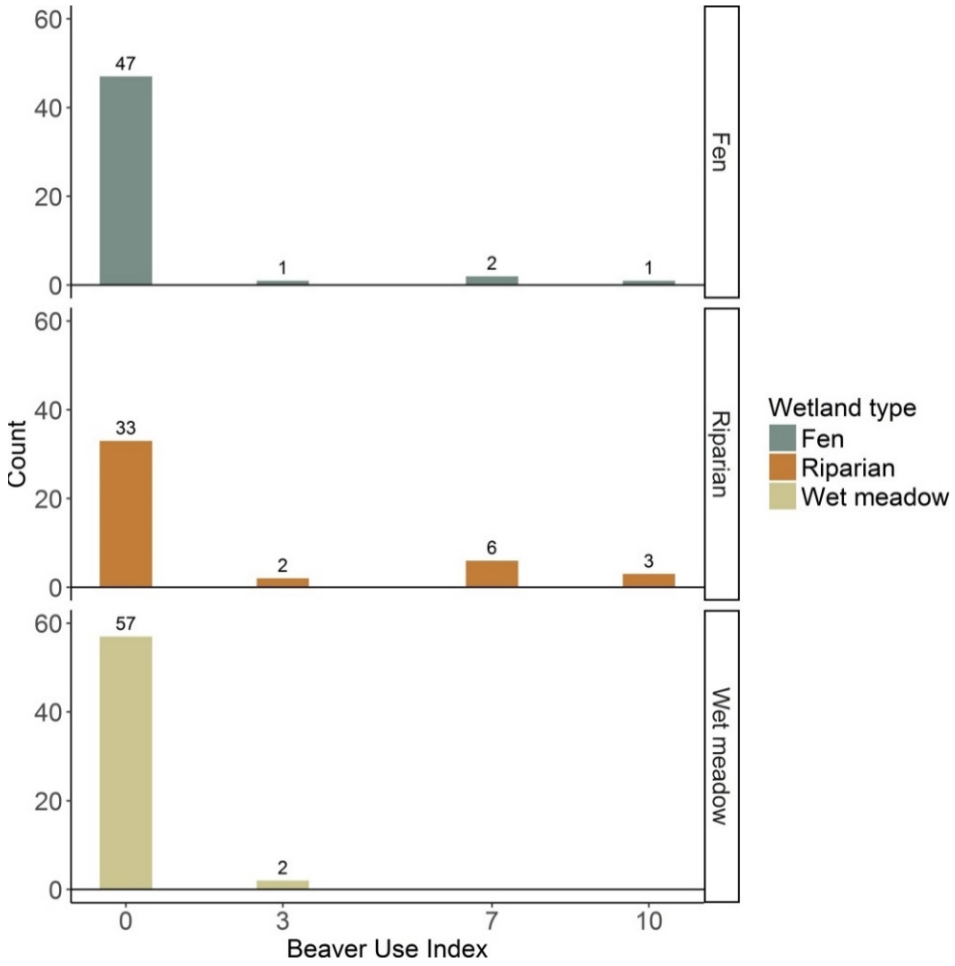


Figure 22. Baseline Beaver Use Index (BUI) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. BUI ranges from 0 (no beaver use) to 10 (maximum beaver use) and is estimated in the field using observations of dams, food caches, animal tracks, spoor, browse evidence and actual animal observations. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Spacing between bars reflects the unequal distance between each class (i.e., medium use scores of 7 are closer to maximum use scores of 10 than the low use score of 3). Results are applicable to the sampled sites only. Y-axis values are the count of sites in each class. There are a total of 51 fen, 44 riparian wetland, and 59 wet meadow sites.

Importantly BUI is only assessed in habitat that is viable beaver habitat. So for example we do not call high alpine meadows potential beaver habitat or sites with steep confined channels wetland where beaver would not be expected. This does not include woody vegetation as a prerequisite for viable habitat as this is not always historically knowable (a site could have had woody vegetation at one point with no evidence currently). So a site without current wood for food or lumber (i.e., Moraine Park) is still called viable habitat because of its topology. This constraint applies to all summaries of BUI presented in this report.

3.4.5.1.1 Spatial pattern

Figure 23 shows the spatial distribution of UUI at best events across all sites. These results largely reflect patterns noted above, with no sites with zero ungulate use and riparian valley bottom sites more utilized by elk and moose.

Figure 24 shows the spatial distribution of BUI at best events across all sites. These results largely reflect patterns noted above, with very few sites with any level of beaver use. Note that sites where there was no potential for beaver (and thus no possible BUI score) are indicated with different symbology. Two sites, upper Endo Valley and Wild Basin had both beaver use and actual beaver presence.

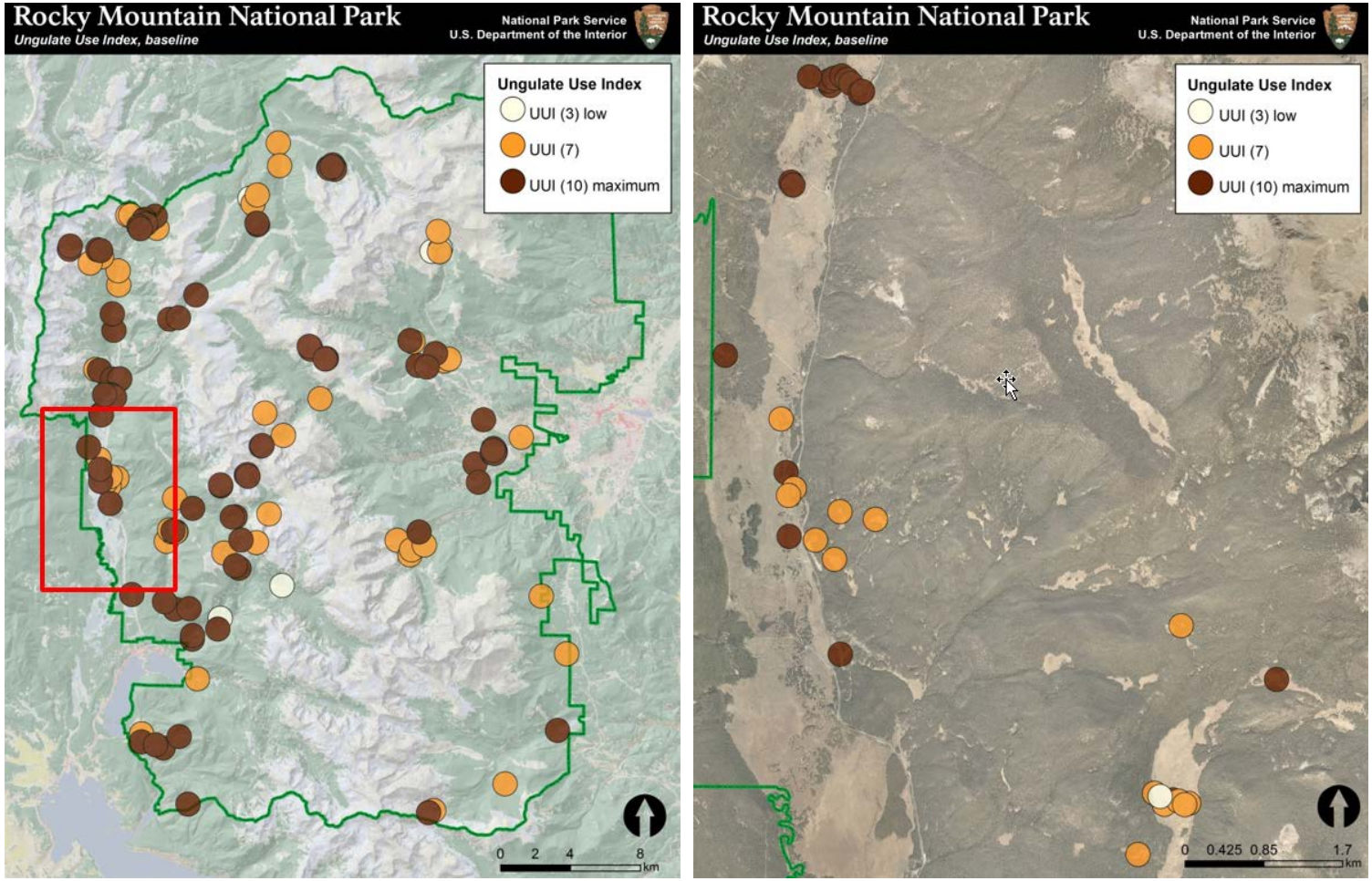


Figure 23. Map of Ungulate Use Index (UUI) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows areas (interior of the red box). The map on the right is an example of finer scale patterning. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). UUI ranges from 0 (no ungulate use) to 10 (maximum ungulate use) and is estimated in the field using observations of animal tracks, wallows, beds, spoor, browse evidence and actual animal observations. Note that there were no zero (0) UUI sites in the baseline data set. Darker brown indicates sites with higher UUI and increasingly lighter shades indicate a lower UUI. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

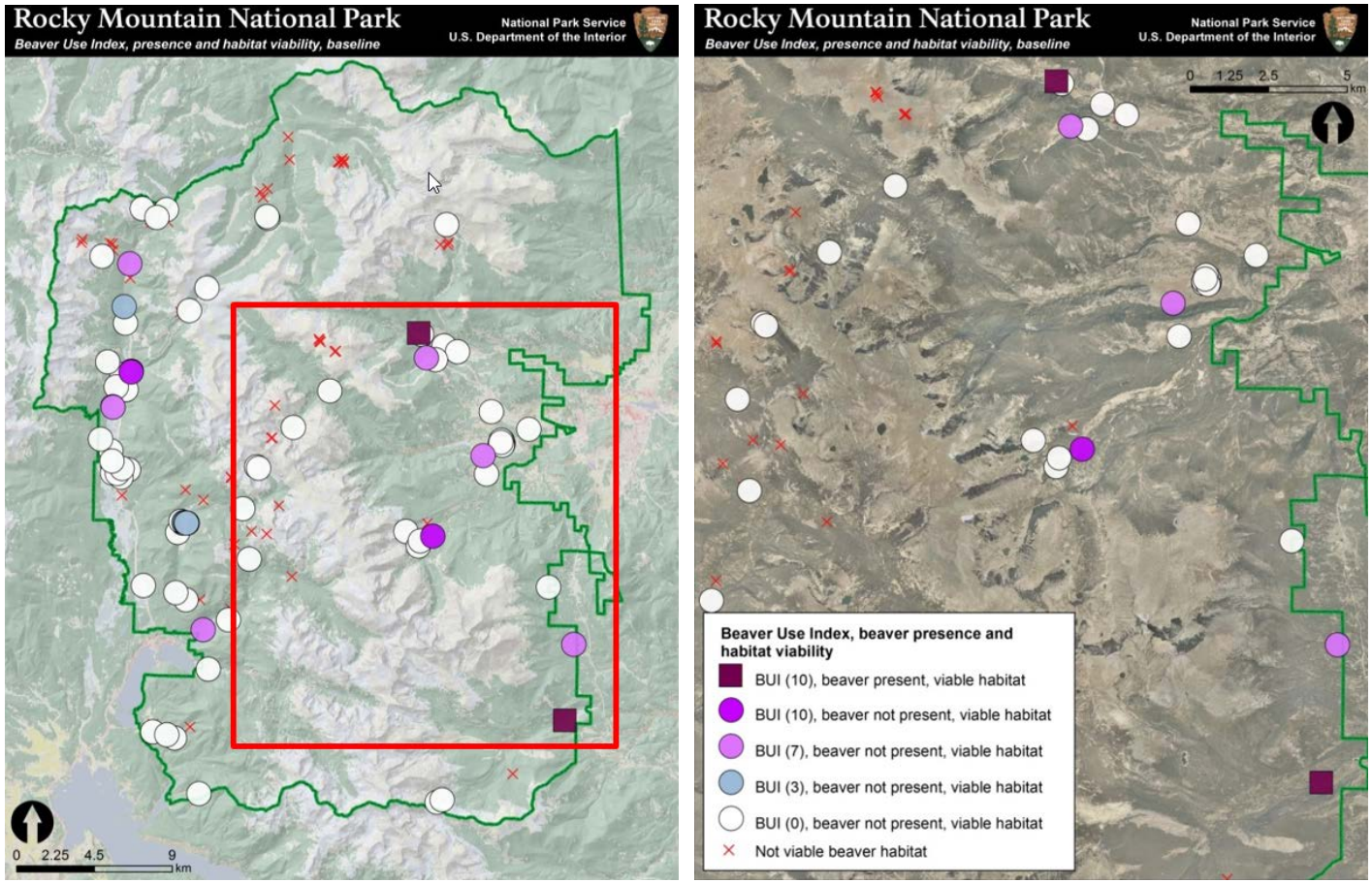


Figure 24. Map of Beaver Use Index (BUI), beaver presence and current beaver habitat viability at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the park's central eastern side (Moraine and Horseshoe Park and Wild Basin; interior of the red box). The map on the right is an example of finer scale patterning. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). BUI ranges from 0 (no beaver use) to 10 (maximum beaver use) and is estimated in the field using observations of dams, food caches, animal tracks, spoor, browse evidence and actual animal observations. Presence is defined by clear evidence of living beaver on or near the site at the time of sampling. Viability is based on woody vegetation, topography and stream slope. Dark purple (squares with actual beaver present, circles if not) indicates sites with higher BUI and increasingly lighter shades indicate a lower BUI. The legend in the right-hand map applies to both panels. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005). Two sites, upper Endo Valley and Wild Basin had both beaver use and actual beaver presence.

3.4.5.2 Parkwide scale

Table 6 presents parkwide results from the ‘best’ survey sites for UUI, BUI, beaver presence/absence, beaver viable habitat, and beaver historical influence indicators. Because these are all categorical responses, the structure of the design-based inference methods and the results generated vary from continuous responses.

Parkwide scale results largely reflect patterns at the site scale. Ungulate activity was pervasive across all wetland types, with the majority of area in all three types in medium high or high use classes.

For beaver, habitat use was (and is) a rare occurrence in Rocky Mountain National Park. This likely had a sampling effect on our survey and by random chance we did not include sites where beaver were currently active. Regardless, the patterns we see are reasonable, including relatively higher levels of beaver activity in riparian systems. Very little wetland area across all three types was classified as viable beaver habitat.

Table 6. Design-based proportion and total area in Ungulate Use Index (UUI) and Beaver Use Index (BUI) classes and a suite of beaver presence/absence and habitat viability indicators at wetland ecological integrity sites in Rocky Mountain National Park. Parkwide scale estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. Note that null response classes are not included here. For example there are no beaver activity classes in fens other than zero and we only show the zero class. Values at 100% of area have no standard error or confidence bounds and are left blank.[a]

Indicator	Wetland type	Category	N	%	SE prop	LCB prop	UCB prop	Area (m^2)	SE area	LCB area	UCB area
Beaver Use Index	Fen	None (0)	33	100	–	–	–	914.6	–	–	–
Beaver Use Index	Meadow	None (0)	40	100	–	–	–	1572	–	–	–
Beaver Use Index	Riparian	None (0)	18	93.3	5.2	83.2	100	1544	85.8	1376	1654
Beaver Use Index	All wetland	None (0)	91	99.3	0.5	98.3	100	4112	21.8	4069	4141
Beaver Use Index	Riparian	Med High (7)	1	3.4	3.7	0	10.6	56.5	60.4	0	174.9
Beaver Use Index	All wetland	Med High (7)	1	0.4	0.4	0	1.1	14.6	15.6	0	45.2
Beaver Use Index	All wetland	High (10)	1	0.3	0.4	0	1.1	13.9	15.2	0	43.7
Beaver Use Index	Riparian	High (10)	1	3.3	3.5	0	10.1	54	57.8	0	167.4
Beaver Historical Use Relevant	Fen	No	33	100	–	–	–	914.6	–	–	–
Beaver Historical Use Relevant	Meadow	No	40	100	–	–	–	1572	–	–	–
Beaver Historical Use Relevant	Riparian	No	18	93.3	5.2	83.2	100	1544	85.8	1376	1654
Beaver Historical Use Relevant	All Wetland	No	91	99.3	0.5	98.3	100	4112	21.8	4069	4141
Beaver Historical Use Relevant	Riparian	Yes	2	6.7	5.2	0	16.8	110.6	85.8	0	278.7

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Table 6 (continued). Design-based proportion and total area in Ungulate Use Index (UUI) and Beaver Use Index (BUI) classes and a suite of beaver presence/absence and habitat viability indicators at wetland ecological integrity sites in Rocky Mountain National Park. Parkwide scale estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. Note that null response classes are not included here. For example there are no beaver activity classes in fens other than zero and we only show the zero class. Values at 100% of area have no standard error or confidence bounds and are left blank.[a]

Indicator	Wetland type	Category	N	%	SE prop	LCB prop	UCB prop	Area (m^2)	SE area	LCB area	UCB area
Beaver Historical Use Relevant	All wetland	Yes	2	0.7	0.5	0	1.7	28.5	21.8	0	71.3
Beaver Habitat Potential	Fen	No	33	100	–	–	–	914.6	–	–	–
Beaver Habitat Potential	Meadow	No	40	100	–	–	–	1572	–	–	–
Beaver Habitat Potential	Riparian	No	19	96.6	3.7	89.4	100	1598	60.4	1480	1654
Beaver Habitat Potential	All wetland	No	92	99.6	0.4	98.9	100	4126	15.6	4096	4141
Beaver Habitat Potential	Riparian	Yes	1	3.4	3.7	0	10.6	56.5	60.4	0	174.9
Beaver Habitat Potential	All wetland	Yes	1	0.4	0.4	0	1.1	14.6	15.6	0	45.2
Beaver Present at Time of Sample	Fen	No	33	100	–	–	–	914.6	–	–	–
Beaver Present at Time of Sample	Meadow	No	40	100	–	–	–	1572	–	–	–
Beaver Present at Time of Sample	Riparian	No	20	100	–	–	–	1654	–	–	–
Beaver Present at Time of Sample	All wetland	No	93	100	–	–	–	4141	–	–	–
Ungulate Activity	Fen	Medium (3)	3	3.8	3.3	0	10.2	34.6	30.1	0	93.6
Ungulate Activity	Meadow	Medium (3)	1	5.2	5.8	0	16.7	81.8	91.9	0	261.8

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Table 6 (continued). Design-based proportion and total area in Ungulate Use Index (UUI) and Beaver Use Index (BUI) classes and a suite of beaver presence/absence and habitat viability indicators at wetland ecological integrity sites in Rocky Mountain National Park. Parkwide scale estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. Note that null response classes are not included here. For example there are no beaver activity classes in fens other than zero and we only show the zero class. Values at 100% of area have no standard error or confidence bounds and are left blank.[a]

Indicator	Wetland type	Category	N	%	SE prop	LCB prop	UCB prop	Area (m^2)	SE area	LCB area	UCB area
Ungulate Activity	Riparian	Medium (3)	1	4.1	4.4	0	12.6	67.8	72	0	208.9
Ungulate Activity	All wetland	Medium (3)	5	4.6	3.6	0	11.6	189.8	149.2	0	482.1
Ungulate Activity	Fen	Med High (7)	14	64.8	10.3	44.7	85	593	94.1	408.6	777.5
Ungulate Activity	Meadow	Med High (7)	16	65.7	12.8	40.6	90.8	1033	201.3	638	1427
Ungulate Activity	Riparian	Med High (7)	9	39.4	13.1	13.7	65.1	652.2	217.1	226.7	1078
Ungulate Activity	All wetland	Med High (7)	39	62.7	7.8	47.4	78	2595	322.8	1963	3228
Ungulate Activity	Fen	High (10)	16	31.4	9.5	12.7	50	286.9	87.1	116.2	457.7
Ungulate Activity	Meadow	High (10)	23	29.1	10.5	8.5	49.7	457.6	165	134.2	780.9
Ungulate Activity	Riparian	High (10)	10	56.5	13.5	30	82.9	934.4	223.4	496.6	1372
Ungulate Activity	All wetland	High (10)	49	32.7	6.9	19.2	46.3	1356	285.5	795.9	1915

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

3.4.6 Ungulate and beaver habitat use: patterns across time at sentinel sites

Patterns across time at each of the four sentinel complexes in UUI and BUI are complex and will take careful modeling and assessment to better understand. General insight from Figure 25 and Figure 26 include high levels of ungulate use across all complexes but with some suggestion of declining scores in later years. This may be due to the decreasing elk population size over this same time period (Ketz et al. 2016). Our UUI data are observational and we have not done formal trend models on these time series, so this should be interpreted with some caution. BUI was zero, with the exception of a low level of use in Big Meadows in early years, possibly from a transitory animal that crews saw evidence of in a season or two, or observer error.

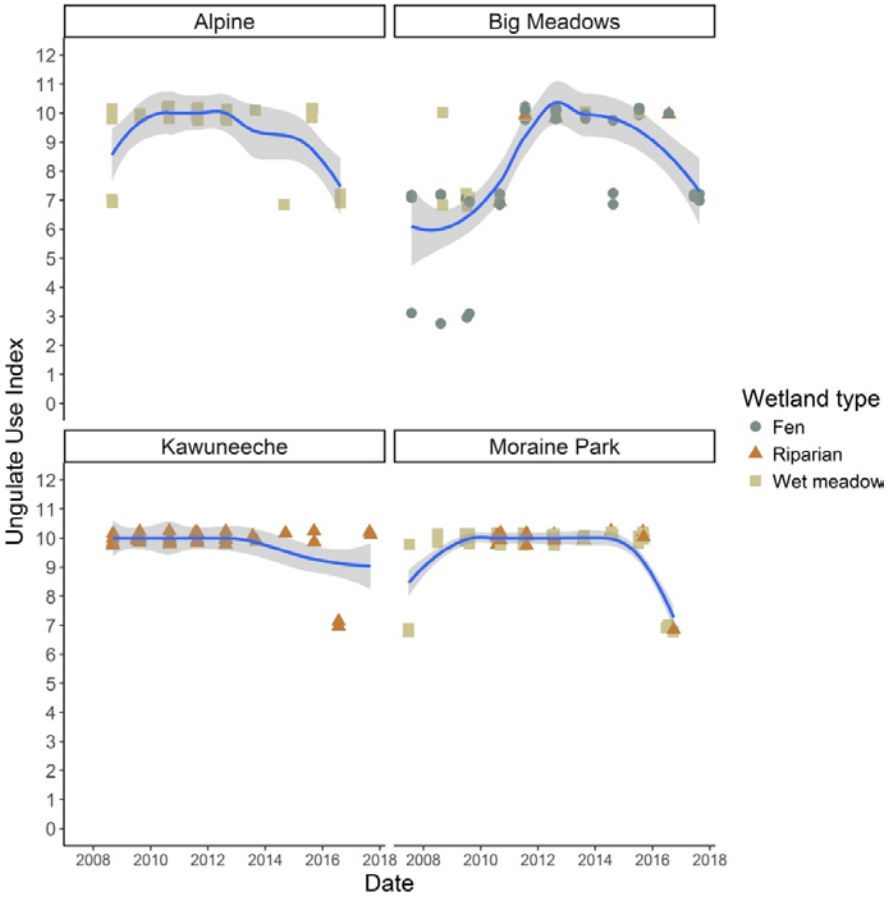


Figure 25. Ungulate Use index (UUI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. UUI ranges from 0 (no ungulate use) to 10 (maximum ungulate use) and is estimated in the field using observations of animal tracks, wallows, beds, spoor, browse evidence and actual animal observations. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Our UUI data are observational and we have not done formal trend models on these time series, so this should be interpreted with some caution. Point symbology is based on wetland type with light blue circles for fens, brow triangles for wet meadows and light tan squares for riparian wetland. Points are slightly offset so overlapping results are more visible. Data collection at Alpine and Kawuneeche began in 2009 and was missed in 2017 at the Alpine site.

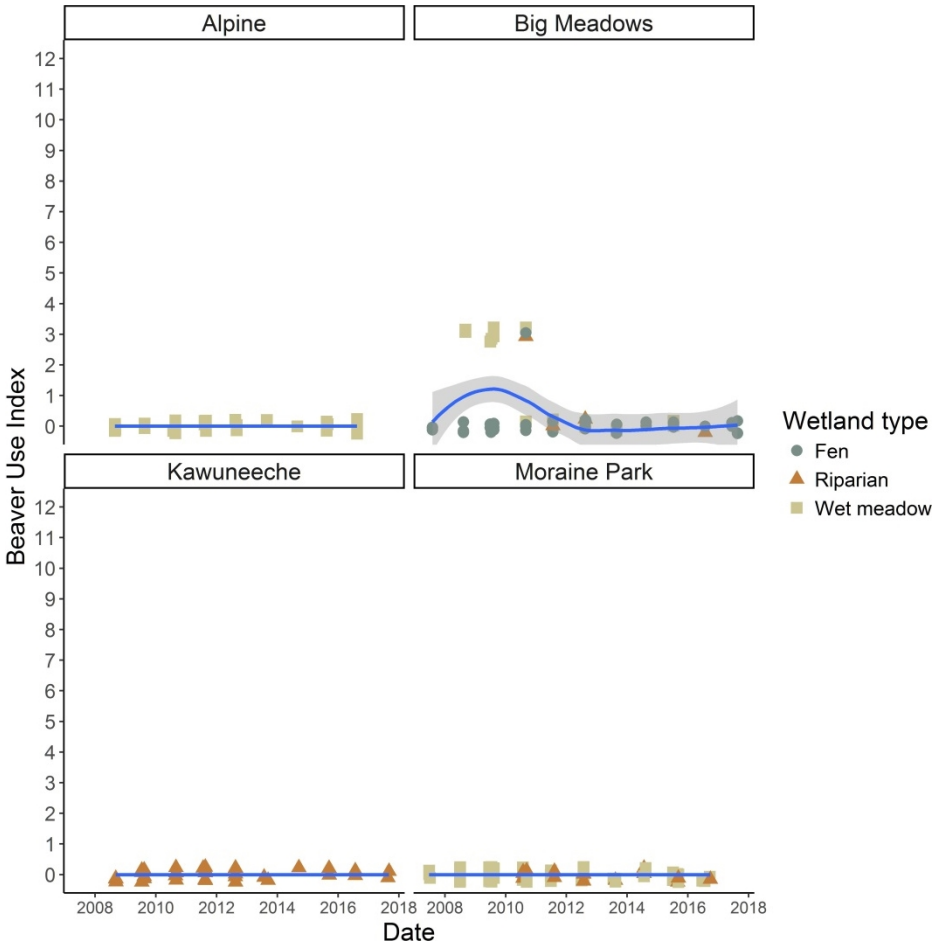


Figure 26. Beaver Use index (UUI) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. BUI ranges from 0 (no beaver use) to 10 (maximum beaver use) and is estimated in the field using observations of dams, food caches, animal tracks, spoor, browse evidence and actual animal observations. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Points are slightly offset so overlapping results are more visible. Data collection at Alpine and Kawuneeche began in 2009 and was missed in 2017 at the Alpine site.

3.5 Vegetation

3.5.1 Overview

Vegetation is a fundamental attribute of wetland ecosystems, driving basic ecosystem processes such as productivity, decomposition, and biogeochemical cycling (Figure 27). Plants largely control the exchange of gases such as O_2 and CO_2, affect processes of soil development, and as primary producers, influence the distribution of energy for higher trophic levels (Turetsky 2003). Wetland vegetation communities are speciose, with a diverse set of life histories that can respond in measurable ways to disturbance. Vegetation is easy and cost effective to measure, with a large literature on taxonomy, field methods, and analytical approaches. Vegetation is more or less immobile, so there are fewer issues than with mobile species regarding spatial disconnect between

response and disturbance. Vegetation can be an excellent indicator of changes in key environmental drivers such as climate mediated hydrologic regime (Cooper 1990, Ahn et al. 2004). Wetland plant communities are very responsive to changes in surface water levels (Cooke and Lefor 1990, Keough et al. 1999). Water levels are, in turn, often responsive to changes in climate. In freshwater wetlands, water levels typically increase during cool periods and decrease during warm periods (Winter 1988, Winter and Rosenberry 1995). Wetland vegetation can serve as an indicator of a variety of other wetland processes. For example, vegetation diversity is often related to patterns in groundwater flow and chemistry (Glaser et al. 1990, Shedlock et al. 1993). Vegetation is responsive to environmental change—in hydrology, soil condition, and land use—and can be a highly visible indicator of stress (Guntenspergen et al. 2002, Chipps et al. 2006). Conversely, wetland vegetation can also affect wetland function; invasive plants may change wetland geomorphology, hydrology, biogeochemistry, productivity, and biodiversity (Zedler and Kercher 2005). In general, wetland vegetation community composition is an excellent indicator of different combinations of climatic and hydrogeologic factors (Bedford et al. 1999). Overall, in intact ecosystems, with sustainable populations of ungulates (in large part because their apex predators are in place; Coughenour 2002), wetlands have higher ecological integrity; their vegetation is characterized by conservative taxa, is generally resistant to invasion, and depending somewhat on wetland type, has a higher cover of native forbs.

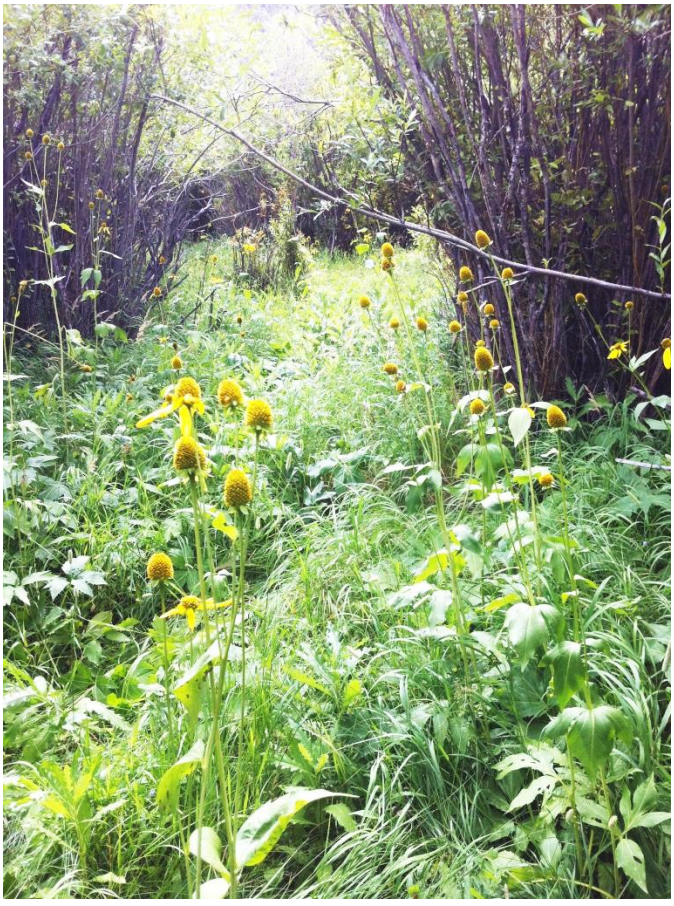


Figure 27. Understory wetland vegetation in Rocky Mountain National Park, 2009. This site has high ecological integrity (Schweiger et al. 2016). NPS/B. SCHWEIGER

WEI monitoring focuses on the estimation and the interpretation of the ecological integrity of wetlands in the park (Schweiger et al. 2015) using vegetation community composition. Ecological integrity is the capacity to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region (Karr 1991). It is a complex, multidimensional concept and usually a single indicator is insufficient to characterize it. Therefore, we use an integrated set of response measures, including community-level floristic composition and vegetation structure, hydrology, and soils. Our primary focus is on multimetric and multivariate indices of wetland ecological integrity from wetland vegetation data (Schweiger et al. 2015). We use indicators of stress, including anthropogenic, "natural," and ungulate overuse of habitat to help understand patterns in these responses and develop bioassessment models of wetland condition. These models and their assessment are summarized in an appendix to Schweiger et al. (2016) and will be further developed in future reports. For a detailed treatment of structural relationships between vegetation and other important WEI indicators, see Schweiger et al. (2016).

We first present a general summary of wetland community composition in the park, including tables of useful and interesting subsets of our vegetation database. We then present baseline data of select vegetation metrics across all sites (including spatially) and at the parkwide scale from our representative survey. We then report these metrics at site-specific scales using data from 2007 to 2017.

3.5.2 Community composition summary

From 2007 to 2017, 377 sample events had species level vegetation data. A complete taxa list is in Rocky Mountain Network - NPS (2019a). At most WEI sites, vegetation was typical of intact, mid to high elevation Rocky Mountain wetland habitat, dominated by obligate and facultative wetland taxa. We identified 659 taxa (562 to species) across all 377 sampled events, 2007–2017. There are an additional 239 records in the database as unknowns—most of these are unique but 60 were found more than once across all sample events. We only include species level records in our analyses.

Along with alpine habitat, wetland has the most diverse and unique vegetation in Rocky Mountain National Park. As of 2017, wetland species in our database comprise 38% of the 1530 known plant genera or species in the park (NPS 2019), in less than 4% of the park's total area. We expect to add approximately 120 species to the park's species list. This is perhaps the best indicator of the ecological value of wetlands to the park and of how vegetation serves as an effective indicator of this.

The five most frequent species across all sample events were, in order of frequency, *Carex aquatilis, Salix planifolia, Deschampsia cespitosa, Calamagrostis canadensis,* and *Carex utriculata.* In fens, the three most frequent taxa were *Carex aquatilis*, *Carex utriculata,* and *Pedicularis groenlandica*. In wet meadows, the three most frequent taxa were *Deschampsia cespitosa*, *Carex aquatilis,* and *Salix planifolia*. Finally, in riparian wetland, the three most frequent taxa were *Calamagrostis canadensis,* the nonnative, invasive (but naturalized) *Taraxacum officinale,* and *Salix planifolia.*

Total species richness was 223 in fens, 385 in wet meadows, and 419 in riparian wetland. Mean alpha diversity (or average taxa per plot) was 21.6 in fens, 27.95 in wet meadow and 36.97 in riparian wetland. Finally, beta diversity (a measure of the proportion of the total contained in each site or the similarity of a site or set of sites to the total) was 9.2 in fens, 12.20 in wet meadows, and 9.11 in riparian wetland. These simple summaries of biodiversity across wetland type suggest that in the park, fens are generally more species poor than the other two wetland types and that riparian wetland is the most speciose of the three. The dominant granitic bedrock geology in the park likely causes the nutrient poor groundwater inflow that supports fens and the nutrient limited flora of this wetland type. The more variable hydrology and small scale topographic variability in meadows and riparian wetland may lead to greater microhabitat structure and subsequent species diversity.

Table 7 presents 16 species from the park's species of concern list. This is a mix of invasive species, rare high conservation value species, and indicator species for wetlands. Of note, *Salix planifolia* was the second most common species in our data set. The park uses this species as a primary indicator of wetland habitat.

Table 8 presents 44 species with high conservation value (Rocchio 2007a, b). These taxa are scored as 10 or 9 and are species which are obligate to high-quality natural areas and can tolerate very little to no anthropogenic habitat degradation. For example *Anemone narcissiflora* var. *zephyra*, with a C score of 10, was found in 8 sample events at sites with very little human disturbance (Figure 28).



Figure 28. Narcissus-flowered anemone (*Anemone narcissiflora* var. *zephyr)* in Rocky Mountain National Park, 2009. This is a highly conservative (C score 10; Rocchio 2007a, b) species found in a few wetlands in the park. ©John Crossley, americansouthwest.net

Table 7. Rocky Mountain National Park species of concern at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table, see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Phalaris arundinacea	reed canary grass	Nonnative	0	8	1	10.25	37.35
Cirsium arvense	Canada thistle	Nonnative	0	7	59	3.37	2.88
Linaria vulgaris	butter and eggs	Nonnative	NA	6	1	5.75	5.10
Phleum pratense	timothy	Nonnative	0	5	99	5.81	4.88
Poa pratensis	Kentucky bluegrass	Nonnative	0	5	113	6.39	5.25
Agrostis gigantea	redtop	Nonnative	0	4	25	9.05	7.53
Cynoglossum officinale	gypsy flower	Nonnative	0	4	1	0.53	0.26
Hieracium aurantiacum	orange hawkweed	Nonnative	NA	4	1	12.40	7.78
Rumex crispus	curly dock	Nonnative	0	1	8	0.23	0.06
Populus tremuloides	quaking aspen	Native	5	NA	23	7.88	4.78
Salix bebbiana	Bebb willow	Native	6	NA	3	28.67	10.63
Salix geyeriana	Geyer willow	Native	6	NA	80	6.16	3.26
Salix monticola	park willow	Native	6	NA	81	8.16	4.56
Salix planifolia	diamond leaf willow	Native	7	NA	222	8.03	5.96
Viola selkirkii	Selkirk's violet	Native	NA	NA	3	0.20	0.04

Table 8. High conservation value species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA 2018. Conservatism (C scores) are from Rocchio (2007a, b) as modified by the ROMN and range from 10 (highly conservative) to 1 (very low conservatism with a 0 applied by definition to nonnative species)—the species in this table are all 9 or 10. All these species are natives as classified by Weber and Wittmann (2001) and modified by the Rocky Mountain Network. Count is the sum of all sample events taxa occurred in across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	C score	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Agrostis humilis	alpine bentgrass	10	34	2.63	1.82
Anemone narcissiflora var. *zephyra*	narcissus anemone	10	8	0.64	0.32
Arnica longifolia	spearleaf arnica	10	1	2.67	1.89
Carex lachenalii	twotipped sedge	10	3	4.10	6.13
Carex nova	black sedge	10	16	1.95	2.21
Epilobium clavatum	talus willowherb	10	1	1.01	1.77
Juncus biglumis	twoflowered rush	10	3	2.17	2.58
Juncus triglumis	three-hulled rush	10	21	3.76	2.92
Mitella stauropetala var. *stenopetala*	drywoods miterwort	10	9	1.42	1.10
Ranunculus macauleyi	Rocky Mountain buttercup	10	1	0.50	0.07
Saxifraga caespitosa ssp. *delicatula*	tufted alpine saxifrage	10	1	2.00	0.36
Actaea rubra ssp. *arguta*	red baneberry	9	11	1.66	0.20
Betula glandulosa	resin birch	9	61	5.21	3.13
Cardamine pensylvanica	Pennsylvania bittercress	9	1	0.05	0.01
Carex bella	southwestern showy sedge	9	1	0.05	0.01

Table 8 (continued). High conservation value species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA 2018. Conservatism (C scores) are from Rocchio (2007a, b) as modified by the ROMN and range from 10 (highly conservative) to 1 (very low conservatism with a 0 applied by definition to nonnative species)—the species in this table are all 9 or 10. All these species are natives as classified by Weber and Wittmann (2001) and modified by the Rocky Mountain Network. Count is the sum of all sample events taxa occurred in across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	C score	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Carex brunnescens	brownish sedge	9	15	22.51	22.24
Carex buxbaumii	Buxbaum's sedge	9	3	0.26	0.23
Carex capillaris	hair-like sedge	9	12	12.11	5.07
Carex disperma	softleaf sedge	9	20	2.39	1.04
Carex echinata ssp. *echinata*	star sedge	9	15	3.98	5.36
Carex illota	sheep sedge	9	31	9.58	8.14
Carex magellanica ssp. *irrigua*	boreal bog sedge	9	18	1.47	1.00
Carex microglochin	fewseeded bog sedge	9	2	1.53	0.26
Carex nelsonii	Nelson's sedge	9	21	1.10	0.93
Carex phaeocephala	dunhead sedge	9	1	1.00	0.20
Carex praeceptorum	early sedge	9	11	5.39	4.16
Cystopteris fragilis	brittle bladderfern	9	1	0.05	0.01
Eriophorum angustifolium	tall cottongrass	9	34	1.18	1.32
Gentiana algida	whitish gentian	9	27	2.06	1.56
Gentiana prostrata	pygmy gentian	9	2	0.28	0.17

Table 8 (continued). High conservation value species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA 2018. Conservatism (C scores) are from Rocchio (2007a, b) as modified by the ROMN and range from 10 (highly conservative) to 1 (very low conservatism with a 0 applied by definition to nonnative species)—the species in this table are all 9 or 10. All these species are natives as classified by Weber and Wittmann (2001) and modified by the Rocky Mountain Network. Count is the sum of all sample events taxa occurred in across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	C score	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Juncus bryoides	moss rush	9	2	12.50	9.69
Juncus castaneus	chestnut rush	9	17	2.50	2.98
Juncus filiformis	thread rush	9	8	2.14	1.39
Kalmia microphylla	alpine laurel	9	14	3.06	2.08
Kobresia myosuroides	Bellardi bog sedge	9	5	4.62	1.89
Koenigia islandica	island purslane	9	14	2.14	3.42
Linnaea borealis ssp. *americana*	twinflower	9	5	0.14	0.06
Listera borealis	northern twayblade	9	1	0.05	0.01
Listera cordata var. *nephrophylla*	heartleaf twayblade	9	9	0.70	0.43
Mitella pentandra	Five stamen miterwort	9	6	1.28	0.97
Moneses uniflora	single delight	9	1	0.05	0.01
Pedicularis parryi	Parry's lousewort	9	12	1.04	0.78
Platanthera sparsiflora var. *ensifolia*	sparse-flowered bog orchid	9	1	1.00	0.67
Salix nivalis	snow willow	9	7	2.25	1.57

Table 9 presents 43 invasive nonnative species (Morse et al. 2004). These taxa can negatively affect the native species and other natural biodiversity within the park, often by outcompeting or hybridizing with native species, or by altering ecological communities or ecosystem processes. They also maintain themselves or recurrently appear in conservation areas or other native species habitats. The most common invasives were *Taraxacum officinale, Poa pratensis,* and *Phleum pratense*. These species had I rank scores of 3 or 5 and likely have more mild impacts to wetland flora. On the other extreme *Phalaris arundinacea* (Table 9, Figure 29), with an I rank score of 8, (while only found once in our data set in a survey site sampled in 2008) has increased at other sites in the park that we do not currently sample as part of the WEI protocol and is excluding many native species. These sites tend to be in front country with many complex sources of current and historical human disturbance.

Table 9. Invasive species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA (2019). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the Rocky Mountain Network and ranges from 0 for a species with no invasive impacts to 8 for a species with likely extensive detrimental impacts to wetland communities. All of these species are nonnatives as classified by Weber and Wittmann (2001), as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Phalaris arundinacea	reed canary grass	8	1	10.25	37.35
Bromus inermis spp. *inermis* var. *inermis*	smooth brome	7	8	2.09	1.72
Cirsium arvense	Canada thistle	7	59	3.37	2.88
Hordeum murinum spp. *glaucum*	smooth barley	6	1	0.05	0.04
Linaria vulgaris	butter and eggs	6	1	5.75	5.10
Madia glomerata	mountain tarweed	6	9	0.85	1.21
Poa compressa	Canada bluegrass	6	11	1.44	1.31
Schedonorus pratensis	meadow fescue	6	2	0.78	0.54
Ceratodon purpureus	ceratodon moss	5	3	2.09	0.83
Phleum pratense	timothy	5	99	5.81	4.88
Poa pratensis	Kentucky bluegrass	5	113	6.39	5.25
Agrostis gigantea	redtop	4	25	9.05	7.53
Agrostis stolonifera	creeping bentgrass	4	1	0.37	0.24
Arabis glabra	tower rockcress	4	1	0.05	0.01
Cynoglossum officinale	gypsy flower	4	1	0.53	0.26

Table 9 (continued). Invasive species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA (2019). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the Rocky Mountain Network and ranges from 0 for a species with no invasive impacts to 8 for a species with likely extensive detrimental impacts to wetland communities. All of these species are nonnatives as classified by Weber and Wittmann (2001), as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Descurainia sophia	herb sophia	4	4	2.53	1.24
Encalypta ciliata	fringed candle snuffer moss	4	2	0.83	0.92
Galium aparine	stickywilly	4	7	0.41	0.28
Hesperis matronalis	dames rocket	4	1	0.53	0.28
Hieracium aurantiacum	orange hawkweed	4	1	12.40	7.78
Nasturtium officinale	watercress	4	2	0.05	0.02
Panicum capillare	witchgrass	4	1	0.05	0.01
Rumex acetosella	common sheep sorrel	4	8	1.02	1.86
Salix alba	white willow	4	1	17.50	4.00
Sonchus arvensis	field sowthistle	4	2	0.05	0.01
Tragopogon lamottei	(blank)	4	2	0.53	0.44
Trifolium hybridum	alsike clover	4	39	5.11	3.66
Trifolium repens	white clover	4	39	4.00	3.29
Agrostis exarata	spike bentgrass	3	1	0.05	0.03
Camelina microcarpa	littlepod false flax	3	1	0.05	0.03

Table 9 (continued). Invasive species at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Nomenclature follows USDA (2019). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the Rocky Mountain Network and ranges from 0 for a species with no invasive impacts to 8 for a species with likely extensive detrimental impacts to wetland communities. All of these species are nonnatives as classified by Weber and Wittmann (2001), as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Cerastium fontanum	common mouse-ear chickweed	3	25	0.41	0.21
Juncus effusus	common rush	3	1	0.05	0.01
Plantago major	common plantain	3	8	0.24	0.06
Poa annua	annual bluegrass	3	1	1.64	1.66
Potentilla norvegica	Norwegian cinquefoil	3	10	0.77	0.28
Taraxacum officinale	common dandelion	3	116	1.59	1.25
Alopecurus pratensis	meadow foxtail	2	16	10.16	6.90
Pohlia nutans	pohlia moss	2	10	0.96	0.35
Spergularia maritima	media sandspurry	2	1	0.05	0.01
Weissia controversa	controverial weissia moss	2	1	0.05	0.11
Rumex crispus	curly dock	1	8	0.23	0.06
Thlaspi arvense	field pennycress	1	8	0.22	0.11
Trifolium pratense	red clover	1	7	1.45	0.76



Figure 29. Highly invasive (I rank score 8; Morse et al. 2004) reed canary grass (*Phalaris arundinacea)* in the foreground of this image taken at a wetland in Kawuneeche Valley, Rocky Mountain National Park, 2017. This species is rapidly gaining a foothold in this valley and other areas of the park. Note also the heavily damaged woody stems in the background. NPS/B. SCHWEIGER

Table 10 presents 103 nonvascular taxa found at WEI sites. We highlight this as a legacy element of the WEI protocol as we no longer collect species level nonvascular data (due to the difficulty and extra cost of identifying mosses and other nonvascular plants to species). Forty-two of the taxa in this list are new to the park (NPS 2019). These include 3 species of *Sphagnum* (*S. angustifolium. S. contortum, S. girgensohnii*) that if confirmed would be novel range expansions of these interesting mosses. Nonvascular taxa are usually higher conservation value and native.

Table 10. Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Amblystegium riparium	none	Native	NA	NA	46	2.51	1.39
Amblystegium serpens var. *juratzkanum*	Juratzk's amblystegium moss	Native	6	NA	3	1.95	0.69
Aulacomnium	aulacomnium moss	Unknown	NA	NA	1	0.05	0.01
Aulacomnium androgynum	aulacomnium moss	Native	6	NA	4	4.50	1.37
Aulacomnium palustre	aulacomnium moss	Native	8	NA	138	5.90	3.11
Barbilophozia lycopodioides (Wallr.) *Loeske*	none	Native	8	NA	3	4.35	2.06
Bartramia subulata	bartramia moss	Native	6	NA	1	0.05	0.01
Blasia pusilla L.	none	Native	NA	NA	8	2.23	0.81
Brachythecium	brachythecium moss	Native	NA	NA	1	0.72	0.14
Brachythecium collinum	brachythecium moss	Native	6	NA	1	4.81	5.18
Brachythecium erythrorrhizon	brachythecium moss	Native	6	NA	17	2.22	0.78
Brachythecium latifolium	none	Native	6	NA	28	3.79	1.69
Brachythecium nelsonii	Nelson's brachythecium moss	Native	6	NA	1	0.17	0.06

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Brachythecium salebrosum	brachythecium moss	Native	NA	NA	1	4.83	1.51
Breidleria pratensis	none	Native	NA	NA	1	2.03	0.95
Bryum	bryum moss	Unknown	NA	NA	2	1.43	0.44
Bryum algovicum var. *algovicum*	bryum moss	Native	8	NA	6	5.50	1.20
Bryum argenteum	silvergreen bryum moss	Native	NA	NA	1	30.36	24.08
Bryum lisae var. *cuspidatum*	bryum moss	Native	8	NA	22	19.35	4.88
Bryum pallescens	bryum moss	Native	8	NA	9	5.52	1.96
Bryum pseudotriquetrum	common green bryum moss	Native	8	NA	69	2.18	1.22
Calliergon cordifolium	calliergon moss	Native	8	NA	3	8.71	5.30
Calliergon giganteum	giant calliergon moss	Native	8	NA	1	3.50	1.30
Calliergon richardsonii	Richardson's calliergon moss	Native	8	NA	1	0.05	0.01
Calliergon stramineum	calliergon moss	Native	8	NA	9	6.87	5.36
Campylium chrysophyllum	goldenleaf campylium moss	Native	NA	NA	1	0.25	0.09
Campylium hispidulum	hispid campylium moss	Native	NA	NA	1	9.00	1.30

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Campylium protensum	none	Native	NA	NA	2	0.84	0.11
Campylium stellatum	star campylium moss	Native	8	NA	45	2.15	0.81
Campylium stellatum var. *protensum*	star campylium moss	Native	8	NA	7	17.80	4.43
Cephalozia pleniceps (Austin) Lindb.	none	Native	8	NA	2	5.76	1.82
Ceratodon purpureus	ceratodon moss	Nonnative	0	5	3	2.09	0.83
Chiloscyphus polyanthos (L.) Corda	none	Native	8	NA	7	1.53	0.75
Climacium dendroides	tree climacium moss	Native	6	NA	54	3.73	1.84
Conocephalum conicum (L.) Dumort.	none	Native	NA	NA	2	0.05	0.01
Cratoneuron filicinum	cratoneuron moss	Native	8	NA	3	10.85	8.46
Dichelyma falcatum	sickle dichelyma moss	Native	6	NA	1	1.50	0.78
Dicranella	dicranella moss	Native	NA	NA	2	1.50	1.10
Dicranoweisia crispula	dicranoweisia moss	Native	8	NA	1	2.40	4.17
Dicranum muehlenbeckii	Muehlenbeck's dicranum moss	Native	6	NA	3	5.85	3.36
Didymodon asperifolius	didymodon moss	Native	NA	NA	1	1.67	0.42

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Drepanocladus aduncus	drepanocladus moss	Native	8	NA	65	10.59	3.91
Encalypta ciliata	fringed candle snuffer moss	Nonnative	0	4	2	0.83	0.92
Entodon concinnus	entodon moss	Native	NA	NA	1	9.00	2.25
Fontinalis antipyretica	antifever fontinalis moss	Native	8	NA	9	9.33	3.27
Hamatocaulis vernicosus	hamatocaulis moss	Native	8	NA	15	28.39	6.97
Helodium	helodium moss	Unknown	NA	NA	2	0.05	0.02
Helodium blandowii	Blandow's helodium moss	Native	8	NA	10	3.59	1.19
Hygrohypnum bestii	Best's hygrohypnum moss	Native	6	NA	1	0.05	0.01
Hylocomiastrum pyrenaicum	hylocomiastrum moss	Native	8	NA	1	32.60	17.17
Hypnum cupressiforme	hypnum moss	Native	6	NA	8	1.61	0.64
Hypnum lindbergii	Lindberg's hypnum moss	Native	6	NA	10	0.06	0.01
Jungermannia exsertifolia Steph.	none	Native	8	NA	1	0.05	0.03
Jungermannia L. emend. Dumort.	none	Native	8	NA	1	0.05	0.02
Jungermannia sphaerocarpa Hook.	none	Native	8	NA	1	2.50	0.59

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Leptodictyum riparium	streamside leptodictyum moss	Native	8	NA	6	0.05	0.02
Leskeella nervosa	leskeella	Native	NA	NA	1	1.25	0.13
Lophozia (Dumort.) Dumort.	none	Native	NA	NA	13	0.23	0.14
Marchantia polymorpha L.	none	Native	6	NA	10	2.75	1.30
Mnium arizonicum	Arizona calcareous moss	Native	6	NA	2	0.37	0.35
Mnium thomsonii	Thomson's calcareous moss	Native	6	NA	2	1.03	0.20
Oncophorus wahlenbergii	Wahlenberg's oncophorus moss	Native	7	NA	14	1.58	0.38
Paraleucobryum enerve	paraleucobryum moss	Native	8	NA	4	0.05	0.02
Peltigera canina (L.) Willd.	felt lichen	Native	NA	NA	1	2.35	1.27
Philonotis fontana	philonotis moss	Native	6	NA	22	3.70	2.60
Philonotis fontana var. *americana*	American philonotis moss	Native	6	NA	6	0.95	0.62
Plagiomnium cuspidatum	toothed plagiomnium moss	Native	8	NA	2	2.52	0.54
Plagiomnium ellipticum	elliptic plagiomnium moss	Native	8	NA	36	2.92	1.33
Plagiothecium denticulatum	toothed plagiothecium moss	Native	6	NA	16	2.06	0.78

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Plagiothecium laetum	plagiothecium moss	Native	6	NA	11	0.99	0.29
Pohlia cruda	pohlia moss	Native	6	NA	7	10.00	2.86
Pohlia nutans	pohlia moss	Nonnative	0	2	10	0.96	0.35
Pohlia proligera	pohlia moss	Native	NA	NA	2	11.17	2.43
Polytrichastrum alpinum	alpine polytrichastrum moss	Native	7	NA	1	0.05	0.02
Polytrichastrum longisetum	none	Native	NA	NA	80	4.32	2.48
Polytrichum	polytrichum moss	Unknown	7	NA	8	4.96	2.72
Polytrichum juniperinum	juniper polytrichum moss	Native	7	NA	2	0.28	0.10
Preissia quadrata (Scop.) Nees	none	Native	6	NA	1	0.05	0.01
Pseudocalliergon turgescens	pseudocalliergon moss	Native	8	NA	6	17.40	5.10
Racomitrium canescens	racomitrium moss	Native	6	NA	1	2.00	2.32
Rhizomnium magnifolium	grandleaf rhizomnium moss	Native	6	NA	1	0.05	0.01
Rhizomnium pseudopunctatum	rhizomnium moss	Native	6	NA	8	1.58	0.77
Rhytidium rugosum	rhytidium moss	Native	NA	NA	1	1.67	0.42

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Sanionia uncinata	sanionia moss	Native	8	NA	4	11.53	8.87
Sarmenthypnum sarmentosum	sarmenthypnum moss	Native	8	NA	8	0.36	0.09
Scapania subalpina (Nees) Dumort.	none	Native	8	NA	1	0.05	0.01
Schistidium rivulare	streamside schistidium moss	Native	6	NA	7	24.01	7.05
Scorpidium cossonii	none	Native	NA	NA	19	20.68	9.50
Sphagnum	sphagnum	Native	8	NA	12	29.73	11.85
Sphagnum angustifolium	sphagnum	Native	8	NA	1	0.05	0.01
Sphagnum contortum	contorted sphagnum	Native	8	NA	3	23.67	4.65
Sphagnum girgensohnii	Girgensohn's sphagnum	Native	8	NA	4	27.56	4.55
Sphagnum russowii	Russow's sphagnum	Native	8	NA	24	3.84	2.47
Sphagnum squarrosum	sphagnum	Native	NA	NA	2	2.58	0.89
Sphagnum teres	sphagnum	Native	8	NA	9	1.10	0.60
Sphagnum warnstorfii	Warnstorf's sphagnum	Native	8	NA	7	13.22	6.53
Timmia austriaca	Austria timmia moss	Native	6	NA	2	4.70	5.11

Table 10 (continued). Nonvascular species at wetland ecological integrity sites in Rocky Mountain National Park from 319 sample events across 154 sites from 2007 to 2014 (nonvascular taxa were removed from the protocol in 2015). Nomenclature follows USDA (2019). Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Invasiveness (I ranks) is from Morse et al. (2004) as modified by the network and ranges from 0 for a species with no invasive impacts to 8 for a species with detrimental impacts to wetland communities. Nativity is from Weber and Wittmann (2001) as modified by the network. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. NA is not assigned. For a full taxonomic table see Rocky Mountain Network - NPS (2019a).

Species	Common name	Nativity	C score	I rank	Count	Mean absolute cover (cm^2)	Mean relative cover (%)
Tomentypnum nitens	tomentypnum moss	Native	8	NA	30	9.63	4.46
Tritomaria polita (Nees) Jörg.	none	Native	NA	NA	1	0.02	0.01
Warnstorfia	warnstorfia moss	Native	8	NA	9	7.34	3.26
Warnstorfia exannulata	warnstorfia moss	Native	8	NA	47	6.24	5.03
Warnstorfia fluitans	warnstorfia moss	Native	8	NA	3	3.28	2.32
Weissia controversa	controverial weissia moss	Nonnative	0	2	1	0.05	0.11

3.5.3 Baseline

We generated 206 vegetation metrics (Appendix E; Rocky Mountain Network - NPS (2019b)) as indicators of wetland vegetation condition in the park. These are classified into 11 groups: floristic quality (conservatism), duration, ground cover, life form composition, degree of invasion, endemism (perhaps better thought of as "conservation value"), noxiousness, taxonomic diversity, taxonomic composition, wetland status, and salt tolerance. Vegetation metrics are direct and purposefully one dimensional assays of vegetation composition and structure. They have significant explanatory power in and of themselves and we present several throughout this report. Details of metric calculation are in Schweiger et al. (2015) and Appendix E. Note that the metrics (other than those specific to nonvascular taxa) in this report do not include nonvascular species data as they span the time period when the collection of this information was discontinued and would thus produce inconsistent results.

We selected the results from seven metrics to present in this report. This selection was based on several criteria. First, many of these were the component metrics for bioassessment and structural models developed in Schweiger et al. (2016). Second, metrics were selected that were likely of ecological interest and management importance. Finally, we wanted representation of most of the 11 categories of metric type (difficult choice, with a limit of seven). To introduce the ecological context for vegetation metrics, we briefly summarize the background of two classes of metrics, conservatism and degree of invasion—likely the two most important types of metrics we develop (Ervin et al. 2006, Johnston et al. 2008).

The conservatism of a species is defined as its degree of fidelity to a specific habitat or range of environmental conditions (Wilhelm and Ladd 1988, Herman et al. 1997, Matthews et al. 2015). Anthropogenic impacts usually cause dramatic shifts in ecological processes and habitat conditions and push disturbance regimes outside a natural range of intensity, frequency, and duration. Species that are more conservative are not able to adapt to human induced alterations compared to broad-niche generalists and are often the first to disappear from habitats impacted by human activities. We use an expert-derived metric of the degree of conservatism in a wetland community calculated as the mean of conservatism scores (also known as "C scores") for all species in a sample. Rocchio (2007a, b) assigned C scores to all species in the Colorado flora following the methods described by Swink and Wilhelm (1994). C values range from 0 to 10 and represent an estimated probability that a plant is likely to occur in a landscape relatively unaltered from pre-European settlement conditions. Nonnative species are given a default C value of 0. A low C value is assigned to plants that have demonstrated little fidelity to any remnant natural community or area or species with a wide ecological tolerance that may be found almost anywhere. A C value of 10 is assigned to species that are obligate to intact reference quality natural areas and that cannot tolerate habitat degradation.

Invasive species have well-established undesirable effects on ecosystem function (Byers et al. 2002, Levine et al. 2003, Fridley et al. 2007). Invasive species have been linked to reduced overall species diversity (Meiners et al. 2001), altered resource dynamics (Ehrenfeld 2003), and shifted interactions between species (Christian and Wilson 1999). We calculate a community scale degree of invasion following Iacona et al. (2014) by averaging the relative cover-weighted scores of the invasiveness of

all species in a sample (also known as “I-ranks”, Morse et al 2004). I-ranks are scored based on the ability of a species to: change ecosystem processes; invade relatively undisturbed ecological communities; disperse to new areas readily; and cause substantial impacts on rare or vulnerable species or ecological communities, or high-quality examples of more common communities. Invasive species also tend to have wide distribution and general abundance where present and are difficult to control. We present two different indices of invasiveness. The two invasion indices differ in how mean I-rank scores are weighted. The first index (Index 1) is weighted by the cover of invasive taxa. Assemblages with few invasive taxa but high cover of species will have higher index scores. We treat this as the potential for a site to become highly invaded as invasive taxa with high cover often have established a foothold in the community and should they be released from competition or other mechanisms they might rapidly expand. The second index (Index 2) is weighted by the percentage of the species list at a site that is composed of invasive taxa. The cover of individual invasive species is not factored into the index. We treat this index more as the realized degree of invasion, with sites with high scores already containing multiple invasive taxa.

3.5.3.1 Site scale

Figure 30 through Figure 34 give the distribution of seven vegetation metrics across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. These are the primary site scale baselines for these important indicators.

Mean conservatism (Rocchio 2007a, b), weighted by cover, was higher in fen sites, followed by wet meadows and then riparian wetland sites (Figure 30). Fens have unique soils and stable groundwater-driven hydrology, both of which can favor endemic, conservative species. Conservatism is a generally useful biometric of wetland condition (Rocchio 2007a, b, USEPA 2015). Conservative species persist better in habitats with less human disturbance. This may be due to the magnitude and accelerated rate at which most human disturbance occurs and the inability of conservative species to adapt to these types of changes. Conversely, there appears to be little negative effect of natural disturbances regimes on conservatism. Conservative species may be able to respond to the more ‘evolutionary familiar’ pace and extent of natural disturbance regimes. For example, through natural succession, it can often take several decades or longer (Butler 2012) for typical beaver ponds in Rocky Mountain National Park to transition into a wet meadow with the fine-textured hydric soils (Westbrook et al. 2011) supportive of conservative species (i.e., silvery sedge, *Carex canescens*). In contrast, human modification can drain or completely replace a wetland in a matter of months (Nummi and Kuuluvainen, 2013, Hyvönen and Nummi 2008)—few if any conservative species may accommodate such a rate of change. Alternatively, it may be the maintenance of high water tables (either from beaver habitat modification or successful human restoration) that supports conservative taxa. In 2008 the final steps of the restoration of a golf course in Moraine Park were completed. An earlier restoration to remove an agricultural drainage ditch in Big Meadows was completed in the late 1980s (Cooper 1990, Cooper et al. 1998). These management actions have resulted in beneficially altered hydrologic regimes at both sites and the reestablishment of several obligate and conservative species, including cotton grass (*Eriophorum angustifolium*), elephant head lousewort (*Pedicularis*

groenlandica), and Aulacomnium moss (*Aulacomnium palustre*). Shrub production, ungulate activity levels/browsing, and the biomass of tall shrubs appears to have less influence on conservatism in the park. This is somewhat surprising given the often strong connections among herbivores, canopy structure, and understory species composition observed in many ecosystems, including wetlands (Augustine et al. 1998, Xiong et al. 2003, Wolf et al. 2007, Kaczynski and Cooper 2015). While this needs more focused research, it may be that conservative wetland taxa are so sensitive to human disturbances, especially hydrologic alterations, that they have been largely removed from the park's low elevation large valley bottom riparian and wet meadows, where the interplay between shrubs and ungulates largely occurs.

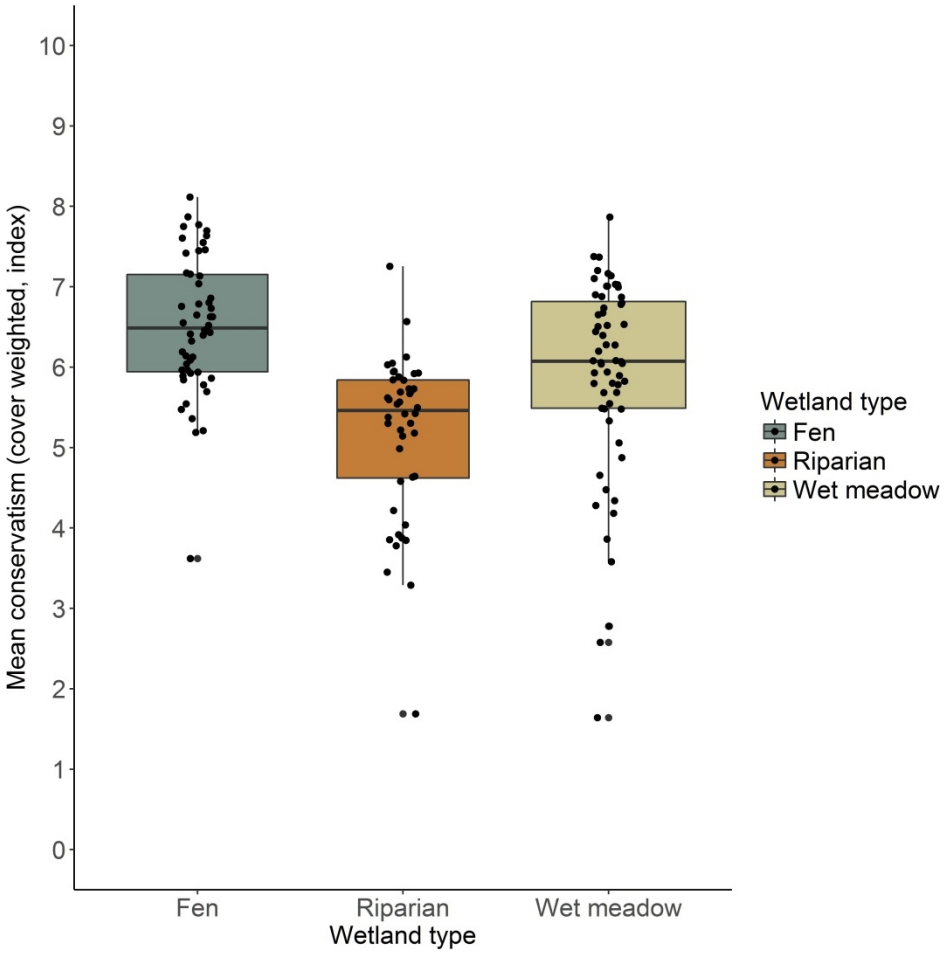


Figure 30. Mean conservatism (Rocchio 2007a, b; cover weighted, index) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Conservatism is averaged across all species in a sample and ranges from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Both indices of invasiveness suggest riparian wetland sites had the highest degree of invasion, with more sites with high cover of invasive species (Index 1) and more sites with composition dominated by invasive species (Index 2; Figure 31). Both indices also suggest that fen sites typically did not have high degrees of invasion. Many invasive taxa are not able to survive in the saturated soils of fens. The two indices characterize wet meadow sites differently with the first suggesting there is a high degree of variation in wet meadows, with many sites having high cover of invasive species (similar to riparian wetland). However the second suggests that very few wet meadows have a species list dominated by invasive taxa. These patterns follow from the transitional nature of wet meadow and its often more speciose composition. While protected landscapes might mitigate some effects of plant invasions, the borders of even large parks like Rocky Mountain National Park offer little protection in time or space (RMNP 2004, Allen et al. 2009). In Rocky Mountain National Park, many invasive plants were already present at the time of the park's establishment, particularly European pasture grasses and associated forbs introduced to create hay meadows for domestic livestock and pack stock (Cooper et al. 1998). High levels of human disturbance directly predict a greater degree of invasion in park wetlands. Moreover, anthropogenic soil disturbance, proximity to roads, hydrologic alterations, and reduced natural land cover in wetland buffers all indirectly influence degree of invasion acting through composite human disturbance.

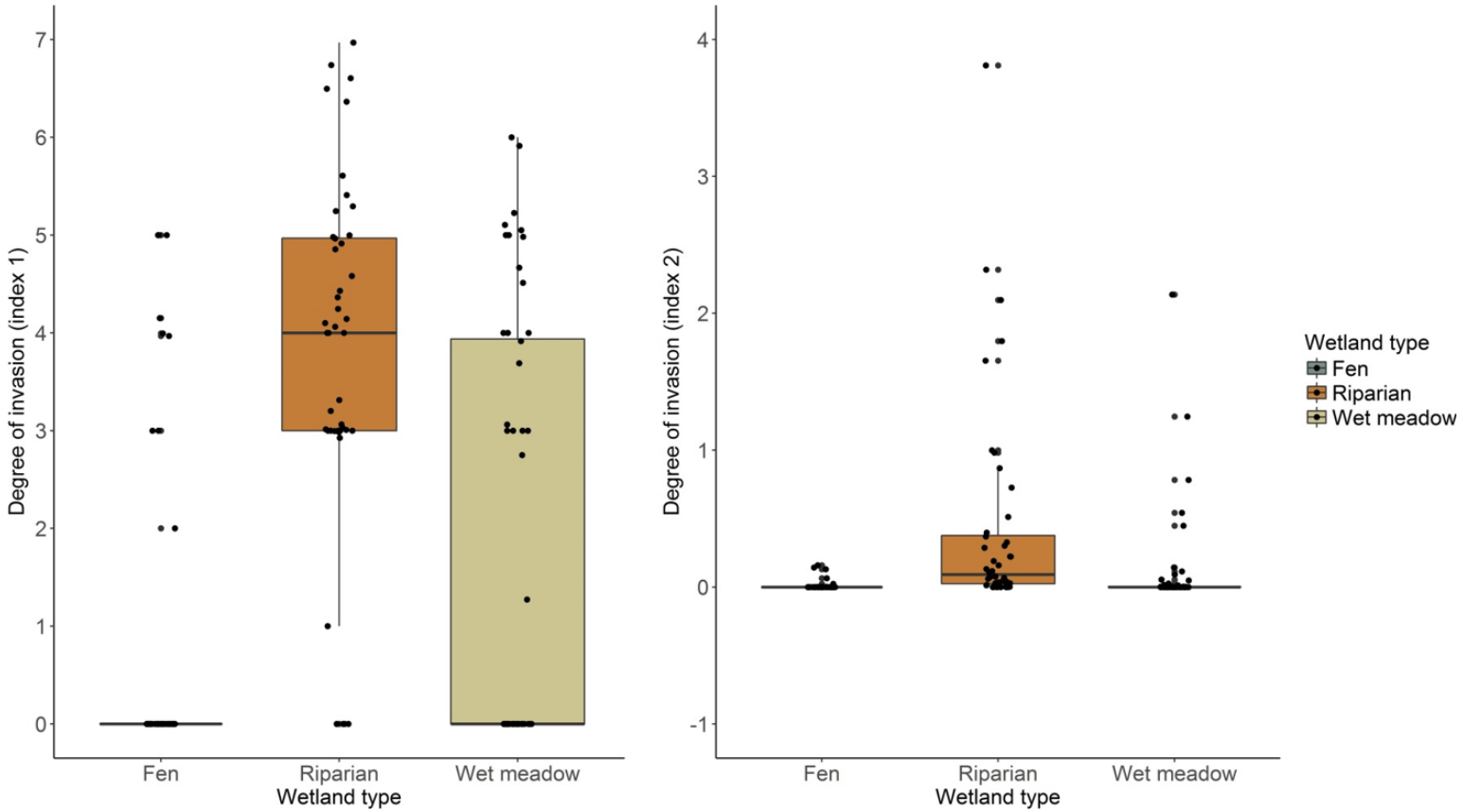


Figure 31. Degree of invasion by wetland type at wetland ecological integrity sites in Rocky Mountain National Park: (left) cover weighted mean I-rank (Morse et al. (2004), (right) percent of assemblage as invasive taxa weighted mean I-rank. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Note the different scales in each panel. Results are applicable to the sampled sites only. Both degree of invasion indices range from 0 for an assemblage with no invasive species to 8 (in left panel, index 1) for an assemblage dominated by high cover of highly invasive species, and 4 (in right panel, index 2) for an assemblage with a high percentage of highly invasive species. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier. The legend in the right panel applies to both figures.

Mean wetland affinity was generally high for sites from all three wetland types (Figure 32). Wetland affinity is from Tiner (2012) as modified by the Rocky Mountain Network—we reversed the scoring scale to be more intuitive. It ranges from 5 for a taxa obligate to wetlands to 1 for a taxa adapted to upland conditions. Fens had the highest scores, with most species found in fens obligate to wetland habitat. Riparian wetland had the lowest wetland affinity, with some sites including more upland habitat and thus taxa not necessarily adapted to wetland conditions. This is also one reason why riparian wetland was the most diverse of the three types (see section 3.7.1). Many of the patterns in wetland affinity are connected to the drivers of conservatism and native forbs discussed above and below. Several conservative species are wetland obligates and/or native forbs. Likewise fewer wetland obligates are invasive species, so the drivers of where invasive species occur in the park may also lie behind wetland specialized taxa.

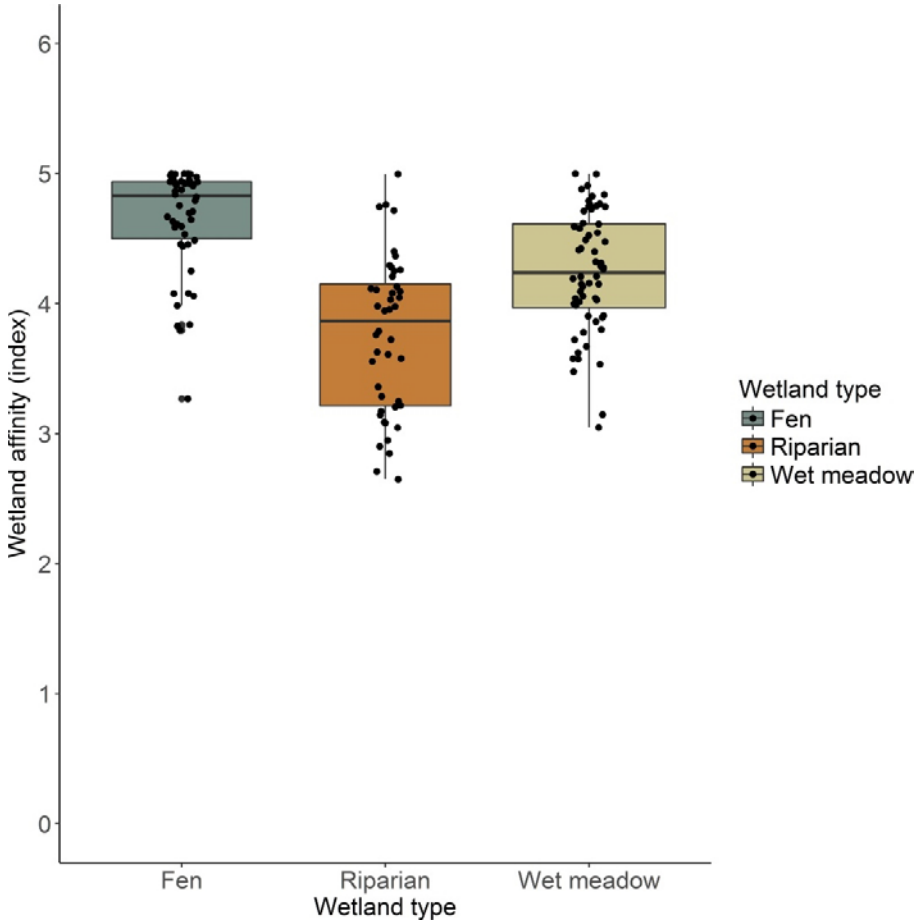


Figure 32. Wetland affinity (cover weighted, index) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Wetland affinity ranges from 0 for an assemblage with no wetland taxa to 5 for an assemblage dominated by high cover of species specialized for wetlands. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Native forb cover is our simplest metric computationally, but the most complex in terms of its ecological interpretation. It is also the metric with the greatest variation in response across wetland type and thus may be more difficult to generalize across our diverse data set (Figure 33). Nonetheless, native forb cover responds both directly and indirectly to human and natural disturbance. Increased composite human disturbance, elevated human disturbance of soils, decreased distance to roads, less natural buffer areas, and higher hydrologic alterations all reduce native forb cover. The pattern is opposite what we saw with invasive taxa even though several native forb species can be invasive, such as largeleaf avens (*Geum macrophyllum*) and Norwegian cinquefoil (*Potentilla norvegica*). Yet the more important invasive taxa in the park are nonnative and the response of native forbs to human disturbance is not likely due to the life history characteristics of invasive taxa. Native forb response to human disturbance in the park is identical in direction and similar in magnitude to the response of conservatism. Many native forbs are conservative species, for example felwort (*Swertia perennis*) and brook saxifrage (*Micranthes odontoloma*). Yet other native forbs had below average conservatism (i.e., woodland strawberry (*Fragaria vesca*) or common cowparsnip (*Heracleum sphondylium*)) and occurred in sites with combinations of predictors such as minimal human hydrologic alteration and more natural wetland buffers that predict higher levels of conservatism. Therefore, the native forb response is not entirely due to forbs that are invasive or the sensitivity of conservative native forb species to human disturbance.

One intriguing possibility behind the pattern with native forbs is via hydrology as impacted by beaver. Persistent historical beaver habitat modifications often lead to more hydric conditions. Monocots tend to be more flood tolerant than dicots due to adaptions like hollow stems, adventitious roots, and a lack of woody tissue—all developed during monocots' evolution in aquatic or semi-aquatic habitats (Takhtajan 1969). Many native forbs lack these adaptations and have shallow root systems that may require more specific water table conditions (Zedler and Kercher 2005). Our data indicate some non-linearity between native forb cover and hydric conditions, with peak cover values midway along the hydric gradient, especially in riparian sites. Yet, overall native forb cover decreased with increased hydric conditions. Thus, beavers likely still play an important role in native forb cover via their effects on hydrologic regime, though these effects are not quite as simple as the clear benefit to wetland condition that remnant beaver features provide via reducing invasives and elevating conservatism.

Finally, many of the patterns in absolute and relative cover of Salicaceae and Betulaceae are driven by the same factors as conservatism and wetland affinity (Figure 34). Most species in the park in these families are conservative and wetland dependent (section 3.7.1). These species have higher absolute and relative cover in riparian wetland, although they occur (and can be quite abundant) in all three types. Perhaps some of the more nuanced linkages between human disturbance and invasion relevant to the cover of these woody species are the complex indirect connections through hydric conditions and/or woody shrub productivity. Composite human disturbance is directly associated with decreased productivity of both short and tall shrubs, likely due to residual effects of how many wetlands in the low valley areas of the park were once heavily used for visitor recreation and/or as pasture to support livestock. In turn, the productivity of shrubs may have a direct and positive effect on the prevalence of invasives in wetland vegetation, perhaps because of the potentially complex

connection between site productivity and potential species richness (Grace et al. 2016) or the often superior competitive ability of invasive species for limiting resources (Schoener 1983, Tilman 1999).

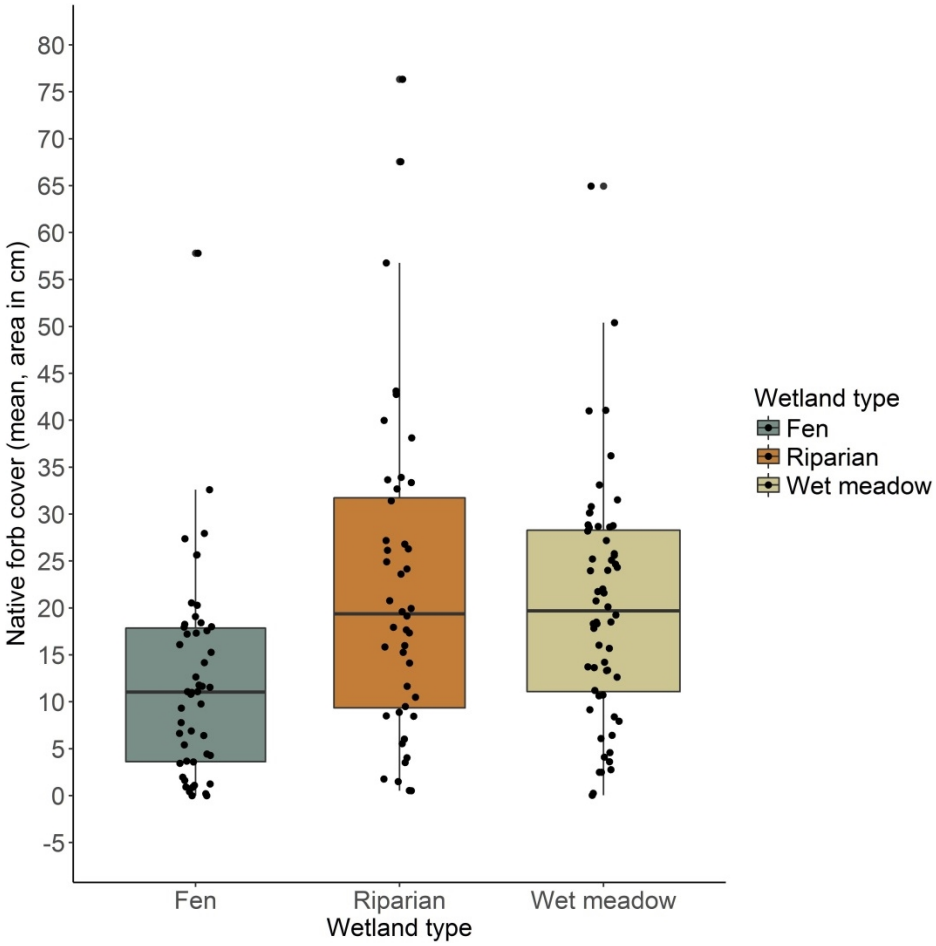


Figure 33. Native forb cover (averaged across all absolute cover values from sampled subplots in a site, square cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Native forb cover ranges from 0 for assemblage with no native forbs to around 80 for an assemblage with high absolute cover of native forbs. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

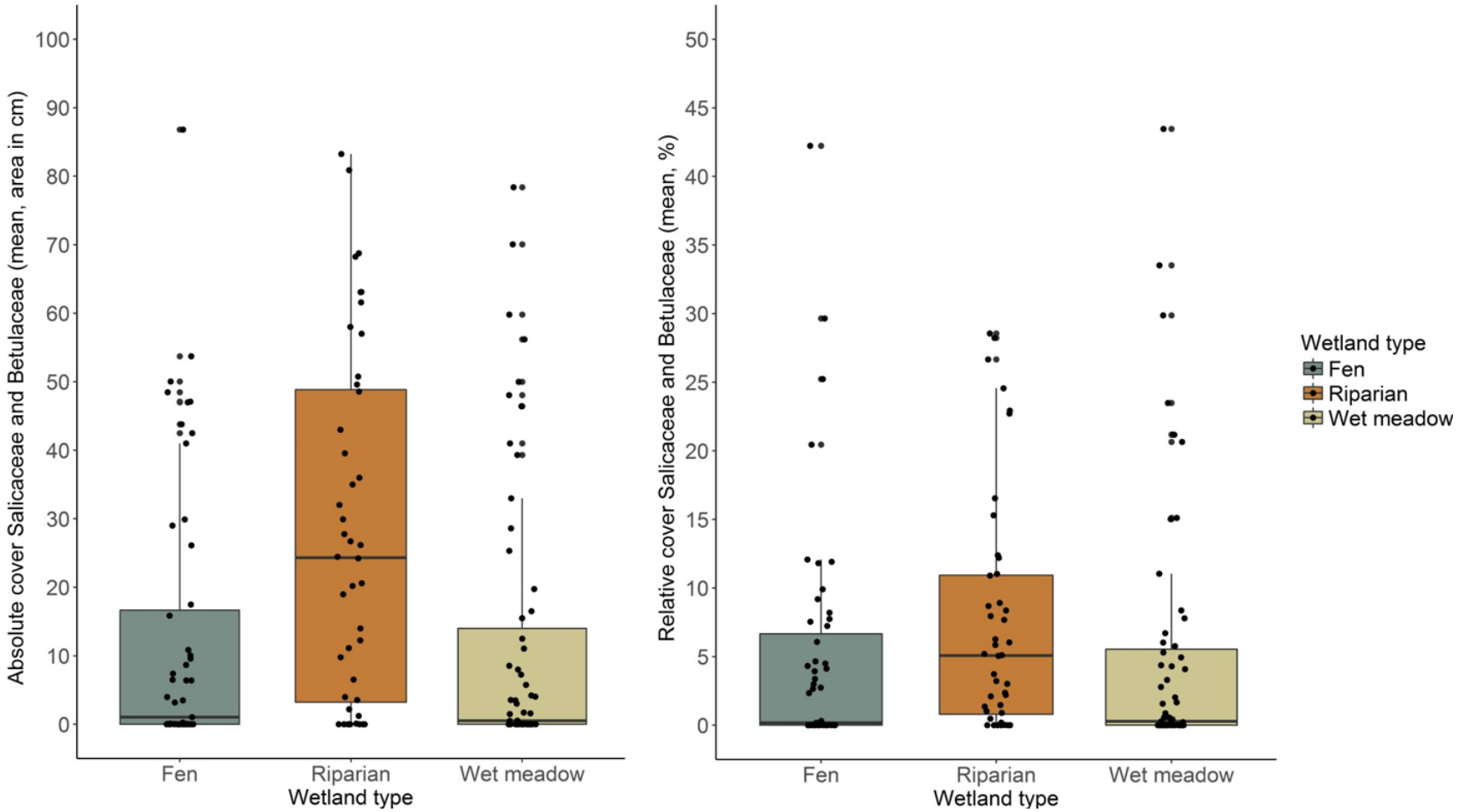


Figure 34. Absolute (left; units are square cm) and relative (right; units are %) cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Not all species occur at all sites. Both indicators are averaged across all cover values from sampled subplots in a site. Note the different scales in the two panels. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier. The legend in the right panel applies to both figures.

3.5.3.1.1 Spatial pattern

Figure 35 through Figure 41 show the spatial distribution of the seven metrics we focus on here. These results are complex and will require more detailed analyses. Many of them follow from the discussion above on the drivers behind these metrics. Conservatism was higher in remote areas, often higher in elevation. Front country sites tended to have lower conservatism. Both degree of invasion metrics were essentially the opposite of this—higher in front country lower elevation areas. Wetland affinity was higher in fens, although there also appeared to be higher scores in valley bottom sites. The pattern with native forbs was complex, but native forb cover also appeared to be higher in remote areas, often higher in elevation. The cover of willows, especially relative to other species, was higher in valley bottom areas, often where riparian wetland occur.

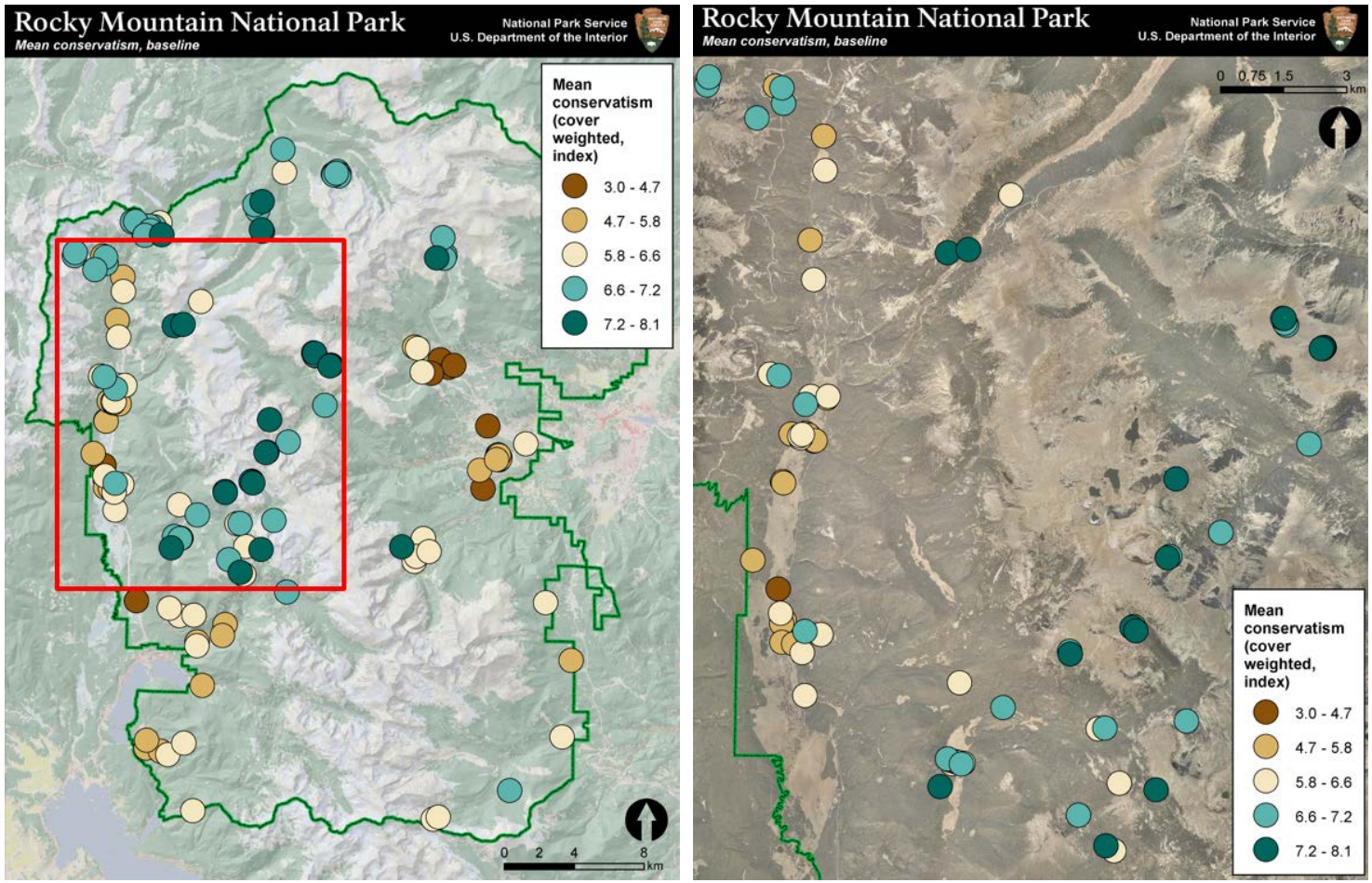


Figure 35. Map of mean conservatism (Rocchio 2007a, b; cover weighted, index) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box). The map on the right is an example of finer scale patterning. Conservatism is averaged across all species in a sample and ranges from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker green indicates sites with higher mean conservatism and increasingly lighter shades of green to cream brown to dark brown indicate lower mean conservatism. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

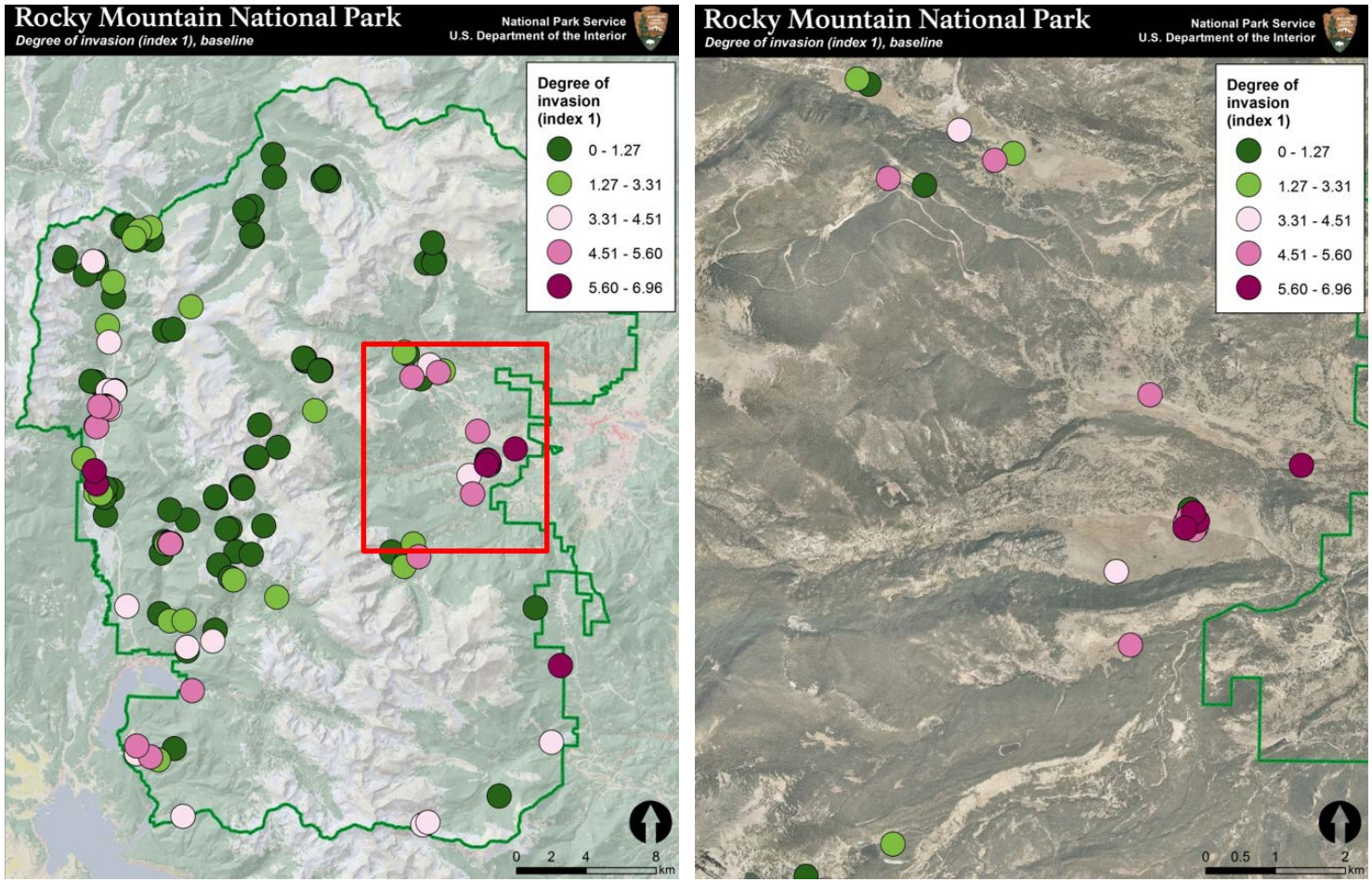


Figure 36. Map of degree of invasion (cover weighted mean I-rank; index), in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park Meadows areas (interior of the red box). The map on the right is an example of finer scale patterning. The degree of invasion index 1 ranges from 0 for an assemblage with no invasive species to 8 for an assemblage dominated by high cover of highly invasive species. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker maroon indicates sites with a higher degree of invasion and increasingly darker shades of green indicate lower mean invasion. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

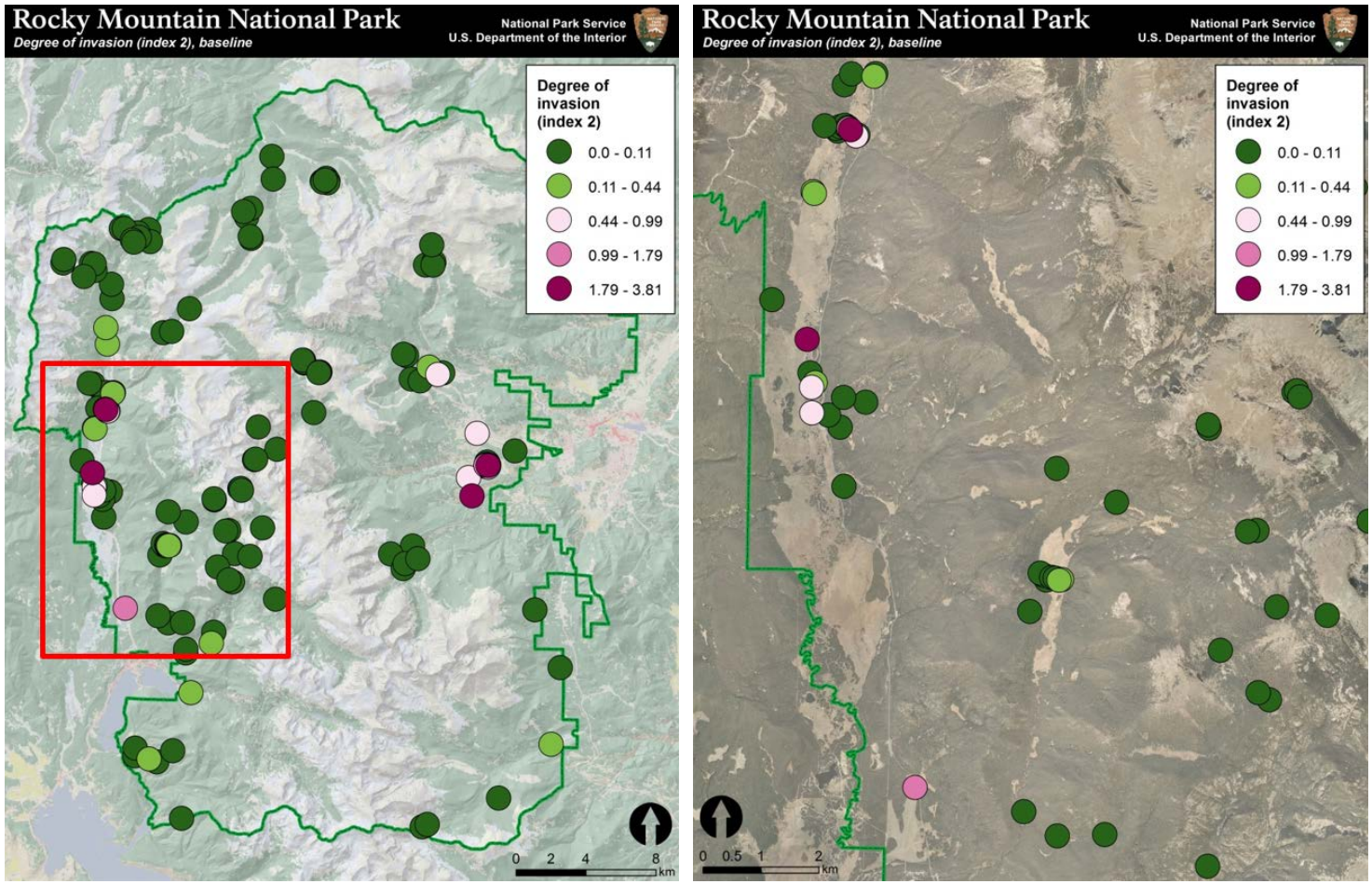


Figure 37. Map of degree of invasion index 2 (percent of assemblage as invasive taxa weighted mean I-rank) in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box). The map on the right is an example of finer scale patterning. The degree of invasion index 2 ranges from 0 for an assemblage with no invasive species to 4 for an assemblage with a high percentage of highly invasive species. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker maroon indicates sites with a higher degree of invasion and increasingly darker shades of green indicate lower mean invasion. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

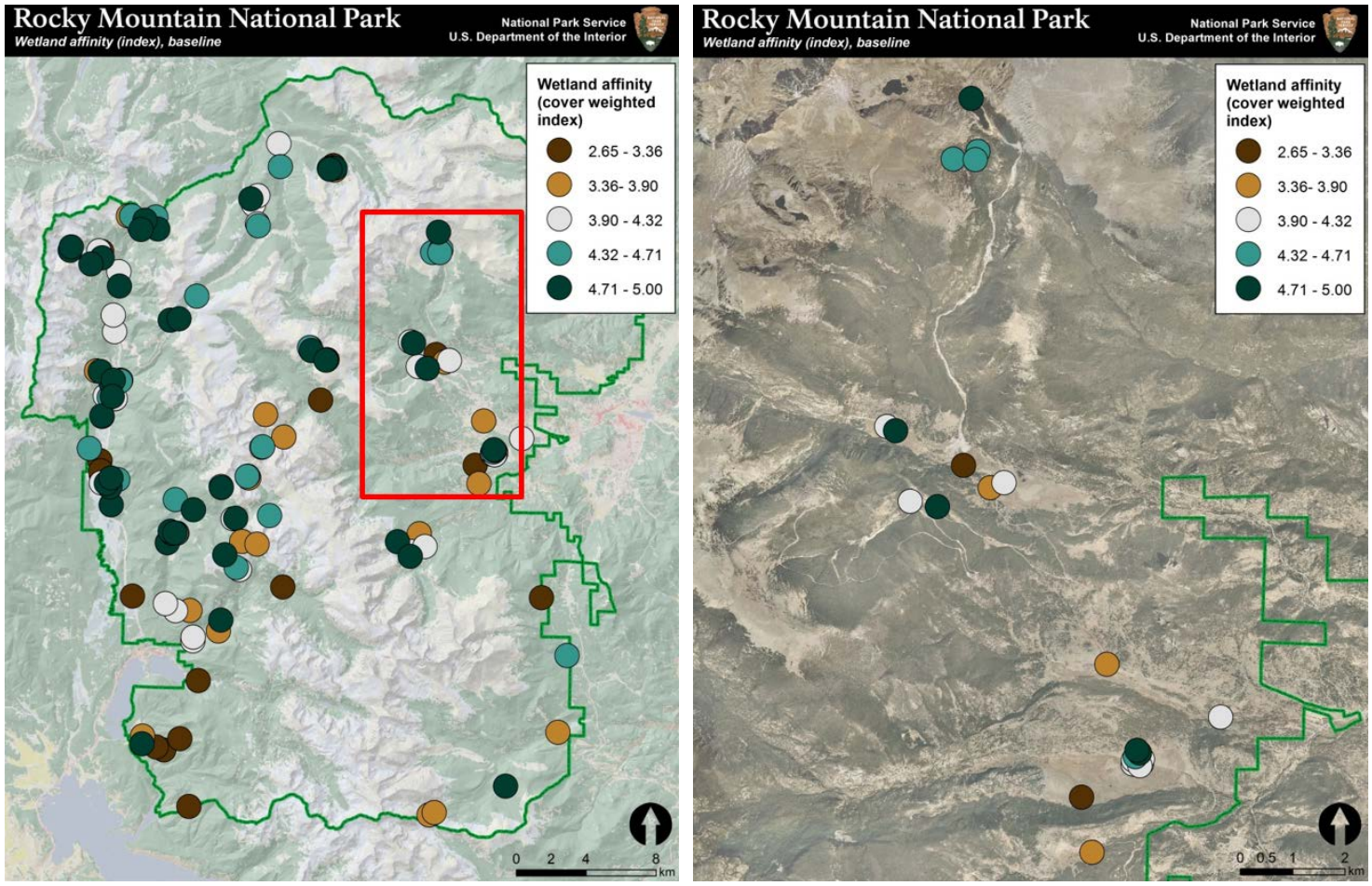


Figure 38. Map of wetland affinity (Tiner 2012; cover weighted, index) in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park areas (interior of the red box). The map on the right is an example of finer scale patterning. Wetland affinity ranges from 0 for an assemblage with no wetland taxa to 5 for an assemblage dominated by high cover of species specialized for wetlands. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker maroon indicates sites with a higher degree of invasion and increasingly darker shades of green indicate lower mean invasion. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

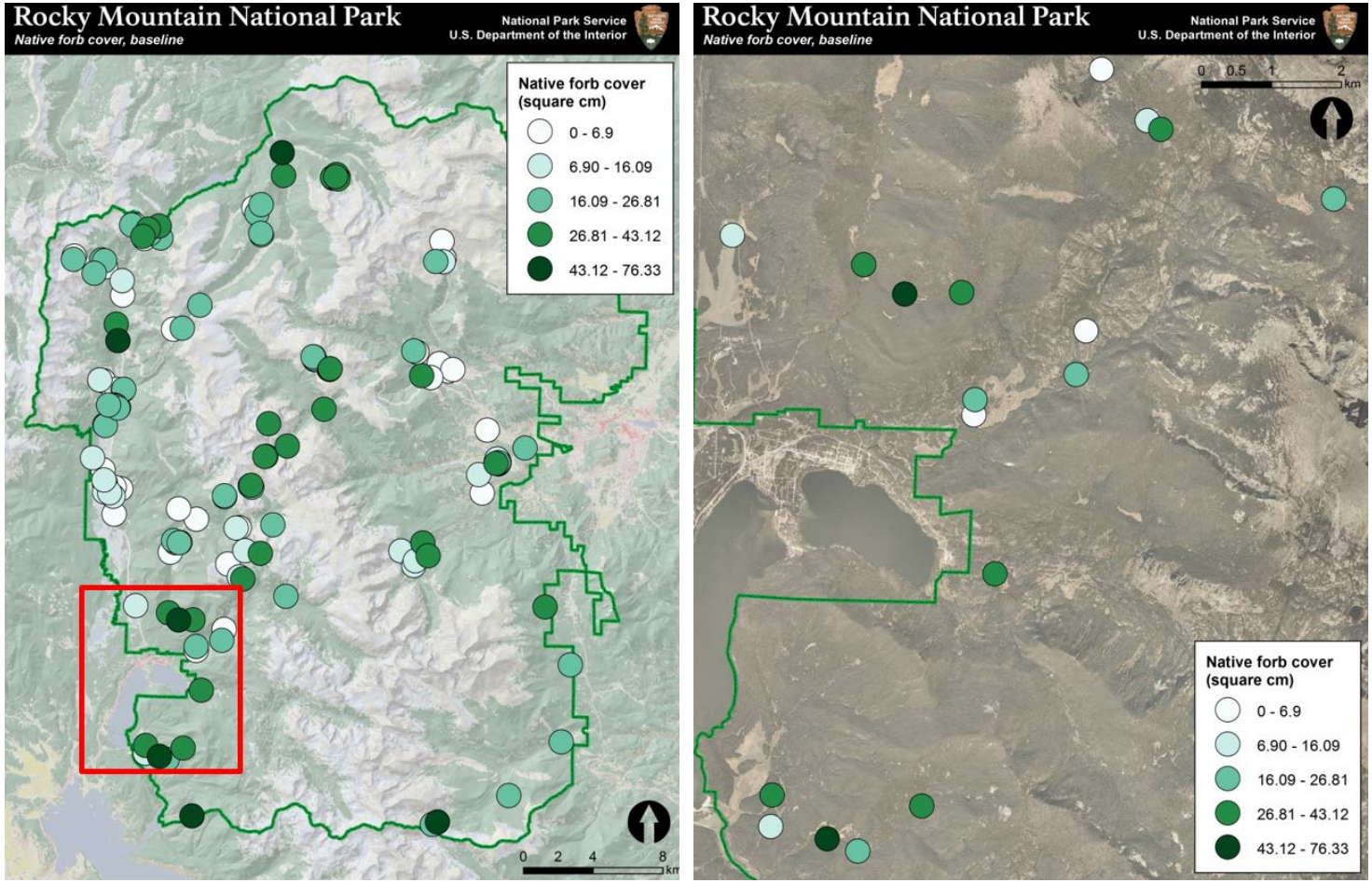


Figure 39. Map of native forb cover (cm^2) in (left) Rocky Mountain National Park and (right) the Grand Lake area (interior of the red box). The map on the right is an example of finer scale patterning. Native forb cover is averaged across all absolute native forb cover values from sampled subplots in a site, Native forb cover ranges from 0 for assemblage with no native forbs to around 80 for an assemblage with high absolute cover of native forbs. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker green indicates sites with a higher native forb cover and increasingly lighter shades of green indicate lower cover. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

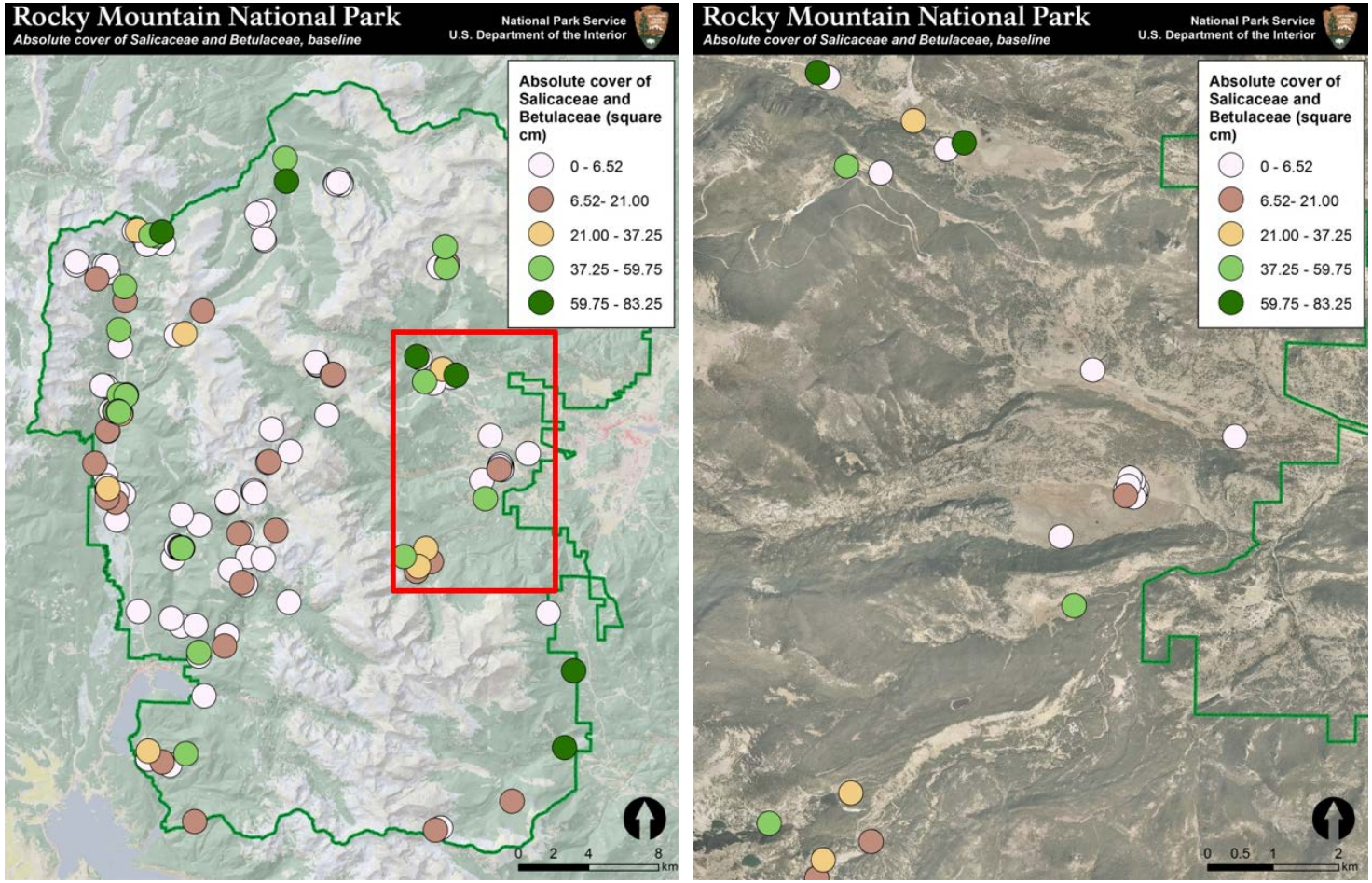


Figure 40. Map of absolute cover (cm^2) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) in (left) Rocky Mountain National Park and (right) Moraine and Horseshoe Park areas (interior of the red box). The map on the right is an example of finer scale patterning. Absolute cover is averaged across all absolute cover values from sampled subplots in a site. These cover values range from 0 for assemblage with no willow or birch to around 80 for an assemblage with high absolute cover of these taxa. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Not all species occur at all sites. Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker green indicates sites with higher cover and increasingly lighter shades of green to brown to white indicate lower cover. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

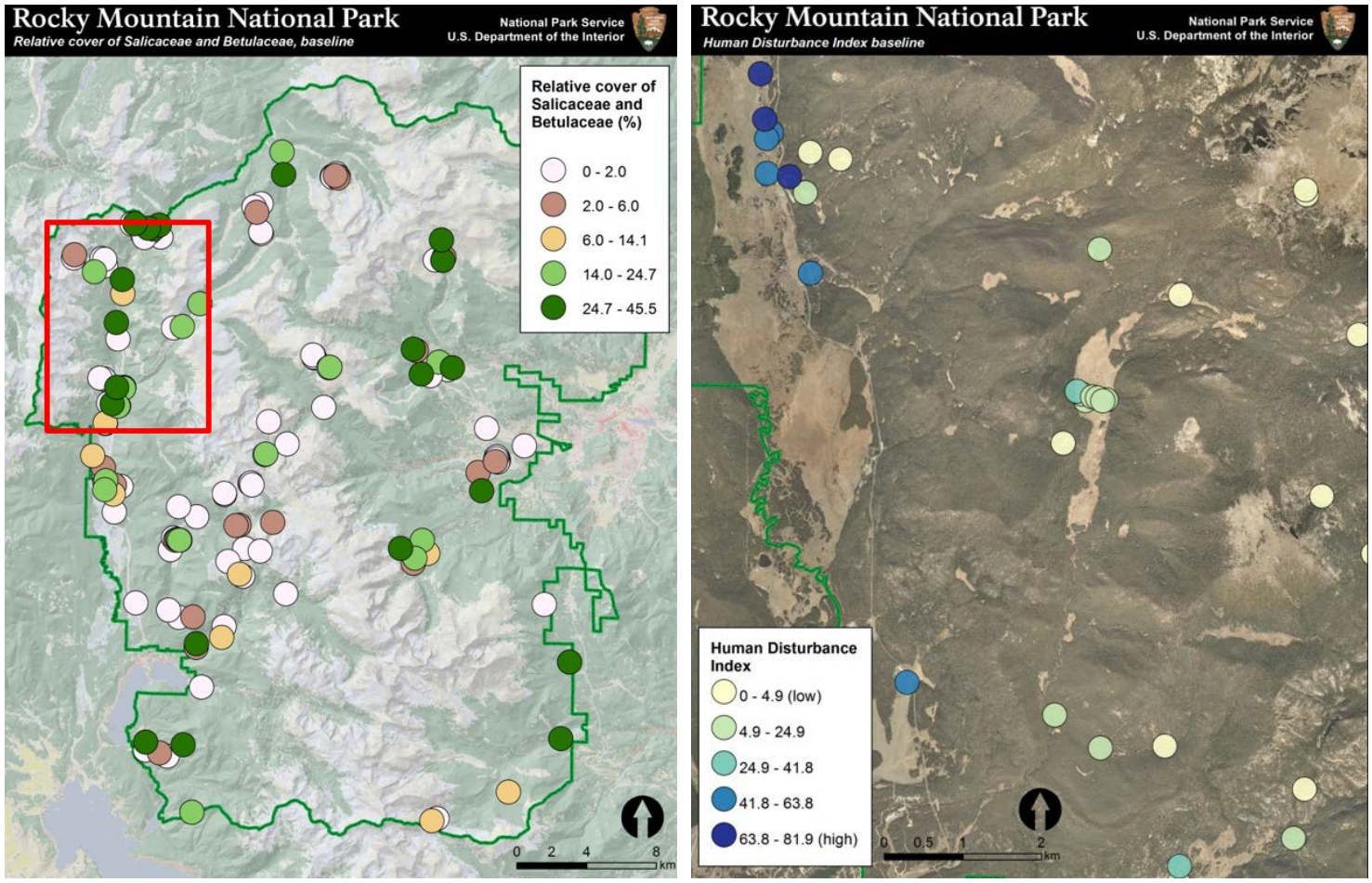


Figure 41. Map of relative cover (%) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) in (left) Rocky Mountain National Park and (right) upper Colorado River valley area (interior of the red box). The map on the right is an example of finer scale patterning. Relative cover is averaged across all relative cover values from sampled subplots in a site. These cover values range from 0 for assemblage with no willow or birch to around 45 for an assemblage with high relative cover of these taxa. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Not all species occur at all sites. Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker green indicates sites with higher cover and increasingly lighter shades of green to brown to white indicate lower cover. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.5.3.2 Parkwide scale

Figure 42 shows one example of a CDF of mean conservatism across wetland type. The left y-axis shows the percentage of the wetland in the park and the right y-axis gives the estimated area of wetland. The 95% confidence intervals (dotted lines) around the percent values (heavy line) are also shown. A CDF describes the 'value so far' of cumulative mean conservatism from the lowest to highest score, moving from left to right. The CDFs clearly show that the population of fens had higher conservatism than the other two wetland types and less variation (seen in the tighter confidence interval about the CDF).

Figure 43 shows a second example CDF for vegetation metrics—wetland affinity across wetland type. The left y-axis shows the percent of the wetland in the park and the right y-axis gives the estimated area of wetland. The 95% confidence intervals (dotted lines) around the percent values (heavy line) are also shown. A CDF describes the 'value so far' of cumulative HDI from the lowest to highest score moving from left to right. For example, compared across wetland type, riparian wetland had a lower wetland affinity and more variation. As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

Appendix E presents design-based parkwide scale results from the 'best' survey sites for 28 example vegetation metrics. We also include calculation details for the seven metrics focused on in this narrative.

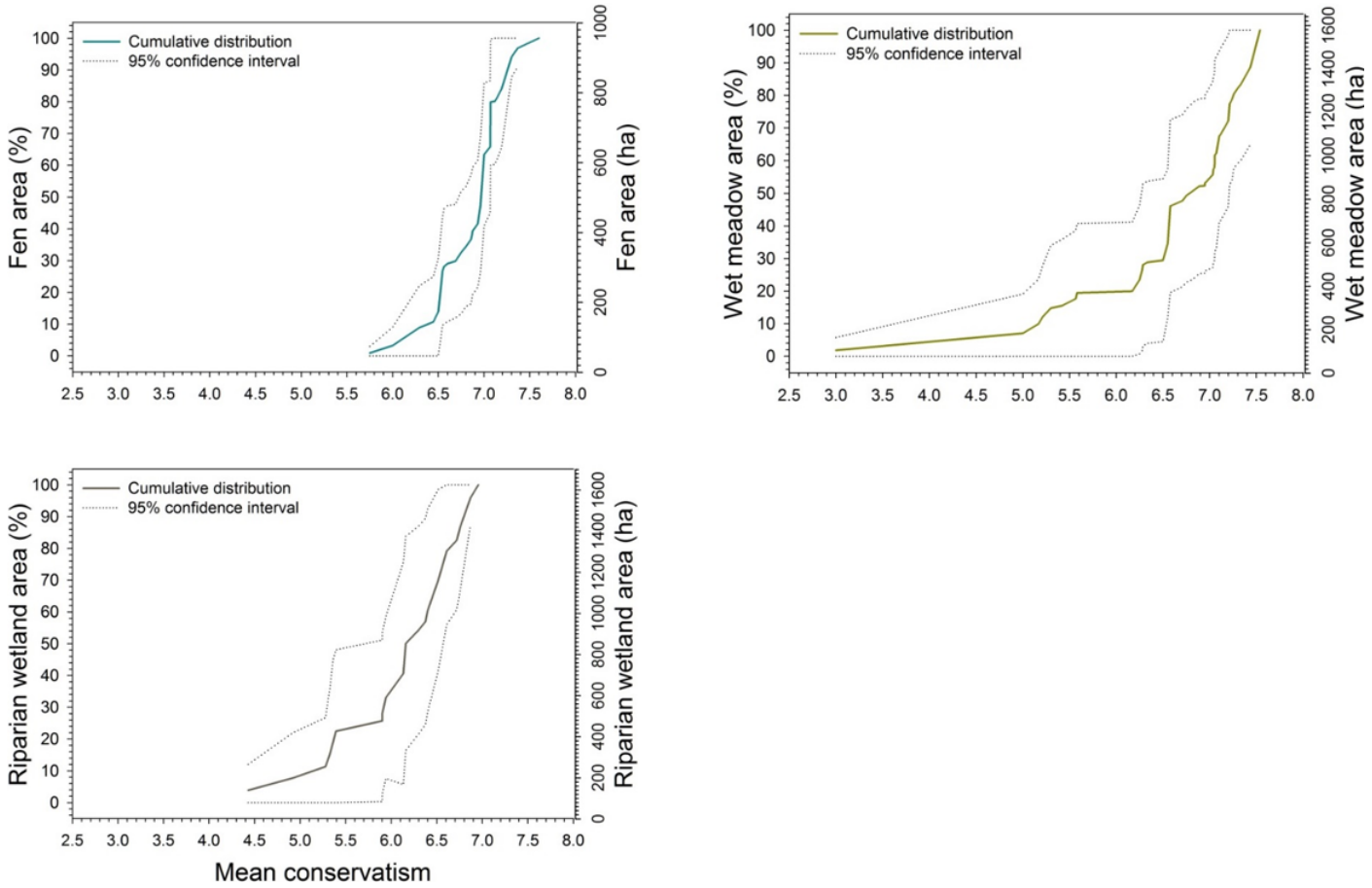


Figure 42. Mean conservatism (Rocchio 2007a, b; cover weighted, index; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Conservatism is averaged across all species in a sample and ranges from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

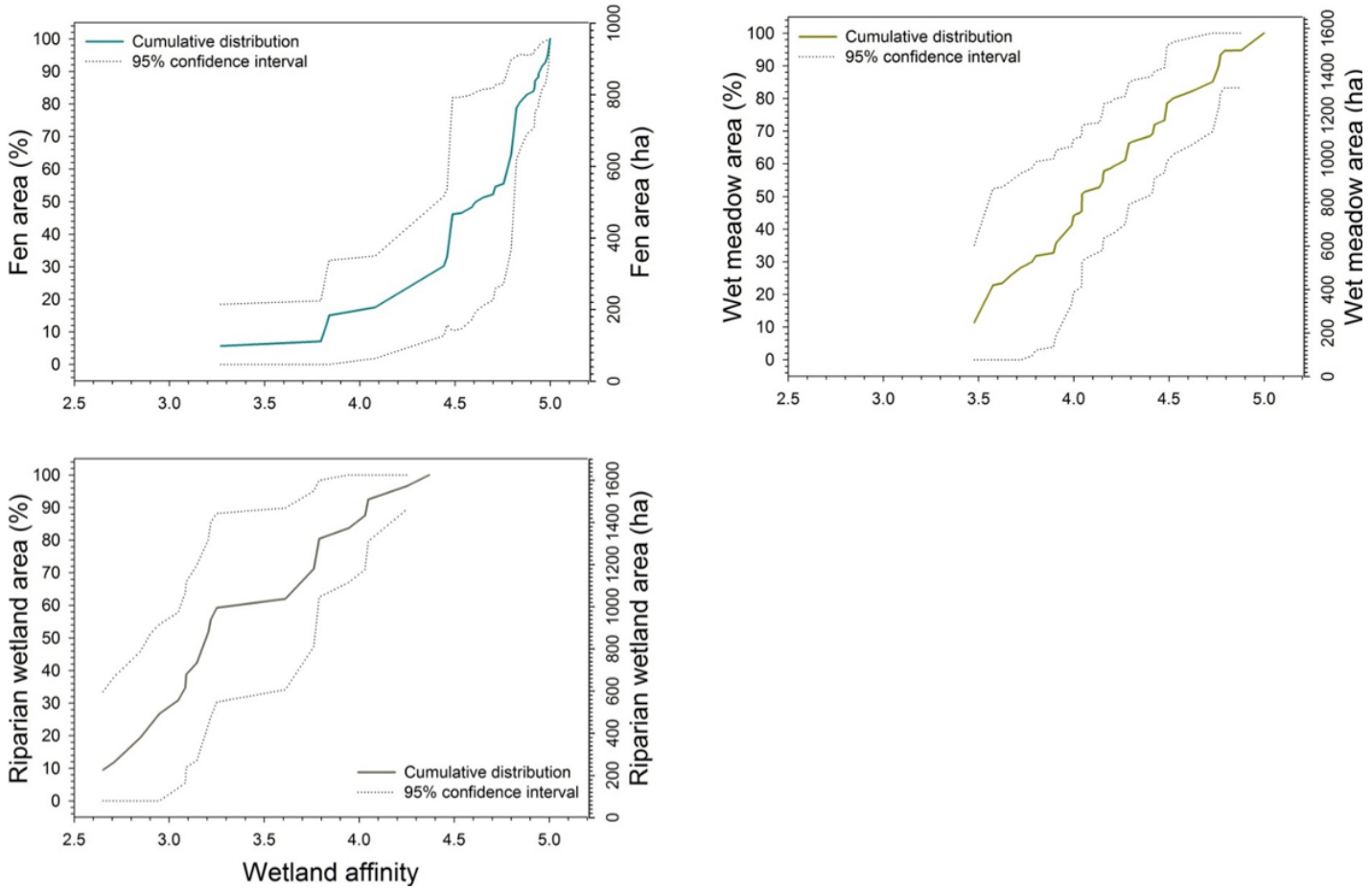


Figure 43. Wetland affinity (Tiner 2012; cover weighted, index; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Wetland affinity ranges from 0 for an assemblage with no wetland taxa to 5 for an assemblage dominated by high cover of species specialized for wetlands. Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

3.5.4 Patterns across time at sentinel sites

Results across time at each of the four sentinel complexes in the seven focal vegetation metrics are given in Figure 44 through Figure 48. Patterns in each are complex and will take careful modeling and assessment to better understand.

Mean conservatism was stable across all four sentinel sites (Figure 44). It was lower in Kawuneeche Valley and Moraine Park, with a slight suggestion of increasing values in Moraine Park. This may reflect the park's restoration of the site.

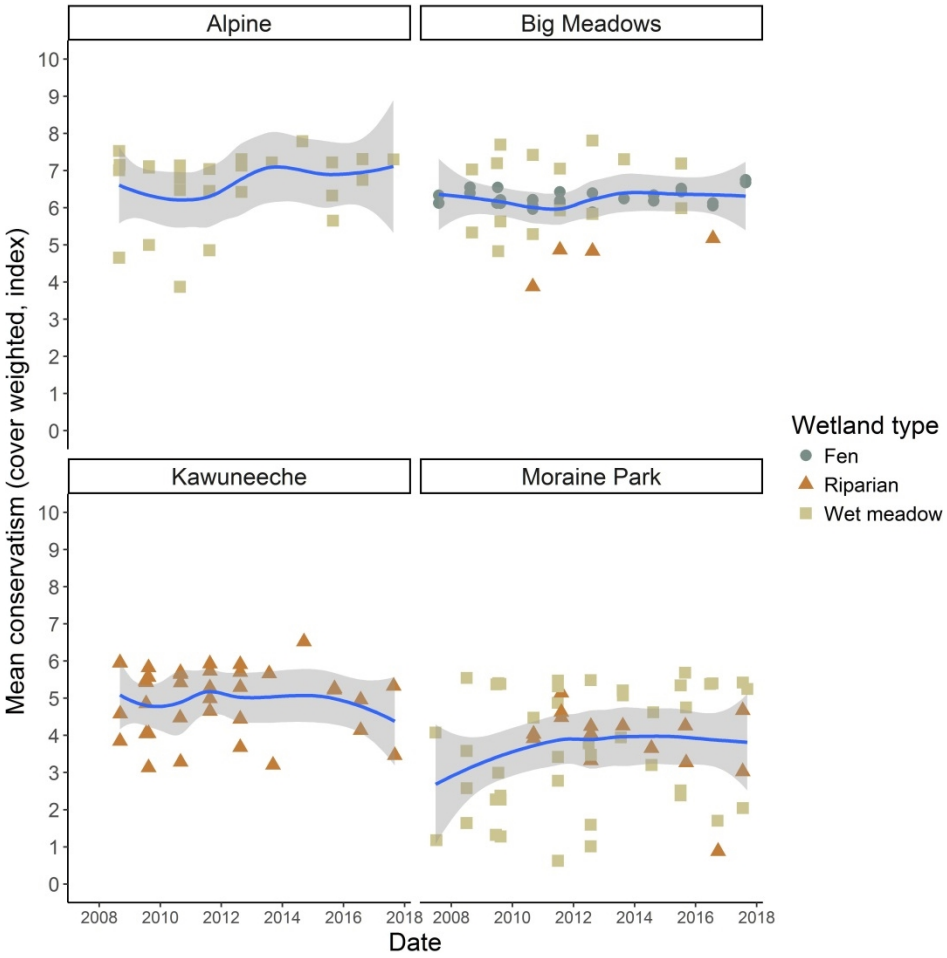


Figure 44. Mean conservatism (Rocchio 2007a, b; cover weighted, index) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Conservatism is averaged across all species in a sample and ranges from 10 (highly conservative) to 1 (very low conservatism with a 0 applied by definition to nonnative species). The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Data collection at Alpine and Kawuneeche began in 2009.

The degree of invasion indices both indicated that the Alpine and Big Meadows sites were relatively uninvaded, especially when the index includes a weighting factor from the percent of the species list at the sites that are invasive (index 2) (Figure 45). Big Meadows had uncommon invasive species that reached locally higher abundance in some years. Moraine Park and Kawuneeche Valley were both more invaded, with a fair degree of variation across years. In Moraine Park the importance of invasive species with high cover may be decreasing over time but the percentage of the species lists at the sites that are invasive may be increasing. Of note the single occurrence of an invasive nonnative species in the Alpine site was of *Salix alba*. This is a lower elevation species, not typical for the alpine in Rocky Mountain National Park. We do not have a specimen but the botanist was well qualified and certain the identification was correct. The species was only seen in one season and did not survive the harsh winter.

Native forb cover was generally low at all four sites, especially the more human disturbed Moraine Park (Figure 46). It was somewhat elevated in Kawuneeche Valley, which is interesting as understory forbs can play an important role in riparian wetland condition. Patterns across time were variable.

Wetland affinity was stable and uniformly high at all four sites, especially in the fens at Big Meadows (Figure 47). There was more variation at Moraine Park and Kawuneeche Valley.

Cover of Salicaceae and Betulaceae varied across the four complexes (Figure 48). It was zero or near zero in Moraine Park—this site lost all of its woody vegetation in the past and has yet to recover. Woody cover appeared to decline in Kawuneeche Valley, especially absolute values. Most sites in Big Meadows had lower cover, although as noted in the woody vegetation section below (section 3.7), a single site in the complex was dominated by a patch of short *Salix planifolia* and this skewed woody metrics in the site.

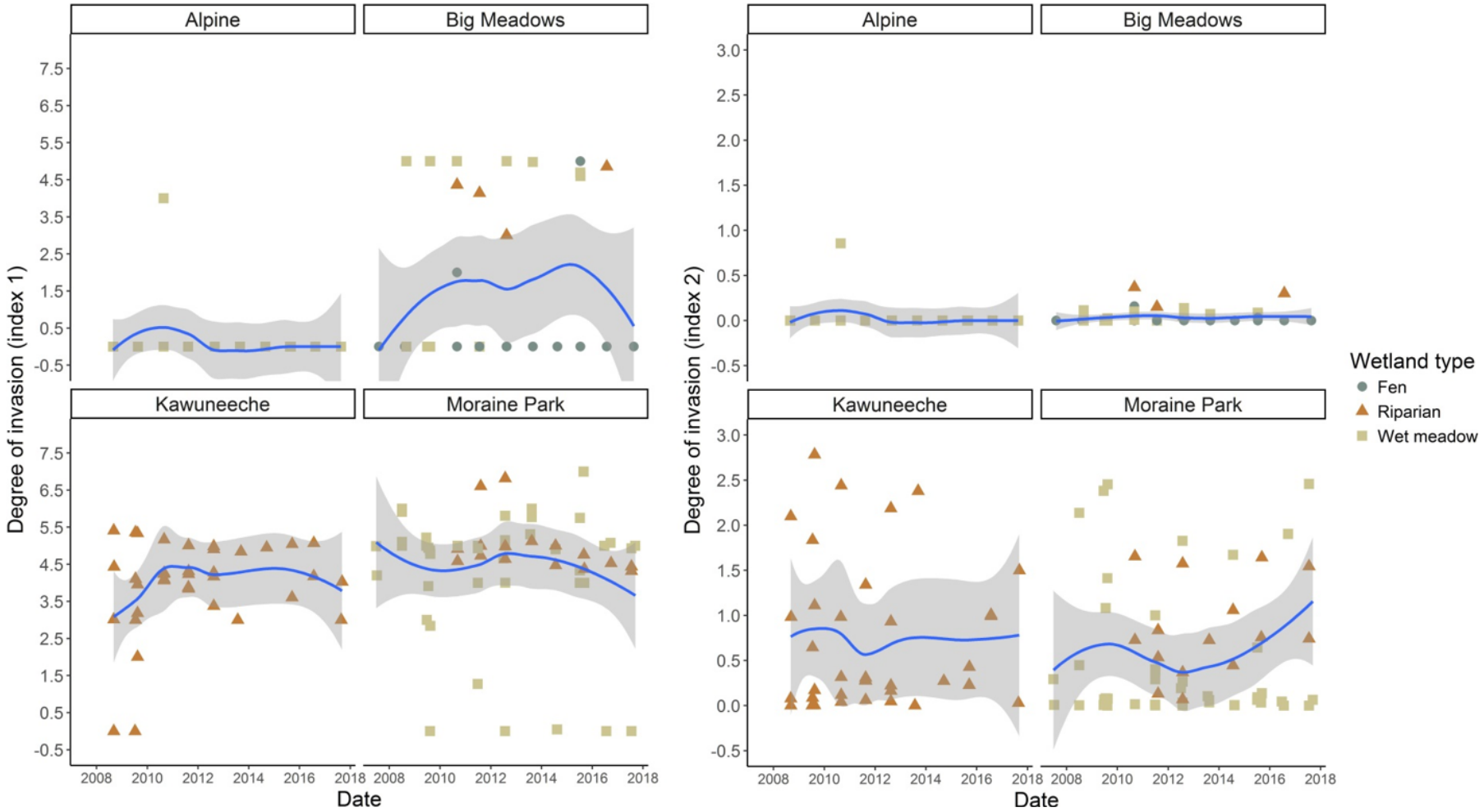


Figure 45. Degree of invasion: (left) cover weighted mean I-rank (Morse et al. 2004; index), (right) percent of assemblage as invasive taxa weighted mean I-rank by wetland type at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Note the different scales in each panel. Both degree of invasion indices range from 0 for an assemblage with no invasive species to 8 (index 1) for an assemblage dominated by high cover of highly invasive species and 4 for an assemblage with a high percentage of highly invasive species. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Data collection at Alpine and Kawuneeche began in 2009. The legend in the right-hand panel applies to both figures.

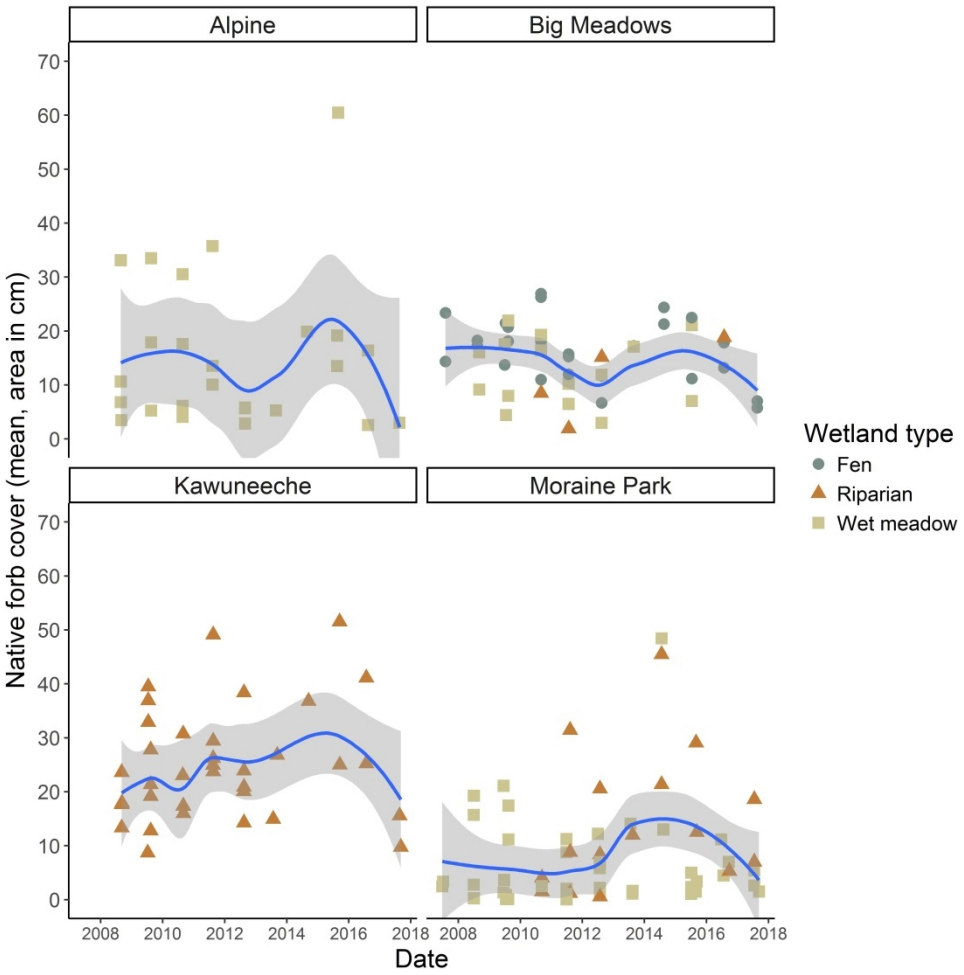


Figure 46. Native forb cover (averaged across all absolute cover values from sampled subplots in a site, square cm) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Native cover ranges from 0 for assemblage with no native forbs to around 80 for an assemblage with high absolute cover of native forbs. The dark horizontal line inside each box represents the median. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Data collection at Alpine and Kawuneeche began in 2009.

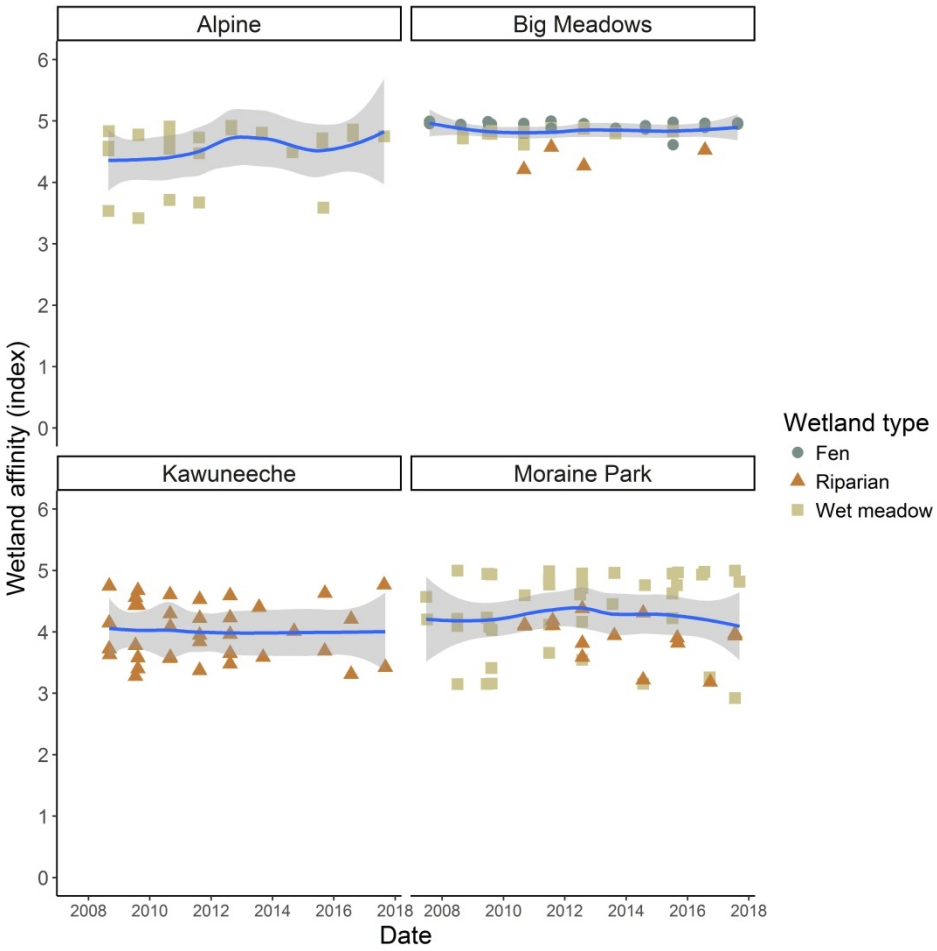


Figure 47. Wetland affinity (cover weighted, index) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Wetland affinity ranges from 0 for an assemblage with no wetland taxa to 5 for an assemblage dominated by high cover of species specialized for wetlands. The dark horizontal line inside each box represents the median. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Data collection at Alpine and Kawuneeche began in 2009.

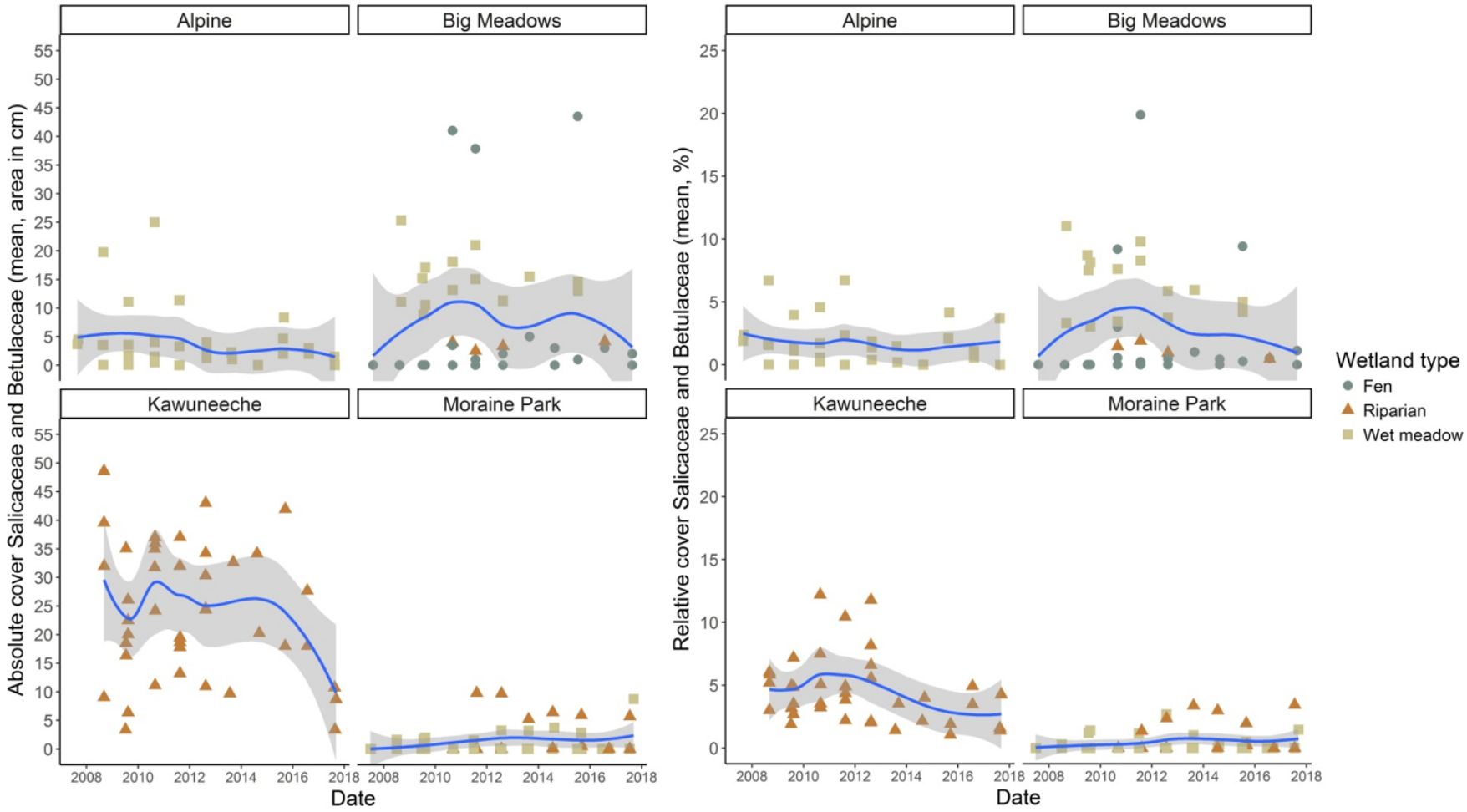


Figure 48. Absolute (left; units are square cm) and relative (right; units are %) cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) by wetland type at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. The dark horizontal line inside each box represents the median. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Data collection at Alpine and Kawuneeche began in 2009. The legend in the right-hand panel applies to both figures.

3.6 Groundwater hydrology: depth to water from ground surface

3.6.1 Overview

Hydrologic regime is fundamental to wetlands as one of the three controls on what make habitat a wetland (soils and vegetation being the other two). It is the primary site-level ecological driver of wetlands, strongly influencing vegetation, biogeochemistry, and ecosystem processes, such as primary production and decomposition (Keddy and Keddy 2000). Hydrologic regime acts as a filter on the pool of potential species capable of occupying a wetland, allowing only those species with the required physiological, morphological, or life history adaptations to establish and be recruited (Mitsch and Gosselink 2007). Groundwater and vegetation data collected in tandem improve understanding of natural variability in wetland ecosystem properties (Winter and Rosenberry 1995). The source of water supporting a wetland—whether it is principally precipitation, surface, or groundwater—and the flow paths taken before and after entering the system, can also affect a variety of important ecological functions.

Changes in groundwater level occur from both natural and anthropogenic sources of disturbance in wetlands, and wetland vegetation communities can be modified by local changes in groundwater level (Ehrenfeld and Schneider 1991, van der Valk 1994). Moreover, since groundwater level in most wetlands is affected by processes occurring throughout the catchment, groundwater level is also a good indicator of disturbance on a larger scale.

We present hydrologic indicators in the following sections. First, we present baseline data from all sites using instantaneous summer hand measured depth to water from ground surface (DTW, also referred to as groundwater or water table depth; Figure 49). Results are given across all sites (including spatially) and at the parkwide scale from our representative survey. We then report example site-specific continuous DTW data over variable periods (depending on site) from 2007 to 2014.

Note that many WEI monitoring sites do not necessarily meet requirements for wetland groundwater depths as set by the National Research Council (1995) and the Corps of Engineers (2008). We consider sites to be wetland if they meet two out of the three requirements (wetland vegetation, wetland soils, wetland hydrology). Following the WEI protocol, we do not exclude such sites from WEI monitoring because of this.



Figure 49. Rocky Mountain Network crewmember measuring depth to water from ground surface at an Alpine sentinel site in Rocky Mountain National Park, 2007. NPS/B. SCHWEIGER

3.6.2 Baseline

3.6.2.1 Site scale

Figure 50 shows instantaneous summer hand measured depth to water from ground surface (DTW) across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. This is the primary site scale baseline for this important indicator. It suggests that fen sites had a typical groundwater table height near the surface, that riparian wetland sites had deeper water table but with lots of variation, and that wet meadow sites were intermediate, but also with more variation in DTW.

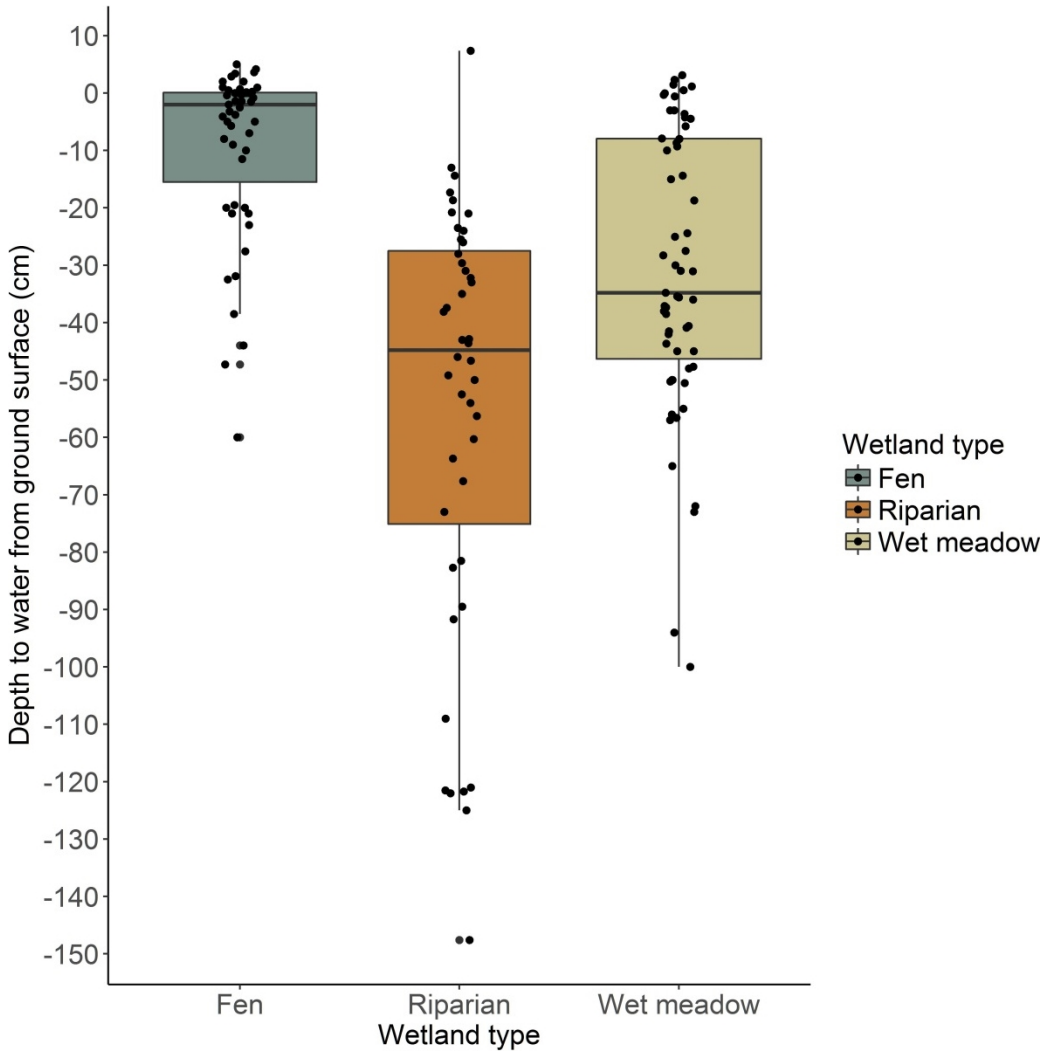


Figure 50. Depth to water from ground surface (DTW, cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Ground surface elevation is at 0 on the y-axis. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. The dark line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (or the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. The points (dots) outside the whiskers are outliers.

3.6.2.1.1 Spatial pattern

Figure 51 shows the spatial distribution of DTW across the park. These results are complex and will require more detailed analyses. There was no visually obvious structure in the distribution of DTW across the park. Moreover the park scale map should be used with caution as it masks results at a smaller scale, as seen in the panel focused on the Kawuneeche Valley. At this larger scale, the drier riparian sites on the valley floor and the wetter fens to the east and west are more evident.

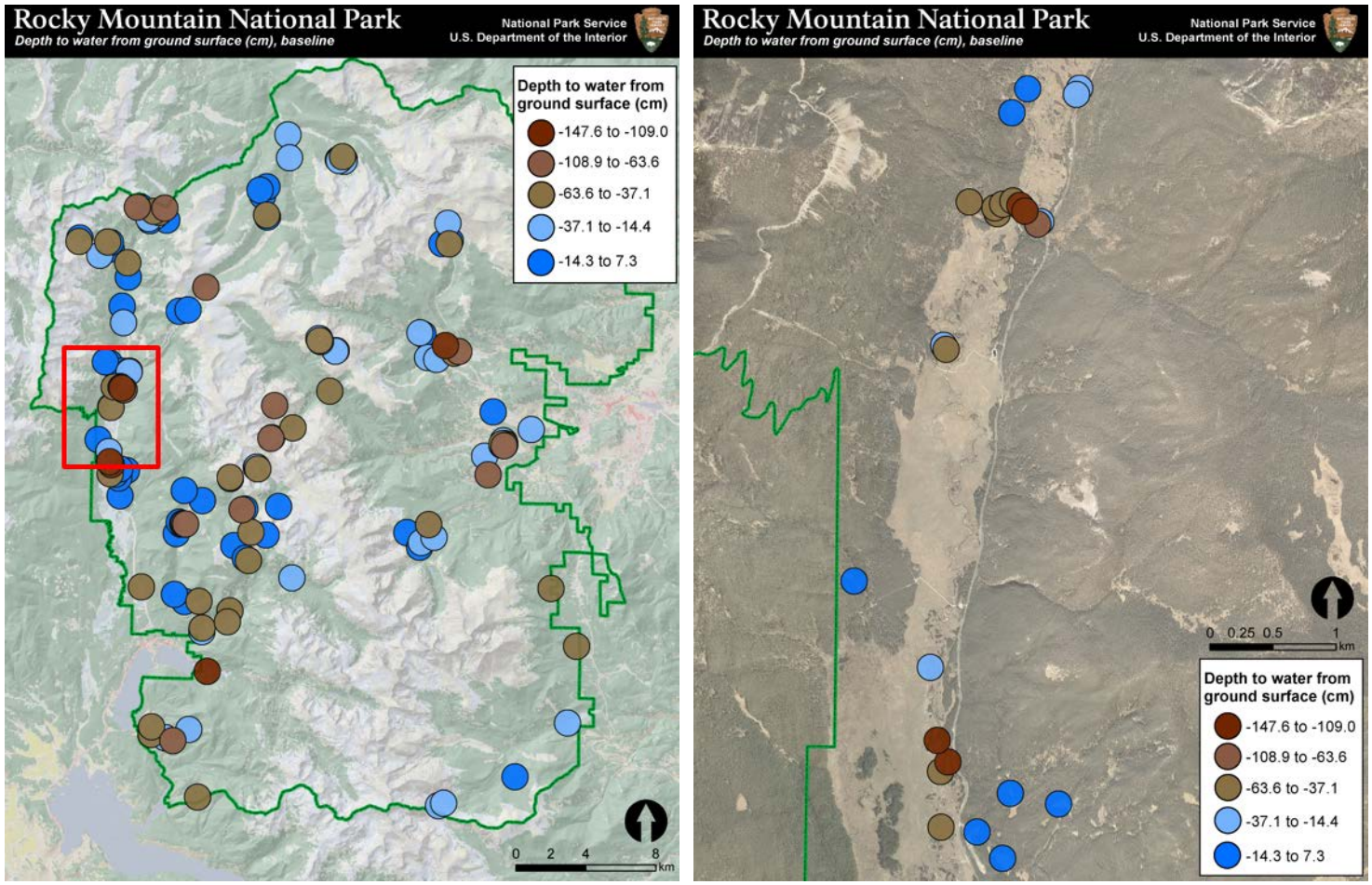


Figure 51. Map of hand measured depth to water from ground surface (DTW, cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley area (interior of the red box). The map on the right is an example of finer scale patterning. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker blue indicates sites with higher water tables (or more positive DTW) and increasingly darker shades of brown indicate deeper water tables (more negative DTW). The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.6.2.2 Parkwide scale

Table 11 presents design-based parkwide scale results from the 'best' survey sites for DTW across wetland type. Parkwide and site scale results followed a similar pattern, with DTW increasing in this order: fens, wet meadows, and riparian wetland.

Table 11. Summary statistics for depth to water from ground surface (DTW, cm) for all sample sites and the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' sample events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from 93 randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park.[a]

		DTW (parkwide scale)			
Wetland Type	**N**	**Mean**	**SE**	**LCB**	**UCB**
Fen	33	-5.97	2.29	-10.45	-1.48
Meadow	40	-39.58	9.66	-58.51	-20.66
Riparian	20	-46.47	10.47	-66.98	-25.95
All	93	-28.36	6.32	-40.75	-15.96

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Figure 52 shows the CDF of DTW across wetland type. The left y-axis shows the percentage of the wetland in the park and the right y-axis gives the estimated area of wetland. The 95% confidence intervals (dotted lines) around the percentage values (heavy line) are also shown. A CDF describes the 'value so far' of cumulative DTW from the lowest to highest score moving from left to right. For example, compared across wetland type, fens had more area with a water table closer to the surface than riparian wetland, with its longer tail on the left side of the CDF representing high negative DTW values (or a deep water table). As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

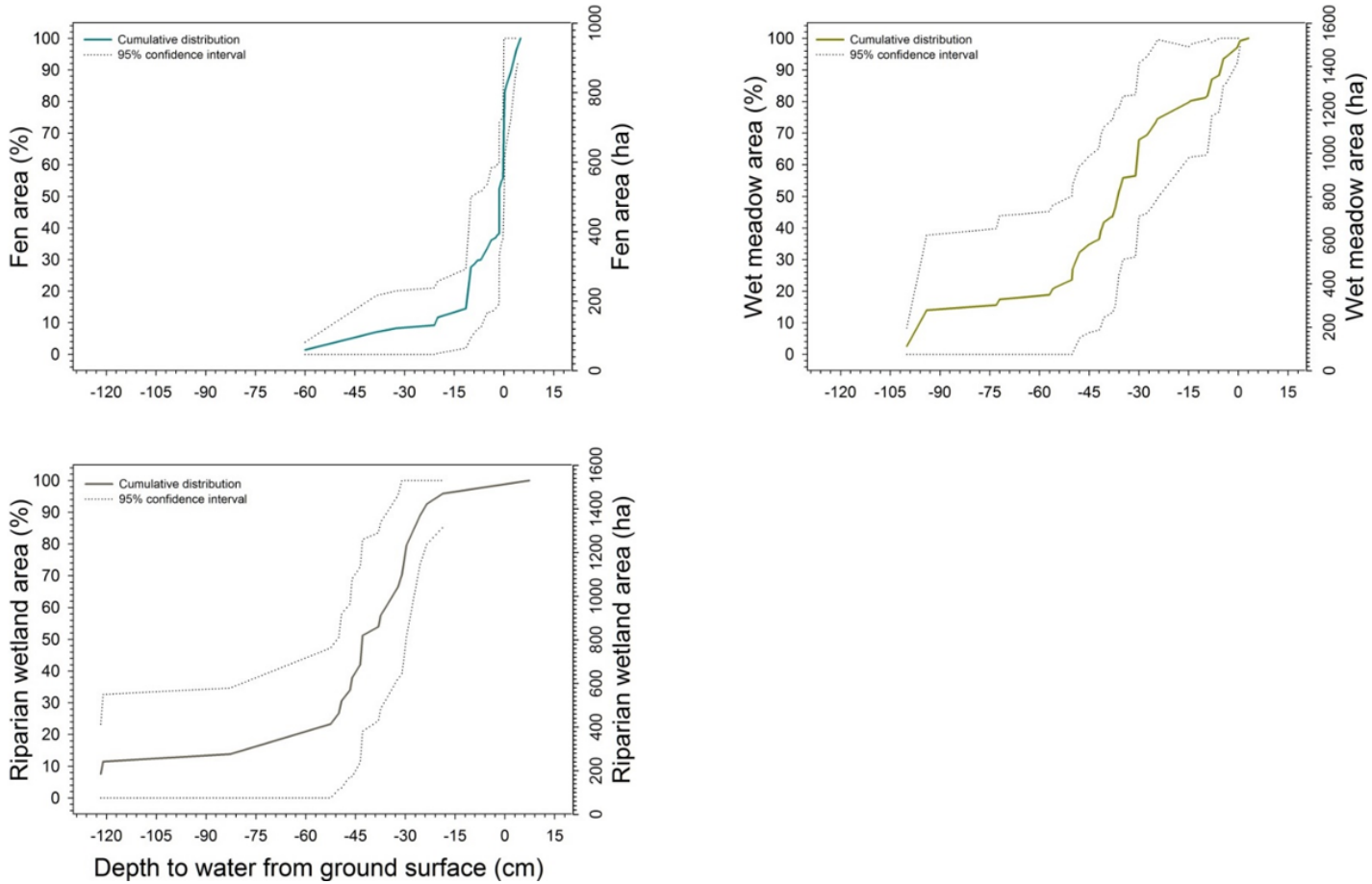


Figure 52. Depth to water from ground surface (cm, DTW; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. DTW ranged from around 130 below ground (relatively deep water table) to around 20 above ground (a saturated site). Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

3.6.3 Patterns across time at sentinel sites

3.6.3.1 Instantaneous depth to groundwater

Patterns across time at each of the four sentinel complexes in DTW are complex and will take careful modeling and assessment to better understand. DTW was fairly stable at the Alpine and Big Meadows sites (Figure 53). There was a slight drop in DTW in the drought year of 2012, with a return to wetter conditions in 2013 across most sentinel complexes. There is some suggestion of higher water tables (more positive DTW values) in the Kawuneeche Valley, Big Meadows, and Moraine Park sites, but this may just be the more pronounced (visually) positive slopes in the LOWESS fits with the transition from dry to wet conditions in 2012 and 2013. Kawuneeche Valley does appear to have increasingly positive values for DTW across the period of record.

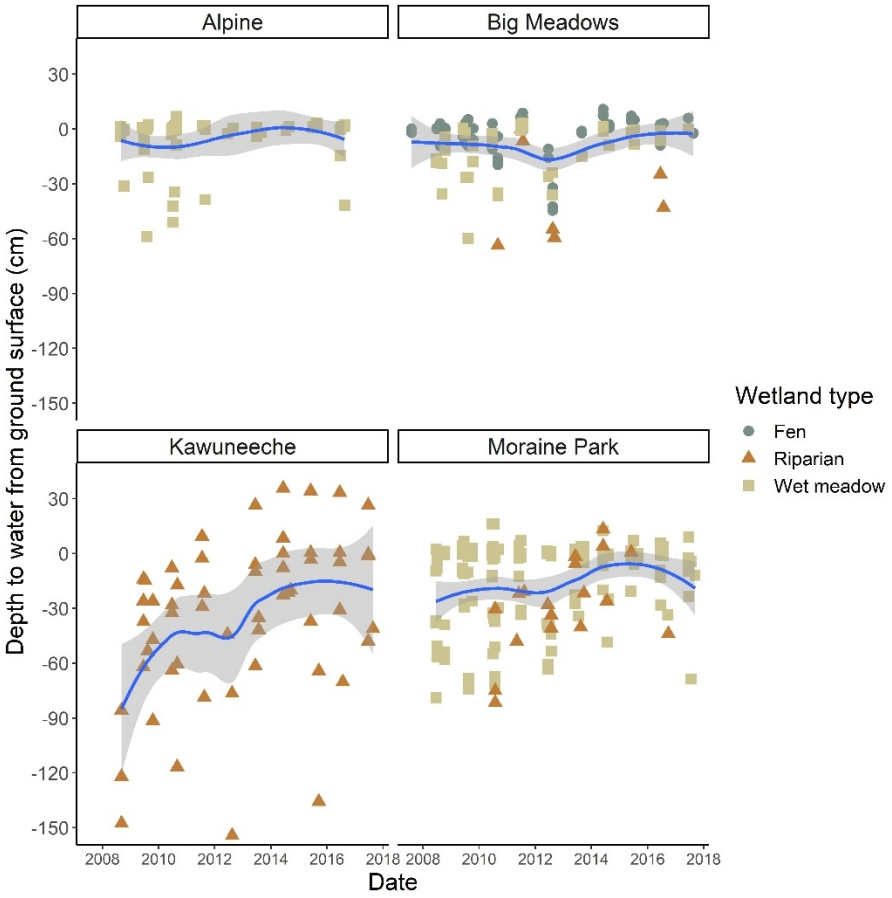


Figure 53. Depth to water from ground surface (cm, DTW) by wetland type at sentinel wetland ecological integrity sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Data are instantaneous summer time measurements collected by hand. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Data collection at Alpine and Kawuneeche began in 2009.

3.6.3.2 Continuous depth to groundwater

At a subset of sites we use data loggers to collect continuous ground water depth. As of publication we had quality checked these data through late summer, 2014. Additional years are being processed. We present visualizations of these data across year for logged sites in each of the four sentinel complexes (we have similar results available on request for several other sites where loggers were maintained). These data also allow a more complete examination of hydrologic regime as estimated by a suite of simple metrics summarized below.

Figure 54 shows logs of hourly DTW as daily averages on snow free days at six sites from 2007 to 2014 in the Moraine Park sentinel complex. Results suggest that two general hydrologic regimes characterized the complex: 1) site 590 and 506 with stable and high water tables (DTW consistently close to 0) over all years, and 2) sites 505, 589, 596 and 724 with more variable patterning across site and year. The second group of sites often had a characteristic spring pulse driven by runoff in the nearby Big Thompson River, followed by a falling water table, then a late summer monsoon driven increase in water table height. The high water table sites are wet meadows but may be transitioning into fens with these stable and wet hydrologic regimes. The other sites have hydrologic regimes typical to many riparian sites in Rocky Mountain National Park.

Figure 55 shows logs of hourly DTW as daily averages on snow free days at three sites from 2009 to 2014 in the Kawuneeche Valley sentinel complex. Results suggest that the hydrologic regime of the site was characterized by a spring pulse driven by runoff in the nearby Colorado River, followed by a falling water table, and then a late summer monsoon driven increase in water table height. However the magnitude of the decrease in water table height varied across sites and years and in some cases did not elevate the site's water table (i.e., site 618 in 2009, bottom panel). These hydrologic regimes are typical to many riparian sites in the park.

Figure 56 shows logs of hourly DTW as daily averages on snow free days at six sites from 2008 to 2014 in the Big Meadows sentinel complex. Results suggest that the hydrologic regime of the site was characterized by a very high, often saturated, water table. Some sites (i.e., 604 in 2008 and 511 in 2012) were more variable and may be influenced by precipitation.

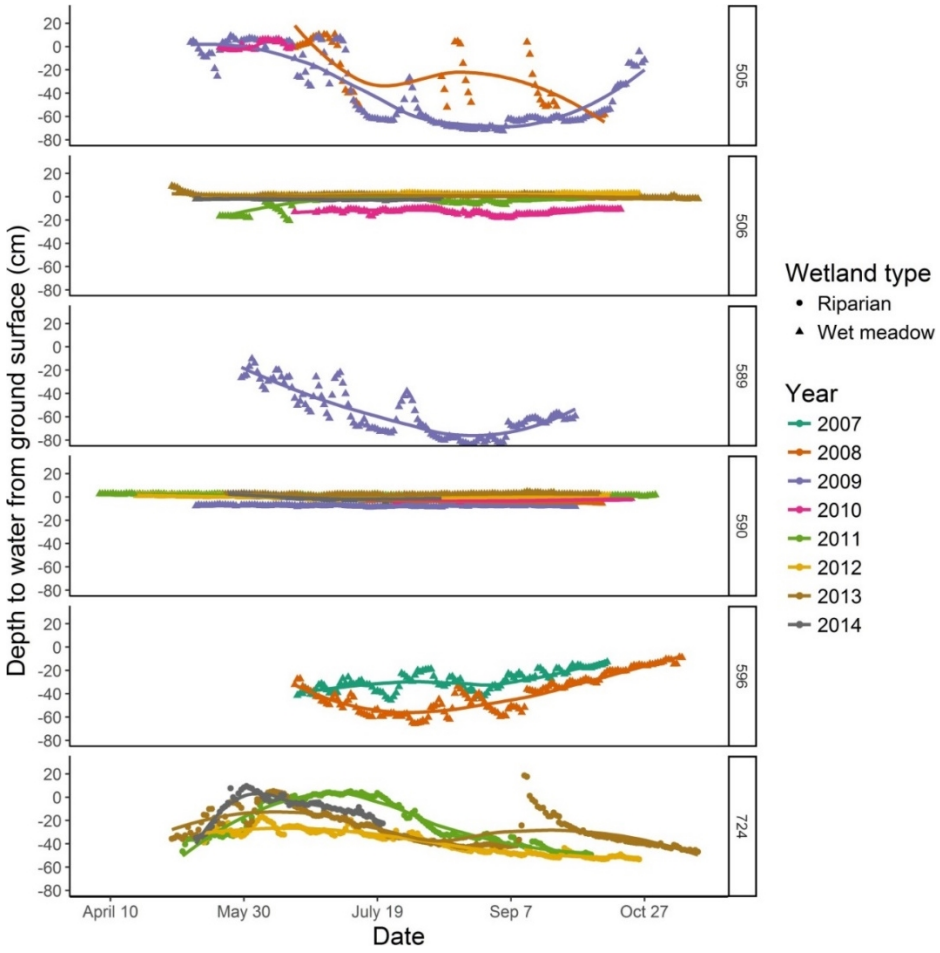


Figure 54. Daily mean depth to water from ground surface (cm, DTW) at six wetland ecological integrity sites within the Moraine Park sentinel complex in Rocky Mountain National Park, 2007 to 2014. Results apply only to these specific sites. Means are taken over hourly readings from snow free days (spring through early fall) as collected by data loggers in each site's well. Ground surface elevation is at 0 on the y-axis. Note that due to the timing of logger installations and downloads, some logs may not reflect snow on/off timing and not all years in all sites were logged.

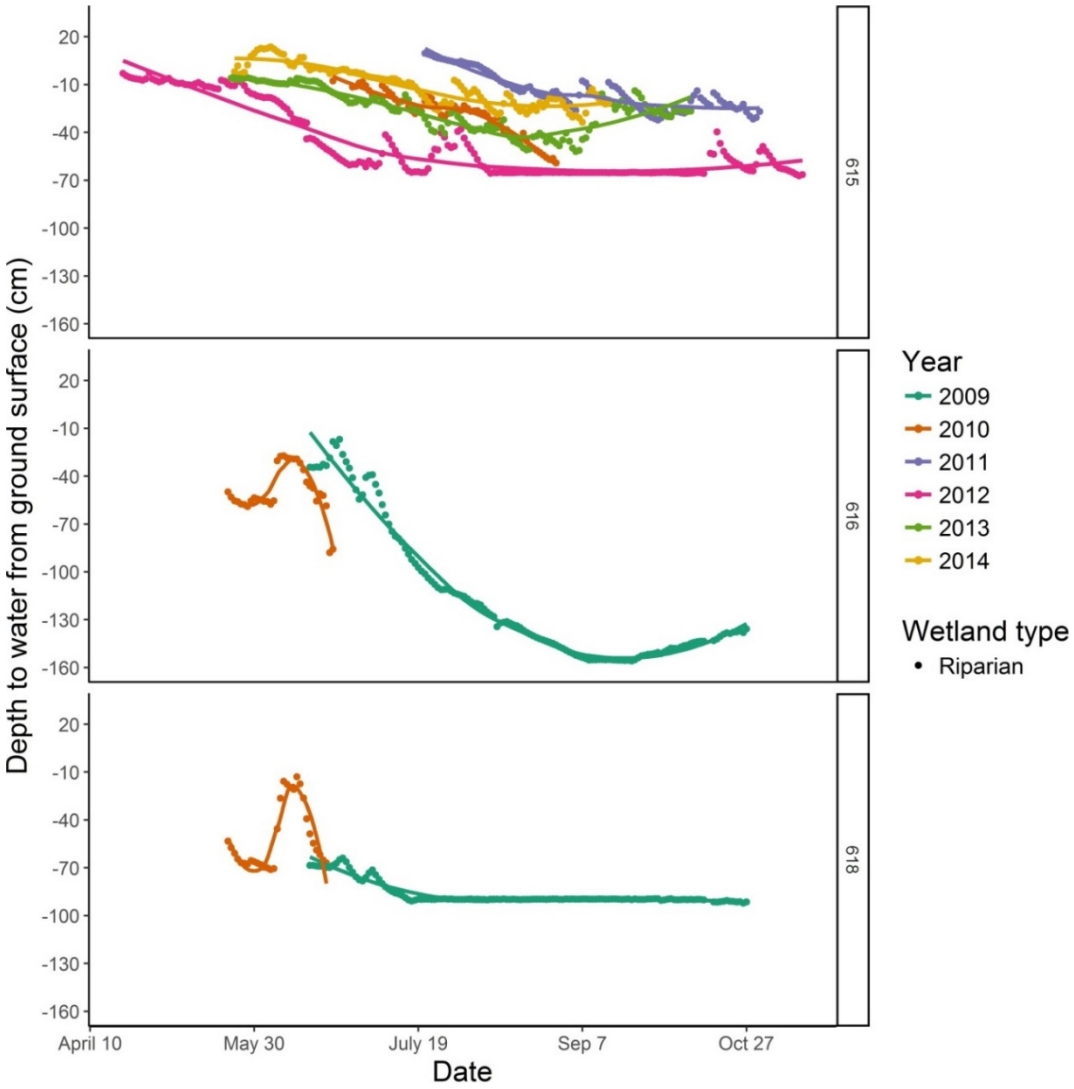


Figure 55. Daily mean depth to water from ground surface (cm, DTW) at three wetland ecological integrity sites within the Kawuneeche Valley sentinel complex in Rocky Mountain National Park, 2009 to 2014. Results apply only to these specific sites. Means are taken over hourly readings from snow free days (spring through early fall) as collected by data loggers in each site's well. Ground surface elevation is at 0 on the y-axis. Note that due to the timing of logger installations and downloads, some logs may not reflect snow on/off timing and not all years in all sites were logged.

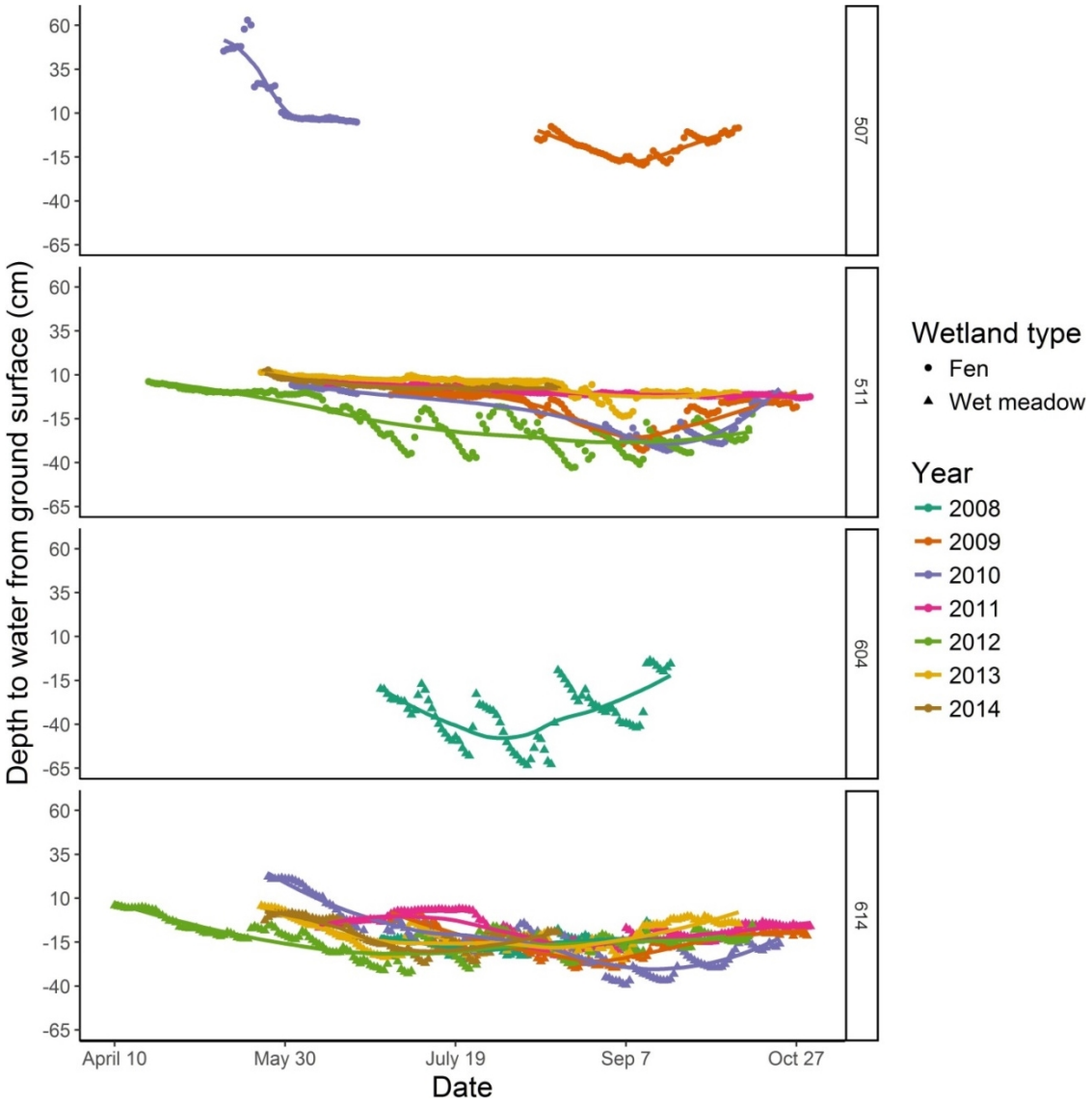


Figure 56. Daily mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sites within the Big Meadows sentinel complex in Rocky Mountain National Park, 2008 to 2014. Results apply only to these specific sites. Means are taken over hourly readings from snow free days (spring through early fall) as collected by data loggers in each site's well. Ground surface elevation is at 0 on the y-axis. Note that due to the timing of logger installations and downloads, some logs may not reflect snow on/off timing and not all years in all sites were logged.

Figure 57 shows logs of hourly DTW as daily averages on snow free days at four sites from 2008 to 2014 in the Alpine sentinel complex. Results suggest that the hydrologic regime of the site was usually characterized by a high water table, especially in site 605. Some sites (i.e., 605 in 2010) had extreme fluctuations in water table height, which may have been driven by rapid freeze/thaw cycles, and others varied markedly across years (i.e., 551), likely driven by extremely variable alpine weather patterns. Note that this Alpine sentinel site is difficult to log given extreme conditions impacting instrument performance and short summer seasons.

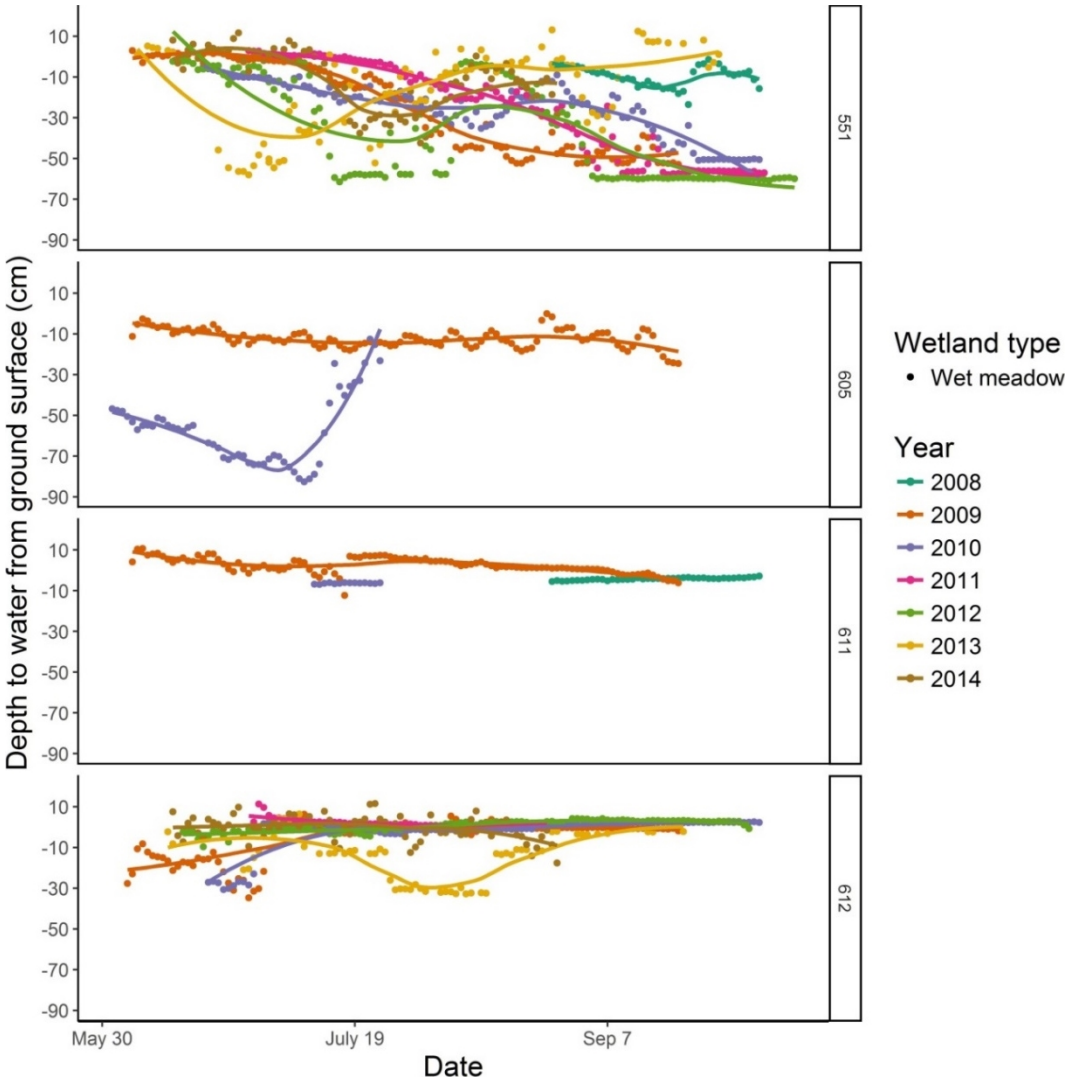


Figure 57. Daily mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sites within the Alpine sentinel complex in Rocky Mountain National Park, 2008 to 2014. Results apply only to these specific sites. Note that this site is difficult to log given extreme conditions impacting instrument performance and short summer seasons. Means are taken over hourly readings from snow free days (spring through early fall) as collected by data loggers in each sites well. Ground surface elevation is at 0 on the y-axis. Note that due to the timing of logger installations and downloads, some logs may not reflect snow on/off timing and not all years in all sites were logged.

From 2007 to 2014 we generated 133 DTW logs from 33 sites. Of these, 71 were in sentinel sites and 68 had more than 30 snow free days. Of the other 62 logs outside of sentinel complexes, five sites had more than a year of logging with more than 30 snow free days. Summaries of these other site logs are useful and are available upon request, but here we focus on the logs at sentinel sites with more than 30 snow free days.

Snow has negative impacts to the quality of logger based DTW. Moreover the important period for monitoring depth to water is the growing season. Day of snowmelt-off and first sustained snow

cover, while important phenological DTW metrics, need to be treated with caution and are not summarized here. These are a function of both patterns in climate as well as methodological issues (i.e., a logger may not have been deployed or working properly when snowmelted or covered a site). Future reports will include these metrics after additional quality checks have been done on these data. In this section, we estimate a series of metrics from the logger data. See Appendix F for additional results.

Figure 58 gives the mean proportions by year and sentinel site of logs with daily mean depth to water from ground surface that classifies a site as “dry” (below -40 cm) or “saturated” (above -5 cm). Means are across loggers within a sentinel complex and thus may hide some site level or wetland type effects. Patterns are complex and will require more careful analyses. Visually, saturated days appeared to increase across year in Moraine Park. The proportion of dry days in Kawuneeche Valley may have decreased from 2009 to 2013. Big Meadows had very few dry days. The Alpine complex may have had more saturated days than the other sentinel sites.

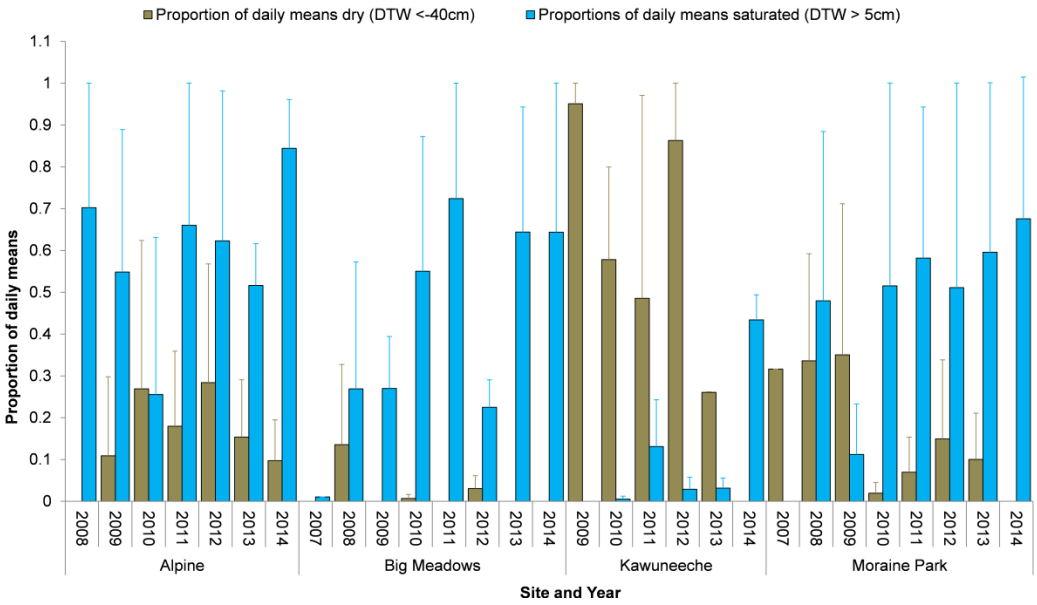


Figure 58. Annual mean proportions of depth to water (DTW) logs in each sentinel complex with daily mean depth to water from ground surface below -40 cm (“dry”) or above -5 cm (“saturated”) at four wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2014. Results apply only to these specific sites. Proportions are taken over hourly readings summarized to daily means from snow free days (spring through early fall) as collected by all data loggers in each sentinel site. Note that the number of days included vary from 31 to 229 days due to variable snow free periods, and logger installation and download timing. Logs shorter than 30 days are omitted. Zero value bars are null and are year-site combinations with no dry or saturated days (e.g., there were no dry days in Moraine Park, 2014).

Figure 59 gives the maximum and minimum depth to water from ground surface across snow free periods at sentinel sites. Means are across loggers in a sentinel complex and thus may hide some site level or wetland type effects. Patterns are complex and will require more careful analyses. Visually,

it appears that minimum water table depth in Kawuneeche Valley may have increased from 2009 to 2013, matching the pattern in proportion dry. Similarly, minimum water table depth in Moraine Park may have increased from 2009 to 2013, here matching the increase in proportion of saturated days.

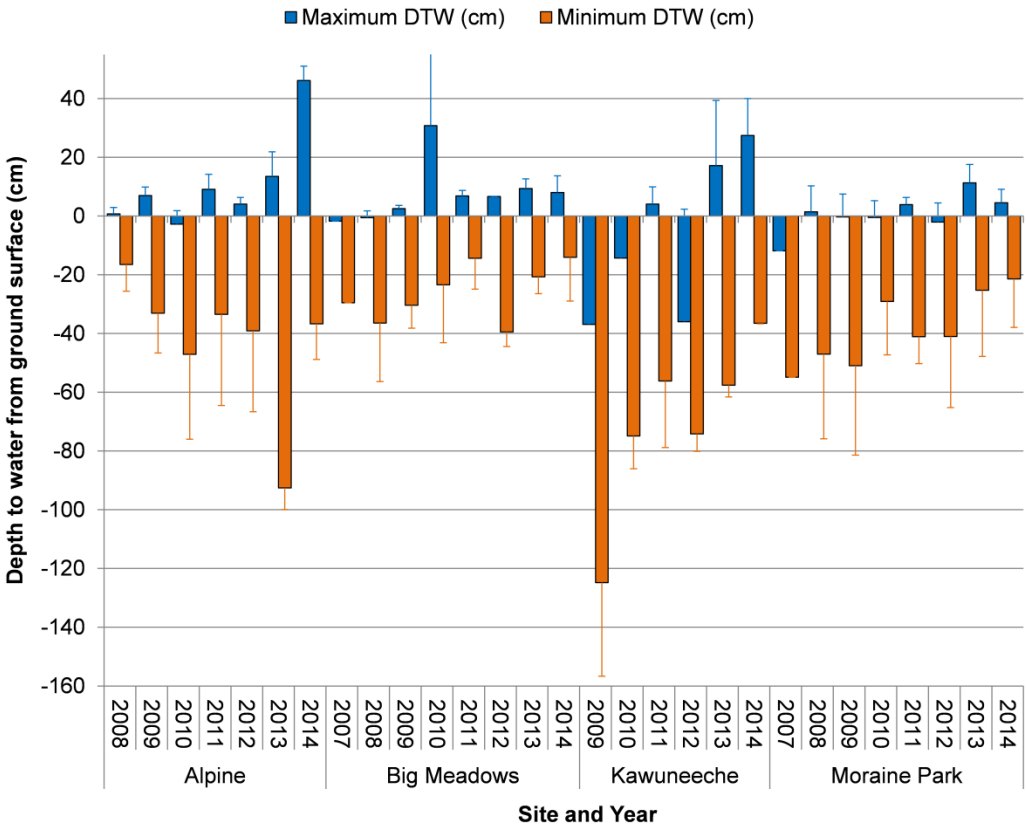


Figure 59. Maximum (dark blue bars) and minimum (orange bars) mean depth to water from ground surface (cm, DTW) at four wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2014. Results apply only to these specific sites. Values are averaged to daily means from hourly readings on snow free days (spring through early fall) as collected by all data loggers in each sentinel site. Note that the number of days included vary from 31 to 194 days due to variable snow free periods, and logger installation and download timing. Logs shorter than 30 days are omitted.

3.7 Woody vegetation

3.7.1 Overview

Estimating status and trends in woody vegetation across time and space is one of the core objectives of the WEI protocol in Rocky Mountain National Park (Figure 60, Figure 61). The woody species component of wetland vegetation is particularly important in influencing the suitability of habitat for both plants and animals (vertebrates) in wetlands. In turn, ungulate herbivory on woody species impacts ecosystem structure and function via trophic relationships and nutrient cycling (Hobbs et al. 1982, Zeigenfuss et al. 2002, Augustine et al. 1998, Schoenecker 2012). Rocky Mountain Network WEI woody data help improve understanding of various wetland relationships and ungulate and beaver habitat use (Allen 1983, Baker et al. 1997, Mitchell et al. 2000, Peinetti et al. 2002, Westbrook et al. 2006).



Figure 60. Network crews sample a Kawuneeche Valley site in 2008 in Rocky Mountain National Park. This site had relatively dense woody stems, with high levels of browse, dead stems, and dieback. NPS/B. SCHWEIGER



Figure 61. Network crews sample a site near Poudre Pass in 2007, Rocky Mountain National Park. Unlike many wetlands in the park with low woody stem density, this wetland had dense shorter woody stems. NPS/B. SCHWEIGER

WEI data on woody species include stand composition by five height classes, and three general indicators of ungulate impacts and other sources of stress on woody species, including the percentage

of stems that were clearly dead, the percentage of the crown of each woody plant that had dieback, and the percentage of live stems that had evidence of ungulate browse. We focus on 17 species of Salicaceae (willow, aspen and cottonwood) and Betulaceae (alder and birch) important for ungulates and beaver (Table 12). WEI methods are general rapid assessments and not intended to generate rigorous site-specific estimates of utilization of woody species by ungulate herbivores, such as off take (see Bilyeu et al. 2008). We also include select metrics of woody taxa cover important for ungulates and beaver in the following section.

We generated 22 vegetation metrics from woody species data. Details of metric calculation are in Schweiger et al. (2015). These metrics are direct and purposefully one dimensional assays of woody vegetation composition and structure. They have significant explanatory power in and of themselves and we summarize seven examples in this report. For more detailed analyses, Schweiger et al. (2016) present metrics that are arithmetic transformations using height and cover data that estimate woody production and the volume of browse and dieback. These are important in structural modeling that relates stem condition to ungulates, beaver and vegetation condition indicators.

We present woody stem count and damage indicators in the following sections. First, we present baseline data across all sites (including spatially) and at the parkwide scale from our representative survey. We then report sentinel site specific change from 2007 to 2017.

Table 12. Species of Salicaceae (willow, aspen and cottonwood) and Betulaceae (alder and birch) important for ungulates and beaver at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Rocky Mountain National Park (ROMO) species of concern are as defined by park staff. Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). All of these species are native as defined by Weber and Wittmann (2001) and as modified by the network. Wetland affinity is from Tiner (2012) as modified by the network (we reversed the scoring scale) and ranges from 5 for a taxa obligate to wetlands to 1 for a taxa adapted to upland conditions. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. For a table of all taxa see Rocky Mountain Network - NPS (2019a).

Family	Species	Common name	ROMO species of concern	Conservatism	Wetland affinity	Count	Mean absolute cover (%)	Mean relative cover (%)
Betulaceae	*Alnus incana* spp. *tenuifolia*	thinleaf alder	–	6	4	22	14.42	12.34
	Betula glandulosa	resin birch	–	9	5	26	6.69	3.63
Salicaceae	*Populus tremuloides*	quaking aspen	Yes	5	4	10	7.50	6.15
	Salix bebbiana	Bebb willow	Yes	6	4	1	29.00	9.10
	Salix boothii	Booth's willow	–	7	4	4	4.09	3.16
	Salix brachycarpa	shortfruit willow	–	8	4	4	2.91	0.88
	Salix drummondiana	Drummond's willow	–	6	4	13	12.53	8.36
	Salix eriocephala	Missouri River willow	–	6	5	6	9.13	6.63
	Salix geyeriana	Geyer willow	Yes	6	4	26	5.41	3.70
	Salix lucida spp. *lasiandra*	Pacific willow	–	–	4	1	0.05	0.04
	Salix lutea	yellow willow	–	6	4	1	1.03	0.44
	Salix melanopsis	dusky willow	–	3	–	1	2.50	1.90

Table 12 (continued). Species of Salicaceae (willow, aspen and cottonwood) and Betulaceae (alder and birch) important for ungulates and beaver at wetland ecological integrity sites in Rocky Mountain National Park from 337 sample events across 154 sites from 2007 to 2017. Rocky Mountain National Park (ROMO) species of concern are as defined by park staff. Conservatism (C scores) are from Rocchio (2007a, b) as modified by the Rocky Mountain Network and range from 10 (highly conservative) to 1 (very low conservatism, with a 0 applied by definition to nonnative species). All of these species are native as defined by Weber and Wittmann (2001) and as modified by the network. Wetland affinity is from Tiner (2012) as modified by the network (we reversed the scoring scale) and ranges from 5 for a taxa obligate to wetlands to 1 for a taxa adapted to upland conditions. Count is the sum of all sample events in which taxa occurred across all 154 sites (with a maximum of 337 and a minimum of 1). Absolute and relative covers are first averaged across all cover values from sampled subplots in a site, and then across all sites with a given taxa. For a table of all taxa see Rocky Mountain Network - NPS (2019a).

Family	Species	Common name	ROMO species of concern	Conservatism	Wetland affinity	Count	Mean absolute cover (%)	Mean relative cover (%)
Salicaceae (continued)	*Salix monticola*	park willow	Yes	6	4	28	11.24	6.56
	Salix nivalis	snow willow	–	9	4	4	2.68	1.81
	Salix petrophila	alpine willow	–	–	3	2	7.13	8.43
	Salix planifolia	diamondleaf willow	Yes	7	5	88	12.60	9.47
	Salix wolfii	Wolf's willow	–	8	5	20	7.58	4.24

3.7.2 Baseline

3.7.2.1 Site scale

Figure 62 shows the distribution of stem height classes across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. This is the primary site scale baseline for this important indicator. It suggests that wetland sites from all three types had a classic inverted J-shape pattern, with a higher proportion of shorter stems. The size structure of woody stems is determined by many factors, including differences in seed size, time of germination of each seed in relation to its neighbors, growth rate of each plant, competition, and herbivory. Importantly, in Rocky Mountain National Park, with often severe levels of ungulate browse, an unknown number of stems in the shorter size classes are actually older individuals. Therefore, these data must be used with caution to assess regeneration status. Another notable observation from these results is the near absence of taller stems in fen and wet meadow sites. This has implications for the suitability of these sites for beaver. Figure 63 shows a similar pattern across stem densities.

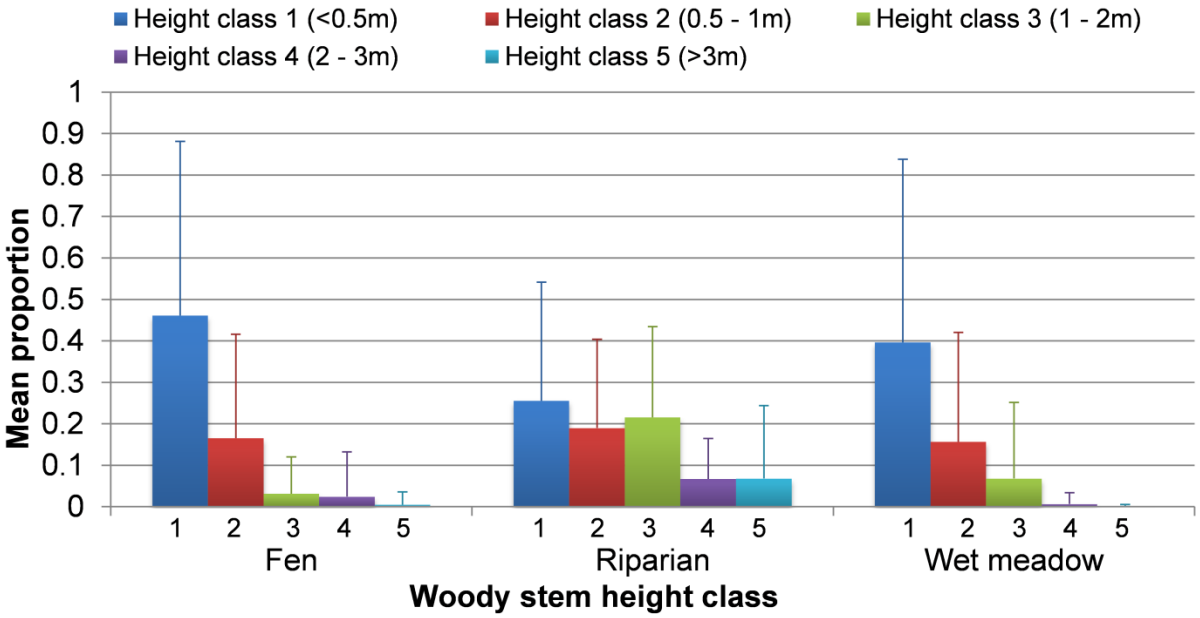


Figure 62. Mean proportion of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in five height classes by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Not all species occur at all sites or sample events. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Error bars are standard deviations.

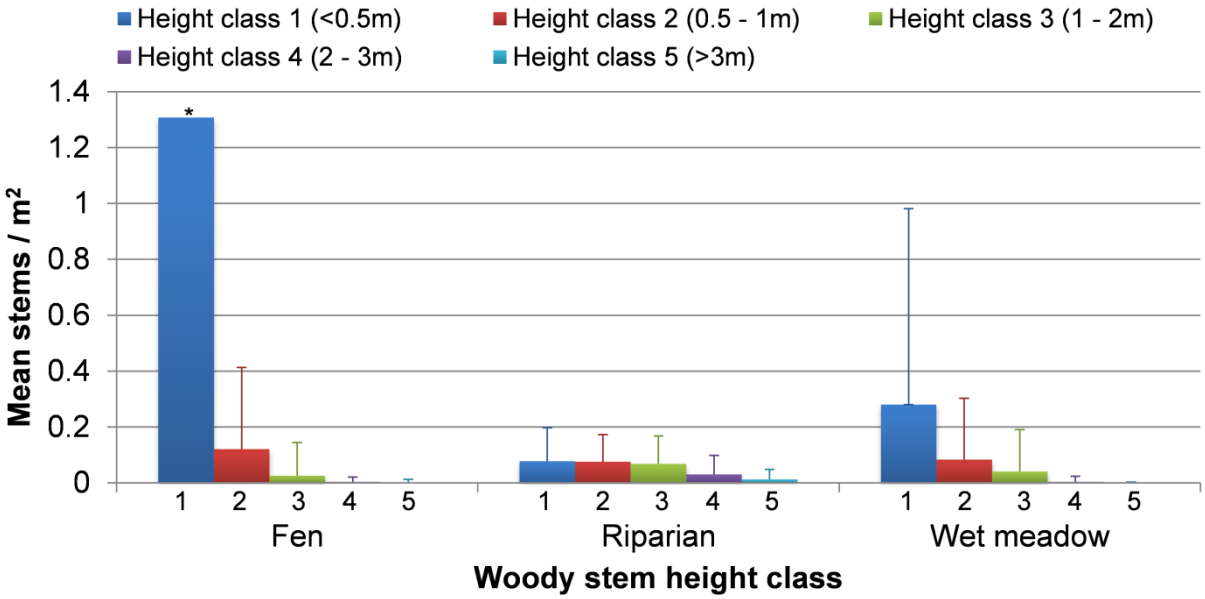


Figure 63. Mean stems per square meter of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in five height classes by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Results apply only to these specific sites. Not all species occur at all sites or sample events. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites. Error bars are standard deviations. *Large standard deviation omitted for improved visualization (size class 1, fens = 7.6).

Figure 64 shows the three woody stem damage metrics across wetland type and all best sample events. This is the primary site scale baseline for these important indicators. They suggest that riparian wetland had higher median levels of dead stems, but that the other two indicators were relatively equivalent across wetland type. Riparian wetlands are often in valley bottoms where historical human use was concentrated and the effects of ungulate habitat use are likely most severe. There was a high level of variation in each indicator but very few sites with low or zero levels—where there was wood it got hammered. Note that there are only 95 events in these data sets because we do not include sites where there was no wood. Only where there was wood is the interest in the condition of woody stems relevant. That said, some sites with no wood are likely because damage to stems has been so severe in the past that they are absent (parts of Moraine Park are a good example of this).

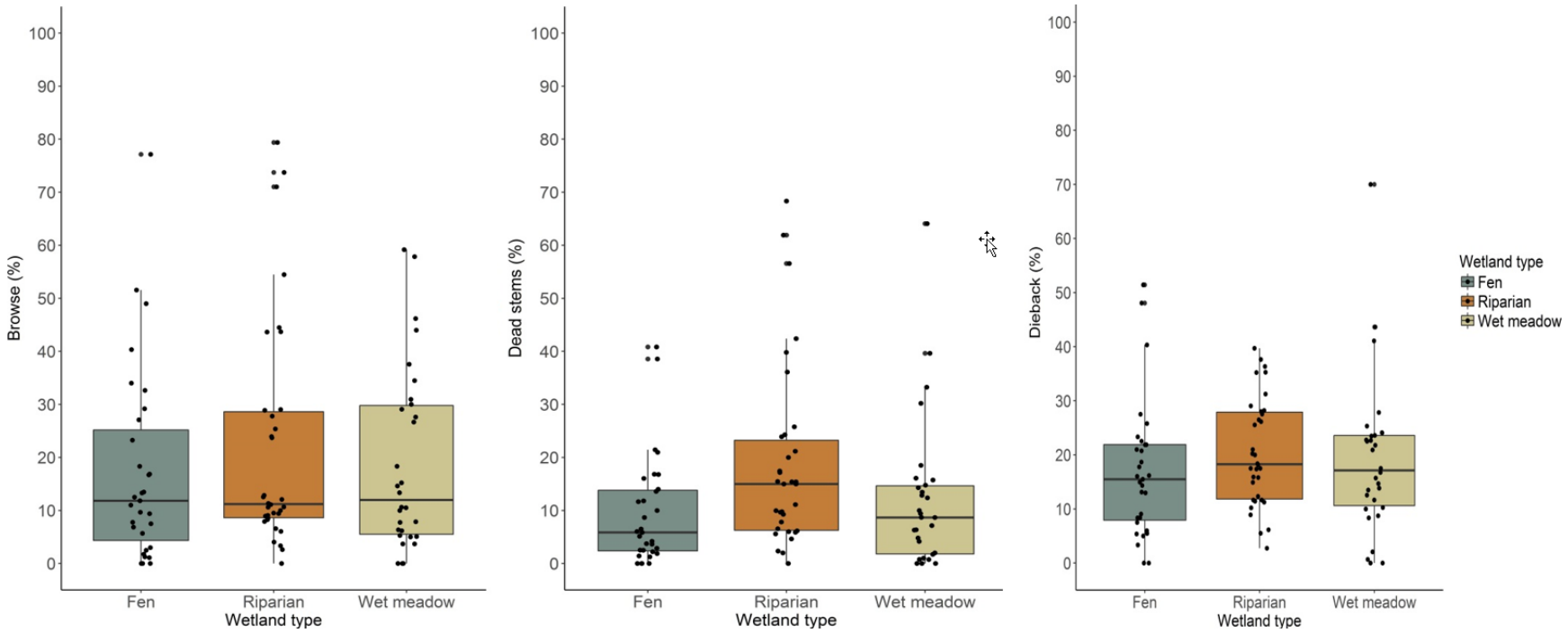


Figure 64. Damage on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch): (left) Ungulate browse on live stems (%), (center) Dead stems (%), (right) Dieback (%) at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' sample event at each site with woody stems and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Not all species occur at all sites or sample events and these data cannot be generated where there are no stems (so only 95 out of 154 sites are in these figures). Indicator details are provided in main text. The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier. The legend in the right panel applies to all panels.

3.7.2.1.1 Spatial pattern

Figure 65 shows the spatial distribution of the proportion of wood in a site by height class. Note that to make this symbology work, sites are offset from their actual location where pie symbols would overlap. These results are complex and will require more detailed analyses. However, at a simple level they show the preponderance of sites with mostly small stems and the patchy nature of more evenly distributed height distributions.

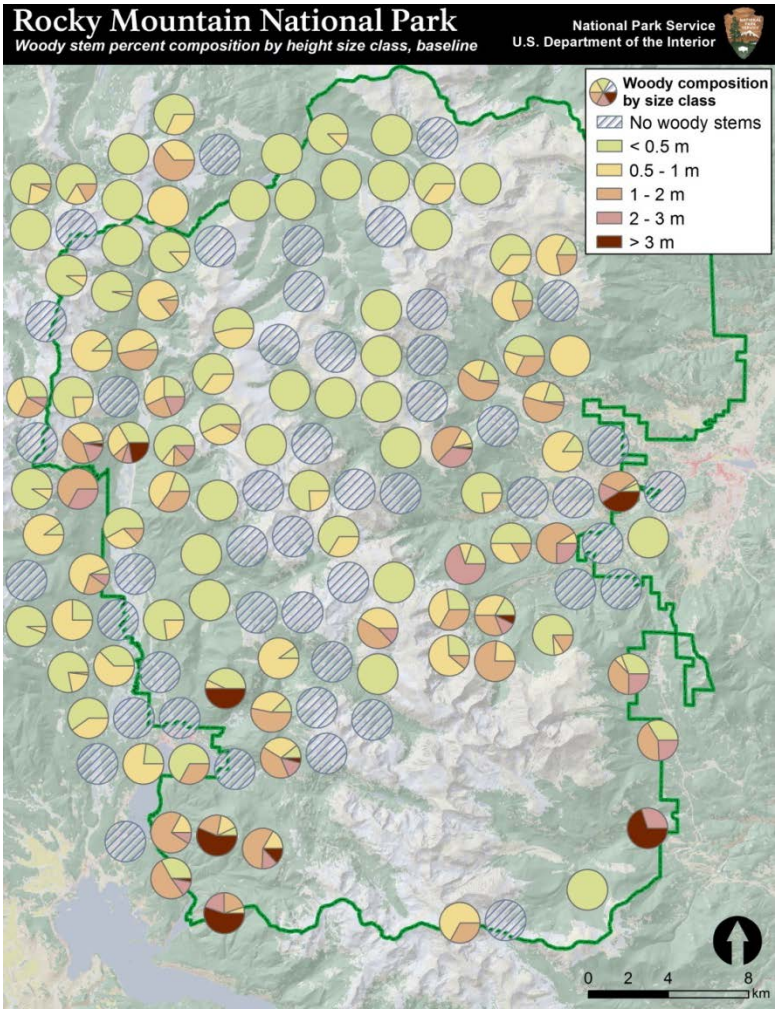


Figure 65. Map of the proportion of stems of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) across five height classes at wetland ecological integrity sites in Rocky Mountain National Park. Not all species occur at all sites. Sites with no woody stems are included as striped gray circles. Circle diameters do not vary with stem density, though this metric varied markedly across sites—see Figure 66. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Site locations are adjusted so no symbols overlap. See Figure 66 for actual location of sites.

Figure 66 shows the spatial distribution of total woody stem density across the park. Note that to make this symbology work, sites are offset from their actual location where pie symbols would overlap. These results are complex and will require more detailed analyses. However at a simple

level they showed the rarity of very high density sites. The park-scale map should be used with caution as it masks results at a smaller scale, which can be seen in the panel focused on the Kawuneeche Valley.

Figure 67, Figure 68 and Figure 69 show the percent browse on live stems, dead stems, and dieback (respectively). These results largely reflected patterns noted above, with riparian front country low elevation sites having higher percentages of each of the three indicators. This is especially apparent for the Kawuneeche Valley sentinel complex.

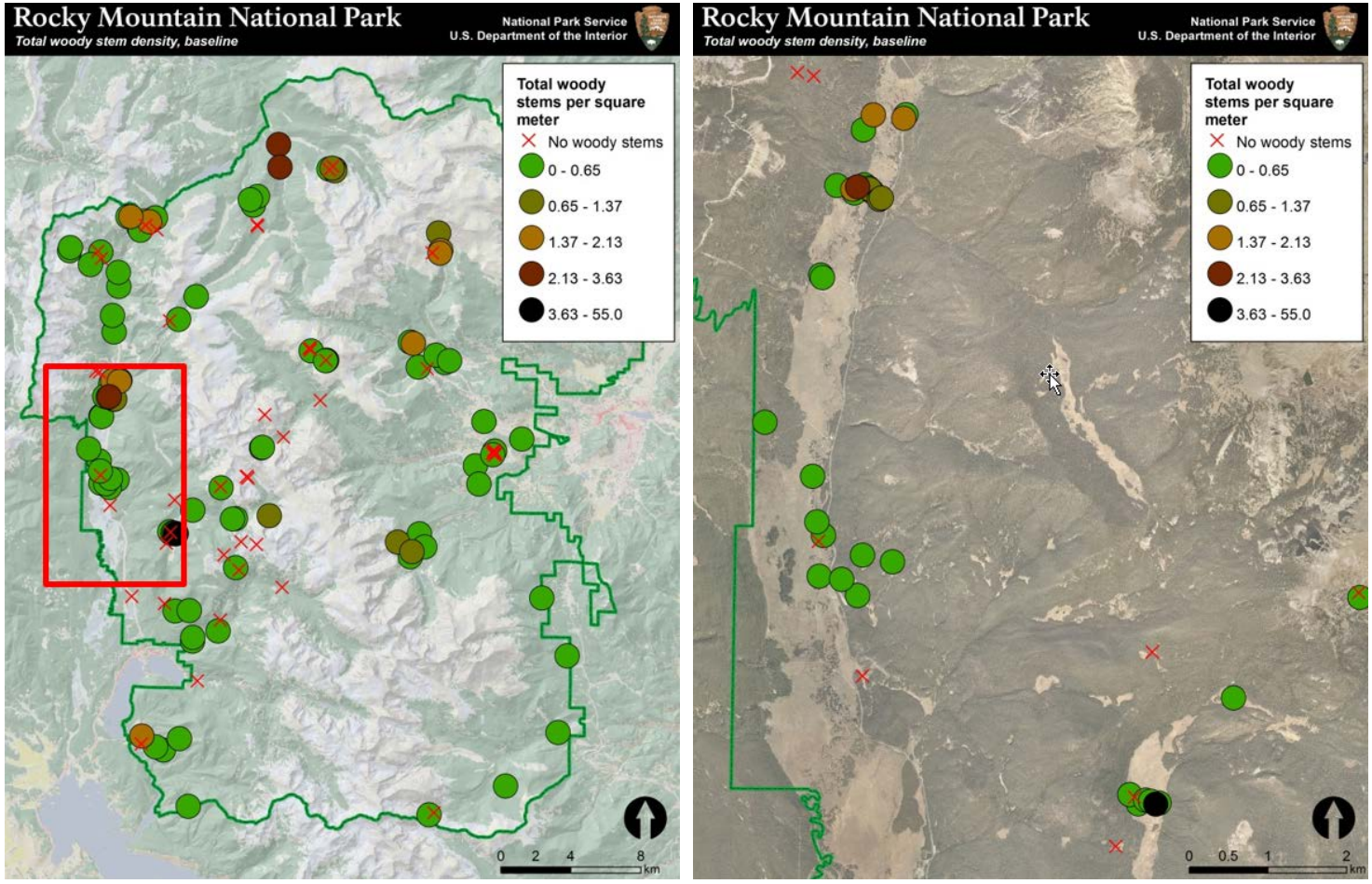


Figure 66. Map of total stems per square meter of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley and Big Meadows area (interior of the red box). The map on the right is an example of finer scale patterning. Not all species occur at all sites. Sites with no woody stems are included as red crosses. Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Green indicates sites with lower stem density and increasingly darker shades of brown to black indicate higher density. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

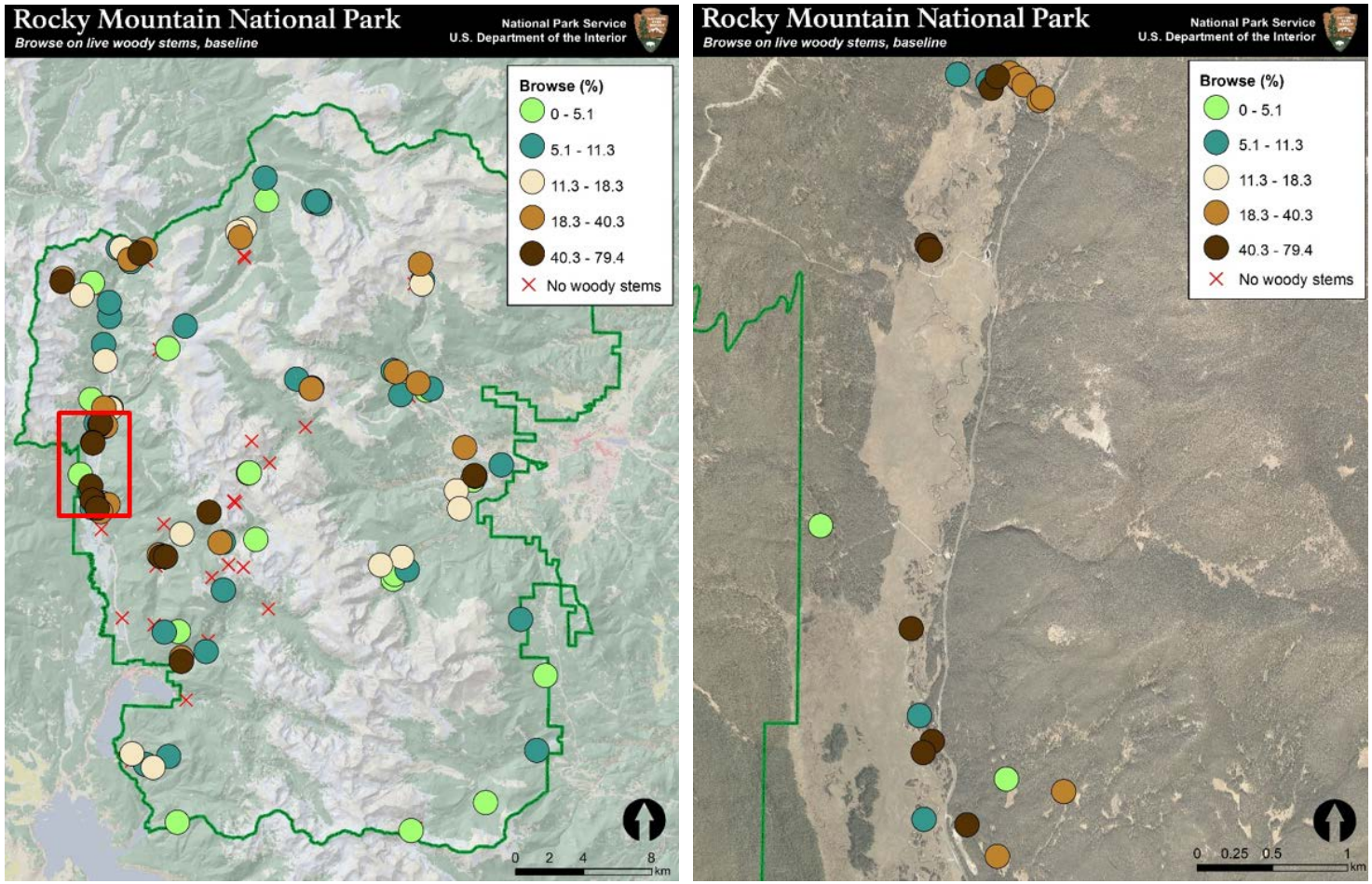


Figure 67. Browse (%) on live stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley (interior of the red box). The map on the right is an example of finer scale patterning. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Not all species occur at all sites or sample events and these data cannot be generated where there are no stems (95 out of 154 sites). Sites with no woody stems are included as red crosses. Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Lighter green indicates sites with less browse and increasingly darker shades of brown indicate higher browse. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

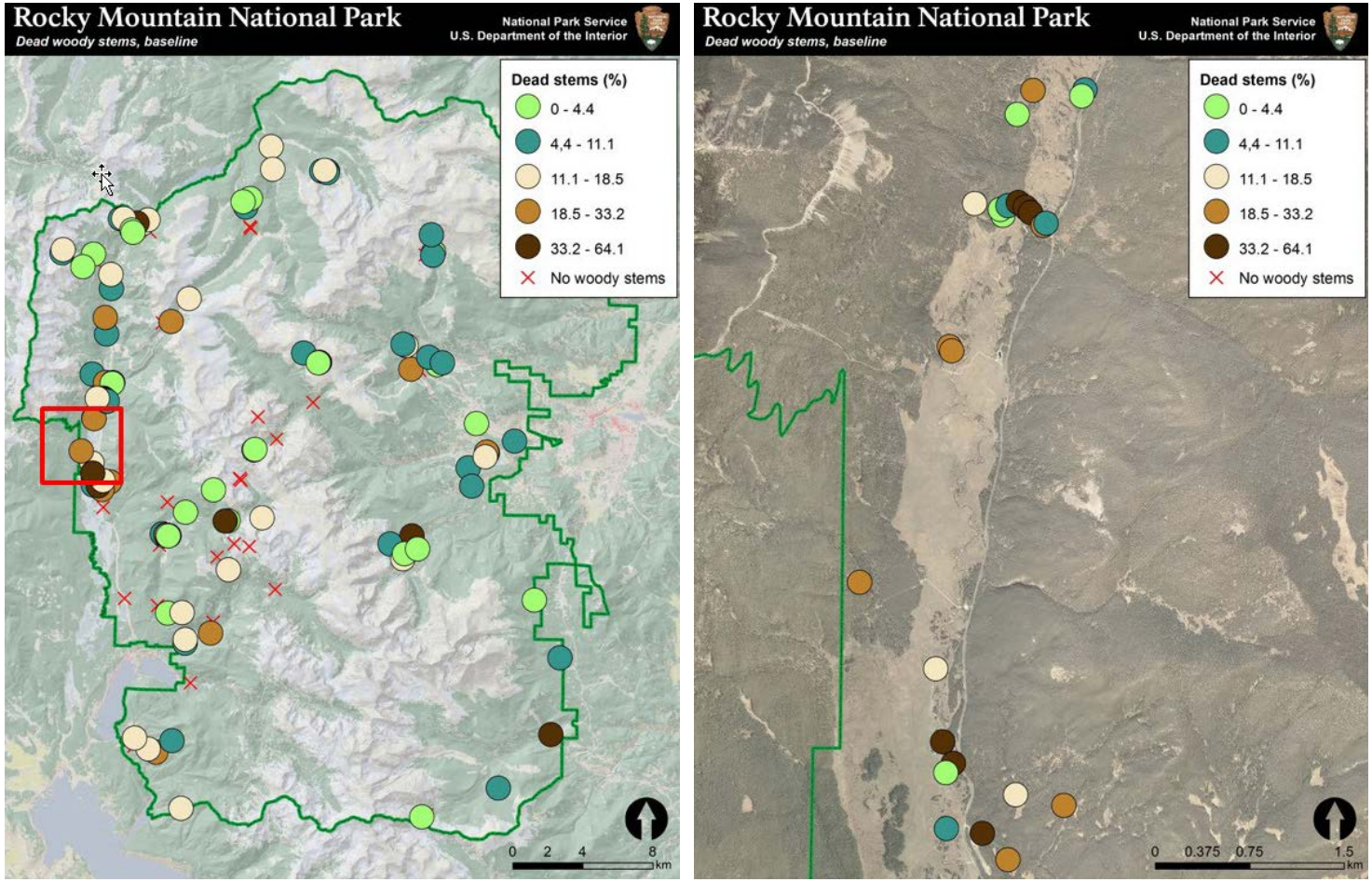


Figure 68. Dead stems (%) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (a) Rocky Mountain National Park and (b) the lower Kawuneeche Valley (interior of the red box). The map on the right is shown as an example of finer scale patterning. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Not all species occur at all sites or sample events and these data cannot be generated where there are no stems (95 out of 154 sites). Sites with no woody stems are included as red crosses. Point symbology is derived using Jenks (1967) that locates "natural' boundaries in a data set based on maximizing similarities within classes. Lighter green indicates sites with less dead stems and increasingly darker shades of brown indicate higher dead stems. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

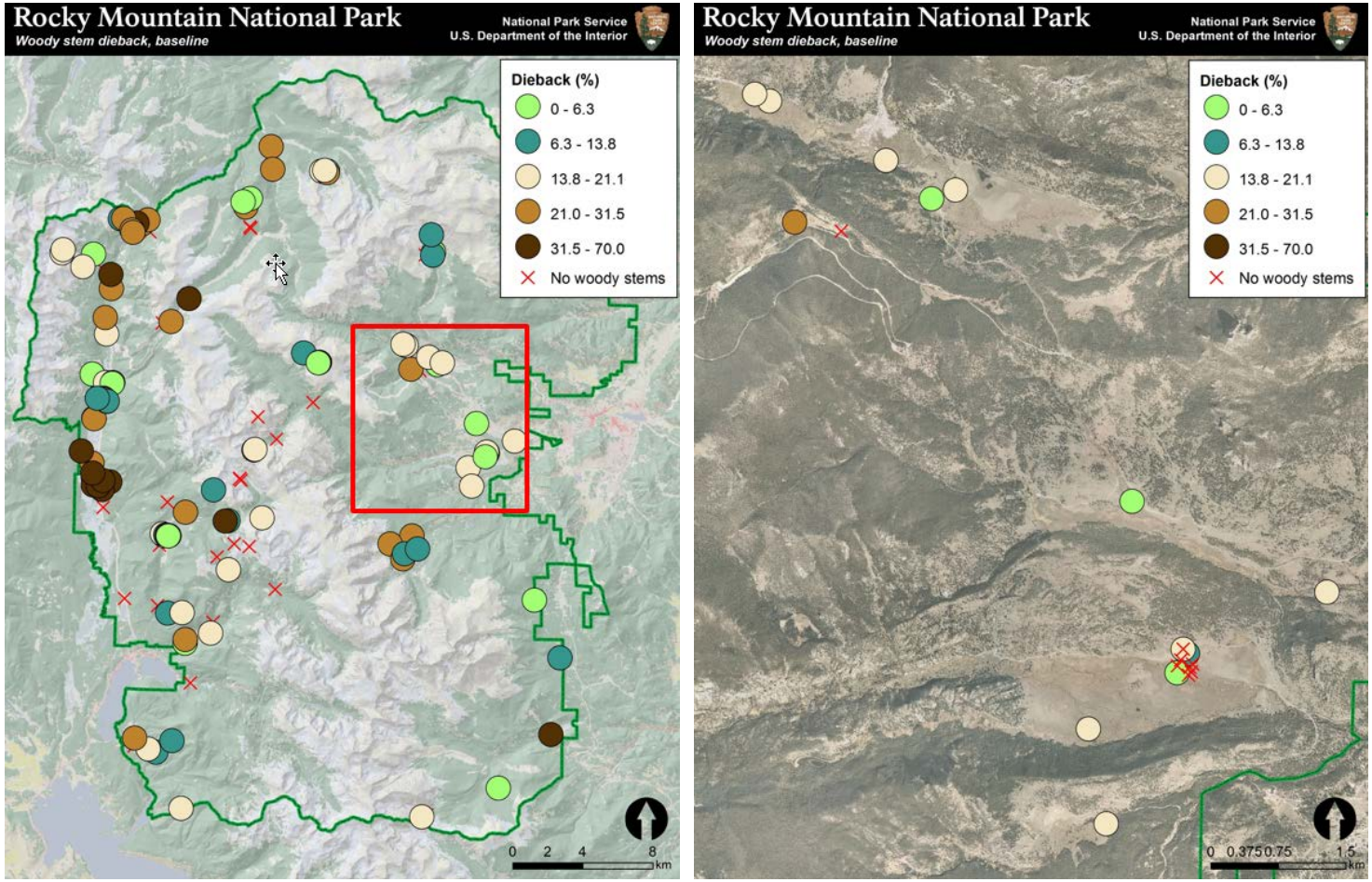


Figure 69. Dieback (%) on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the lower Kawuneeche Valley (interior of the red box). The map on the right is an example of finer scale patterning. Data are from the 'best' sample event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Not all species occur at all sites or sample events and these data cannot be generated where there are no stems (95 out of 154 sites). Sites with no woody stems are included as red crosses. Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Lighter green indicates sites with less dieback and increasingly darker shades of brown indicate higher dieback. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.7.2.2 Parkwide scale

Table 13 presents design-based parkwide scale results from the 'best' survey sites for proportion and density of woody stems by height class and wetland type. We also include the absolute and relative cover of these 17 taxa from understory data. We include sites with no woody stems in the dataset used for these estimates. Patterns generally followed results presented above. The design-based results did have lower short stem densities for fens. A single sentinel site in Big Meadows had a very high density of short stems. While stems can be dense in fens, this is more of a sampling artifact than representative of typical conditions in fens. Note also that only riparian wetland had tall, size class 5 stems at the parkwide scale.

Table 13. Baseline parkwide scale summary statistics for woody stem density (m^2), proportion by height class, and absolute and relative cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' sample events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from 93 randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park.[a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Fen	Mean stem density height class 1	33	0.29	0.08	0.14	0.44
Fen	Mean stem density height class 2	33	0.10	0.06	0.00	0.23
Fen	Mean stem density height class 3	33	0.04	0.04	0.00	0.11
Fen	Mean stem density height class 4	33	0.00	0.00	0.00	0.01
Fen	Mean stem density height class 5	33	0.00	–	–	–
Fen	Mean density all heights	33	0.43	0.08	0.28	0.58
Fen	Proportion of stems in height class 1	33	0.52	0.10	0.32	0.73
Fen	Proportion of stems in height class 2	33	0.12	0.06	0.00	0.24
Fen	Proportion of stems in height class 3	33	0.04	0.04	0.00	0.11
Fen	Proportion of stems in height class 4	33	0.04	0.05	0.00	0.15
Fen	Proportion of stems in height class 5	33	0.00	–	–	–
Fen	Absolute cover	33	13.56	6.23	1.35	25.78
Fen	Relative cover	33	0.08	0.04	0.00	0.16
Mdw	Mean stem density height class 1	40	0.42	0.33	0.00	1.06
Mdw	Mean stem density height class 2	40	0.08	0.03	0.01	0.14
Mdw	Mean stem density height class 3	40	0.05	0.03	0.00	0.11
Mdw	Mean stem density height class 4	40	0.00	0.00	0.00	0.01

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0. Height class 1 = <0.5 m; 2 = 0.5–1 m; 3 = 1–2 m; 4 = 2–3 m; 5 = >3 m.

Table 13 (continued). Baseline parkwide scale summary statistics for woody stem density (m^2), proportion by height class, and absolute and relative cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' sample events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from 93 randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park.[a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Mdw	Mean stem density height class 5	40	0.00	0.00	0.00	0.00
Mdw	Mean density all heights	40	0.55	0.32	0.00	1.17
Mdw	Proportion of stems in height class 1	40	0.34	0.16	0.03	0.65
Mdw	Proportion of stems in height class 2	40	0.12	0.04	0.03	0.21
Mdw	Proportion of stems in height class 3	40	0.08	0.04	0.00	0.16
Mdw	Proportion of stems in height class 4	40	0.00	0.00	0.00	0.01
Mdw	Proportion of stems in height class 5	40	0.00	0.00	0.00	0.00
Mdw	Absolute cover	40	14.12	6.16	2.05	26.19
Mdw	Relative cover	40	0.05	0.02	0.02	0.09
Rip	Mean stem density height class 1	20	0.05	0.04	0.00	0.13
Rip	Mean stem density height class 2	20	0.03	0.01	0.00	0.05
Rip	Mean stem density height class 3	20	0.04	0.01	0.01	0.06
Rip	Mean stem density height class 4	20	0.02	0.01	0.00	0.04
Rip	Mean stem density height class 5	20	0.03	0.02	0.00	0.06
Rip	Mean density all heights	20	0.17	0.04	0.08	0.25
Rip	Proportion of stems in height class 1	20	0.23	0.11	0.01	0.46
Rip	Proportion of stems in height class 2	20	0.14	0.06	0.02	0.25
Rip	Proportion of stems in height class 3	20	0.18	0.05	0.08	0.28
Rip	Proportion of stems in height class 4	20	0.06	0.03	0.00	0.11
Rip	Proportion of stems in height class 5	20	0.15	0.09	0.00	0.32
Rip	Absolute cover	20	26.24	7.07	12.39	40.09
Rip	Relative cover	20	0.10	0.03	0.04	0.16
All	Mean stem density height class 1	93	0.34	0.18	0.00	0.69
All	Mean stem density height class 2	93	0.08	0.03	0.02	0.14

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0. Height class 1 = <0.5 m; 2 = 0.5–1 m; 3 = 1–2 m; 4 = 2–3 m; 5 = >3 m.

Table 13 (continued). Baseline parkwide scale summary statistics for woody stem density (m^2), proportion by height class, and absolute and relative cover of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' sample events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from 93 randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park.[a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
All	Mean stem density height class 3	93	0.04	0.02	0.00	0.09
All	Mean stem density height class 4	93	0.00	0.00	0.00	0.01
All	Mean stem density height class 5	93	0.00	0.00	0.00	0.01
All	Mean density all heights	93	0.47	0.18	0.11	0.82
All	Proportion of stems in height class 1	93	0.40	0.09	0.22	0.58
All	Proportion of stems in height class 2	93	0.12	0.04	0.04	0.20
All	Proportion of stems in height class 3	93	0.07	0.03	0.01	0.13
All	Proportion of stems in height class 4	93	0.02	0.02	0.00	0.06
All	Proportion of stems in height class 5	93	0.02	0.01	0.00	0.03
All	Absolute cover	93	15.17	4.40	6.55	23.79
All	Relative cover	93	0.07	0.02	0.03	0.11

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0. Height class 1 = <0.5 m; 2 = 0.5–1 m; 3 = 1–2 m; 4 = 2–3 m; 5 = >3 m.

Table 14 gives results for the three damage metrics at the parkwide scale. They followed the same patterns as with site scale results in section 3.7.2.1, but in general show that parkwide, each type had fewer disturbances than at the site scale. Sentinel and gradient sites were often targeted to wetlands with higher use by ungulates.

Table 14. Baseline parkwide summary statistics for ungulate browse (%), dead stems (%), and dieback (%) on stems of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (three species of alder and birch) at wetland ecological integrity sites in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' sample events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park. [a]

Damage metric	Wetland type	Mean (%)	SE	LCB	UCB
Ungulate browse	Fen	10.37	3.09	4.32	16.42
	Wet meadow	13	2.49	8.11	17.89
	Riparian	11.89	5.27	1.55	22.22
	All	11.81	1.96	7.97	15.64
Dead stems	Fen	11.11	2.94	5.34	16.88
	Wet meadow	12.53	2.44	7.76	17.31
	Riparian	13.66	5.5	2.87	24.44
	All	12.1	1.98	8.22	15.99
Dieback	Fen	15.19	3.75	7.83	22.54
	Wet meadow	19.63	2.29	15.13	24.12
	Riparian	19.1	5.02	9.27	28.93
	All	17.78	2.42	13.04	22.52

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Figure 70 shows the CDF of total stem density across wetland type. A CDF describes the 'value so far' of cumulative stem density from the lowest to highest score, moving from left to right. For example, compared across wetland type, wet meadows had more area with a higher total stem density than riparian wetland and fens. Most of this density came from small size classes (see Figure 61 for a visual example).

Figure 71 shows an example CDF of one of the damage metrics—percent browsed across wetland type. A CDF describes the 'value so far' of cumulative HDI from the lowest to highest score moving from left to right. For example, compared across wetland type, riparian wetland percent browse more rapidly reached higher levels, indicating that more riparian wetland area had higher levels of browse. As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

As noted above, our damage metrics are general rapid assessments and are not intended to generate rigorous site-specific estimates of utilization or offtake (see Bilyeu et al. 2008). They should not be interpreted as if they were true measures of offtake; however, they are likely correlated with this more specific assay of ungulate use.

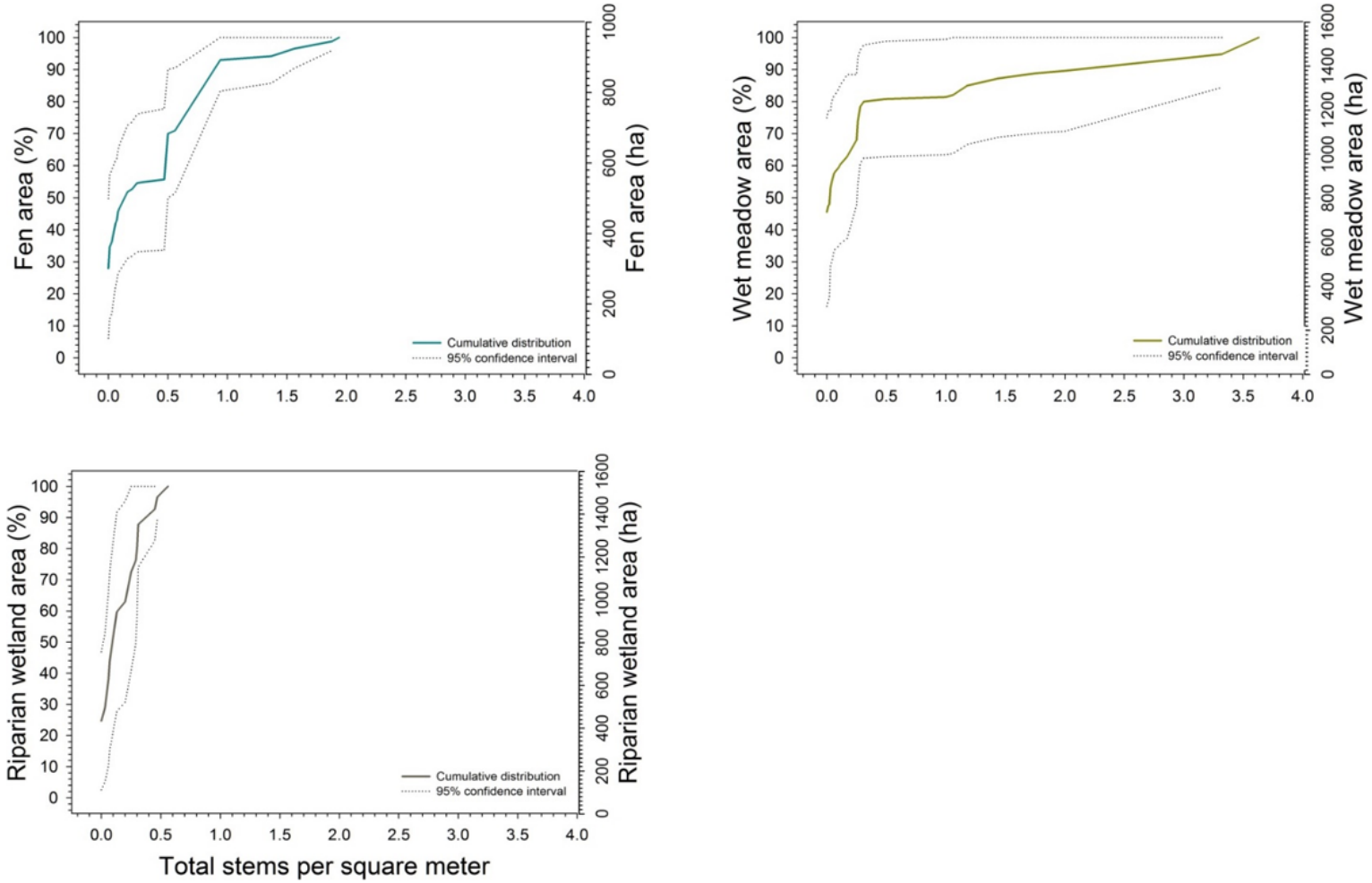


Figure 70. Total stems per square meter (all x-axes) of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Not all species occur at all sites. Parkwide scale estimates are derived from data at the 93 'best' sample events across all wetland types from 2007 to 2011 (with most in 2008). We include samples with zero woody stems. The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

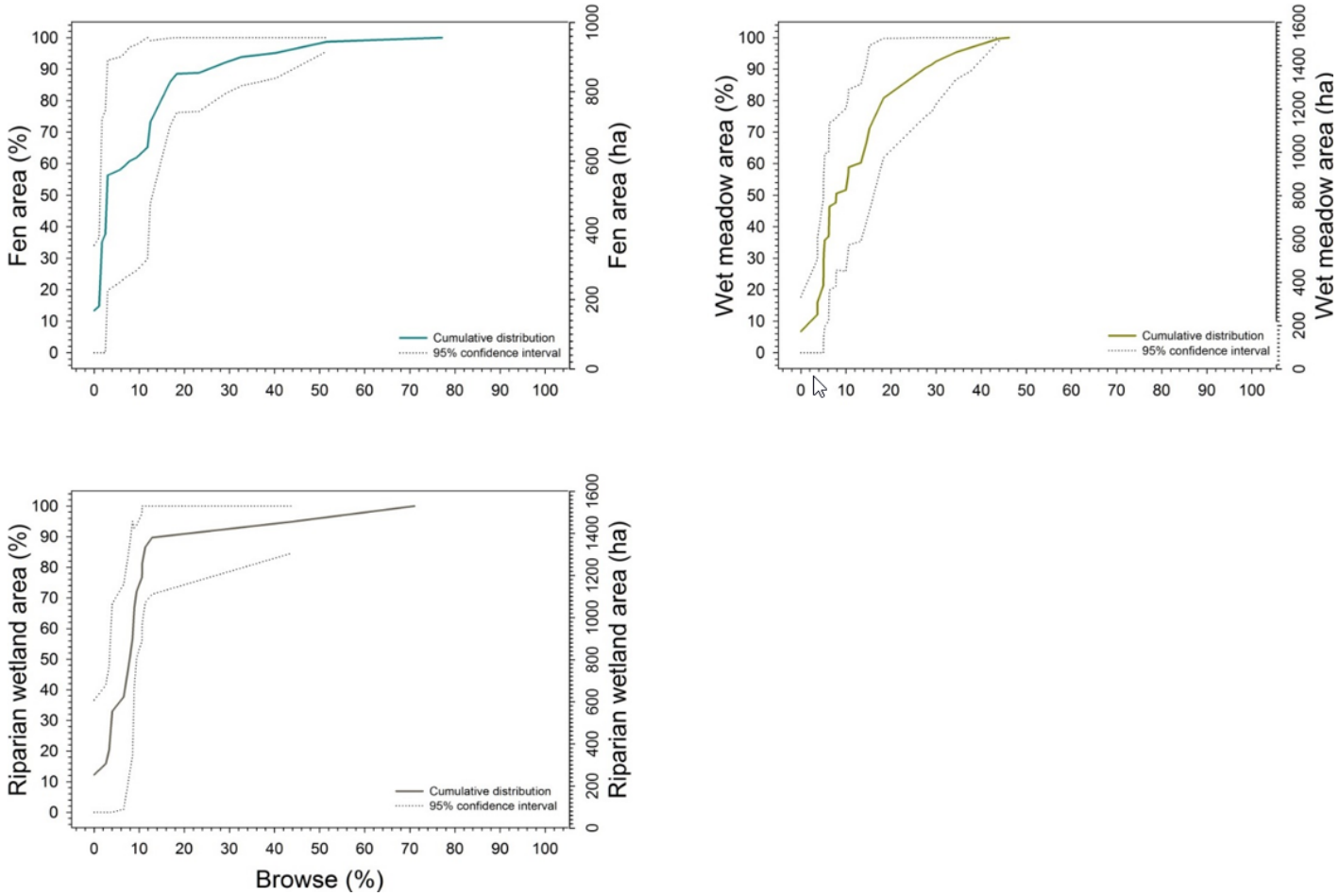


Figure 71. Browse (%) (all x-axes) on live stems of Salicaceae (17 species of willow, aspen, and cottonwood) and Betulaceae (3 species of alder and birch) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Not all species occur at all sites. Parkwide scale estimates are derived from data from the 'best' sample events (only sites with wood stems where the metric is possible) across all wetland types from 2007 to 2011 (with most in 2008). We only include the 61 sites with woody stems out of 93 total survey sites as this indicator is not relevant if there is no wood in a site. The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

3.7.3 Patterns across time at sentinel sites

Patterns across time at each of the four sentinel complexes in the proportional allocation of stems across height classes are given in Figure 72. These are complex and will take careful modeling and assessment to better understand. General patterns include the aforementioned high density in small height classes in Big Meadows in a single site. While this was a persistent effect, we believe it was a sampling effect and not entirely representative of woody stems in fens in general.

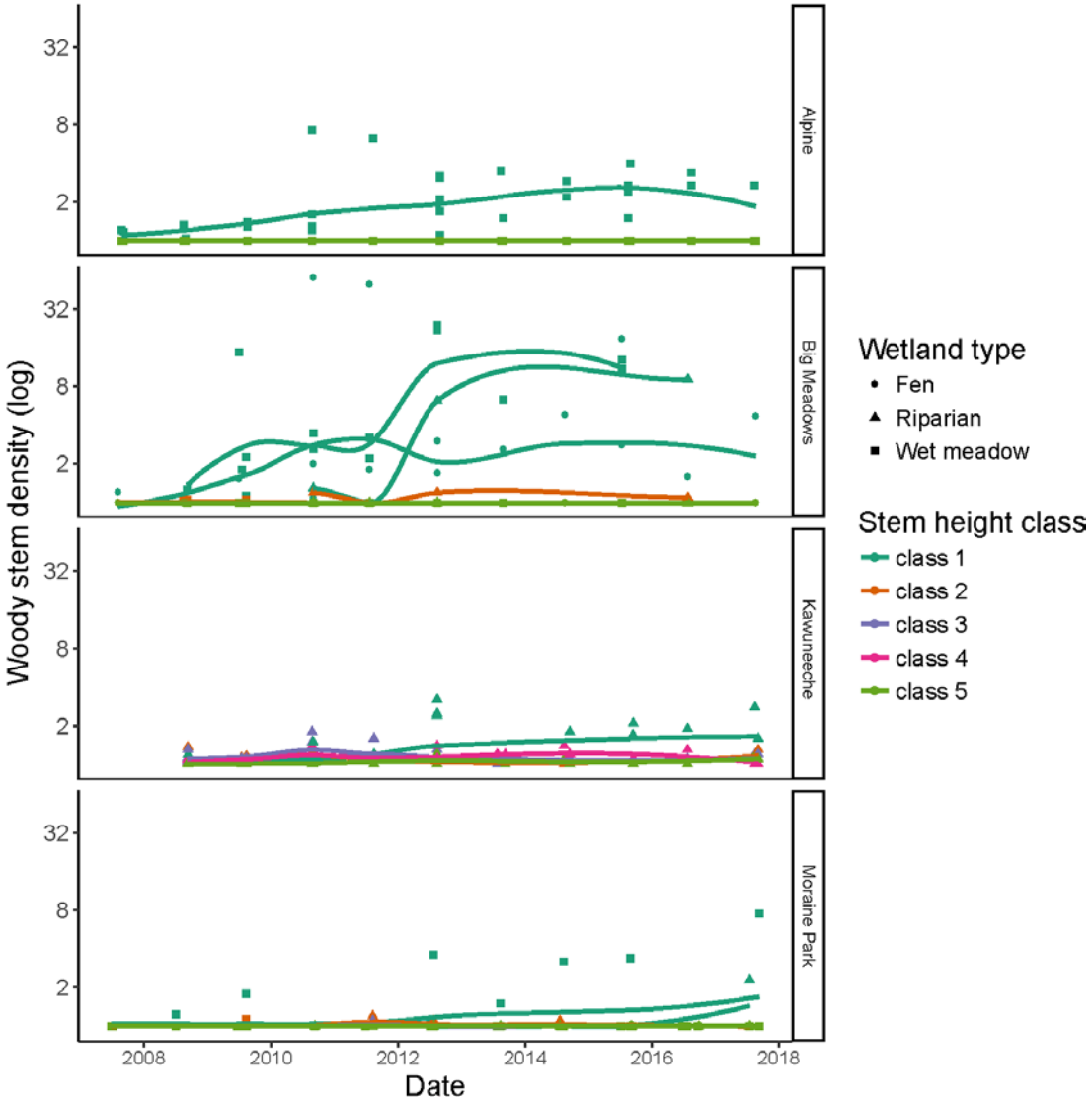


Figure 72. Woody stems per square meter (log transformed) in five height classes of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch) for wetland ecological integrity plots in sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Not all species occur at all sites or sample events. Height classes are as follows: 1: <0.5 m; 2: 0.5–1 m; 3: 1–2 m; 4: 2–3 m; 5: >3m. Fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit. LOWESS models were not possible for all sites given variation in the data. Point symbology is based on wetland type circles for fens, triangles for wet meadows squares for riparian wetland. Data collection at Kawuneeche began in 2009.

We also saw the more even allocation across stem height classes in the riparian wetland of Kawuneeche Valley. Finally, there was a very subtle suggestion of increasing density in Moraine Park and Kawuneeche Valley. These patterns are mirrored for total stem density in Figure 73.

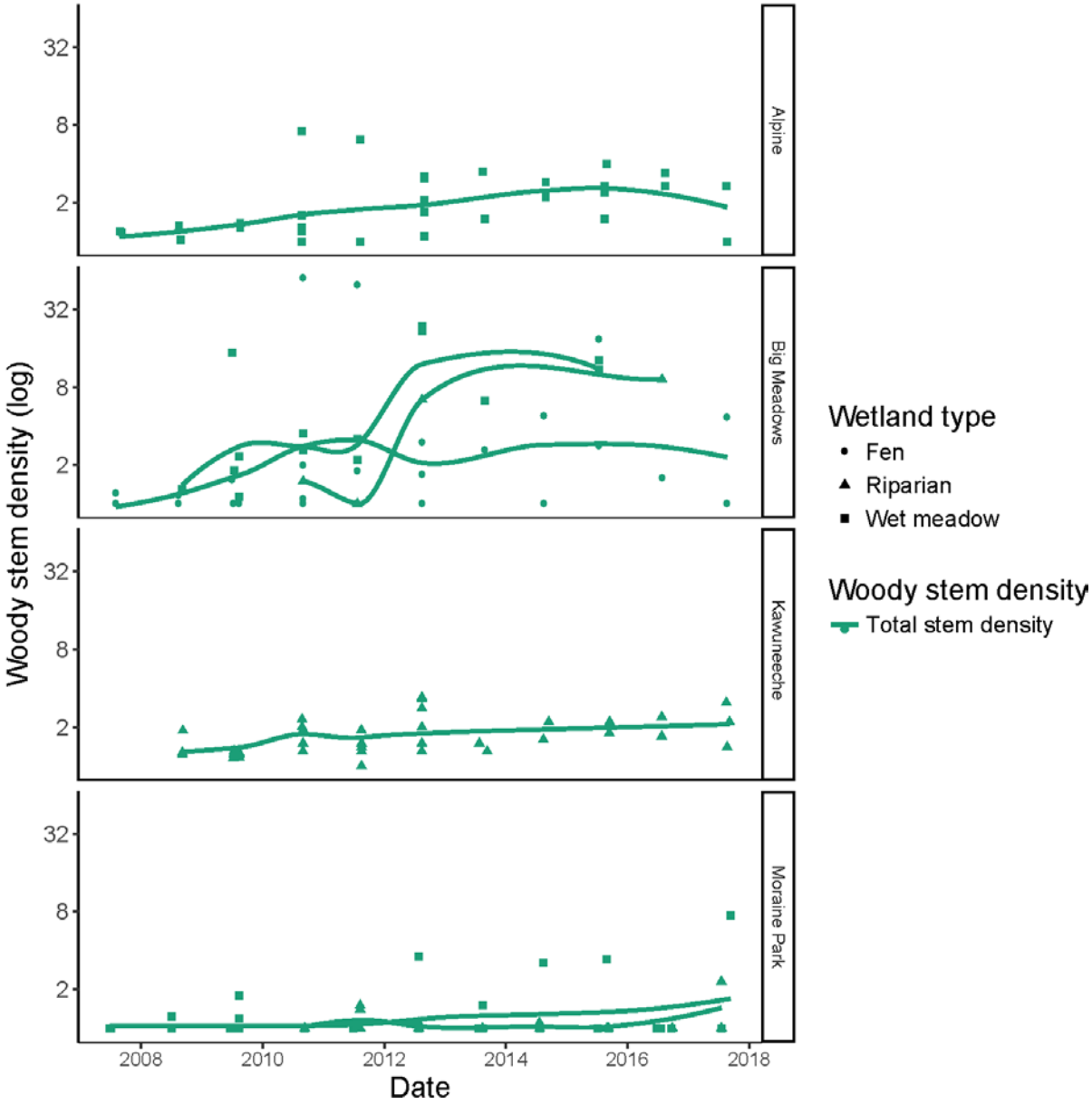


Figure 73. Total woody stems per square meter (log transformed) of Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch) for wetland ecological integrity plots in sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Not all species occur at all sites or sample events. Fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit. LOWESS models were not possible for all sites given variation in the data. Point symbology is based on wetland type circles for fens, triangles for wet meadows squares for riparian wetland. Data collection at Kawuneeche began in 2009.

Patterns across time at each of the four sentinel complexes in the three damage indicators are given in Figure 74. These are complex and will take careful modeling and assessment to better understand. Damage to stems was lower at the Alpine site. There are woody stems at this site and it is often heavily used by elk. There may be less use of woody stems in the Alpine site because stems are naturally short and less available to browsers. There was a suggestion of increasing percent browse at Kawuneeche Valley over time and declining levels of all three indicators at Big Meadows. Moraine Park was highly variable, but because there was so little wood in the complex, these results are not really relevant as indicators of ungulate use of the site (UUI results suggest that ungulates are active in the complex, see Figure 25).

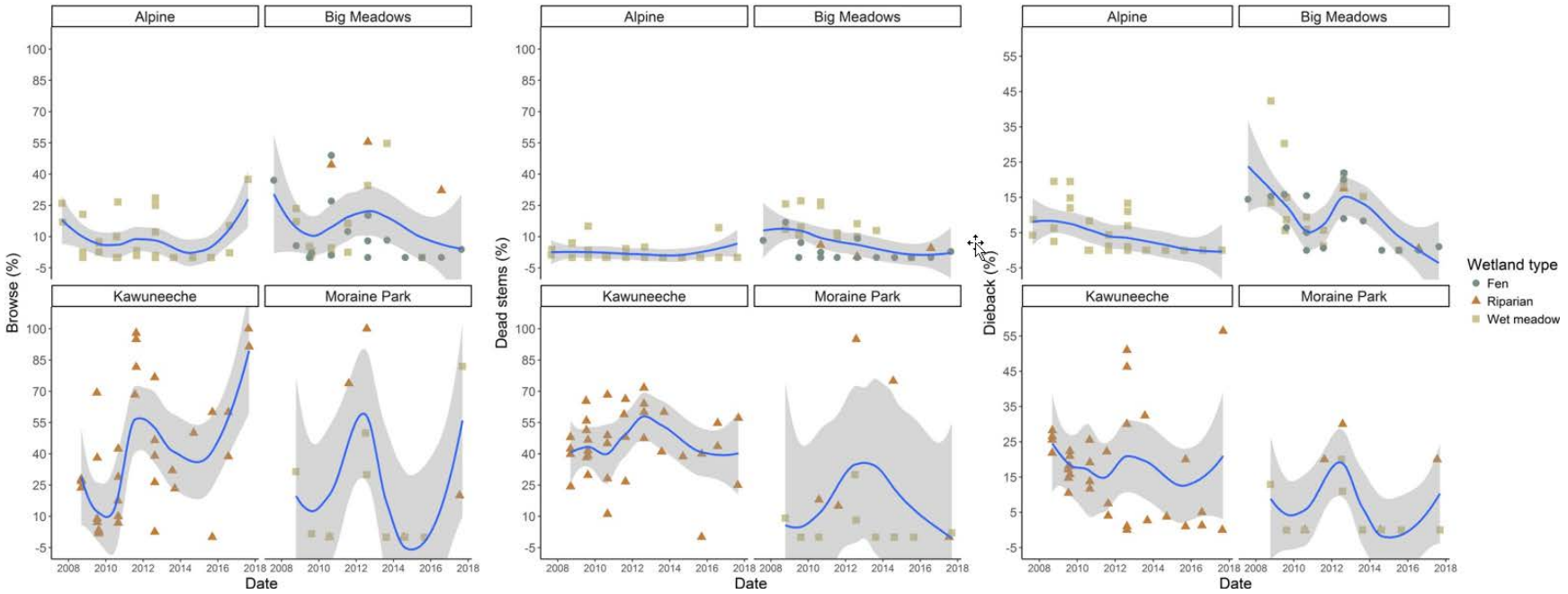


Figure 74. Damage indicators on Salicaceae (17 species of willow, aspen and cottonwood) and Betulaceae (3 species of alder and birch): (left) Browse on live stems (%), (center) Dead stems (%), and (right) Dieback (%) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Not all species occur at all sites or sample events. Indicator details are provided in main text. The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. The legend on the right applies to all panels. Some points overlap in select panels. Data collection at Alpine and Moraine Park began in 2009.

3.8 Soil Chemistry

3.8.1 Overview

Wetland soil is both the medium in which chemical reactions take place that influence wetland vegetation and the primary storage area of available nutrients and chemicals for most wetland plants (Figure 75; Mitsch and Gosselink 2007). Global and local disturbances can alter soil chemistry, which may result in altered vegetation composition. Soil characteristics provide useful indicators of wetland condition. Fens, for example, are distinguished chiefly by the occurrence of organic soils. Certain soil indicators also provide information about hydrologic regime. For example, redoximorphic features (soil color features influenced by oxidation and reduction processes in the soil) like mottles (blotches of differently colored soil) are most likely to occur in soils that cycle between anaerobic (reduced) and aerobic (oxidized) conditions. By contrast, strongly gleyed soils (sticky, waterlogged soil, typically colored gray to blue) suggest prolonged anaerobic conditions. Soil organic matter, carbon, pH, and plant nutrient concentrations can provide a powerful index of productivity and ecosystem processes and are often determinants of vegetation structure (Sollins et al. 1999). Various salts can have significant effects on soil properties and plant growth and these have been well understood for at least half a century by soil scientists (Wong et al. 2010).



Figure 75. Example of a gleyed wetland soil. Rocky Mountain National Park, 2008. NPS/B. SCHWEIGER

The following presents soil chemistry baseline data. Our sample of soil chemistry in Rocky Mountain National Park's wetlands is different than other indicators. For organic matter and peat depth we have samples across all sites sampled through 2008 and most through 2009. This changes the sample size of best events to 119 (from 154 with most other indicators). For ions and nutrients (including percent organic matter), we have samples at the first event at most sites beginning in 2009 through 2017. Most of these sites are sentinel sites. These parameters are resampled on a five year cycle and for a subset of sites we have repeat samples of these parameters. Our estimates of changes through time in soil chemistry at sentinel sites are therefore quite different than for other indicators. For most soil chemistry indicators at sentinel sites, we present two sets of results: first in 2009-2010 (44 events) and then in 2014-2015 (24 events).

3.8.2 Baseline

3.8.2.1 Site scale

Figure 76 shows soil organic matter (at 40 cm depth, as a percentage) across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. Results suggests that response across sites in the three wetland types was different—fens typically had more than 60% organic matter. Riparian wetland and wet meadow sites were similar and much lower. High organic matter is a characteristic trait of peat-building wetlands like fens. A threshold value of 24–36% organic matter at 40 cm is defined by USDA (2015) for a wetland to be considered a fen.

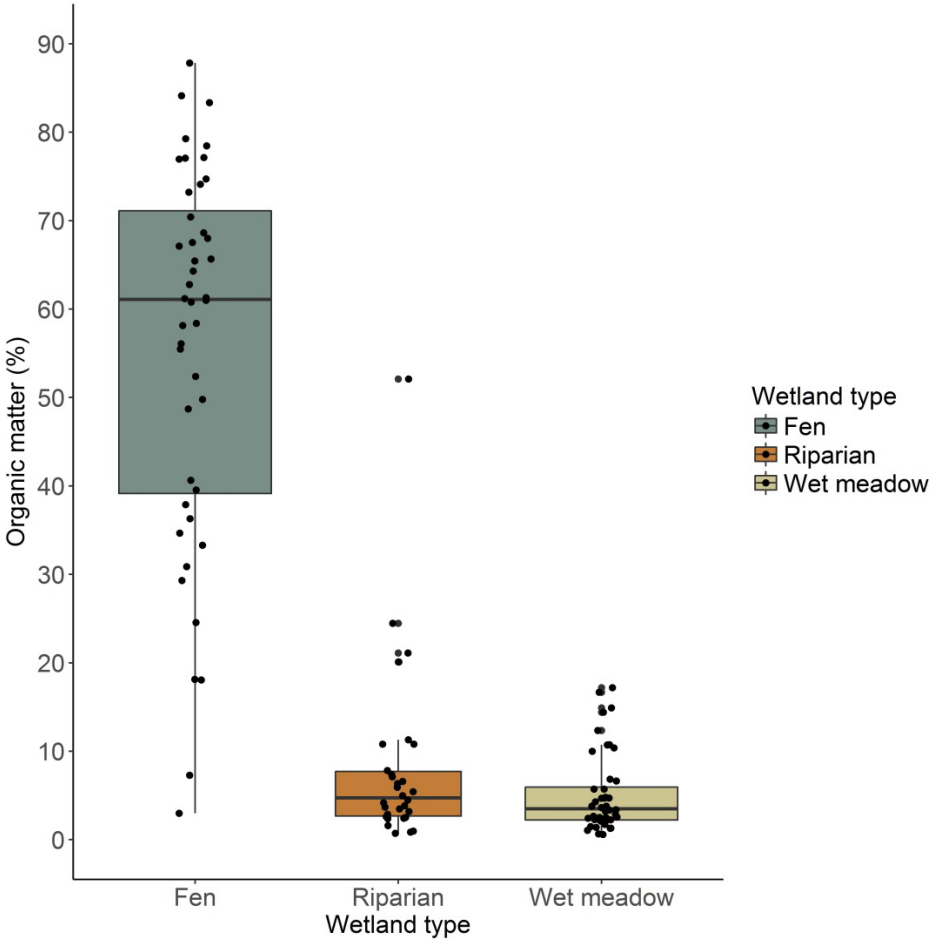


Figure 76. Soil organic matter (at 40 cm depth, %) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' sample event at each site and span 2007 to 2009 (in contrast to other baseline wetland data, these were not collected in 2009–2011). Results are applicable to the sampled sites only. Percent organic matter is a measure of the total organic matter (nitrogen, phosphorous and carbon) in soil and ranges from close to 0 (no organic matter) to 100 (entirely organic soil). The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Figure 77 shows depth to peat (cm) by wetland type across wetland type and best events. This is the primary site scale baseline for this important indicator. It suggests that response across wetland type was different, with fens typically having much deeper peat. A threshold value of 40 cm of peat in order to classify a wetlands as a fen is established by NRCS (1999). Driver (2010) recommends a value of 20 cm, when coupled with a growing season maximum water table depth of 40 cm, as more appropriate for fen classification at Rocky Mountain National Park.

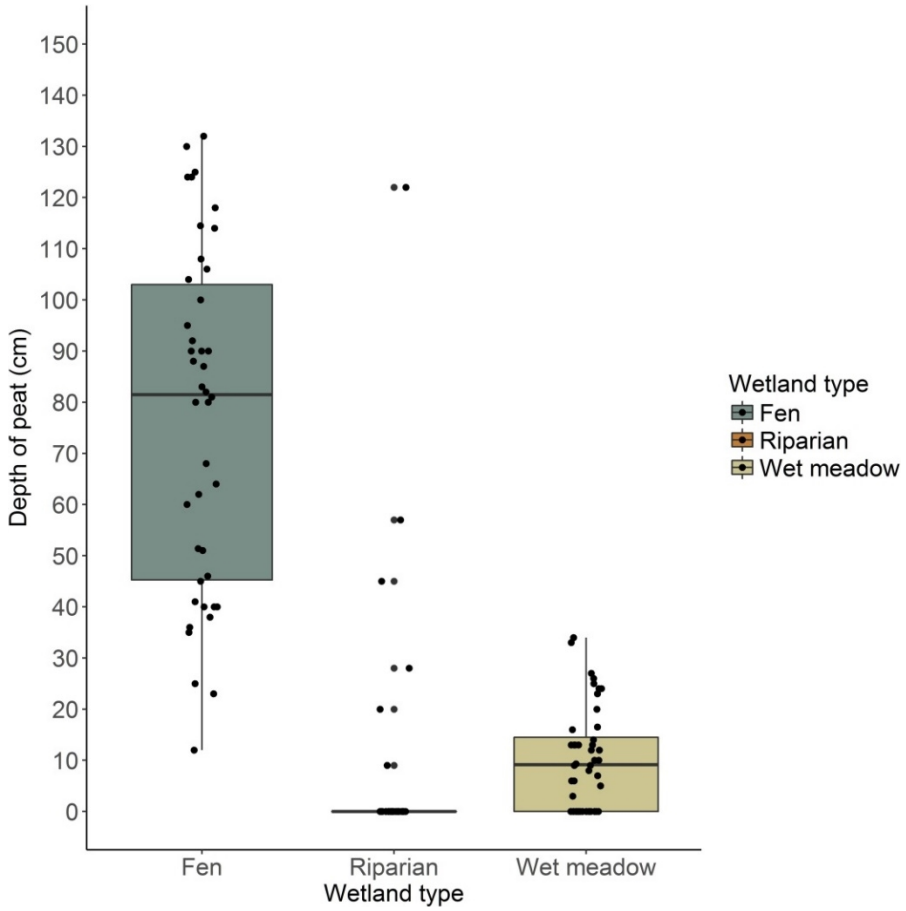


Figure 77. Depth of peat (cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' sample event at each site and span 2007 to 2009 (in contrast to other baseline wetland data, these were not collected in 2009–2011). Results are applicable to the sampled sites only. Depth of peat is a measure of the amount of peat in the first 2 m of soil and ranges from 0 (no peat) to around 2 m (entirely peat). The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Peat thickness and organic content are key indicators for long-term monitoring. Peat may be retained in a wetland for many years after the supporting hydrology is degraded; however, there is likely a threshold in peat thickness or organic content beyond which the peat body degrades and fen

vegetation disappears (Miner and Ketterling 2003). Given the importance of climate (temperature and precipitation) in supporting peat soils (Belyea and Malmer 2004), this response measure is also one of the best connections to climate change.

3.8.2.1.1 Spatial pattern

Figure 78 and Figure 79 show the spatial distribution of percent organic matter and depth of peat (respectively) across the park. These results are complex and will require more detailed analyses. However, at a basic level, they both followed the distribution of fens, as would be expected from the results above. The park scale map should be used with caution as it masks results at a smaller scale, which can be seen in the panel focused on the upper Colorado River area and Kawuneeche Valley.

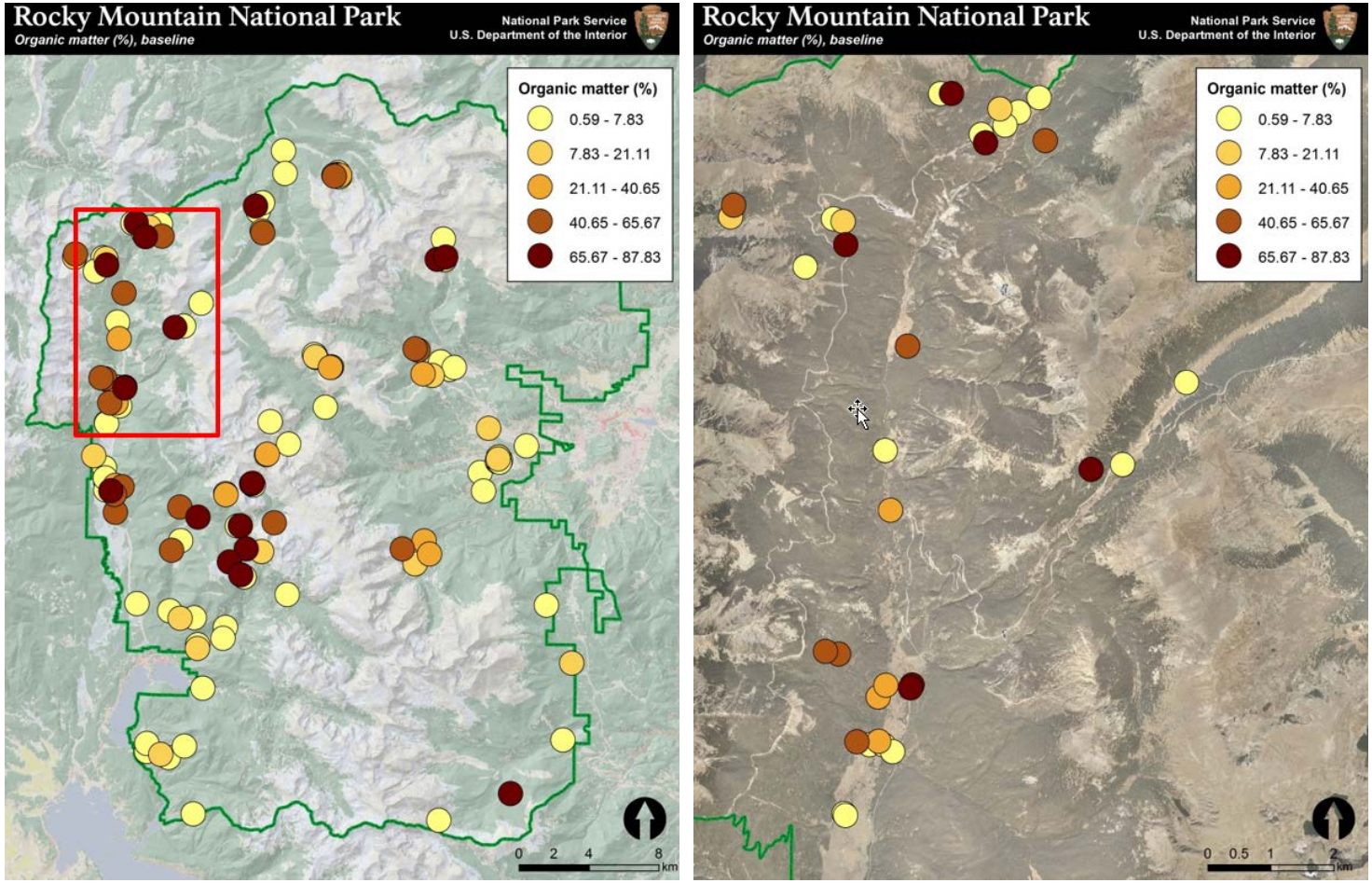


Figure 78. Map of soil organic matter (at 40 cm depth, %) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the upper Colorado River area (interior of the red box). The map on the right is an example of finer scale patterning. Percent organic matter is a measure of the total organic matter (nitrogen, phosphorous and carbon) in soil and ranges from close to 0 (no organic matter) to 100 (entirely organic soil). Data are from the 'best' sample event at each site and span 2007 to 2009 (in contrast to other baseline wetland data, these were not collected in 2009–2011). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker brown indicates sites with more organic matter and lighter shades of brown to yellow indicate lower percentages. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

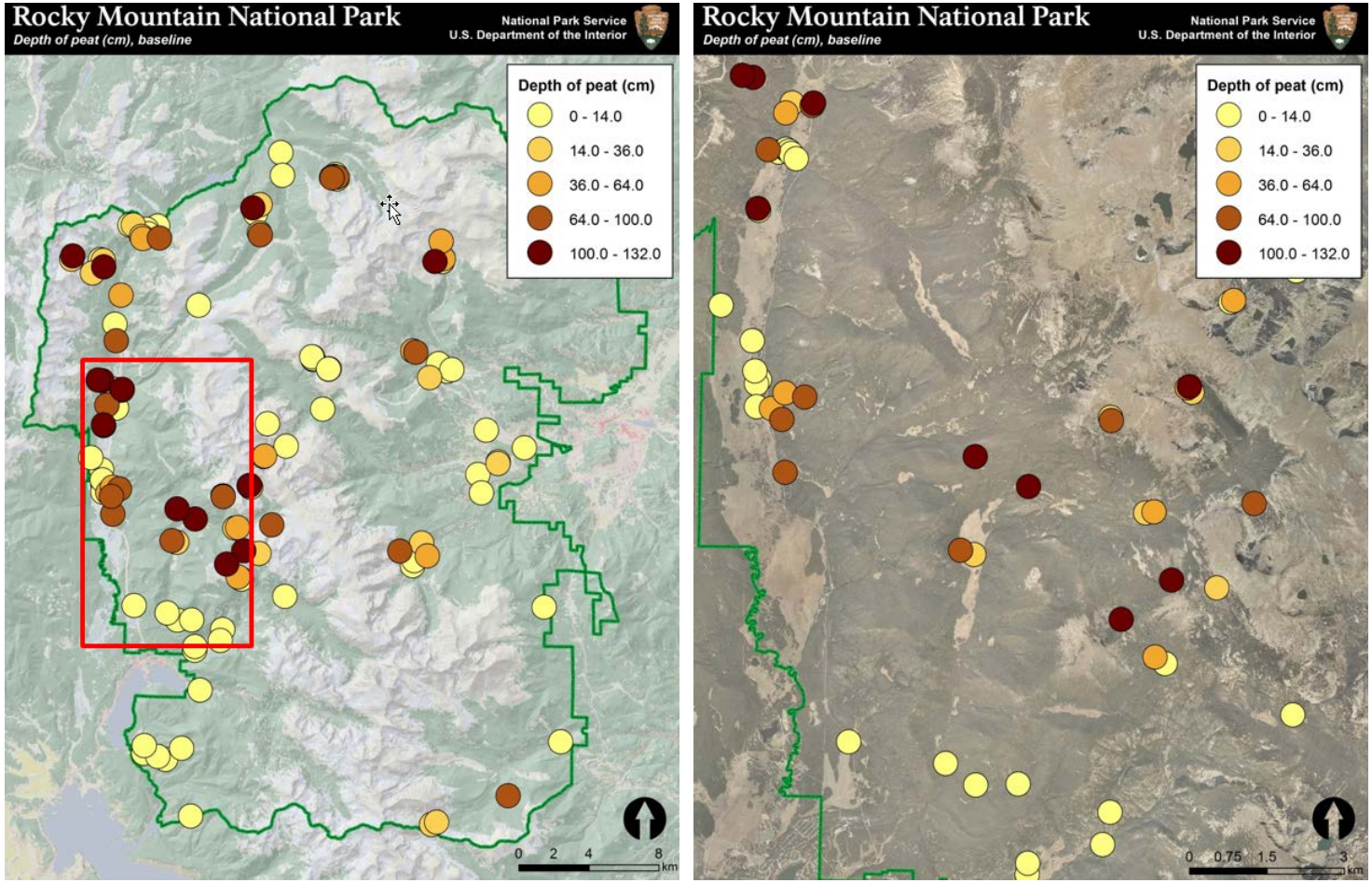


Figure 79. Map of depth of peat (cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Kawuneeche Valley and western side of the Continental Divide area (interior of the red box). The map on the right is an example of finer scale patterning. Depth of peat is a measure of the amount of peat in the first 2 m of soil and ranges from 0 (no peat) to around 2 m (entirely peat). Data are from the 'best' sample event at each site and span 2007 to 2009 (in contrast to other baseline wetland data, these were not collected in 2009–2011). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Darker brown indicates sites with deeper peat and lighter shades of brown to yellow indicate more shallow peat depths. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.8.2.2 Parkwide scale

Table 15 presents design-based parkwide scale results from the 'best' survey sites for percent organic matter and depth of peat (respectively) across wetland type. Patterns in the parkwide scale results for these indicators largely mirror those seen at the site scale.

Table 15. Baseline summary statistics for soil organic matter and depth of peat for all sample sites and the population of fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. Percent organic matter is a measure of the total organic matter (nitrogen, phosphorous and carbon) in soil and ranges from close to 0 (no organic matter) to 100 (entirely organic soil). Estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park. [a]

Soil chemistry indicator	Wetland type	Mean	SE	LCB	UCB
Soil organic matter (at 40 cm depth, %)	Fen	56.61	4.18	48.41	64.81
	Wet meadow	4.43	0.56	3.34	5.52
	Riparian	6.15	1.68	2.86	9.43
	All	23.5	5.59	12.54	34.46
Depth of peat (cm)	Fen	80.62	9.44	62.12	99.11
	Wet meadow	10.77	1.65	7.53	14.01
	Riparian	4.98	–	–	–
	All	34.72	9.31	16.48	52.96

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Figure 80 shows the CDF of percent organic matter across wetland type. A CDF describes the 'value so far' of cumulative percent organic matter from the lowest to highest score, moving from left to right. For example, compared across wetland type, fens had more area with high percent organic matter than riparian wetland or wet meadows. As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

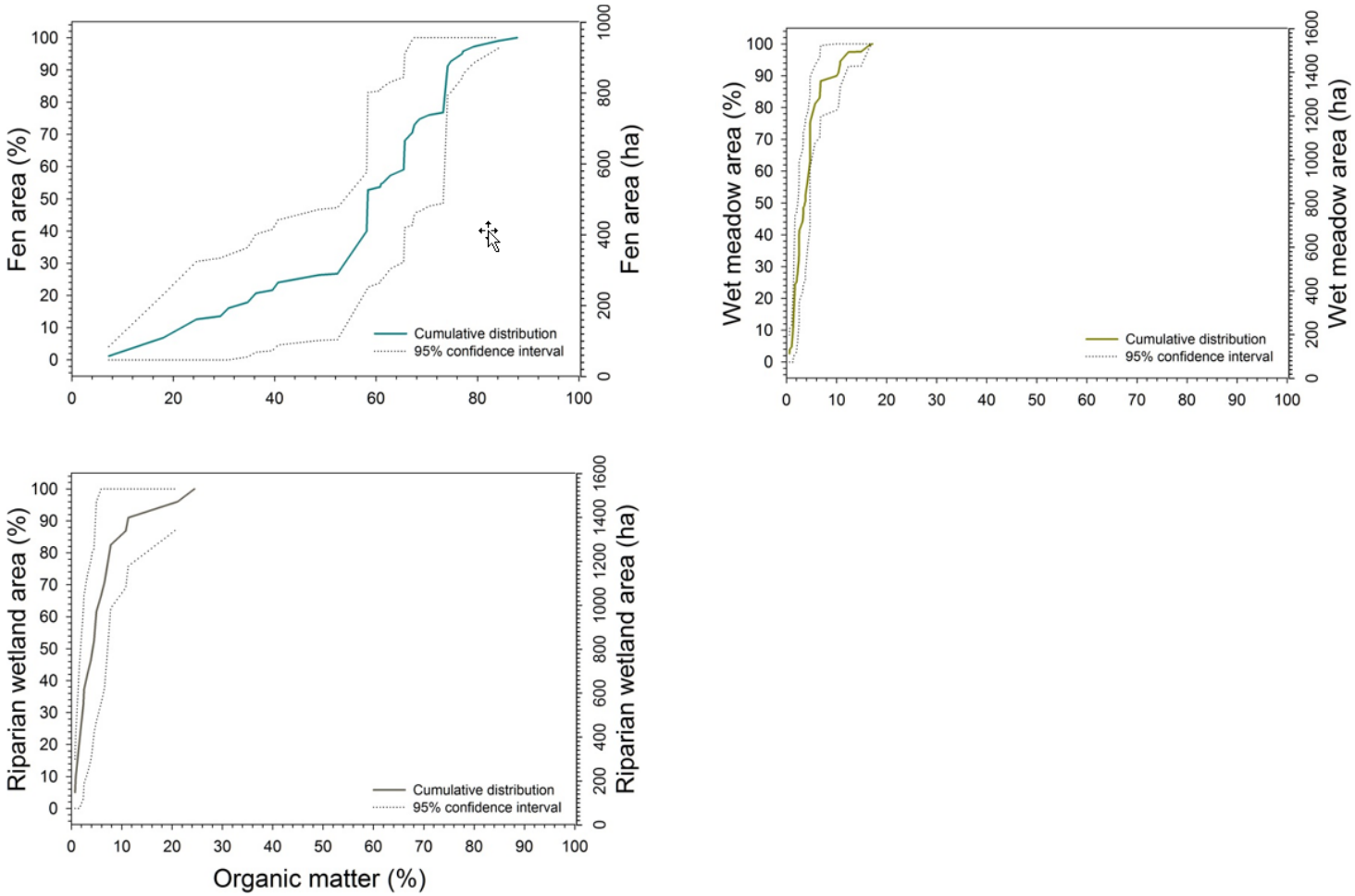


Figure 80. Soil organic matter (at 40 cm depth, %; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Percent organic matter is a measure of the total organic matter (nitrogen, phosphorous and carbon) in soil and ranges from close to 0 (no organic matter) to 100 (entirely organic soil). Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate. Note the CDFs for depth to peat are similar and are not shown here.

3.8.3 Patterns across time

We had sufficient data to look at patterns across time in sentinel complexes only for percent organic matter in Moraine Park (Figure 81). There were suggestions of increasing levels, perhaps in response to the restoration of the site. More data and analysis are needed to further investigate this.

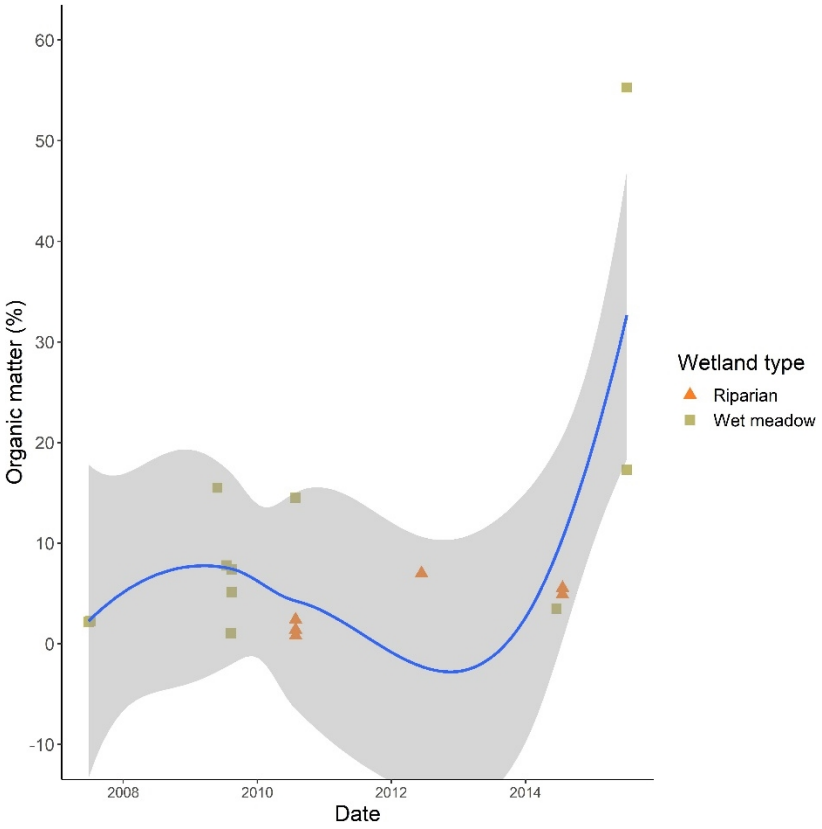


Figure 81. Soil organic matter (at 40 cm depth, %) at the Moraine Park wetland ecological integrity sentinel site in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Data at the other three sentinel sites were insufficient. Percent organic matter is a measure of the total organic matter (nitrogen, phosphorous, and carbon) in soil and ranges from close to 0 (no organic matter) to 100 (entirely organic soil). The fitted line is from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with orange triangles for riparian wetland and green squares for wet meadows. Some points overlap.

Table 16 gives a summary of 11 parameters from 68 sample events at 39 sites structured into two sample periods: 2009–2010 and 2014–2015. We do not make any analytical comparisons across these periods in this report. Moreover the set of sites in each group are not the same, thus any comparisons are not paired and will confound sampling effects (as each set of sites is not a representative sample). Figure 82, Figure 83, and Figure 84 give example graphics for select ions and nutrients.

Table 16. Summary of soil chemistry from 68 sample events at 39 wetland ecological integrity sites structured into two sampled periods (2009–2010; 2014–2015) at Rocky Mountain National Park. With the exception of total nitrogen and carbon, parameters are analyzed as extractable or using an ammonium acetate buffer solution. Results are applicable to the sampled sites only. Given the design behind these samples, there are no parkwide scale analogs. LCB/UCB are lower and upper 95% confidence interval boundaries, respectively. [a]

Parameter	Sample period	Wetland type	N	Mean	SD	LCB	UCB
Calcium (mg/kg)	2009–2010	Fen	9	1945.44	1433.83	2457.06	665.58
Calcium (mg/kg)	2014–2015	Fen	6	2865.50	1129.99	4601.01	1653.76
Calcium (mg/kg)	2009–2010	Riparian	15	1837.26	1198.84	2475.68	1152.84
Calcium (mg/kg)	2014–2015	Riparian	9	1844.56	1008.32	2680.79	1087.90
Calcium (mg/kg)	2009–2010	Wet meadow	19	2857.20	1971.06	3743.34	1838.52
Calcium (mg/kg)	2014–2015	Wet meadow	9	2717.11	131.39	5302.83	3363.89
Cation exchange capacity (meq/100g)	2009–2010	Fen	9	13.85	9.78	17.92	5.30
Cation exchange capacity (meq/100g)	2014–2015	Fen	6	59.47	22.10	96.84	35.61
Cation exchange capacity (meq/100g)	2009–2010	Riparian	15	15.03	10.16	19.89	8.79
Cation exchange capacity (meq/100g)	2014–2015	Riparian	9	21.44	16.38	26.51	6.59
Cation exchange capacity (meq/100g)	2009–2010	Wet meadow	19	20.67	14.51	26.83	12.78
Cation exchange capacity (meq/100g)	2014–2015	Wet meadow	9	19.77	6.36	33.18	17.44
Potassium (mg/kg)	2009–2010	Fen	9	382.71	181.19	584.24	262.17
Potassium (mg/kg)	2014–2015	Fen	6	371.67	94.70	648.63	263.92
Potassium (mg/kg)	2009–2010	Riparian	15	249.89	155.03	344.74	171.29

[a] SD is the standard deviation. * = Phosphorous was incorrectly analyzed in 2014–2015 by the lab.

Table 16 (continued). Summary of soil chemistry from 68 sample events at 39 wetland ecological integrity sites structured into two sampled periods (2009–2010; 2014–2015) at Rocky Mountain National Park. With the exception of total nitrogen and carbon, parameters are analyzed as extractable or using an ammonium acetate buffer solution. Results are applicable to the sampled sites only. Given the design behind these samples, there are no parkwide scale analogs. LCB/UCB are lower and upper 95% confidence interval boundaries, respectively. [a]

Parameter	Sample period	Wetland type	N	Mean	SD	LCB	UCB
Potassium (mg/kg)	2014–2015	Riparian	9	167.64	91.23	244.06	99.41
Potassium (mg/kg)	2009–2010	Wet meadow	19	498.62	229.73	767.51	557.88
Potassium (mg/kg)	2014–2015	Wet meadow	9	95.01	69.41	120.61	33.30
Magnesium (mg/kg)	2009–2010	Fen	9	249.47	158.04	340.90	118.95
Magnesium (mg/kg)	2014–2015	Fen	6	573.32	176.98	969.65	377.67
Magnesium (mg/kg)	2009–2010	Riparian	15	287.87	215.83	359.92	130.10
Magnesium (mg/kg)	2014–2015	Riparian	9	287.19	175.72	398.66	145.01
Magnesium (mg/kg)	2009–2010	Wet meadow	19	420.06	306.38	533.73	235.85
Magnesium (mg/kg)	2014–2015	Wet meadow	9	270.69	141.54	399.84	168.02
Ammonium (mg/kg)	2009–2010	Fen	9	68.51	30.65	106.37	49.26
Ammonium (mg/kg)	2014–2015	Fen	6	157.48	-34.38	349.34	182.82
Ammonium (mg/kg)	2009–2010	Riparian	15	21.77	9.83	33.72	21.57
Ammonium (mg/kg)	2014–2015	Riparian	9	19.61	12.18	27.04	9.66
Ammonium (mg/kg)	2009–2010	Wet meadow	19	34.24	21.52	46.96	26.39
Ammonium (mg/kg)	2014–2015	Wet meadow	9	35.37	20.57	50.17	19.25
Nitrate (mg/kg)	2009–2010	Fen	9	14.63	-1.76	31.02	21.32
Nitrate (mg/kg)	2014–2015	Fen	6	4.72	1.66	7.78	2.92
Nitrate (mg/kg)	2009–2010	Riparian	15	9.83	7.06	12.61	5.01

[a] SD is the standard deviation. * = Phosphorous was incorrectly analyzed in 2014–2015 by the lab.

Table 16 (continued). Summary of soil chemistry from 68 sample events at 39 wetland ecological integrity sites structured into two sampled periods (2009–2010; 2014–2015) at Rocky Mountain National Park. With the exception of total nitrogen and carbon, parameters are analyzed as extractable or using an ammonium acetate buffer solution. Results are applicable to the sampled sites only. Given the design behind these samples, there are no parkwide scale analogs. LCB/UCB are lower and upper 95% confidence interval boundaries, respectively. [a]

Parameter	Sample period	Wetland type	N	Mean	SD	LCB	UCB
Nitrate (mg/kg)	2014–2015	Riparian	9	2.68	1.72	3.63	1.24
Nitrate (mg/kg)	2009–2010	Wet meadow	19	75.98	17.95	134.01	120.40
Nitrate (mg/kg)	2014–2015	Wet meadow	9	7.83	0.38	15.29	9.70
Phosphorous (mg/kg)	2009–2010	Fen	8	0.35	0.17	0.53	0.21
Phosphorous (mg/kg)	2014–2015	Fen	6	*	*	*	*
Phosphorous (mg/kg)	2009–2010	Riparian	15	1.50	0.18	2.81	2.37
Phosphorous (mg/kg)	2014–2015	Riparian	9	*	*	*	*
Phosphorous (mg/kg)	2009–2010	Wet meadow	19	1.05	0.28	1.82	1.59
Phosphorous (mg/kg)	2014–2015	Wet meadow	9	*	*	*	*
pH (s.u.)	2009–2010	Fen	9	4.92	4.73	5.11	0.24
pH (s.u.)	2014–2015	Fen	6	4.94	4.54	5.34	0.38
pH (s.u.)	2009–2010	Riparian	15	5.49	5.15	5.84	0.62
pH (s.u.)	2014–2015	Riparian	9	5.28	4.99	5.57	0.38
pH (s.u.)	2009–2010	Wet meadow	19	5.23	5.00	5.45	0.47
pH (s.u.)	2014–2015	Wet meadow	9	4.89	4.46	5.33	0.57
Sulfate (mg/kg)	2009–2010	Fen	9	114.99	87.04	142.94	36.36
Sulfate (mg/kg)	2014–2015	Fen	6	190.60	-69.32	450.52	247.67
Sulfate (mg/kg)	2009–2010	Riparian	15	43.71	37.59	49.84	11.07

[a] SD is the standard deviation. * = Phosphorous was incorrectly analyzed in 2014–2015 by the lab.

Table 16 (continued). Summary of soil chemistry from 68 sample events at 39 wetland ecological integrity sites structured into two sampled periods (2009–2010; 2014–2015) at Rocky Mountain National Park. With the exception of total nitrogen and carbon, parameters are analyzed as extractable or using an ammonium acetate buffer solution. Results are applicable to the sampled sites only. Given the design behind these samples, there are no parkwide scale analogs. LCB/UCB are lower and upper 95% confidence interval boundaries, respectively. [a]

Parameter	Sample period	Wetland type	N	Mean	SD	LCB	UCB
Sulfate (mg/kg)	2014–2015	Riparian	9	18.92	13.71	24.13	6.78
Sulfate (mg/kg)	2009–2010	Wet meadow	19	135.69	83.93	187.45	107.39
Sulfate (mg/kg)	2014–2015	Wet meadow	9	57.59	-2.76	117.94	78.51
Total carbon %	2009–2010	Fen	9	49.04	31.40	66.68	22.94
Total carbon %	2014–2015	Fen	6	31.30	18.45	44.15	12.24
Total carbon %	2009–2010	Riparian	15	4.98	3.10	6.85	3.39
Total carbon %	2014–2015	Riparian	9	4.13	1.89	6.36	2.91
Total carbon %	2009–2010	Wet meadow	19	12.93	8.99	16.88	8.18
Total carbon %	2014–2015	Wet meadow	9	7.39	3.68	11.10	4.83
Total nitrogen %	2009–2010	Fen	9	1.94	1.36	2.52	0.75
Total nitrogen %	2014–2015	Fen	6	2.93	-0.40	6.26	3.17
Total nitrogen %	2009–2010	Riparian	15	0.48	0.17	0.79	0.56
Total nitrogen %	2014–2015	Riparian	9	1.64	0.55	2.73	1.41
Total nitrogen %	2009–2010	Wet meadow	19	0.86	0.63	1.08	0.47
Total nitrogen %	2014–2015	Wet meadow	9	1.64	0.84	2.45	1.05

[a] SD is the standard deviation. * = Phosphorous was incorrectly analyzed in 2014–2015 by the lab.

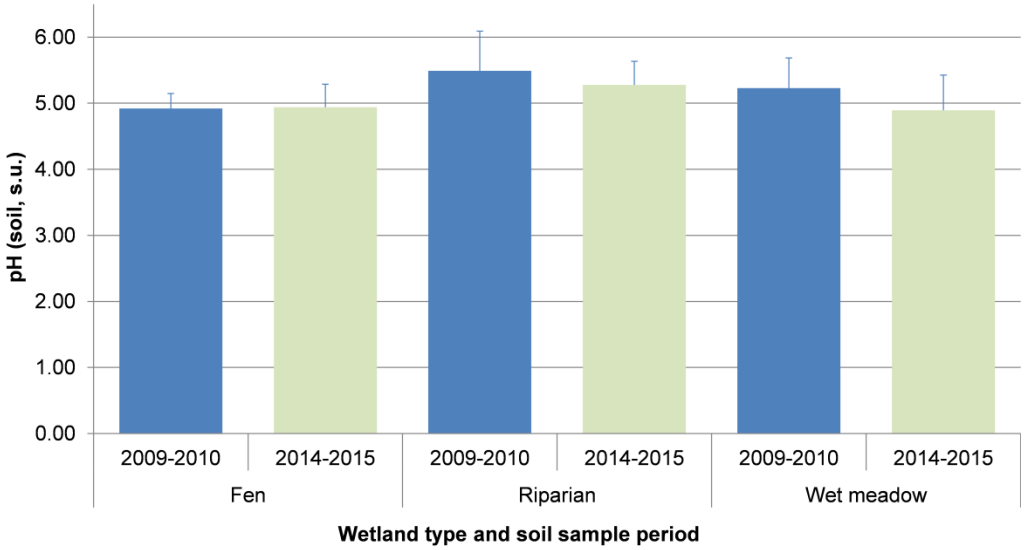


Figure 82. Mean soil pH (s.u.) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park. Results apply only to these specific sites. Data are from 68 sample events at 39 sites structured into two sample periods (2009–2010; 2014–2015). Not all sites were sampled in both periods. Error bars are standard deviations.

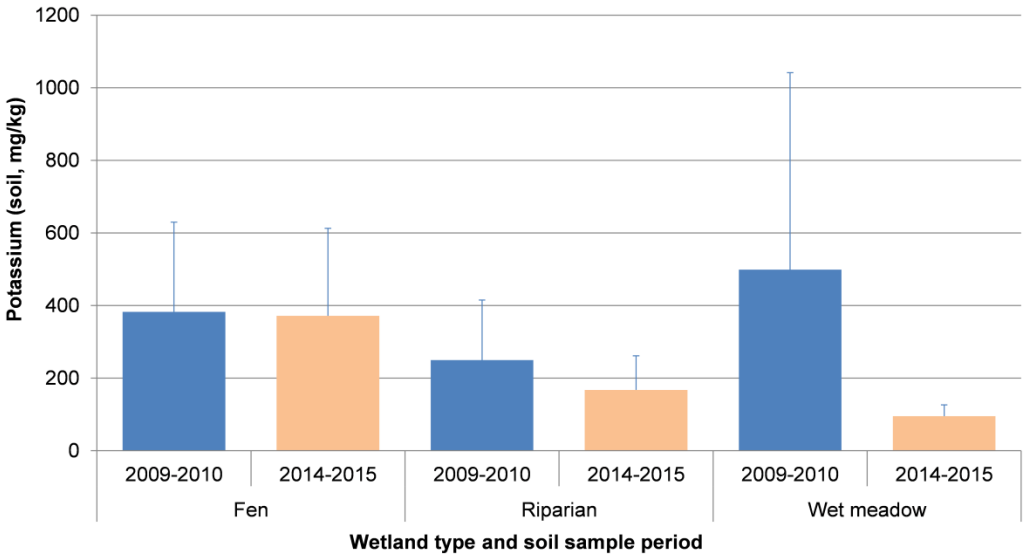


Figure 83. Mean soil potassium (mg/kg) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park. Results apply only to these specific sites. Data are from 68 sample events at 39 sites structured into two sample periods (2009–2010; 2014–2015). Not all sites were sampled in both periods. Error bars are standard deviations.

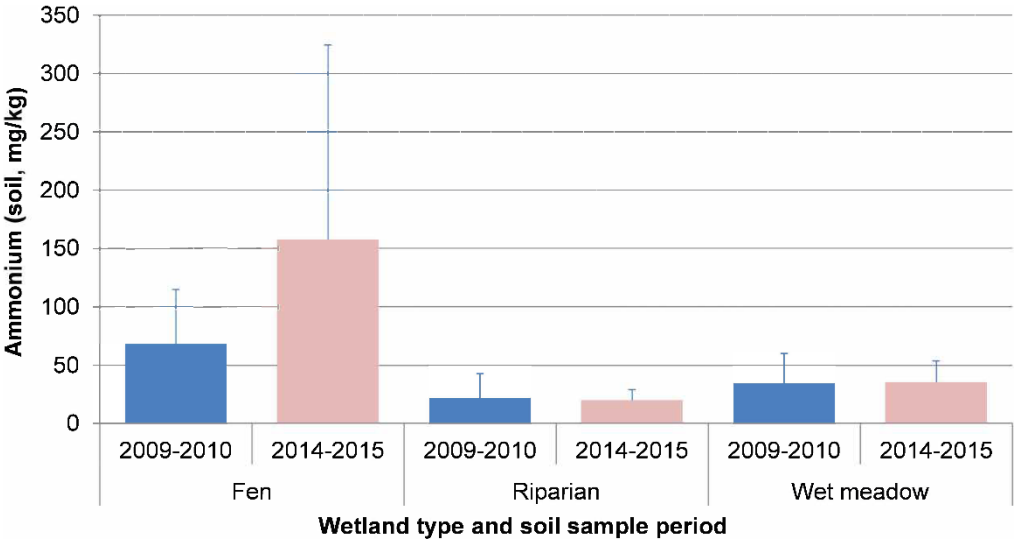


Figure 84. Mean soil ammonium (mg/kg) by wetland type and soil sample period at wetland ecological integrity sites in Rocky Mountain National Park. Results apply only to these specific sites. Data are from 68 sample events at 39 sites structured into two sample periods (2009–2010; 2014–2015). Not all sites were sampled in both periods. Error bars are standard deviations.

Some notable patterns in these parameters included a higher cation exchange capacity (CEC) in fens in the later period. Cation exchange capacity is the capacity of a soil to hold exchangeable cations. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification. Organic matter, such as that found in the park's fens (see Figure 76), has a very high CEC. Thus the relatively low cation exchange capacity in the early period fens is the surprising result here. The ammonia and nitrate results are likely important in the ongoing issue with nitrogen deposition in the park (i.e., Baron et al. 2009). More work will be needed to understand these patterns.

3.9 *In situ* water chemistry

3.9.1 Overview

Much like wetland soils, groundwater is an important matrix for chemical reactions that influence wetland vegetation (Mitsch and Gosselink 2007). Groundwater chemistry also reflects large scale and local disturbances and thus provides useful indicators of wetland condition. Four core *in situ* parameters are required by the NPS Water Resources Division as part of all NPS aquatic monitoring protocols. These parameters contribute some consistency across parks, and more importantly, they can be key indicators of stress in aquatic systems (NPS 2002). Of the four core parameters, only two are relevant or appropriately measurable in wetland groundwater. First, pH (the measure of water hydrogen ion concentration), has many physical and biological effects in wetland systems. Most plant species occur within specific habitat envelopes of pH conditions, and changes in pH will likely result in changes in vegetation communities. In addition, pH determines the solubility of heavy metals and many salts. Second, specific conductance (the ability of a water body to conduct an electric current used as an index of dissolved ion concentrations in water bodies), also affects

important chemical reactions. Changes in conductance also can indicate shifts in major ions or nutrients, such as potassium, calcium, and other anions and cations.

The following presents groundwater *in situ* chemistry baseline data from all sites. Results are given across all sites (including spatially) and at the parkwide scale from our representative survey. We then report example site-specific continuous data over variable periods (depending on site) from 2007 to 2014.

At most sites we only have peak season single point in time measures (Figure 85). Even at sentinel sites, where we have annual revisit data, we have no way to account for likely important diel and seasonal patterns in these indicators.



Figure 85. Collecting an in situ water sample, 2008, in Rocky Mountain National Park. NPS/B. SCHWEIGER

3.9.2 Baseline

3.9.2.1 Site scale

Figure 86 shows groundwater specific conductance across wetland type and best sample events. Importantly these data apply only to the sampled sites. This is the primary site scale baseline for this important indicator. It suggests that response across wetland sites by type was fairly consistent. Riparian wetland sites had slightly higher levels and more variation. This likely follows from the greater contribution from surface water to these sites and the higher levels of solutes, especially in bigger channels like the Big Thompson River or the Colorado River. In surface water, values in wilderness parks like Rocky Mountain National Park are typically very dilute. In 20 years (N = 1305) of data summarized in Mast (2007), the median specific conductance in 112 park surface water sites was 13 us/cm. In this same report, a small number of high elevation (in the Loch Vale watershed) shallow ground water wetlands sampled in 1994 had a median specific conductance value of 25

us/cm. Seven lower elevation groundwater wells (not necessarily in wetland and likely deeper) had a median of 121 us/cm (Mast 2007).

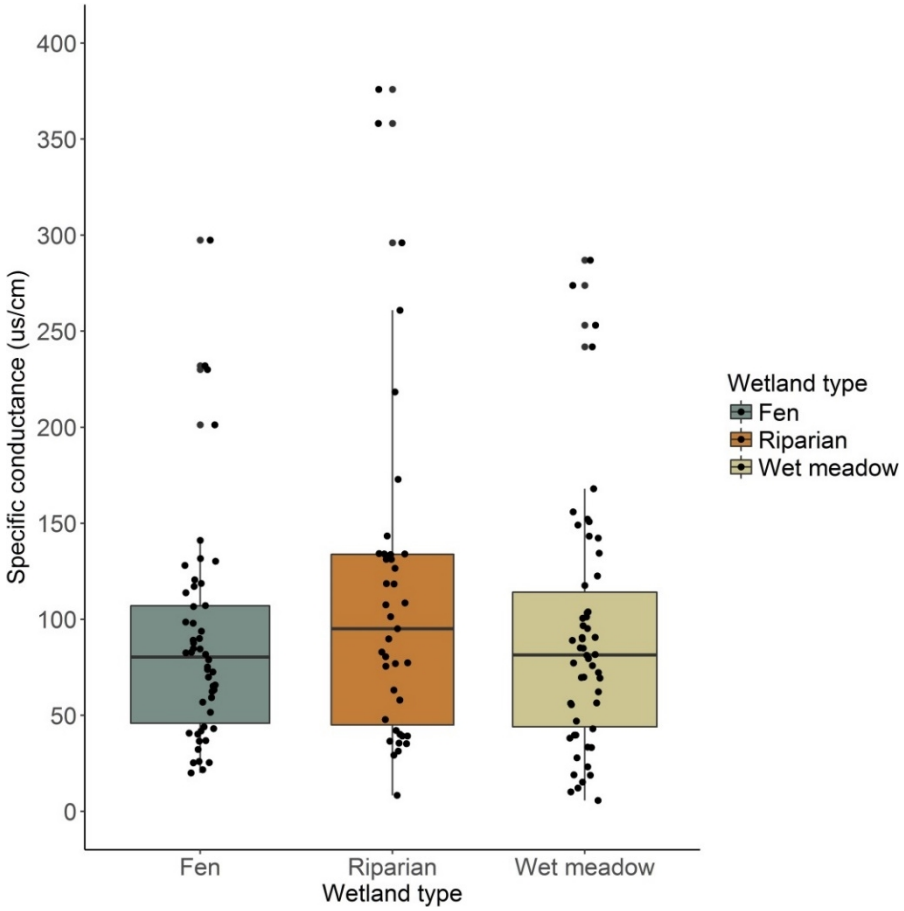


Figure 86. Groundwater specific conductance (us/cm) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. Specific conductance is a measure of total ion concentration in water and ranges from close to 0 (snowmelt) to 10,000 (very ion rich waters). The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Patterns across sites by wetland type are likely reflective of the dominant hydrology and the proximity of the respective wetland types to anthropogenic disturbance. Riparian wetland and wet meadow sites, with hydrology more connected to surface water, generally had higher conductance than fens. Several factors, including geology and human disturbance, influence specific conductivity. Chemically resistant bedrock, short hydrologic residence times characteristic of high-elevation areas, and the slow weathering rates of bedrock cause low values of specific conductivity, and this is reflected in the composition of inflowing groundwater to many fens. Conductance can increase with non-point source pollution (for example deposition of particulates from Front Range air pollution)

and these pollutants are both more common in surface water and tend to increase with proximity to sources.

Figure 87 shows groundwater pH across wetland type at all sites and their best sample events. Importantly these data apply only to the sampled sites. There is value in this perspective as we will continue to monitor these specific sites over time and patterns across these sites may best capture the range in condition. These results contain some somewhat surprising acidic (low pH) values, largely in riparian sites. At time of publication these data were being further examined.

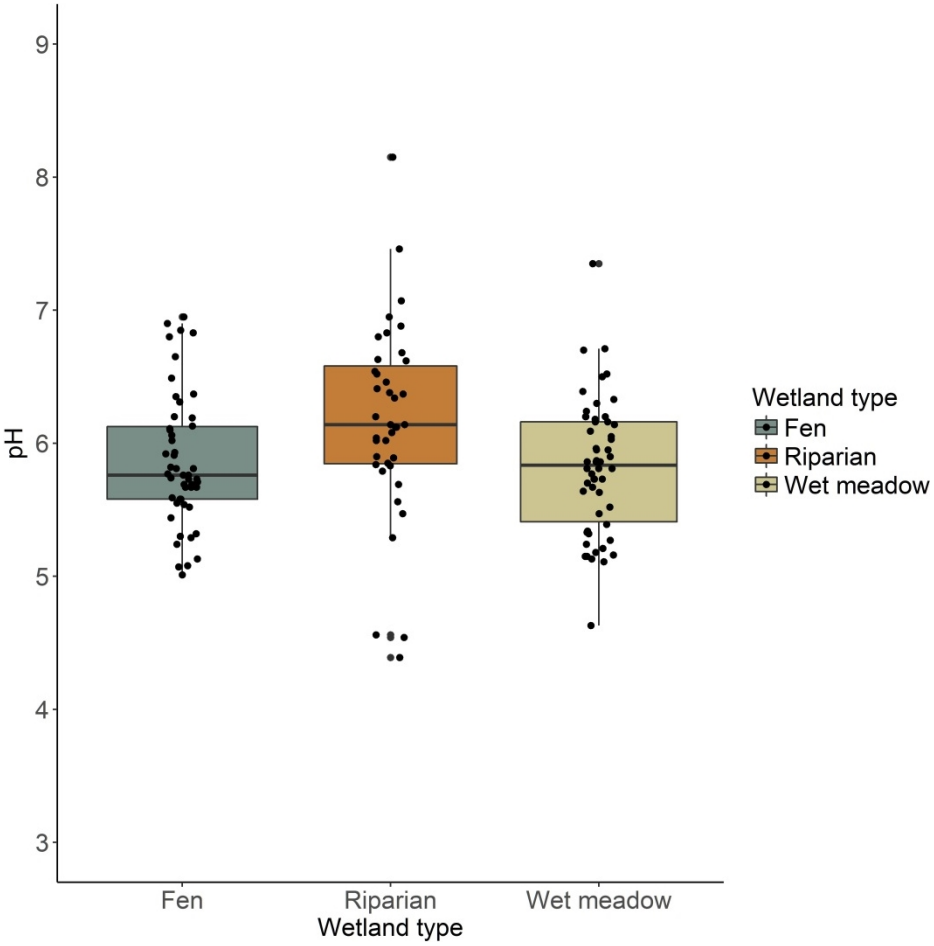


Figure 87. pH (s.u.) by wetland type at wetland ecological integrity sites in Rocky Mountain National Park. Data are from the 'best' sample event at each site and span 2007 to 2011 (with most in 2008). Results are applicable to the sampled sites only. pH is a measure of the acid-base state of water and ranges (on a log scale) from close to 0 (very acidic) to 14 (very basic waters). The dark horizontal line inside each box represents the median. The top of each box is the 75th percentile and bottom is the 25th percentile (defining the interquartile range). The end points of the whiskers are at a distance of 1.5* the interquartile range. Points in each wetland type box are individual site results. Any point outside the whiskers is considered an outlier.

Acidic pH in wetlands can be due to the presence of certain types of vegetation (Sphagnum moss is a good example) that have acidic exudates and create positive feedback systems within the site.

Alternatively, it may reflect an increase in acidic waters from acid snowmelt driven by nutrient deposition. More acidic pH may indicate increased weathering products from warm summer temperatures (Baron et al. 2011). Increases in sulfur compound deposition can lead to surface water acidification (and lower pH in wetlands connected to surface water) and be an indicator of regional or global changes occurring from land use, climate change, or emissions of pollutants (Baron et al. 2011). The effects of acid deposition on lake and stream aquatic ecosystems have been a concern in North America and Europe since the 1970s, due to well-documented effects of acidification on aquatic organisms (Charles and Smol 1991). Acid rain from sulfate or sulfuric acid inputs can increase the acidity of waters to the point where concentrations become toxic to aquatic organisms. Evidence from select lakes in the park suggest that pH has decreased (become more acidic) from 1980 to 2010 (J. Baron, pers. comm.). This pattern may be widespread enough to be causing the low pH in about 20% of the riparian wetland in the park, but we lack any mechanistic studies to make this connection. Water chemistry in riparian systems is driven by contributing stream or lake water and there are several reasons why this may be basic or acidic.

3.9.2.1.1 Spatial pattern

Figure 88 and Figure 89 show the spatial distribution of groundwater specific conductance and pH (respectively) across the park. These results largely reflected patterns noted above, with slightly higher conductance in front country low elevation riparian sites. This was especially apparent for the Moraine Park and Kawuneeche Valley sentinel complexes. pH showed a potentially interesting pattern across low to high elevations, with more acidic conditions up high. This could reflect patterns in nutrient and acid deposition but needs more work to understand.

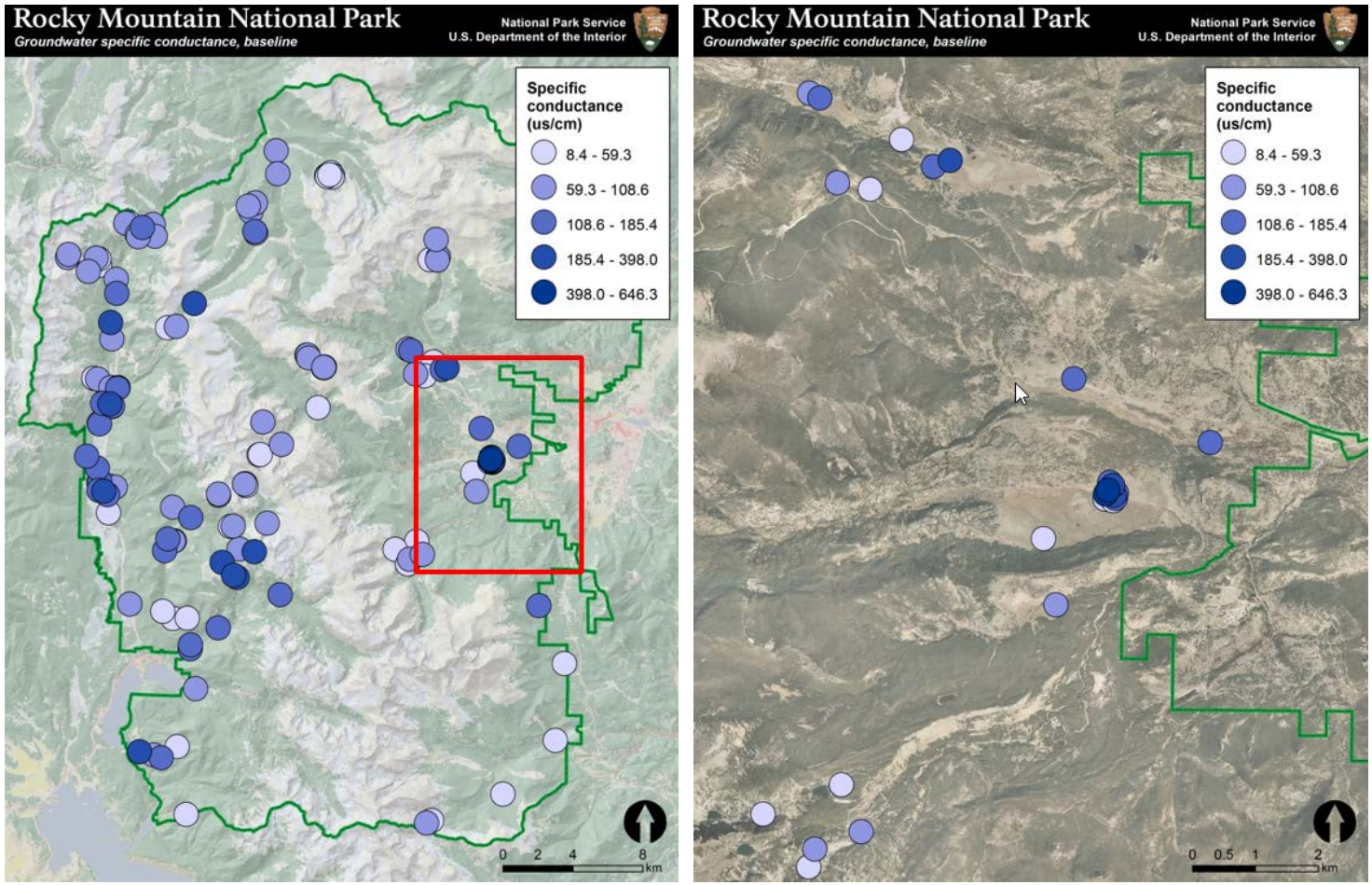


Figure 88. Map of groundwater specific conductance (us/cm) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Moraine and Horseshoe Park area (interior of the red box). The map on the right is an example of finer scale patterning. Specific conductance is a measure of total ion concentration in water and ranges from close to 0 (snowmelt) to 10,000 (very ion rich waters). Samples are from the 'best' sample event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Lighter blue indicates sites with lower conductance and increasingly darker shades of blue indicate higher conductance. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

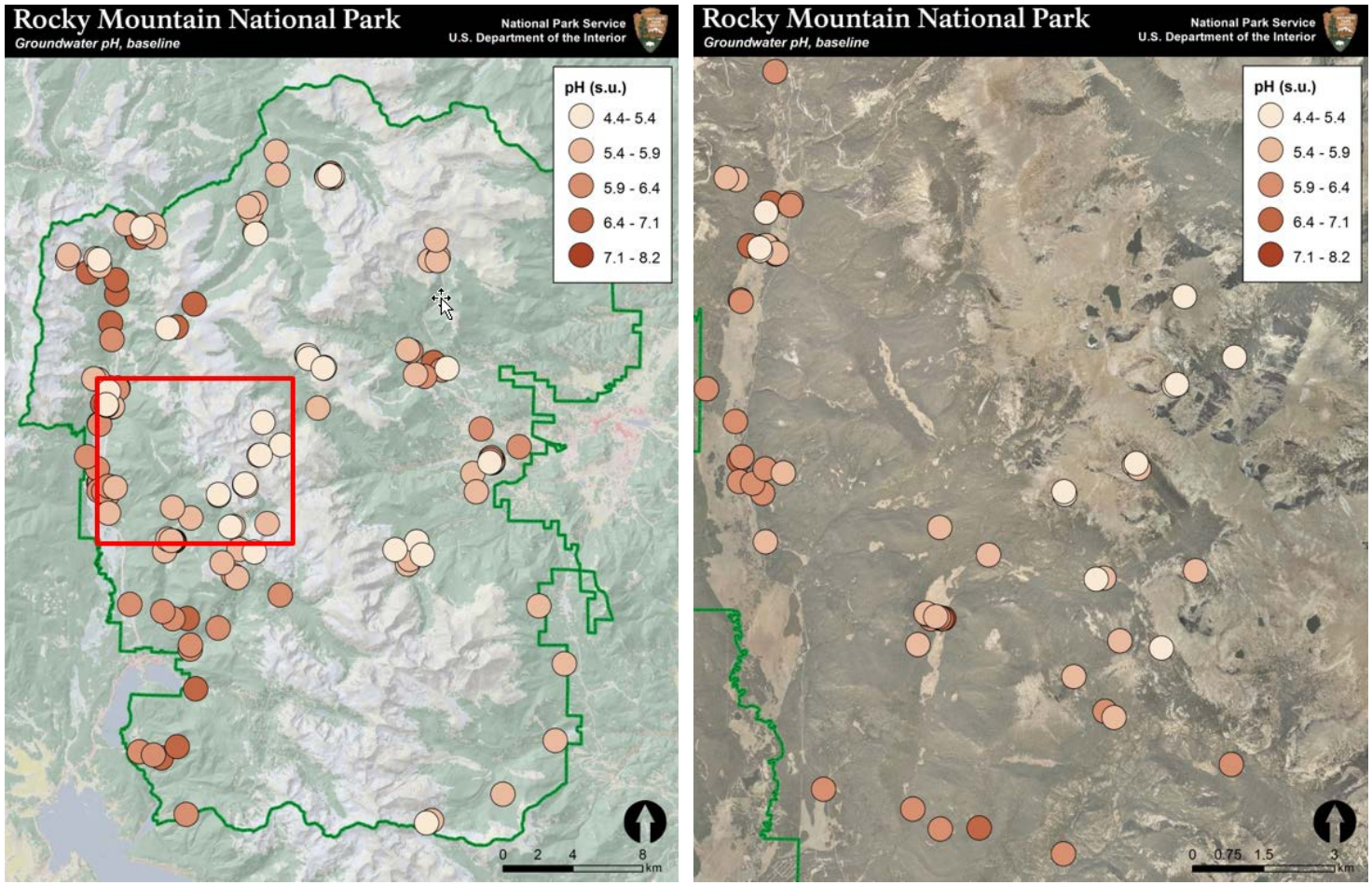


Figure 89. Map of groundwater pH (s.u.) at wetland ecological integrity sites in (left) Rocky Mountain National Park and (right) the Kawuneeche Valley and western side of the Continental Divide area (interior of the red box). The map on the right is an example of finer scale patterning. pH is a measure of the acid-base state of water and ranges (on a log scale) from close to 0 (very acidic) to 14 (very basic waters). Samples are from the 'best' event at each site and span 2007 to 2011 (with most in 2008). Point symbology is derived using Jenks (1967) that locates 'natural' boundaries in a data set based on maximizing similarities within classes. Lighter orange indicates sites with lower conductance and increasingly darker shades of orange indicate higher conductance. The background on the left map is from elevation (USGS 2017) and land cover (McKay et al. 2014) data layers and on the right map is from the park (Salas et al. 2005).

3.9.2.2 Parkwide scale

Table 17 present design-based parkwide scale results from the 'best' survey sites for groundwater specific conductance and pH (respectively) across wetland type. Patterns in the parkwide scale results for specific conductance largely mirror those seen at the site scale. For pH, the tendency for riparian sites to have lower pH is absent, suggesting this may be sampling bias at the site scale or specific to a few targeted sentinel or gradient sites.

Table 17. Baseline summary statistics for groundwater specific conductance (us/cm) for all sample sites and the population of fens, wet meadows, riparian wetland and all wetland in Rocky Mountain National Park. Specific conductance is a measure of total ion concentration in water and ranges from close to 0 (snowmelt) to 10,000 (very ion rich waters). Estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). Site scale results are from all sites and represent a broader range of disturbances, including some specifically targeted to non-reference wetlands. They are applicable to the set of sites included only. Parkwide scale values are derived from randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park. [a]

***In situ* water chemistry indicator**	**Wetland type**	**Mean**	**SE**	**LCB**	**UCB**
Groundwater specific conductance (us/cm)	Fen	67.62	10.23	47.57	87.67
	Wet meadow	84.46	12.63	59.7	109.21
	Riparian	84.33	12.42	59.97	108.68
	All	78.25	9.65	59.34	97.17
Groundwater pH (s.u.)	Fen	5.65	0.11	5.43	5.86
	Wet meadow	5.74	0.11	5.52	5.96
	Riparian	5.93	0.3	5.35	6.51
	All	5.72	0.09	5.54	5.91

[a] SE = standard error, LCB and UCB = lower and upper bounds on a 95% confidence interval.

Figure 90 and Figure 91 show the CDFs of groundwater specific conductance and pH (respectively) across the park. A CDF describes the 'value so far' of cumulative conductance or pH from the lowest to highest score, moving from left to right. For example, compared across wetland type, riparian wetland had a smaller range in conductance, with a shorter tail as the distribution reaches 100%, and fens had less of a tail on the left side of the CDF or less area with lower pH. Our confidence intervals in the riparian estimates were rather wide due to both lower sample size and higher levels of variation in riparian wetland. As described in section 2.3.3 of the methods, CDFs are an excellent tool for visualizing the role of assessment points and will be accordingly applied in future reports.

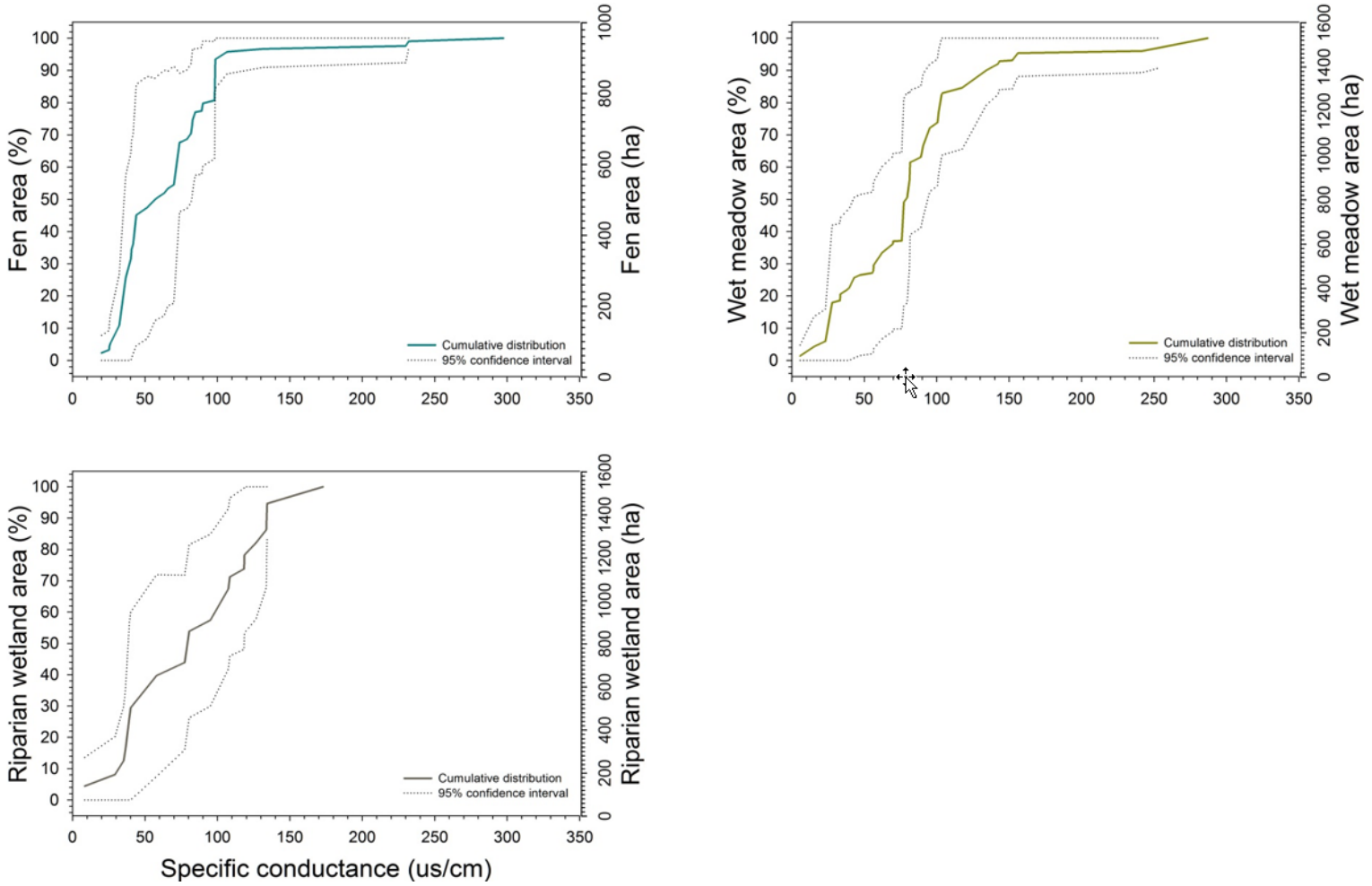


Figure 90. Groundwater specific conductance (us/cm; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. Specific conductance is a measure of total ion concentration in water and ranges from close to 0 (snowmelt) to 10,000 (very ion rich waters). Parkwide scale estimates are derived from data from the 93 'best' sample events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

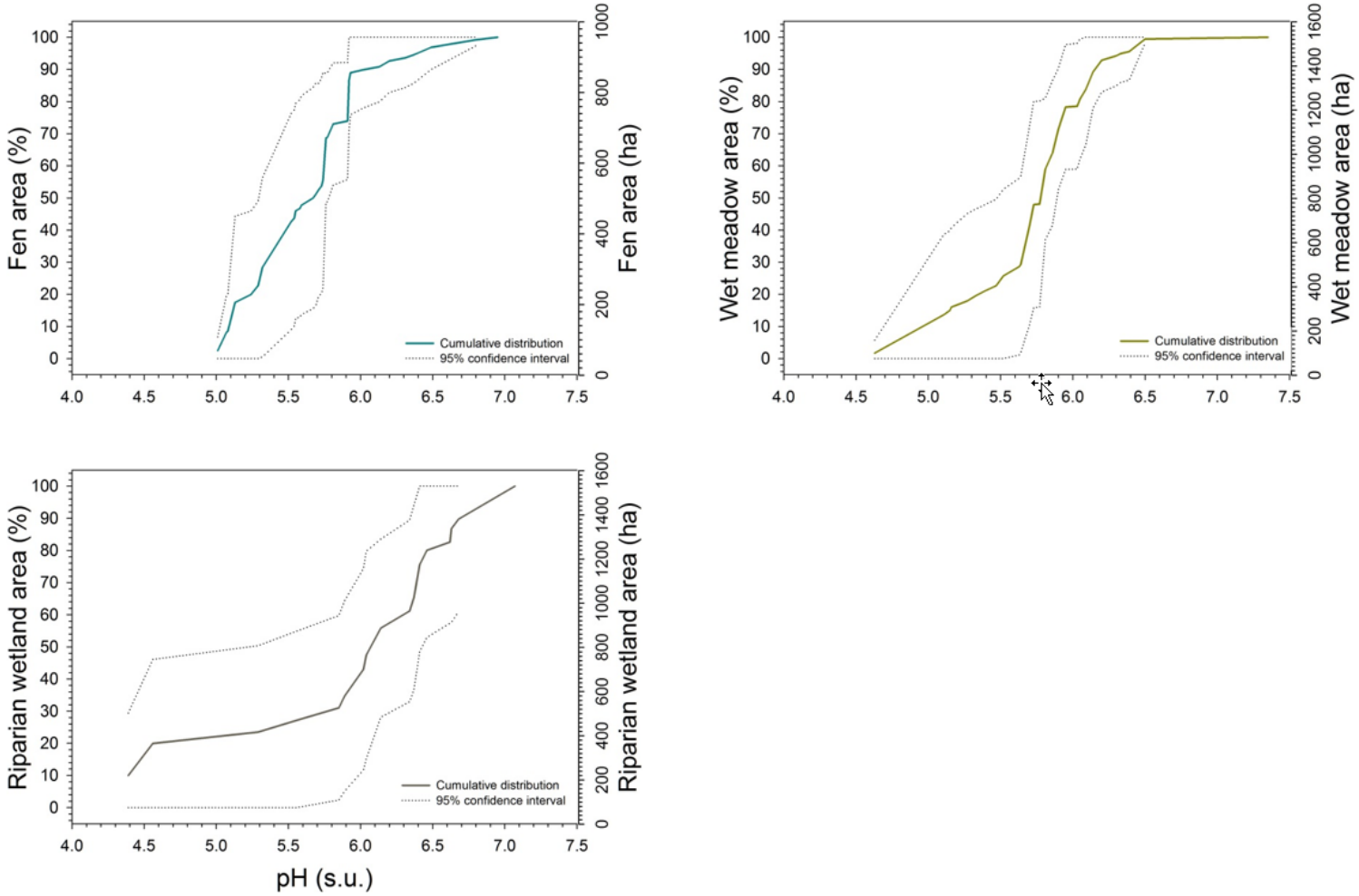


Figure 91. Groundwater pH (s.u.; all x-axes) for the population of (top left) fens, (top right) wet meadows, and (bottom left) riparian wetland in Rocky Mountain National Park. pH is a measure of the acid-base state of water and ranges (on a log scale) from close to 0 (very acidic) to 14 (very basic waters). Parkwide scale estimates are derived from data from the 93 'best' events across all wetland types from 2007 to 2011 (with most in 2008). The estimates are derived using design-based inference (Stevens 1997) and are statistically unbiased. The heavy line in each panel is the cumulative distribution function (CDF) and may be read as the percent total area (left y-axis) or estimated area (right y-axis, in hectares). Dotted lines are a 95% confidence interval around the CDF generated from a local neighborhood variance estimate.

3.9.3 In situ *water chemistry: patterns across time at sentinel sites*

Patterns across time at each of the four sentinel complexes in groundwater specific conductance and pH are complex and will take careful modeling and assessment to better understand. Specific conductance at the Alpine and Big Meadows sites was low and relatively stable from 2008 to 2018 (Figure 92). These sites are wet meadow and fen (Big Meadows has one riparian site but its hydrology has a large groundwater contribution). Specific conductance at the Moraine Park and Kawuneeche Valley sites was much more variable and elevated. There were suggestions of decreasing levels in Kawuneeche Valley. pH was similar and stable across all four sites (Figure 93). There were low acidic values at some Alpine site sample events, possibly due to atmospheric deposition of nutrients at high elevation. The low values in Moraine Park need more examination.

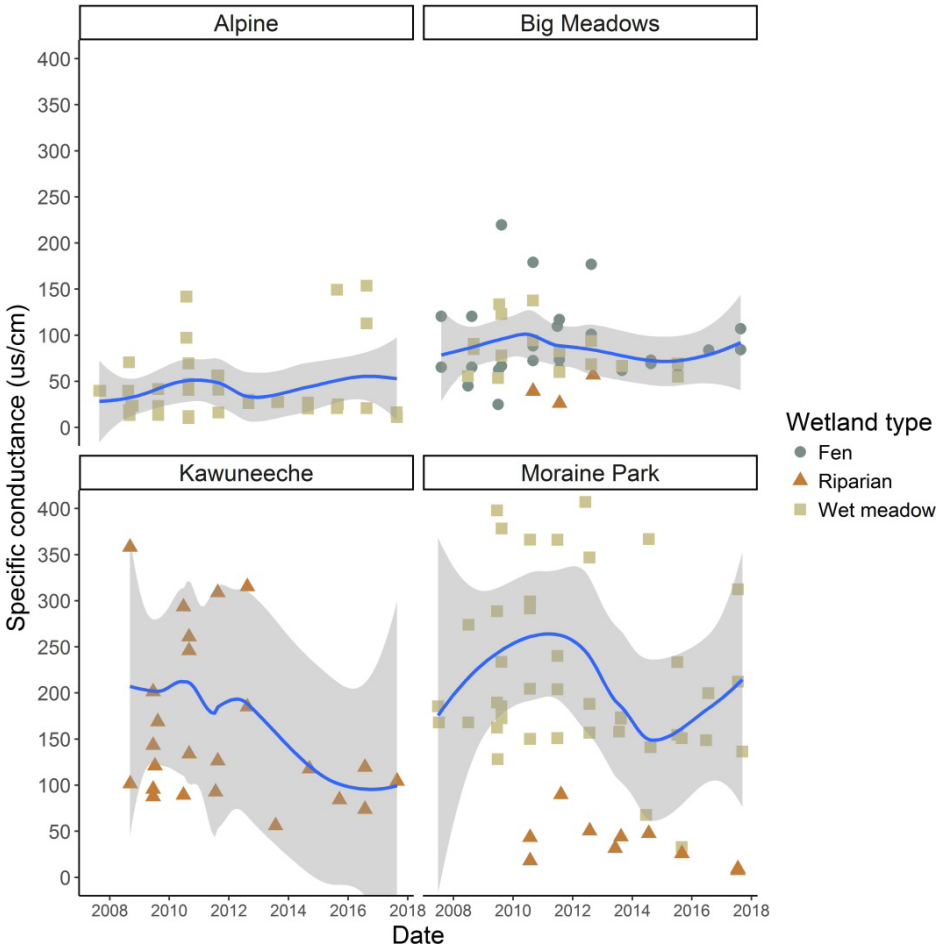


Figure 92. Groundwater specific conductance (us/cm) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. Specific conductance is a measure of total ion concentration in water and ranges from close to 0 (snowmelt) to 10,000 (very ion rich waters). The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band).). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Some points overlap in select panels. Data collection at Alpine and Kawuneeche began in 2009.

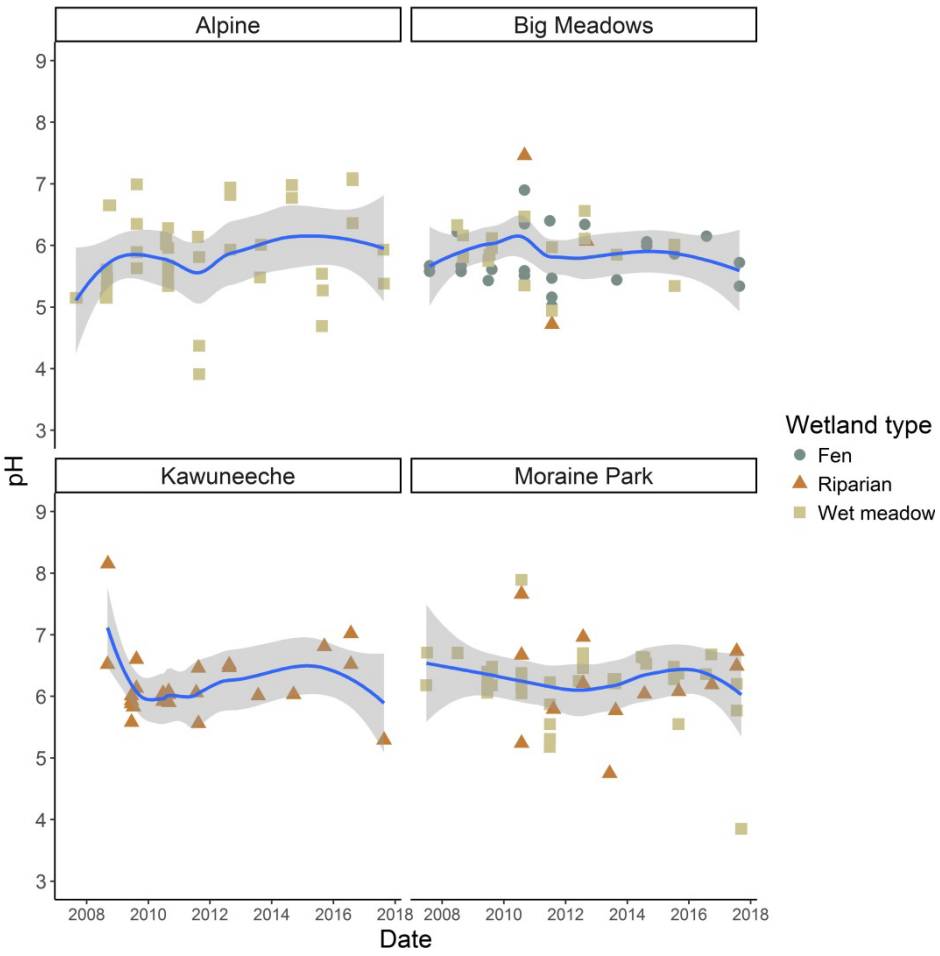


Figure 93. Groundwater pH (s.u.) at wetland ecological integrity sentinel sites in Rocky Mountain National Park, 2007 to 2017. Results apply only to these specific sites. pH is a measure of the acid-base state of water and ranges (on a log scale) from close to 0 (very acidic) to 14 (very basic waters). `The fitted lines are from a LOWESS (LOcally WEighted Scatter-plot Smoother) nonparametric model (Cleveland et al. 1988). This is a weighted, sliding-window average that calculates a line of best fit and includes a 95% confidence interval (shown as a light gray band). Point symbology is based on wetland type with light blue circles for fens, brown triangles for wet meadows and light tan squares for riparian wetland. Some points overlap in select panels. Data collection at Alpine and Kawuneeche began in 2009.

4 Quality assurance and quality control: signal to noise

A key statistic used as part of our QAQC is the ratio of the "signal" to "noise" (S:N) in a response measure (Kaufmann et al. 1999). This is the ratio of variance between multiple sites (signal) and the variance of repeated visits to the same site (noise). Noise includes measurement variation, the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, uncertainty in the precise relocation of plots, and variation between years. A low S:N value indicates that a metric has nearly as much variability within a site (over time) as it does across different sites, and thus indicates a measure that does not distinguish well between sites. Responses with high S:N values are more likely to show consistent responses to stressors than are metrics with low S:N values. A response that is perfectly correlated with a hypothetical stressor and that has no sampling variability will have an $R^2 = 1.0$ with that stressor. As S:N decreases, the maximum possible R^2 value of the regression decreases because the sampling variability of the metric increases. There is no fixed threshold below which we consider a response poor based on S:N. However, we do use a general rule of thumb from Stoddard et al. (2008) of S:N < 1.0. A S:N below 1.0 indicates that visiting a single site twice would yield as much response variability as visiting two different sites.

S:N is derived using a general linear model to compare within-year variance among streams (signal) with the variance between repeat visits within the same year (noise). The noise variance includes the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, and uncertainty in the precise relocation of plots. When describing S:N for the initial sample years in Rocky Mountain National Park, we restrict data used in the models to survey sites sampled between 2007 and 2009. We do include within visit QAQC samples.

Table 18 presents S:N estimates for several WEI response measures. In general, S:N was high, with an average across all measures of 6.9. This bodes well for the WEI protocol overall. The average for vegetation metrics was 7.6. This is surprisingly high given the impacts of season, different crews, and the complexity of correctly identifying many wetland species.

Table 18. Signal to Noise for select wetland ecological integrity indicators. Values in red are below a rule of thumb acceptance threshold of 1.0 (Stoddard et al. 2008).

Category	Metric name	S:N
Conservatism	Absolute Cover Intolerant	3.556
Conservatism	Absolute Cover Tolerant	9.418
Conservatism	C Cover Weighted All	2.994
Conservatism	C Cover Weighted Native	2.994
Conservatism	C Mean	13.672
Conservatism	C Mean Native	12.814
Conservatism	Percent of Spp. Intolerant	9.890

[a] Values below a rule of thumb threshold of acceptable S:N. (also in red font).

Table 18 (continued). Signal to Noise for select wetland ecological integrity indicators. Values in red are below a rule of thumb acceptance threshold of 1.0 (Stoddard et al. 2008).

Category	Metric name	S:N
Conservatism	Percent of Spp. Tolerant	7.481
Conservatism	Floristic Quality Index	7.374
Conservatism	FQI Cover Weighted	6.747
Conservatism	FQI Cover Weighted Native	6.747
Conservatism	Floristic Quality Index Native	7.506
Conservatism	Floristic Quality Index Adjusted	16.763
Conservatism	FQIA Cover Weighted	2.051
Conservatism	Percent Cover Intolerant	6.282
Conservatism	Percent Cover Tolerant	6.408
Conservatism	Rel. Proportion Tolerant to Intolerant Absolute Cover	13.518
Disturbance	HDI	1.998
Disturbance	Land Use	1.561
Disturbance	Macrohabitat Patch Diversity	1.367
Duration	Absolute Cover Annual	0.340[a]
Duration	Rel. Proportion Annual to Perennial Absolute Cover	0.408[a]
Duration	Absolute Cover Perennial	1.074
Duration	Percent Abs Cover Annual	0.438[a]
Duration	Percent Absolute Cover Perennial	8.949
Ground Cover	Total basal area	0.305[a]
Ground Cover	Total Cover	1.093
Ground Cover	Bare Ground	2.108
Ground Cover	Basal Area	0.301[a]
Ground Cover	Litter	1.669
Ground Cover	Water	4.006
Hydrology	Depth To Water	3.910
Lifeform	Absolute Cover Forb	7.096
Lifeform	Absolute Cover Graminoid	2.577
Lifeform	Absolute Cover Rhizomatous	4.085
Lifeform	Absolute Cover Shrub	33.498

[a] Values below a rule of thumb threshold of acceptable S:N. (also in red font).

Table 18 (continued). Signal to Noise for select wetland ecological integrity indicators. Values in red are below a rule of thumb acceptance threshold of 1.0 (Stoddard et al. 2008).

Category	Metric name	S:N
Lifeform	Absolute Cover Woody	34.408
Lifeform	Percent Forb	4.629
Lifeform	Percent Graminoid	5.703
Lifeform	Percent Rhizomatous	2.744
Lifeform	Rel. Proportion Rhizomatous to Non Rhizomatous Cover	0.868[a]
Nativity	Rel. Proportion Annual to Perennial Native Abs. Cover	0.519[a]
Nativity	Absolute Cover Annual and Native	0.668[a]
Nativity	Absolute Cover Dominant Native	1.781
Nativity	Rel. Proportion Native Forb to Graminoid Abs. Cover	9.838
Nativity	Absolute Cover Forb Native	5.510
Nativity	Absolute Cover Gram Native	4.009
Nativity	Absolute Cover Invasive	10.115
Nativity	Absolute Cover Native	1.204
Nativity	Absolute Cover Perennial Native	1.610
Nativity	Absolute Cover Shrub Native	33.498
Nativity	Absolute Cover Woody Native	34.408
Nativity	Invasive Richness	8.953
Nativity	Percent of Spp. Native Forbs	4.386
Nativity	Percent of Spp. Non Native	4.745
Nativity	Cover Weighted Mean Invasive	7.830
Nativity	Cover Weighted Mean Invasive Irank	7.577
Nativity	Cover Weighted Mean Invasive Noxious	15.104
Nativity	Mean Invasive	5.372
Nativity	Mean Invasive Irank	1.277
Nativity	Percent Annual Native	0.539[a]
Nativity	Percent Dominant Native	4.132
Nativity	Percent Forb Native	3.607
Nativity	Percent Graminoid Native	10.899
Nativity	Percent Invasive	6.523

[a] Values below a rule of thumb threshold of acceptable S:N. (also in red font).

Table 18 (continued). Signal to Noise for select wetland ecological integrity indicators. Values in red are below a rule of thumb acceptance threshold of 1.0 (Stoddard et al. 2008).

Category	Metric name	S:N
Nativity	Percent Non Native	6.523
Nativity	Percent Perennial Native	11.859
Nativity	Percent Shrub Native	21.023
Nativity	Percent Woody Native	15.112
Nativity	Rel. Proportion Annual to Perennial Native Total Cover	0.519[a]
Nativity	Rel. Proportion Native Forb to Graminoid Total Cover	9.802
Nativity	Rel. Proportion Native to Total Cover	6.310
Richness	Richness	7.627
Richness	Richness Asteraceae	8.081
Richness	Richness Bryophytes	1.467
Richness	Richness Cyperaceae	2.184
Richness	Richness Poaceae	2.289
Richness	Richness Salicacae	11.297
Richness	Simpson Diversity	1.973
Richness	Simpson Diversity Native	1.660
Taxonomic Status	Absolute Cover Asteraceae	6.869
Taxonomic Status	Absolute Cover Brassicaceae	10.230
Taxonomic Status	Absolute Cover Bryophyte	0.777[a]
Taxonomic Status	Absolute Cover Carex	12.911
Taxonomic Status	Rel. Proportion Cyperaceae to Cyperaceae and Poaceae Absolute Cover	10.558
Taxonomic Status	Absolute Cover Cyperaceae	4.913
Taxonomic Status	Absolute Cover Poaceae	6.120
Taxonomic Status	Absolute Cover Salicaceae	14.141
Taxonomic Status	Absolute Cover Salix	14.271
Taxonomic Status	Percent Carex	9.800
Taxonomic Status	Percent Cyperaceae	9.393
Taxonomic Status	Percent Poaceae	4.964
Taxonomic Status	Percent Salicaceae	18.842

[a] Values below a rule of thumb threshold of acceptable S:N. (also in red font).

Table 18 (continued). Signal to Noise for select wetland ecological integrity indicators. Values in red are below a rule of thumb acceptance threshold of 1.0 (Stoddard et al. 2008).

Category	Metric name	S:N
Taxonomic Status	Percent Salix	19.032
Taxonomic Status	Percent Asteraceae	6.267
Taxonomic Status	Percent Brassicaceae	6.897
Taxonomic Status	Percent Bryophyte	1.324
Taxonomic Status	Rel. Proportion Cyperace Cyperaceae+Poaceae Tot. Cover	10.491
Water Chemistry	Groundwater pH	3.098
Water Chemistry	Groundwater Specific Conductance	3.269
Wetland Status	Absolute Cover Hydrophytes	2.970
Wetland Status	Relative Cover Hydrophytes	5.152
Wetland Status	Percent Hydrophytes	5.164
Wetland Status	Wet Indicator Mean	10.048
Wetland Status	Wet Indicator Native	12.893
Wetland Status	Wet Indicator Total	10.048
Wetland Status	Wet Rich Native	5.212
Wetland Status	Wet Rich Total	5.400
Wetland Status	Wet Score Weighted	16.662
Woody Damage	Percent Dead Stems Target Woody Species	3.957
Woody Damage	Percent DieBack Target Woody Species	3.267
Woody Damage	Percent Live Browsed Target Woody Species	0.741[a]
Mean for All Metrics		**6.989**

[a] Values below a rule of thumb threshold of acceptable S:N. (also in red font).

There are some notable patterns in the types of measures that had low and high S:N. Most metrics that included some aspect of species duration, such as annual vs. perennial, had low S:N, often below the threshold of 1.0. The occurrence of annual species was highly dependent on when a site was sampled and as this varied across revisits, it increased the noise component of these metrics. All metrics based on estimating basal area also had low S:N. Basal area is very difficult to estimate for graminoid species (which dominate many wetland sites) using plot based methods and is also strongly affected by season and the phenology of a site.

The woody damage metrics had an interesting S:N pattern. The percentage dieback and dead stems were fairly high, suggesting less variation among site revisits than across space in these aspects of woody stems. However, the percent live browse was 0.74. This may be due to seasonal variation in

when elk and other ungulates browse new growth or to the difficulty in estimating this more subtle response.

A few classes of metrics had notably high S:N. Vegetation metrics based on woody species occurrence were consistently estimated across crews and season. Likewise, most metrics based on conservatism scores were also quite high. This last result is perhaps most surprising and useful. It suggests that taxa at the extremes of the C score scale were consistently identified and less affected by season. Perhaps, very weedy and very unique taxa received special attention by field crews. Measures of disturbance like the HDI also tended to have low S:N (but not below the threshold). There is a degree of subjectivity in the HDI processes.

5 Conclusions and Future Directions

5.1 Management applications

The Rocky Mountain Inventory and Monitoring Network selected wetland communities as one of 12 high priority vital signs for monitoring because of the tremendous ecological importance of wetlands and the ecological services they provide, the aesthetic and recreational value of wetlands (including wildlife dependent on wetlands) to park visitors, and because NPS and other federal and state agencies must manage wetlands in accordance to federal laws, such as the Clean Water Act. Wetlands are an important vital sign in Rocky Mountain National Park because park wetlands have been heavily impacted since the late 1800s by many factors, including direct human impacts to park hydrology (e.g., building drainage ditches and roads), over-concentrations of elk due to the removal of large predators, loss of beaver, and, more recently, introduction of nonnative moose.

An important objective in preparing this data report on park wetland monitoring was to make our methods and results accessible to a broad audience. This report provides a complete description of our entire park wetland monitoring dataset and quality assured data that are now available for the park, others in the NPS, partners and potential scientific partners interested in understanding wetlands in the Rocky Mountains, agencies charged with wetland protection and management, and the public. The data are currently available on the NPS IRMA Data Store (Integrated Resource Management Applications; https://irma.nps.gov/Portal/), and from network staff. As we continue WEI monitoring in the park, we will publish annual updates (by Dec. 31st each year) to the park's WEI dataset on IRMA.

Network WEI monitoring provides a periodic unbiased estimate of the parkwide status of the ecological integrity of fens, wet meadows, and riparian wetlands. By monitoring a subset of wetlands annually in the park, we can also estimate trends at these select sites (such as Moraine Park). By analyzing our WEI data along with auxiliary datasets, we have already provided insights into important relationships among human activities (past and current) and wetland health and conditions. We can (and have) used WEI data to evaluate the relationship between human and natural disturbances and wetland health. We have used it to examine specific relationships between important aspects of wetland systems (e.g., beaver) and specific wetland conditions, such as degree of invasion by exotic plants, native forb cover, and shrub biomass and productivity (Schweiger et. al. 2016). Network wetland data can also be used to understand patterns in wetland condition by natural and human gradients, such as wetland type (fen, wet meadow, or riparian), elevation, distance from roads, or as a comparison between wetland inside wilderness vs outside of wilderness, to name just a few examples.

Finally, our parkwide survey and continuing annual wetland monitoring provide scientifically based assessment of wetland conditions and indicators that provide a "snapshot" (circa 2007–2009) of park wetlands for future comparison.

This information can also serve as a basis for informed wetland restoration. For example, patterns in wetland conditions estimated from network WEI data provide both a way to prioritize wetland sites for restoration and to understand the effectiveness of restoration activities at the site-specific and

broader scales (e.g., parkwide, or in comparison with wetlands in adjacent lands). A current example of the utility of WEI data is the partnership between Rocky Mountain National Park and Colorado State University to understand the effects of “simulated beaver structures” (SBSs) on wetland hydrology and vegetation communities before and after installation.

5.2 Future directions

We will continue working over the next several years with park management to monitor select wetlands relative to planned installation (fall 2019 or later) of SBSs in three wetlands as a pilot wetland restoration effort on the East side of Rocky Mountain National Park. This work is a collaboration of multiple research efforts: park resource management and research staff are studying elk and moose populations and woody vegetation; Colorado State University scientists are studying stream and groundwater hydrology and chemistry, and sedimentation; and NPS Biological Resource Management Division staff are studying wetland “acoustic complexity” (i.e., how wetland animals such as birds and amphibians may respond to restoration by measuring the complexity of animal songs and calls).

The large wetland complex at the lower end of Wild Basin may be one of the most “intact” riparian wetlands in the park, judging by the presence of active beaver dams, the presence and extent of larger willows, alder and river birch, a high water table, and other indicators. In 2018, we expanded our wetland monitoring at select sentinel wetlands to include Wild Basin at the request of park resource management staff. This is especially important because moose are rapidly expanding in the park, including in Wild Basin (H. Abouelezz, Rocky Mountain National Park landscape ecologist, pers. comm.), and are likely already impacting this high quality wetland complex. We have included the Wild Basin site in the rotation of wetland sentinel site monitoring to better evaluate annual trends in wetland conditions in the park.

As we continue monitoring the Wild Basin sentinel wetland, we will analyze and report on trends in wetland indicators across all our wetland sentinel sites, which include alpine wetland near Forest Canyon Overlook, Big Meadows, and Moraine Park. We propose to do this analysis and report in 2020. We will likely include wetland monitoring information from the SBS wetlands (Beaver Meadows, Cow Creek, and Horseshoe Park) in this trend analysis.

We have had discussions with park management over the past several years about how to adapt our wetland monitoring data to inform a parkwide wetland restoration effort. We will continue these discussions and contribute wetland data and analyses to a proposal or project to restore park wetlands more broadly (i.e., beyond the SBS project and restoration efforts by the park under the Elk and Vegetation Management Plan).

A primary goal of Rocky Mountain Network vital signs monitoring in general and WEI monitoring in the park specifically is to understand patterns of wetland condition across the park. This monitoring complements the long history of vegetation monitoring the park has done relative to elk use on the winter range on the East side of the park. It also complements research on specific wetlands, such as the Kawuneeche Valley and Big Meadows, by collaborators, including David Cooper and many of his students at Colorado State University. We will work with the park over the

next several years to repeat the parkwide wetland survey. This will be a substantial effort (as it was in 2007–2010) and will require careful planning, coordination and cooperation with park staff and other partners. Wetland surveys, along with these other studies, provide a detailed basis for understanding long-term changes in park wetlands in response to rapid climate change and other broad scale stressors.

Literature Cited

Ahn, C., D. C. White, and R. E. Sparks. 2004. Moist-soil plants as ecohydrologic indicators for recovering the flood pulse in the Illinois River. Restoration Ecology 12:207-213.

Allen, A. W. 1983. Habitat suitability index models: Beaver. FWS/OBS-82/10.30. Revised. USDI Fish and Wildlife Service, Washington, DC.

Allen, J. A., C. S. Brown, and T. J. Stohlgren. 2009. Nonnative plant invasions of United States National Parks. Biological Invasions 1:2195-2207.

Augustine, D. J., L. E. Frelich, and P. A. Jordan. 1998. Evidence for two alternate stable states in an ungulate grazing system. Ecological Applications 8:1260-1269.

Baker, W. L., J. A. Munroe, and A. E. Hessl. 1997. The effects of elk on aspen in the winter range in Rocky Mountain National Park. Ecography 20:155-165.

Baker, B. W., H. R. Peinetti, M. B. Coughenour, and T. L. Johnson. 2012. Competition favors elk over beaver in a riparian willow ecosystem. Ecosphere 3:art95. DOI: 10.1890/ES12-00058.1.

Baron J. S., C. T. Driscoll, J. L. Stoddard, and E. E. Richer. 2011. Empirical critical loads of atmospheric nitrogen deposition for nutrient enrichment and acidification of sensitive US lakes. BioScience. 61:602-613.

Baron, J. S., M. D. Hartman, L. E. Band, and R. B. Lammers. 2000. Sensitivity of a high-elevation Rocky Mountain watershed to altered climate and CO2. Water Resources Research 36:89-99.

Bedford, B. L., and K. S. Godwin. 2003. Fens of the United States: Distribution, characteristics, and scientific connection versus legal isolation. Wetlands 23:608-629.

Bedford, B. L., M. R. Walbridge, and A. Aldous. 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology 80:2151-2169.

Belyea, L. R., and N. Malmer. 2004. Carbon sequestration in peatland: patterns and mechanisms of response to climate change. Global Change Biology 10:1043-1052.

Bergman, E. J., J. D. Diamond, S. Ferrero, M. Fisher, K. Fox, L. Gepfert, A. Holland, A. Howell, J.J. Huntington, I. Levan, and L. Martin. 2013. Wildlife Research Report: Evaluation and incorporation of life history traits, nutritional status and browse characteristics in Shira's moose management in Colorado. Colorado Parks and Wildlife. Wildlife Research 2014.

Bilyeu, D. M., D .J. Cooper, and N. T Hobbs. 2008. Water tables constrain height recovery of willow on Yellowstone's northern range. Ecological Applications 18:80-92.

Boarman, W. I., and M. Sazaki. 2006. A highway's road-effect zone for desert tortoises (*Gopherus agassizii*). Journal of Arid Environments 65:94-101.

Britten, M., E. W. Schweiger, B. Frakes, D. Manier, and D. Pillmore. 2007. Rocky Mountain Network vital signs monitoring plan. Natural Resource Report NPS/Network/NRR—2007/010. National Park Service, Fort Collins, Colorado.

Bureau of Land Management (BLM). 1999. Draft environmental impact statement for the Pinedale Anticline oil and gas exploration and development project. Bureau of Land Management, Pinedale Field office, Sublette County, Wyoming.

Burkett, V., and J. Kusler. 2000. Climate change: Potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36:313-320.

Butler, D. R. 2012. Characteristics of beaver ponds on deltas in a mountain environment. Earth Surface Processes and Landforms 37:876-882.

Byers, J. E., S. Reichard, J. M. Randall, I. M. Parker, C. S. Smith, W. M. Lonsdale, I. A. E. Atkinson, T. R. Seastedt, M. Williamson, E . Chornesky, and D. Hayes. 2002. Directing research to reduce the impacts of nonindigenous species. Conservation Biology 16:630-640.

Charles, D. F., and J. P. Smol. 1991. A Long-term perspective on chemical changes in lakes and reservoirs - interpreting the biological record in sediments. Abstracts of Papers of the American Chemical Society 201:55-ENVR.

Chimner, R. A., and D. J. Cooper. 2003a. Carbon dynamics of pristine and hydrologically modified fens in the southern Rocky Mountains. Canadian Journal of Botany 81:477-491.

Chimner, R. A., and D. J. Cooper. 2003b. Influence of water table levels on CO2 emissions in a Colorado subalpine fen: an in situ microcosm study. Soil Biology and Biochemistry 35:345-351.

Chipps, S. R., D. E. Hubbard, K. B. Werlin, N. J. Haugerud, K. A. Powell, J. Thompson, and T. Johnson. 2006. Association between wetland disturbance and biological attributes in floodplain wetlands. Wetlands 26:497-508.

Christian, J. M., and S. D. Wilson. 1999. Long-term ecosystem impacts of an introduced grass in the northern Great Plains. Ecology 80:2397-2407.

Clayton, J. A., and C. J. Westbrook. 2008. The effect of the grand ditch on the abundance of benthic invertebrates in the Colorado River, Rocky Mountain National Park. River Research and Applications 24:975-987.

Cleveland, W. S., S. J. Devlin, E. and Grosse. 1988. Regression by local fitting. Journal of Econometrics 37:87-114.

Colorado Parks and Wildlife (CPW). 2013. Moose reintroduction. https://cpw.state.co.us/Documents/WildlifeSpecies/Mammals/MooseReintroductionFactSheet.pdf

Cooke, J. C., and M. W. Lefor. 1990. Comparison of vesicular arbuscular mycorrhizae in plants from disturbed and adjacent undisturbed regions of a coastal salt-marsh in Clinton, Connecticut. Environmental Management 14:131-137.

Cooper, D. J. 1990. The ecology of wetlands in Big Meadows, Rocky Mountain National Park, Colorado: the correlation of vegetation, soils and hydrology. US Department of the Interior, Fish and Wildlife Service, Biological Report 90(15).

Cooper, D. J., J. Dickens, N. T. Hobbs, L. Christensen, and L. Landrum. 2006. Hydrologic, geomorphic and climatic processes controlling willow establishment in a montane ecosystem. Hydrological Processes 20:1845-1864.

Cooper, D. J., L. H. MacDonald, S. K. Wenger, and S. W. Woods. 1998. Hydrologic restoration of a fen in Rocky Mountain National Park, Colorado, USA. Wetlands 18:335-345.

Cooper, D. J., and J. S. Sanderson. 1997. A montane *Kobresia myosuroides* fen community type in the Southern Rocky Mountains of Colorado, USA. Arctic and Alpine Research 29:300-303.

Coughenour, M. B. 2002. Elk in the Rocky Mountain National Park ecosystem – A model-based assessment. USGS Biological Resources Division and US National Park Service. US Department of the Interior, Estes Park, Colorado.

Davis, B. N. K., K. H. Lakhani, T. J. Yates, A. J. Frost, and R. A. Plant. 1993. Insecticide drift from ground-based, hydraulic spraying of peas and Brussel sprouts: bioassays for determining buffer zones. Agriculture, Ecosystems and Environment 43:93-108.

de Jong, F. M. W., G. R. de Snoo, and J. C. van de Zande. 2008. Estimated nationwide effects of pesticide spray drift on terrestrial habitats in the Netherlands. Journal of Environmental Management 86:721-730.

Driver, K. M. 2010. Distinguishing the hydrologic regimes and vegetation of fens and fens in the Rocky Mountains. Thesis. Colorado State University, Fort Collins, Colorado.

Dungan, J., L. A. Shipley, and G. R. Wright. 2010. Activity patterns, foraging ecology, and summer range carrying capacity of moose (Alces alces shirasi) in Rocky Mountain National Park, Colorado. Alces:46:71-87.

Ehrenfeld, J. G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems 6:503-523.

Ehrenfeld, J. G., and J. P. Schneider. 1991. *Chamaecyparis thyoides* wetlands and suburbanization: Effects on hydrology, water quality and plant community composition. Journal of Applied Ecology 28:467-490.

Eigenbrod, F., S. J. Hecnar, and L. Fahrig. 2009. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. Ecology and Society 14:24.

Ervin, G. N., B. D. Herman, J. T. Bried, and D. C. Holly. 2006. Evaluating nonnative species and wetland indicator status components of wetlands floristic assessment. Wetlands 26:1114-1129.

Faber-Langendoen, D., J. Rocchio, M. Schafale, C. Nordman, M. Pyne, J. Teague, and P. Comer. 2006. Ecological integrity assessment and performance measures for wetland mitigation. Final Report. NatureServe, Arlington, Virginia.

Fancy, S., J. Gross, and S. Carter. 2009. Monitoring the condition of natural resources in U.S. national parks. Environmental Monitoring and Assessment 151:161-174.

Fridley, J. D., J. J. Stachowicz, S. Naeem, D. F. Sax, E. W. Seabloom, M. D. Smith, T. J. Stohlgren, D. Tilman, and B. Von Holle. 2007. The invasion paradox: reconciling pattern and process in species invasions. Ecology 88:3-17.

Gage, E. A., and D. J. Cooper. 2005. Patterns of willow seed dispersal, seed entrapment, and seedling establishment in a heavily browsed montane riparian ecosystem. Canadian Journal of Botany 83:678-687.

Glaser, P. H., J. A. Janssens, and D. I. Siegel. 1990. The response of vegetation to chemical and hydrological gradients in the Lost River peatland, northern Minnesota. Journal of Ecology 78:1021-1048.

Grace, J. B., T. M. Anderson, E. W. Seabloom, E. T. Borer, P. B. Adler, W. S. Harpole, Y. Hautier, H. Hillebrand, E. M. Lind, M. Pärtel, and J. D. Bakker. 2016. Integrative modelling reveals mechanisms linking productivity and plant species richness. Nature 529:390-393.

Guntenspergen, G. R., S. A. Peterson, S. G. Leibowitz, and L. M. Cowardin. 2002. Indicators of wetland condition for the prairie pothole region of the United States. Environmental Monitoring and Assessment 78:229-252.

Hansen, A. J., R. L. Knight, J. M. Marzluff, S. Powell, K. Brown, P. H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications 15:1893-1905.

Herman, K. D., L. A. Masters, M. R. Penskar, A. A. Reznicek, G. S. Wilhelm, W. R. Brodowicz, 1997. Floristic quality assessment: development and application in the state of Michigan (USA). Natural Areas Journal 17:265-279.

Hobbs, N. T., D. L. Baker, J. E. Ellis, D. M. Swift, and R. A. Green. 1982. Energy- and nitrogen-based estimates of elk winter-range carrying capacity. The Journal of Wildlife Management 46:12-21.

Horvitz, D. G., and D. J. Thompson. 1952. A generalization of sampling without replacement from a finite universe. Journal of the American Statistical Association 47:663-685.

Hyvönen, T., and P. Nummi. 2008. Habitat dynamics of beaver *Castor canadensis* at two spatial scales. Wildlife Biology 14:302-308.

Iacona, G. D., F. D. Price, and P. R Armsworth. 2014. Predicting the invadedness of protected areas. Diversity and Distributions. 20:430-439.

Jenks, G. F. 1967. "The Data Model Concept in Statistical Mapping." International Yearbook of Cartography 7:186-190.

Johnston, C. A., D. M. Ghioca, M. G. Tulbure, B. L. Bedford, M. Bourdaghs, C. B. Frieswyk, L. Vaccaro, J. B. Zedler. 2008. Partitioning vegetation response to anthropogenic stress to develop multi-taxa wetland indicators. Ecological Applications 18:983-1001.

Kaczynski, K. M., and D. J. Cooper. 2015. Post-fire response of riparian vegetation in a heavily browsed environment. Forest Ecology and Management 338:14-19.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Applications 1:66-84.

Kaufmann, P. R., P. Levine, E. G. Robison, C. Seeliger, and D. V. Peck. 1999. Surface waters: Quantifying physical habitat in wadeable streams. EPA/620/R-99/003, Environmental Protection Agency.

Keddy, P. A., and P. Keddy. 2000. Wetland ecology: Principles and conservation. Cambridge University Press, New York.

Keough, J. R., T. A. Thompson, G. R. Guntenspergen, and D. A. Wilcox. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. Wetlands 19:821-834.

Ketz, A. C., T. L. Johnson, R. J. Monello, and N. T. Hobbs. 2016. Informing management with monitoring data: the value of Bayesian forecasting. Ecosphere 7(11):e01587. doi:10.1002/ecs2.1587

Larson, D. L. 1995. Effects of climate on numbers of northern prairie wetlands. Climatic Change 30:169-180.

Levine, J. M., M. Vilà, C. M. D'Antonio, J. S. Dukes, K. Grigulis, and S. Lavorel. 2003. Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London: Biological Sciences 270:775-781.

Lovich, J. E., and J. R. Ennen. 2011. Wildlife conservation and solar energy development in the desert southwest, United States. BioScience 61:982-992.

Lubow, B. C., F. J. Singer, T. L. Johnson, and D. C. Bowden. 2002. Dynamics of interacting elk populations within and adjacent to Rocky Mountain National Park. Journal of Wildlife Management 66:757-775.

Mack, J. J. 2007. Developing a wetland IBI with statewide application after multiple testing iterations. Ecological Indicators 7:864-881.

Mast, M. A. 2007. Assessment of historical water-quality data for National Park units in the Rocky Mountain Network, Colorado and Montana, through 2004. USGS Scientific Investigations Report 2007–5147. US Geological Survey, Reston, Virginia.

Matthews, J. W., G. Spyreas and C. M. Long. 2015. A null model test of Floristic Quality Assessment: Are plant species' Coefficients of Conservatism valid? Ecological Indicators 52:1-7.

McDonald, R. I., R. T. T. Forman, P. Kareiva, R. Neugarten, D. Salzer, and J. Fisher. 2009. Urban effects, distance, and protected areas in an urbanizing world. Landscape and Urban Planning 93:63-75.

McKay L., T. Bondelid, T. Dewald, J. Johnston, R. Moore, and A. Rea. 2014. NHDPlus Version 2: User Guide. US Environmental Protection Agency. https://nctc.fws.gov/courses/references/tutorials/geospatial/CSP7306/Readings/NHDPlusV2_User_Guide.pdf , accessed September, 2016.

Meiners, S. J., S. A. Pickett, and M. L. Cadenasso. 2001. Effects of plant invasions on the species richness of abandoned agricultural land. Ecography 24: 633–644.

Miner, J. J., and D. B. Ketterling. 2003. Dynamics of peat accumulation and marl flat formation in a calcareous fen, Midwestern United States. Wetlands 23:950-960.

Mitchell, D., J. Tjornehoj, and B. W. Baker. 2000. Beaver populations and possible limiting factors in Rocky Mountain National Park, 1999. Unpublished report. US Geological Survey, Midcontinent Ecological Science Center, Fort Collins, Colorado.

Mitsch, W. J., and J. G. Gosselink. 2007. Wetlands. Fourth edition. John Wiley, New York.

Morse, L. E., J. M. Randall, N. Benton, R. Hiebert, and S. Lu. 2004. An invasive species assessment protocol: evaluating nonnative plants for their impact on biodiversity. Version 1. All US Government Documents, Utah Regional Depository. Paper 537.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. Wiley, New York.

Naiman, R. J., H. DeCamps, and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209-212.

Nasen, L. C. 2009. Environmental effects assessment of oil and gas development on a grassland ecosystem. M.S. Thesis. Department of Geography and Planning, University of Saskatchewan, Saskatoon.

National Park Service (NPS). 2002. Recommendations for core water quality monitoring parameters: Final report from the freshwater workgroup subcommittee. US Department of the Interior, National Park Service, Rocky Mountain National Park, Estes Park, Colorado.

National Park Service (NPS). 2007. Final environmental impact statement; elk and vegetation management plan Rocky Mountain National Park, Colorado. US Department of the Interior, National Park Service, Estes Park, Colorado.

National Park Service (NPS). 2013. Foundation Document: Rocky Mountain National Park. US Department of the Interior, National Park Service, Rocky Mountain National Park, Estes Park, Colorado.

National Park Service (NPS). 2015. NPS Stats. National Park Service visitor use statistics. https://irma.nps.gov/Stats/

National Park Service (NPS). 2019. Species Checklist for Rocky Mountain National Park. https://irma.nps.gov/NPSpecies/Reports/SpeciesList/Species%20Checklist/ROMO/1,2,4,5,3,11,12,7,9,6,8,10,13,14,16,15,17/false

National Research Council. 1995. Wetlands: characteristics and boundaries. The National Academies Press, Washington, DC.

Natural Resources Conservation Service (NRCS). 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 0120 A 57.2:K 52/2006 tmp97352131. Natural Resources Conservation Service.

Natural Resources Conservation Service. 2015. United States Department of Agriculture, Soil Survey Geographic (SSURGO) Database. https://sdmdataaccess.sc.egov.usda.gov.

Naugle, D. E. (ed). 2011. Energy development and wildlife conservation in Western North America. Island Press, Washington, DC.

Nummi, P., and T. Kuuluvainen. 2013. Forest disturbance by an ecosystem engineer: beaver in boreal forest landscapes. Boreal Environment Research 18:13-25.

Odell, E. A., and R. L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.

Olsen, A. R., J. Sedransk, D. Edwards, C. A. Gotway, W. Liggett, S. Rathbun, K. H. Reckhow, and L. J. Young. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environmental Monitoring and Assessment 54:1-45.

Overton, W. S., and S. V. Stehman. 1996. Desirable design characteristics for long-term monitoring of ecological variables. Environmental and Ecological Statistics 3:349-361.

Packard, F. 1947. A survey of the beaver population of Rocky Mountain National Park, Colorado. Journal of Mammalogy 28:219-227.

Palomino, D., and L. M. Carrascal. 2007. Threshold distances to nearby cities and roads influence the bird community of a mosaic landscape. Biological Conservation 140:100-109.

Parris, K. M., and A. Schneider. 2008. Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecology and Society 14:29.

Patten, D. T., 1998. Riparian ecosystems of semi-arid North America: Diversity and human impacts. Wetlands 18:498-512.

Peinetti, H. R., M. A. Kalkhan, and M. B. Coughenour. 2002. Long-term changes in willow spatial distribution on the elk winter range of Rocky Mountain National Park (USA). Landscape Ecology 17:341-354.

Potter, K. M., and B. L. Conkling, editors. 2015. Forest health monitoring: national status, trends, and analysis 2013. General Technical Report SRS-207. US Department of Agriculture Forest Service, Southern Research Station. Asheville, North Carolina.

Rocchio, J. 2007a. Assessing ecological condition of headwater wetlands in the southern Rocky Mountains using a vegetation index of biotic integrity (Version 1.0). Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Rocchio, J. 2007b. Floristic quality assessment indices for Colorado plant communities. Report prepared for the Colorado Department of Natural Resources and US EPA Region 8. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado.

Rocky Mountain National Park (RMNP). 2004. Vegetation landscape ecology: a list of rare and imperiled plant communities in Rocky Mountain National Park. Park Report. Rocky Mountain National Park, National Park Service, US Department of the Interior, Estes Park, Colorado.

Rocky Mountain Network - NPS. 2019a. Vegetation Taxa List for Rocky Mountain National Park Wetlands Ecological Integrity monitoring (2007-2017). Tabular dataset. NPS Integrated Resource Management Applications Data Store. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2259528.

Rocky Mountain Network - NPS. 2019b. Vegetation Metrics for Rocky Mountain National Park Wetlands Ecological Integrity monitoring (2007-2017). Tabular dataset. NPS Integrated Resource Management Applications Data Store. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2259529.

Salas D. E., J. Stevens, and K. Schulz. 2005. USGS-NPS Vegetation Mapping Program: Rocky Mountain National Park, Colorado: 2001-2005 Vegetation Classification and Mapping. Bureau of Reclamation Tech. Memorandum 8260-0502. Denver, Colorado.

Schoenecker, K. A. 2012. Ecology of bison, elk and vegetation in an arid ecosystem. Dissertation, Colorado State University, Fort Collins, USA.

Schoener, T. W. 1983. Field experiments on interspecific competition. American Naturalist 122:240-285.

Schweiger, E. W., J. B. Grace, D. Cooper, B. Bobowski, and M. Britten. 2016. Using structural equation modeling to link human activities to wetland ecological integrity. Ecosphere 7(11):e01548. doi:10.1002/ecs2.1548.

Schweiger, E. W., E. Gage, K. Driver, D. Cooper, L. O'Gan, and M. Britten. 2015. Rocky Mountain Network wetland ecological integrity monitoring protocol: Narrative, version 1.0. Natural Resource Report NPS/ROMN/NRR—2015/991. National Park Service, Fort Collins, Colorado.

Shedlock, R. J., D. A. Wilcox, T. A. Thompson, and D. A. Cohen. 1993. Interactions between groundwater and wetlands, southern shore of Lake Michigan. Journal of Hydrology 141:127-155.

Singer, F. J., and L. C. Zeingenfuss. 2002. Ecological evaluation of the abundance and effects of elk herbivory in Rocky Mountain National Park, Colorado, 1994-1999. Final report to the National Park Service, Rocky Mountain National Park, on Cooperative Agreement No. I445-0009-94-1074.

Singer, F. J., L. C. Zeigenfuss, R. G. Cates, and D. T. Barnett. 1998. Elk, multiple factors, and persistence of willows in national parks. Wildlife Society Bulletin 1998:419-428.

Singer, F. J., L. C. Zeigenfuss, B. Lubow, and M. J. Rock. 2002. Ecological evaluation of potential overabundance of ungulates in U.S. National Parks: A case study in F. J. Singer, editor, Ecological evaluation of the abundance and effects of elk in Rocky Mountain National Park, Colorado, 1994-1999. USGS Open File Report 02-208. US Geological Survey, Fort Collins, Colorado.

Sollins, P., C. Glassman, E. A. Paul, C. Swanston, K. Lajtha, J. W. Heil, and E. T. Elliott. 1999. Soil carbon and nitrogen: Pools and fractions. Pages 89-105 in G. P. Robertson, editor, Standard soil methods for long-term ecological research. Oxford University Press, Cary, North Carolina.

Stevens Jr., D. L. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:167-195.

Stevens, D. R., and S. Christianson. 1980. Beaver populations on east slope of Rocky Mountain National Park. Park Report. Rocky Mountain National Park, National Park Service, US Department of the Interior, Estes Park, Colorado.

Stoddard, J. L., Alan T. Herlihy, David V. Peck, Robert M. Hughes, Thomas R. Whittier, Ellen Tarquinio. 2008. A process for creating multimetric indices for large-scale aquatic surveys. Journal of the North American Benthological Society 27:878-891.

Stohlgren, T., M. B. Coughenour, G. W. Chong, D. Binkley, M. A. Kalkhan, L. D. Schell, D. J. Buckley, and J. K. Berry. 1997. Landscape analysis of plant diversity. Landscape Ecology 12:155-170.

Sutula, M. A., E. D. Stein, J. N. Collins, A. E. Fetscher, and R. Clark. 2006. A practical guide for the development of a wetland assessment method: The California experience. Journal of the American Water Resources Association 42:157-175.

Swink, F., and G. Wilhelm. 1994. Plants of the Chicago region. The Morton Arboretum, Lisle, Illinois.

Takhtajan, A. 1969. Flowering plants: origin and dispersal. Oliver and Boyd, Edinburgh, Scotland.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: A search for general principles 101. Ecology 80:1455-1474.

Tiner, R. W. 2012. Defining hydrophytes for wetland identification and delineation. ERCD/CRREL CR-12-1. US Army Corps of Engineers, Engineer Research and Development Center, Washington, DC.

Turetsky, M. R. 2003. The role of bryophytes in carbon and nitrogen cycling. The bryologist, 106(3):395-409.

US Army Corps of Engineers (USACE). 2008. Interim regional supplement to the Corps of Engineers wetland delineation manual: Western mountains, valleys and coastal regions. US Army Engineer Research and Development Center, Washington DC.

US Environmental Protection Agency (USEPA). 2015. National wetland condition assessment: technical report. EPA 843-R-15-006. United States Environmental Protection Agency, Washington, DC.

US Fish and Wildlife Service (USFWS). 1991. National wetlands inventory map report of San Luis Valley for the 1:100,000 map units of: Pueblo SW, Montrose SE, Durango NE, Durango SE, Trinidad NW and Trinidad SW Denver, Colorado, USA. US Fish and Wildlife Service, Denver, Colorado.

US Geological Survey (USGS). 2017. National Elevation Dataset (NED). Online. https://pubs.er.usgs.gov/publication/70201572 (accessed March, 2019).

USDA, Natural Resources Conservation Service (USDA). 2019. The PLANTS Database (http://plants.usda.gov, 6 February 2019). National Plant Data Team, Greensboro, North Carolina.

van der Valk, A. G. 1994. Effects of prolonged flooding on the distribution and biomass of emergent species along a fresh water wetland coenocline. Vegetation 110:185-196.

Voldseth, R. A., W. C. Johnson, G. R. Guntenspergen, T. Gilmanov, and B. V. Millett. 2009. Adaptation of farming practices could buffer effects of climate change on Northern Prairie Wetlands. Wetlands 29:635-647.

Wang, G. M., N. T. Hobbs, F. J. Singer, D. S. Ojima, and B. C. Lubow. 2002. Impacts of climate changes on elk population dynamics in Rocky Mountain National Park, Colorado, USA. Climatic Change 54:205-223.

Weber, W. A., and R. C. Wittmann. 2001. Colorado flora: Eastern slope. 3rd edition. University Press of Colorado, Boulder.

Westbrook, C. J., D. J. Cooper, and B. W. Baker. 2011. Beaver assisted river valley formation. River Research and Applications 27:247-256.

Westbrook, C. J., D. J. Cooper, and B. W. Baker. 2006. Beaver dams and overbank floods influence groundwater-surface water interactions of a Rocky Mountain riparian area. Water Resources Research 42(6).

Wilbert, M., J. Thomson, and N. W. Culver. 2008. Analysis of habitat fragmentation from oil and gas development and its impact on wildlife: a framework for public land management planning. The Wilderness Society, Washington, DC.

Wilhelm, G., and D. Ladd. 1988. Natural area assessment in the Chicago region. Transactions of the North American Wildlife and Natural Resources Conference 53:361-375.

Willard, B., and J. W. Marr. 1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. Biological Conservation 2.

Willard, B., and J. W. Marr. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biological Conservation 3:181-190.

Winter, T. C. 1988. A conceptual framework for assessing cumulative impacts on the hydrology of non-tidal wetlands. Environmental Management 12:605-620.

Winter, T. C., and D. O. Rosenberry. 1995. The interaction of ground-water with prairie pothole wetlands in the Cottonwood Lake area, east-central North Dakota, 1979-1990. Wetlands 15:193-211.

Wolf, E. C., D. J. Cooper, and N. T. Hobbs. 2007. Hydrologic regime and herbivory stabilize an alternative state in Yellowstone National Park. Ecological Applications 17:1572-1587.

Wong, V. N., R. S. B. Greene, R. C. Dalal, and B. W. Murphy. 2010. Soil carbon dynamics in saline and sodic soils: a review. Soil Use and Management 26(1):2-11.

Woods, S. W., and D. J. Cooper. 2005. Hydrologic factors affecting initial willow seedling establishment along a subalpine stream, Colorado, USA. Arctic Antarctic and Alpine Research 37:636-643.

Woods, S. W., L. H. MacDonald, and C. J. Westbrook. 2006. Hydrologic interactions between an alluvial fan and a slope wetland in the central Rocky Mountains, USA. Wetlands 26:230-243.

Xiong, S., M. E. Johansson, F. M. Hughes, A. Hayes, K. S. Richards, and C. Nilsson. 2003. Interactive effects of soil moisture, vegetation canopy, plant litter and seed addition on plant diversity in a wetland community. Journal of Ecology 91:976-986.

Zedler, J. B., and S. Kercher. 2005. Wetland resources: Status, ecosystem services, degradation, and restorability. Annual Review of Environment and Resources 30:39-74.

Zeigenfuss, L. C., F. J. Singer, and D. Bowden. 1999. Vegetation responses to natural regulation of elk in Rocky Mountain National Park. Biological Science Report USGS/BRD/BSR—1999-0003. U.S. Government Printing Office, Denver, Colorado. Also in F. J. Singer, ed. Ecological evaluation of the abundance and effects of elk in Rocky Mountain National Park, Colorado, 1994-1999. USGS Open File Report 02-208.

Zeigenfuss, L. C., F. J. Singer., S. A. Williams, and T. L. Johnson. 2002. Influences of herbivory and water on willow in elk winter range. Journal of Wildlife Management 66:788-795.

Zwinger, A., and B. Willard. 1972. Above treeline. Natural History 81:60.

Appendix A: Sample Sites

This appendix presents all Rocky Mountain Network wetland ecological integrity (WEI) sample sites in Rocky Mountain National Park (Table A1). The depth to water logger (DTW) column indicates if a logger has ever been in a site and if one was operational in 2017.

Table A1. Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_008	Moraine Park Upper Rip	Riparian	Gradient	–	–	2459	40.350	-105.607	95451305.0
ROMO_154	Lulu City Slope Fen	Fen	Gradient	–	–	2848	40.440	-105.848	458265.1
ROMO_199	Hell's Fen	Fen	Gradient	–	–	2733	40.390	-105.853	88168.8
ROMO_205	Moose Fen	Fen	Gradient	–	–	2683	40.328	-105.852	111532744.7
ROMO_223	Lost Creek Fen	Fen	Gradient	–	–	2772	40.417	-105.851	377424.2
ROMO_275	Kawuneeche Satellite 1 Mdw	Wet meadow	Gradient	–	–	2725	40.383	-105.854	254618.2
ROMO_277	Circle Fen	Fen	Gradient	–	–	2728	40.383	-105.855	249065.6
ROMO_278	Kawuneeche Satellite 2 Mdw	Wet meadow	Gradient	–	–	2728	40.384	-105.854	254348.3
ROMO_294	Kawuneeche Sentinel 1 Rip	Riparian	Gradient	Kawuneeche	–	2722	40.383	-105.852	82316238.3
ROMO_301	Green Mountain Pond Fen	Fen	Sentinel	–	Yes (2017)	2876	40.308	-105.814	50403.4
ROMO_303	Big Meadows Sentinel 1 Fen	Fen	Sentinel	Big Meadows	–	2865	40.313	-105.811	29391008.6
ROMO_308	Big Meadows Sentinel 2 Rip	Riparian	Sentinel	Big Meadows	–	2866	40.313	-105.808	29358225.7
ROMO_373	Spring Fen	Fen	Gradient	–	–	2924	40.325	-105.797	340425.3
ROMO_377	Colorado River Ditch Breach Rip	Riparian	Gradient	–	–	2850	40.448	-105.849	25292502.0
ROMO_501	Fall River Endo Valley Fen	Fen	Gradient	–	Yes (2017)	2618	40.412	-105.649	32651421.2

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_502	Kawuneeche Old 1 Rip	Riparian	Sentinel	–	–	2712	40.373	-105.859	97378995.4
ROMO_503	Poor Revisit Fen	Fen	Survey	–	Yes (removed)	2776	40.341	-105.848	571808.2
ROMO_504	Service Road 2 Fen	Fen	Survey	–	–	2708	40.337	-105.853	1210207.2
ROMO_505	Moraine Park Sentinel 1 Mdw	Wet meadow	Sentinel	Moraine Park	Yes (removed)	2448	40.355	-105.594	1730329.6
ROMO_506	Moraine Park Sentinel 2 Mdw	Wet meadow	Sentinel	Moraine Park	Yes (2017)	2449	40.356	-105.594	1705891.4
ROMO_507	Big Meadows Sentinel 3 Fen	Fen	Sentinel	Big Meadows	Yes (removed)	2868	40.314	-105.812	29358225.7
ROMO_508	Coyote Creek 1 Rip	Riparian	Survey	–	–	2690	40.344	-105.859	107636673.7
ROMO_509	Kawuneeche Old 2 Rip	Riparian	Sentinel	–	–	2711	40.373	-105.859	97454732.2
ROMO_510	Sheep Lake Mdw	Wet meadow	Survey	–	–	2605	40.403	-105.628	462342.3
ROMO_511	Big Meadows Sentinel 4 Fen	Fen	Sentinel	Big Meadows	Yes (2017)	2872	40.314	-105.812	29358225.7
ROMO_512	Lawn Lake Ridge 2 Fen	Fen	Survey	–	–	3394	40.459	-105.637	718914.0
ROMO_513	Baker Lower Rip	Riparian	Survey	–	–	2687	40.350	-105.860	106817063.8
ROMO_514	North Inlet Rip	Riparian	Survey	–	Yes (2017)	2590	40.258	-105.796	72840262.9
ROMO_515	Red Mountain Fen	Fen	Survey	–	Yes (2017)	2958	40.396	-105.861	462358.2
ROMO_516	Lawn Lake Ridge 1 Fen	Fen	Survey	–	–	3294	40.460	-105.631	996492.7
ROMO_517	Lawn Lake Ridge 3 Mdw	Wet meadow	Survey	–	–	3292	40.459	-105.632	1015770.4
ROMO_520	Lawn Lake Head Fen	Fen	Survey	–	–	3356	40.469	-105.633	5255530.7

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_521	Poudre Pass Ranger Station Mdw	Wet meadow	Survey	–	–	3110	40.474	-105.828	2580674.3
ROMO_522	Rainy Riparian Rip	Riparian	Survey	–	Yes (2017)	2683	40.343	-105.859	107709138.9
ROMO_523	Poudre Pass Gauge Mdw	Wet meadow	Survey	–	–	3104	40.476	-105.824	2698998.8
ROMO_524	Rock Hike Mdw	Wet meadow	Survey	–	–	3068	40.295	-105.765	2502423.3
ROMO_525	Skeleton Gulch 2 Mdw	Wet meadow	Survey	–	–	3234	40.459	-105.882	2946048.1
ROMO_526	Skeleton Gulch 1 Fen	Fen	Survey	–	–	3243	40.460	-105.881	2958561.9
ROMO_527	Poudre Pass Lake Fen	Fen	Survey	–	–	3171	40.470	-105.823	1173290.8
ROMO_528	Bennett Creek Mdw	Wet meadow	Survey	–	–	3287	40.476	-105.843	1519971.1
ROMO_529	Summerland Park Ridge Mdw	Wet meadow	Survey	–	–	2666	40.269	-105.778	1405711.5
ROMO_530	Beaver Meadows Creek Rip	Riparian	Survey	–	Yes (2017)	2454	40.363	-105.576	15182289.7
ROMO_531	Lulu Creek Grand Ditch Mdw	Wet meadow	Survey	–	–	3094	40.458	-105.862	5067016.9
ROMO_532	Summerland Park Mid Mdw	Wet meadow	Survey	–	–	2591	40.260	-105.796	146085.1
ROMO_533	Grand Ditch Fen	Fen	Survey	–	Yes (2017)	3091	40.455	-105.860	5274996.5
ROMO_534	Bench Lake Rip	Riparian	Survey	–	–	2826	40.286	-105.736	42900987.5
ROMO_535	Hazeline Lake 1 Fen	Fen	Survey	–	–	3250	40.502	-105.705	80722.0
ROMO_536	Willow Creek Saddle 1 Mdw	Wet meadow	Survey	–	–	3179	40.483	-105.758	150087.5
ROMO_537	Cache La Poudre Boundary Mdw	Wet meadow	Survey	–	–	2977	40.514	-105.741	50944917.5
ROMO_538	Park Cabin Mdw	Wet meadow	Survey	–	–	3123	40.474	-105.831	260253.3
ROMO_539	Willow Creek Saddle 2 Mdw	Wet meadow	Survey	–	–	3187	40.487	-105.755	56543.8

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_540	Cloudy Day Rip	Riparian	Survey	–	–	2680	40.339	-105.859	109319405.4
ROMO_541	Murphy Lake Fen	Fen	Survey	–	–	3255	40.323	-105.746	2075892.5
ROMO_542	Service Road Fen	Fen	Survey	–	–	2694	40.339	-105.856	614809.7
ROMO_543	Cache La Poudre Edge Mdw	Wet meadow	Survey	–	–	3053	40.503	-105.740	446294.3
ROMO_544	Hazeline Lake 2 Mdw	Wet meadow	Survey	–	–	3267	40.502	-105.707	64374.7
ROMO_545	Tonahutu Ridge Fen	Fen	Survey	–	–	3329	40.309	-105.764	137179.4
ROMO_546	Willow Creek Fen	Fen	Survey	–	–	3180	40.486	-105.760	108692.6
ROMO_547	Tonahutu Creek 1 Fen	Fen	Survey	–	–	3025	40.321	-105.768	210833.4
ROMO_548	Alpine Headwaters Revisit Mdw	Wet meadow	Survey	–	Yes (2017)	3665	40.409	-105.719	170818.8
ROMO_549	Bower Baker Mdw	Wet meadow	Survey	–	–	2709	40.356	-105.867	18648353.8
ROMO_550	Grassy Kook Fen	Fen	Survey	–	–	2741	40.341	-105.853	61846.6
ROMO_551	Alpine Sentinel 1 Mdw	Wet meadow	Survey	Alpine	Yes (2017)	3626	40.403	-105.708	310945.2
ROMO_552	Coyote Creek 2 Rip	Riparian	Survey	–	–	2684	40.345	-105.860	107532147.1
ROMO_553	Wild Basin Rip	Riparian	Survey	–	–	2549	40.212	-105.550	82455241.4
ROMO_554	Onahu Creek Fen	Fen	Survey	–	–	3021	40.331	-105.809	197343.3
ROMO_555	Tonahutu Creek 2 Mdw	Wet meadow	Survey	–	–	3022	40.321	-105.770	202814.4
ROMO_556	Hidden Valley Fen	Fen	Gradient	–	Yes (2017)	2801	40.400	-105.646	7486250.2
ROMO_557	Specimen Mtn Fen	Fen	Gradient	–	Yes (2017)	3377	40.423	-105.814	76282.3
ROMO_558	Corral Creek River Rip	Riparian	Survey	–	–	3226	40.503	-105.704	4599540.1

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_559	Corral Creek Fen	Fen	Survey	–	–	3257	40.502	-105.703	4448843.5
ROMO_560	Slope Fen	Fen	Survey	–	–	3273	40.476	-105.840	1617199.6
ROMO_561	Hell's Upper Fen	Fen	Survey	–	–	2736	40.392	-105.852	221403.3
ROMO_562	Forest Meadow Fen	Fen	Survey	–	–	3088	40.458	-105.861	5091297.9
ROMO_563	Hazeline Lake 5 Mdw	Wet meadow	Survey	–	–	3269	40.501	-105.704	4353313.6
ROMO_564	Hazeline Lake 3 Fen	Fen	Survey	–	–	3269	40.501	-105.707	75096.5
ROMO_565	Bear Lake Parking Lot Fen	Fen	Survey	–	–	2909	40.314	-105.645	725961.2
ROMO_566	Beaver Creek Fen	Fen	Survey	–	–	2999	40.397	-105.863	344058.7
ROMO_567	Hazeline Lake 4 Mdw	Wet meadow	Survey	–	–	3248	40.502	-105.705	80722.0
ROMO_568	Little Dutch Creek Upper Mdw	Wet meadow	Survey	–	–	3173	40.451	-105.868	22619.7
ROMO_569	Ditch Road Monday Mdw	Wet meadow	Survey	–	–	3114	40.472	-105.830	2937460.3
ROMO_570	Dream Lake Fen	Fen	Survey	–	–	3026	40.310	-105.659	2154328.3
ROMO_571	Avalanche Mdw	Wet meadow	Survey	–	–	2603	40.263	-105.779	68394936.4
ROMO_572	Lower Pole Creek Rip	Riparian	Survey	–	–	2657	40.202	-105.815	3178758.3
ROMO_573	Alpine Elk Mdw	Wet meadow	Survey	–	–	3642	40.408	-105.718	208807.9
ROMO_574	Endless Drain Rip	Riparian	Survey	–	–	2742	40.173	-105.798	142094.1
ROMO_575	Beaver Mdws Utility Area Rip	Riparian	Survey	–	–	2797	40.273	-105.808	16117631.4
ROMO_576	Tonahutu Creek Lower Mdw	Wet meadow	Survey	–	–	2750	40.277	-105.815	37659933.5
ROMO_577	Tanahutu Little Creek Rip	Riparian	Survey	–	–	2867	40.274	-105.799	1002169.1

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_578	Alberta Falls Mdw	Wet meadow	Survey	–	–	2991	40.302	-105.651	545534.2
ROMO_579	Alpine Pool Mdw	Wet meadow	Survey	–	–	3647	40.408	-105.719	45965.5
ROMO_580	Shadow Mountain Dam Mdw	Wet meadow	Survey	–	–	2564	40.205	-105.830	318541.4
ROMO_581	Finch Lake Fen	Fen	Survey	–	–	3081	40.184	-105.585	3865686.3
ROMO_582	Pole Creek Upper Rip	Riparian	Survey	–	–	2783	40.208	-105.805	626487.6
ROMO_583	Poudre River Fen	Fen	Survey	–	–	3254	40.472	-105.755	2825.3
ROMO_584	Poudre River Mdw	Wet meadow	Survey	–	–	3253	40.473	-105.755	7074.8
ROMO_585	Alpine T-storm Rip	Riparian	Survey	–	–	3367	40.169	-105.637	3571082.2
ROMO_586	Alpine Mdw	Wet meadow	Survey	–	–	3668	40.409	-105.719	170818.8
ROMO_587	Lake Hutch Mdw	Wet meadow	Survey	–	–	3324	40.171	-105.633	3706442.6
ROMO_588	Mills Pass Mdw	Wet meadow	Gradient	–	Yes (2017)	3279	40.424	-105.808	899378.1
ROMO_589	Moraine Park Sentinel 3 Mdw	Wet meadow	Sentinel	Moraine Park	Yes (removed)	2448	40.356	-105.594	1705891.4
ROMO_590	Moraine Park Sentinel 4 Mdw	Wet meadow	Sentinel	Moraine Park	Yes (2017)	2450	40.357	-105.594	1583664.8
ROMO_591	Sphagnum Fen	Fen	Gradient	–	Yes (2017)	2742	40.392	-105.847	75914229.4
ROMO_592	Harbison Mdw	Wet meadow	Gradient	–	Yes (2017)	2651	40.281	-105.837	2876527.3
ROMO_593	Kawuneeche Satellite 3 Fen	Fen	Gradient	–	–	2741	40.391	-105.847	75914229.4
ROMO_598	Haynach Fen	Fen	Gradient	–	–	3364	40.343	-105.761	1613619.8
ROMO_599	Beaver Meadows Heliport Mdw	Wet meadow	Gradient	–	Yes (2017)	2541	40.372	-105.602	3236072.8
ROMO_601	Shy Moose Rip	Riparian	Gradient	–	–	2787	40.425	-105.852	43965637.9

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_602	Nakai Peak Fen	Fen	Survey	–	–	3415	40.337	-105.778	430538.5
ROMO_603	Nakai Peak Mdw	Wet meadow	Survey	–	–	3427	40.338	-105.778	430538.5
ROMO_604	Big Meadows Sentinel 5 Mdw	Wet meadow	Sentinel	Big Meadows	Yes (removed)	2867	40.314	-105.810	29358225.7
ROMO_605	Alpine Sentinel 2 Mdw	Wet meadow	Sentinel	Alpine	Yes (removed)	3635	40.403	-105.708	310945.2
ROMO_606	Forest Canyon Big Thompson Rip	Riparian	Survey	–	–	2859	40.383	-105.712	42919821.1
ROMO_607	Hayden Tarn Mdw	Wet meadow	Survey	–	–	3357	40.358	-105.751	264352.3
ROMO_608	Terra Tomah Chute Mdw	Wet meadow	Survey	–	–	3819	40.375	-105.749	30970.0
ROMO_609	Hayden Spice Rip	Riparian	Survey	–	–	3154	40.363	-105.736	6825940.2
ROMO_610	Hayden Tarn Fen	Fen	Survey	–	–	3351	40.358	-105.751	201455.6
ROMO_611	Alpine Sentinel 3 Mdw	Wet meadow	Sentinel	Alpine	Yes (removed)	3635	40.403	-105.708	310945.2
ROMO_612	Alpine Sentinel 4 Mdw	Wet meadow	Sentinel	Alpine	Yes (2017)	3629	40.403	-105.708	310945.2
ROMO_613	Labor Day Mdw	Wet meadow	Survey	–	–	2950	40.305	-105.649	658485.1
ROMO_614	Big Meadows Sentinel 6 Mdw	Wet meadow	Sentinel	Big Meadows	Yes (2017)	2867	40.313	-105.809	29358225.7
ROMO_615	Kawuneeche Sentinel 2 Rip	Riparian	Sentinel	Kawuneeche	Yes (2017)	2725	40.384	-105.853	82316238.3
ROMO_616	Kawuneeche Sentinel 3 Rip	Riparian	Sentinel	Kawuneeche	Yes (removed)	2722	40.383	-105.852	82316238.3
ROMO_617	Kawuneeche Sentinel 4 Rip	Riparian	Sentinel	Kawuneeche	Yes (2017)	2722	40.383	-105.852	82316238.3

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_618	Kawuneeche Sentinel 5 Rip	Riparian	Sentinel	Kawuneeche	Yes (removed)	2720	40.382	-105.851	82316238.3
ROMO_619	Ditch Meadow Mdw	Wet meadow	Survey	–	–	3097	40.471	-105.835	2847573.9
ROMO_620	Ditch Fen	Fen	Survey	–	–	3070	40.469	-105.834	2847573.9
ROMO_692	Hump Day Drain Rip	Riparian	Survey	–	–	2621	40.203	-105.821	3541487.0
ROMO_693	Longs Riparian Rip	Riparian	Survey	–	–	2883	40.282	-105.562	3027656.6
ROMO_694	Beaver Marsh Rip	Riparian	Survey	–	–	2814	40.307	-105.641	1379948.7
ROMO_695	Kettle Fen	Fen	Survey	–	–	3192	40.302	-105.776	107471.1
ROMO_696	Haynach Lake Fen	Fen	Survey	–	–	3362	40.343	-105.760	1613946.9
ROMO_697	Haynach Mdw	Wet meadow	Survey	–	–	3362	40.342	-105.760	1629977.6
ROMO_698	Rock Hike Fen	Fen	Survey	–	–	3086	40.296	-105.768	2144759.0
ROMO_699	Green Ridge 1 Mdw	Wet meadow	Survey	–	–	2575	40.209	-105.830	32392.2
ROMO_700	Alpine Meadow Big Pool Mdw	Wet meadow	Survey	–	–	3421	40.308	-105.754	210689.1
ROMO_701	Moraine Park Sentinel 5 Mdw	Wet meadow	Sentinel	Moraine Park	Yes (2017)	2450	40.358	-105.595	1583664.8
ROMO_714	Rockwood Rip	Riparian	Survey			2703	40.252	-105.545	3399978.4
ROMO_724	Moraine Park Sentinel 1 Rip	Riparian	Sentinel	Moraine Park	Yes (2017)	2447	40.355	-105.596	97209465.0
ROMO_725	Moraine Park Sentinel 2 Rip	Riparian	Sentinel	Moraine Park	–	2448	40.356	-105.596	97209465.0
ROMO_726	Moraine Park Sentinel 3 Rip	Riparian	Sentinel	Moraine Park	–	2447	40.355	-105.594	97209465.0
ROMO_727	Moraine Park Sentinel 6 Mdw	Wet meadow	Sentinel	Moraine Park	–	2449	40.356	-105.595	1588339.9
ROMO_801	Kawuneeche Sentinel 6 Rip	Riparian	Sentinel	Kawuneeche	–	2719	40.382	-105.850	82316238.3

Table A1 (continued). Rocky Mountain Network wetland ecological integrity sample sites at Rocky Mountain National Park.

Site ID	Site name	Wetland type	Design type	Sentinel complex	DTW logger present	Elevation (m)	Latitude	Longitude	Watershed area (m^2)
ROMO_802	Big Meadows Sentinel 7 Fen	Fen	Sentinel	Big Meadows	–	2867	40.313	-105.808	29358225.7
ROMO_803	Alpine Sentinel 5 Mdw	Wet meadow	Sentinel	Alpine	–	3629	40.403	-105.708	310945.2
ROMO_804	Alpine Sentinel 6 Mdw	Wet meadow	Sentinel	Alpine	–	3626	40.403	-105.708	310945.2
ROMO_N00	Alder Fen	Fen	Gradient	–	–	2744	40.384	-105.857	175274.3
ROMO_N01	Hallowell Park Butter and Eggs Rip	Riparian	Gradient	–	–	2551	40.340	-105.605	13460708.2
ROMO_N02	Endo Valley Alluvial Fan Rip	Riparian	Gradient	–	–	2608	40.406	-105.634	65987132.0
ROMO_N03	Horseshoe Park Rip	Riparian	Gradient	–	–	2598	40.403	-105.625	18600997.8
ROMO_N04	Hidden Valley Restoration Site Rip	Riparian	Gradient	–	–	2788	40.399	-105.640	8639080.6
ROMO_N05	Endo Valley Beaver Ponds Rip	Riparian	Gradient	–	–	2618	40.413	-105.651	1724035.2
ROMO_N06	Dr Coopers Walk Rip	Riparian	Gradient	–	–	3233	40.435	-105.796	4884861.9
ROMO_N07	East Inlet Riparian Rip	Riparian	Gradient	–	–	2589	40.237	-105.793	71135202.8
ROMO_N08	Alpine Visitor Center	N/A	Barologger	–	–	3591	40.442	-105.755	–
ROMO_N12	Beaver Meadows Visitor Center	N/A	Barologger	–	–	2392	40.366	-105.563	–
ROMO_N13	Kawuneeche Visitor Center	N/A	Barologger	–	–	2658	40.267	-105.833	–

Appendix B: Sentinel Site Descriptions

The following are general overviews of each sentinel complex monitored in Rocky Mountain National Park using the wetland ecological integrity (WEI) protocol. They include background relevant to their selection as long-term monitoring sites.

For references in this appendix please see the literature cited section that follows the main narrative.

Big Meadows

General Site Description

Big Meadows is a 63 ha subalpine wetland complex that sits at approximately 2866 m elevation on the west side of Rocky Mountain National Park. The site is part of the Tonahutu watershed and is located 1.5 miles up the Green Mountain trail in a wide, south sloping depression with a steep hillside and South Tonahutu Trail to the east and Tonahutu Creek to the west (Figure B1).

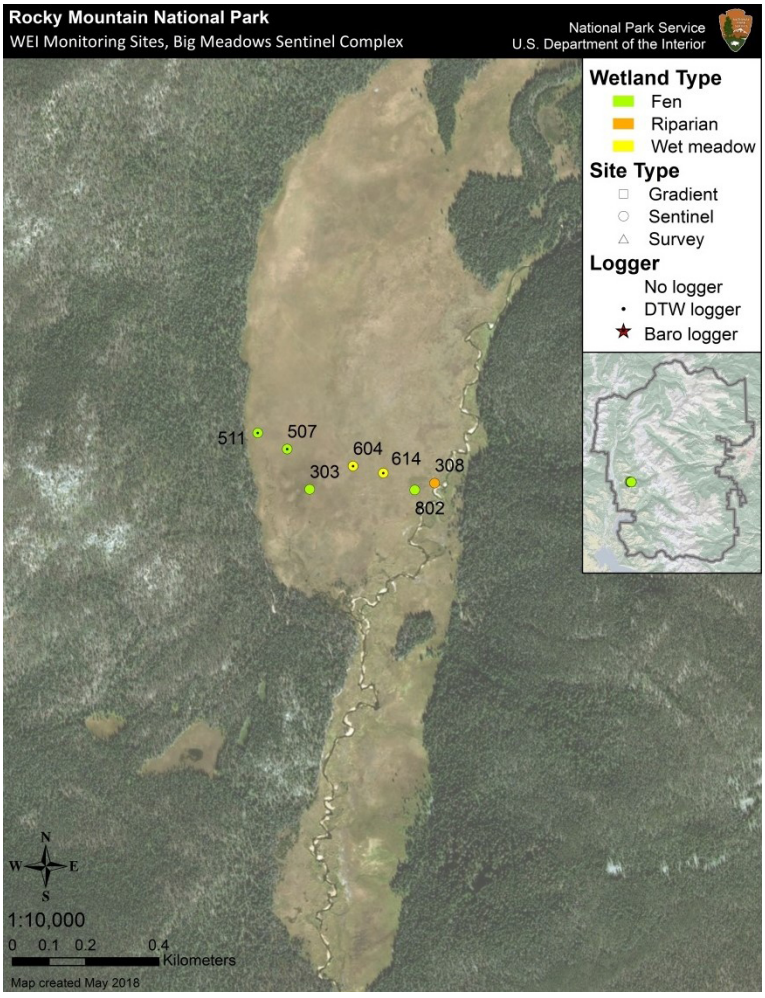


Figure B1. Aerial view of the Big Meadows sentinel site, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009.

The wetland is primarily composed of fen with small inclusions of other wetland types and is bounded on the east side by a narrow riparian wetland corridor. Big Meadows has a history of human use that negatively impacted the extent and quality of the wetland. It was the subject of a large research and restoration project in the early 1990s to correct these disturbances.

The complex was selected as a sentinel site in the park given its history of research and monitoring and because it is representative of sedge-dominated, nutrient-poor fens common in the park at subalpine elevations. It is large, easily accessed along the Green Mountain/South Tonahutu Trail, and has a network of ground monitoring wells already installed.

Site History

Carbon 14 dating of the peat body has revealed that the formation of Big Meadows began 12,000 BPE, soon after the retreat of the Pinedale glaciers (Cooper 1990). In the late 19th and early 20th century, Big Meadows was the site of homesteading and ranching activities. Several log buildings were constructed that still remain on site and the large central fen was longitudinally ditched and drained to dry the wetland and encourage the growth of nonnative grasses for hay production. The ditching resulted in lowered water tables, decomposition/loss of peat soils, and altered vegetation communities. The homestead and all agricultural activities were abandoned when the park was formed in 1915, but the ditch remained and continued to drain the wetland until restoration efforts in 1990 dammed the ditch and restored the hydrology of the fen (Figure B2). Post-restoration, the wetland began to return to a more intact state, and current vegetation, hydrology, and soils are believed to be returning to historical conditions (Cooper et al. 1998).



Figure B2. One of several dams installed along the main drainage ditch during the Big Meadows wetland restoration project, circa 1990. NPS/JEFF-swings-a-mean-hammer CONNOR

Previous Wetland Research/Monitoring

Starting in 1987 and continuing several years after the Big Meadows fen restoration in 1990, the hydrology, soils, and vegetation of the wetland were documented in detail (Cooper 1990). An extensive network of over 40 groundwater monitoring wells was installed, transecting the wetland from east to west. These were used to describe the hydrology, plant communities, and soils of the site by Cooper (1990). Later, Cooper et al. (1998) found that the restoration had raised water tables in the fen but the hydrologic regime was still strongly influenced by precipitation, and in low water years, the water table fell to pre-restoration levels.

Moraine Park

General Site Description

Moraine Park is a wide, gently sloping alluvial valley at approximately 2450 m elevation on the east side of the Continental Divide. The wetland complex is located 5.6 km from the Beaver Meadows entrance station on the Bear Lake Road near the Moraine Park Campground and Fern Lake spurs. Moraine Park is primarily composed of floodplain surrounding the headwaters of the Big Thompson River, with several groundwater seeps/springs along the northern and southern edges of the valley. These seeps/springs create fens and small fens sloping down to the riparian wetland area (Figure B3). Soils in the floodplain are largely alluvial sand, gravel, and cobble. The area receives an average of 35 cm of annual precipitation (Gage and Cooper 2005). The western end of Moraine Park is heavily vegetated, with tall shrub communities with small or relictual beaver ponds. The eastern and central portion of the valley area (where the WEI plots are) is markedly different and dominated with herbaceous vegetation, few tall shrubs, and no beaver activity. The Big Thompson River enters Moraine Park in the west, and, owing in part to extensive historical beaver activity, splits into a series of distributaries conveying water across the site, which converge again in the east end of the valley. Streamflow in both rivers is unregulated, and the annual, snowmelt-driven peak discharge typically occurs in late May or early June (Gage and Cooper 2005).

Moraine Park was an in-holding in the park until 1962. Some of the landscape-altering activities that occurred in Moraine Park and elsewhere in the park began in the 1870s. Logging and most mining operations ended by 1920, but ranching still continued until 1962. By the 1920s, Moraine Park had changed dramatically. Soon after the formation of Rocky Mountain National Park in 1915, the privately-owned Steads hotel and ranch was established overlooking Moraine Park and later a gas station was built convenient to the hotel. At one point in time Moraine Park included three hotels, a swimming pool, post office, numerous cabins, horse corrals, irrigation ditches, fences, and a nine-hole golf course (Figure B4). The golf course, hotel, and gas station were dismantled soon after in 1980. Moraine Park was grazed by cattle and horses, and hay was cut by ranchers. By 2008, all the previous disturbances were removed except for the remains of the golf course.

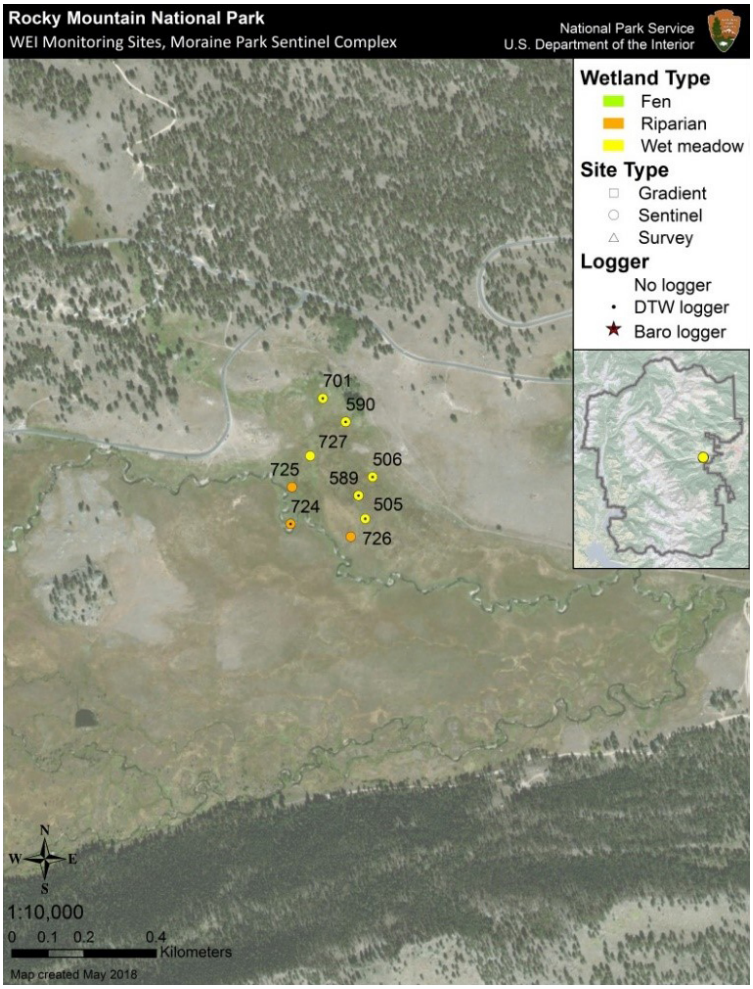


Figure B3. Aerial view of the Moraine Park wetland ecological integrity sentinel site in Rocky Mountain National Park.

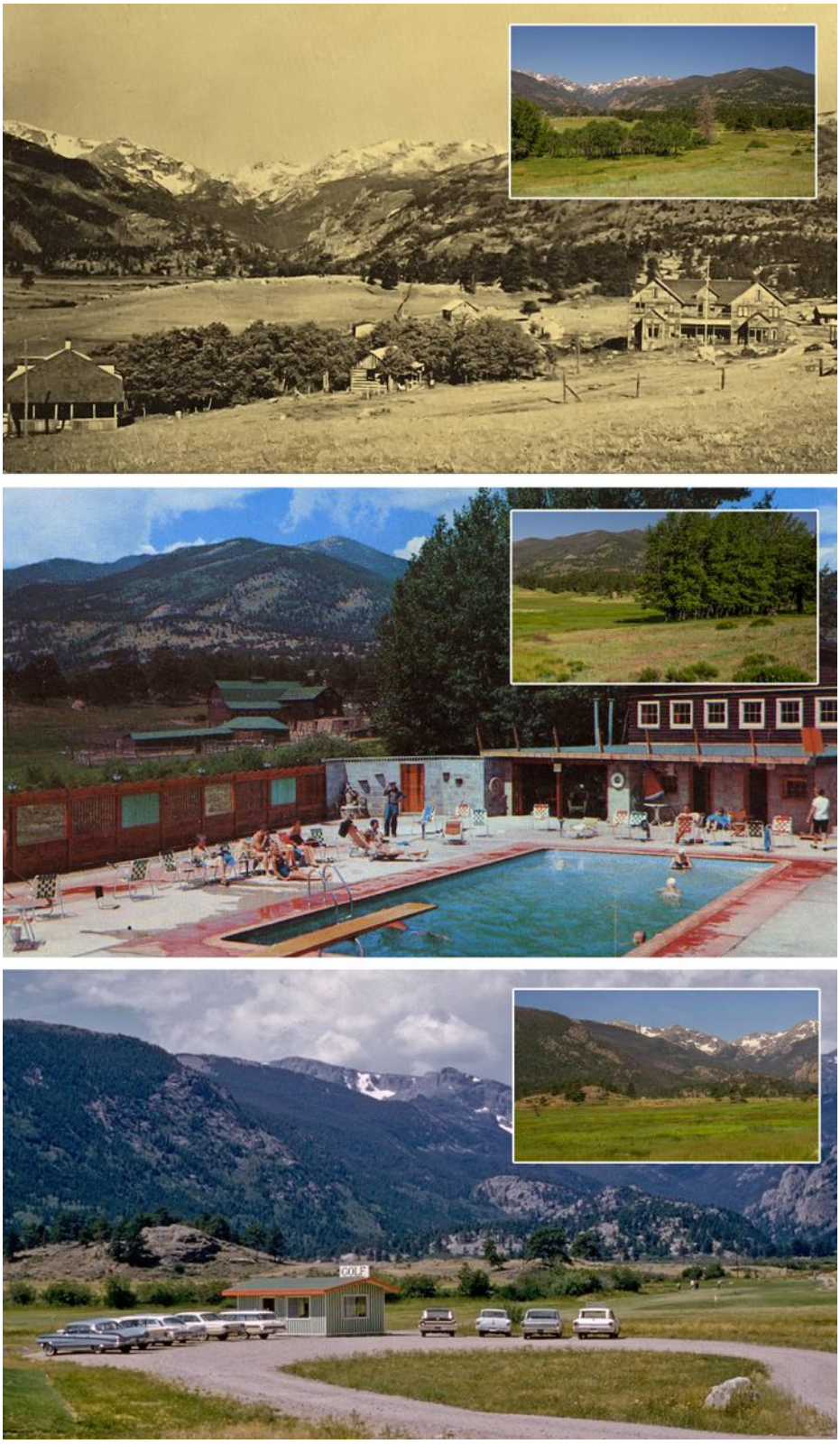


Figure B4. Stead Ranch, circa 1970s. Historical human use of Moraine Park. Inset photos show the same views circa 2010. NPS/ROCKY MOUNTAIN NATIONAL PARK.

Moraine Park is also currently a high use area popular with park visitors. It is heavily used as a fishing spot, has a network of trails on its borders, and is used by hikers, sightseers, and horseback riding concessions. It is also adjacent to a large front country campground.

High levels of current and historical land use, including a large elk population, have contributed to the degradation of the vegetation communities and hydrology of Moraine Park. Over-browsing has damaged tall shrubs and prevented normal rates of willow regeneration, lowering tall shrub cover in the valley. Willow degradation also has negatively impacted floodplain hydrology and beaver populations and likely contributed to the spread of invasive plant species. Historical conditions favored greater willow cover, higher levels of floodplain interaction, and larger, active beaver populations (Ziegenfuss et al. 2002, Gage and Cooper 2005).

Restoration

Wetland restoration of the old golf course area, including re-contouring of eight earthen mounds built for tees, reestablishing wetland hydrology, and planting native species was started in 2009 and completed in 2010. The park also filled in several drainage and irrigation ditches and removed roads and trails used by golf carts that were also constructed on top of fill. The drainage ditches dropped the level of the groundwater and the deepened water table has prevented native wetland plants from growing. Exotic species such as Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), and redtop (*Agrostis gigantea*) prevailed in areas that should have native species. Restoration activities included planting almost 20,000 plants (*Artemisia frigida*, *Carex aquatilis*, *Carex simulata*, *Eriogonum umbellatum*, *Hierochloe hirta*, *Juncus arcticus*, *Koeleria macrantha*, *Pentaphylloides floribunda*, *Rosa woodsii*, *Stipa comata*, *Thermopsis divaricarpa*). Several restoration areas are adjacent to WEI sites and changes in hydrology are likely to have a fairly dramatic effect on vegetation near our plots.

Previous Research

Moraine park was one of the areas examined in the USGS and CSU evaluation of the long-term effects of elk herbivory and abundance in Rocky Mountain National Park (Ziegenfuss et al. 1999, Ziegenfuss et al. 2002). Extremely high winter elk densities, >90 elk/km^2, occur because of habitat loss from development in the lower valleys (Estes Park and surrounding communities; Ziegenfuss et al. 2002). Intense browsing was found to be detrimental to the health of the wetland and its plant communities, suppressing willows and reducing or completely eliminating seed production (Peinetti et al. 2002. Several 100 m^2 chain link elk exclosures were placed along stream channels in Moraine Park to measure shrub recovery in the absence of herbivory. As of 2008, these exclosures had abundant tall willow growth, and one fenced area was home to several beaver and a newly established beaver pond, supporting theories that browsing levels and beaver success are strongly related. In 2000, a network of groundwater monitoring wells, similar to those installed in Big Meadows, was established in Moraine Park. Gage and Cooper (2005) used water table data from these wells to correlate willow cutting survival rate with water table depth. This same research also looked at the relationship between elk herbivory and willow seed dispersal, entrapment, and seedling establishment. This research found that willow cutting and seedling survival was positively correlated with elevated water tables and reduced levels of herbivory.

Alpine

General Site Description

The Alpine sentinel complex is a small, 1.6 ha snowmelt basin that sits at approximately 3600 m elevation (Figure B5) along the Trail Ridge Road corridor. The site is in the uppermost part of the Big Thompson watershed near Forest Canyon Overlook and is located 200 m upslope from Highway 34 and 8.2 km from the summit of Trail Ridge Road. It is just to the south of the summit of Sundance Mountain (3,800 m). The wetland is composed of fen with saturated gravel and areas of thin peat accumulation. Low rates of primary production and extremely short growing seasons at this elevation prevent the accumulation of enough organic material to form peat soil layers; despite constant soil saturation and cold temperatures that inhibit decomposition, there are no true fens found in Rocky Mountain National Park at this elevation. The Alpine sentinel complex is the only known location of *Koenigia islandica*, or Iceland purslane, in the park. *Koenigia islandica* is one of the smallest terrestrial flowering plants and one of the few annual species in arctic and alpine flora. It is typically found in wet gravels near perennial water sources and is thought to be uncommon or rare in Colorado, although it is locally abundant in this wetland (Figure B6).

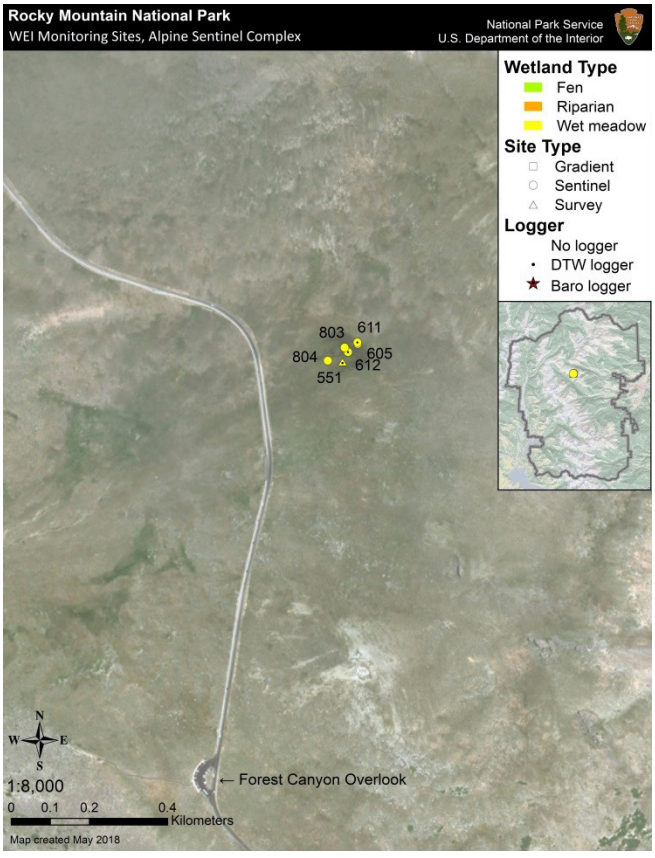


Figure B5. Aerial view of the Alpine sentinel complex, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009.



Figure B6. Alpine wetland ecological integrity sentinel site in Rocky Mountain National Park, 2017. NPS/B. SCHWEIGER

The complex was selected as a network sentinel site for monitoring because it represents a distinctive and characteristic wetland type in the park with diverse and unique plant communities. Given the presence of Trail Ridge Road, it is one of the few alpine wetlands in the park that can be readily accessed.

Site History

Trail Ridge Road was constructed soon after the formation of Rocky Mountain National Park, during the years 1929–1932, to accommodate the increased park visitation and higher motor vehicle traffic that was overwhelming the capacity of Fall River Road. Steps were taken during road construction to preserve the integrity of the Trail Ridge tundra and bedrock (for more information see https://www.nps.gov/romo/learn/historyculture/trail_ridge_road_history.htm), but the new road provided access to greater areas of alpine habitat and the increased visitation caused ecosystem degradation along the road corridor. Damage to the alpine tundra was primarily caused by repeat foot trampling, off-road driving, rock collecting, littering, and flower-picking and was concentrated near parking areas where most visitors congregated (Willard and Marr 1970).

Previous Wetland Research/Monitoring

In 1963, Beatrice Willard published her dissertation describing alpine vegetation on Trail Ridge. It was one of the first studies to describe alpine vegetation communities in stand level detail and served as a reference in the Southern Rocky Mountains for many years (Zwinger and Willard 1972). Her study was focused on a 25.7 km^2 area along Trail Ridge Road centered at Forest Canyon Overlook, and included the Alpine sentinel complex (Figure B7). Using 181 sample locations, she described 14 vegetation community types (Willard and Marr 1970, 1971). During the course of this research, Willard observed the tundra damage from visitors described above and established several research exclosures in areas showing high human impact. Her later research focused more heavily on tundra recovery after human disturbance and demonstrated that areas with higher soil moisture, such as the Alpine sentinel complex, are more susceptible to direct visitor impacts such as trampling (Figure B7; Willard and Marr 1970).

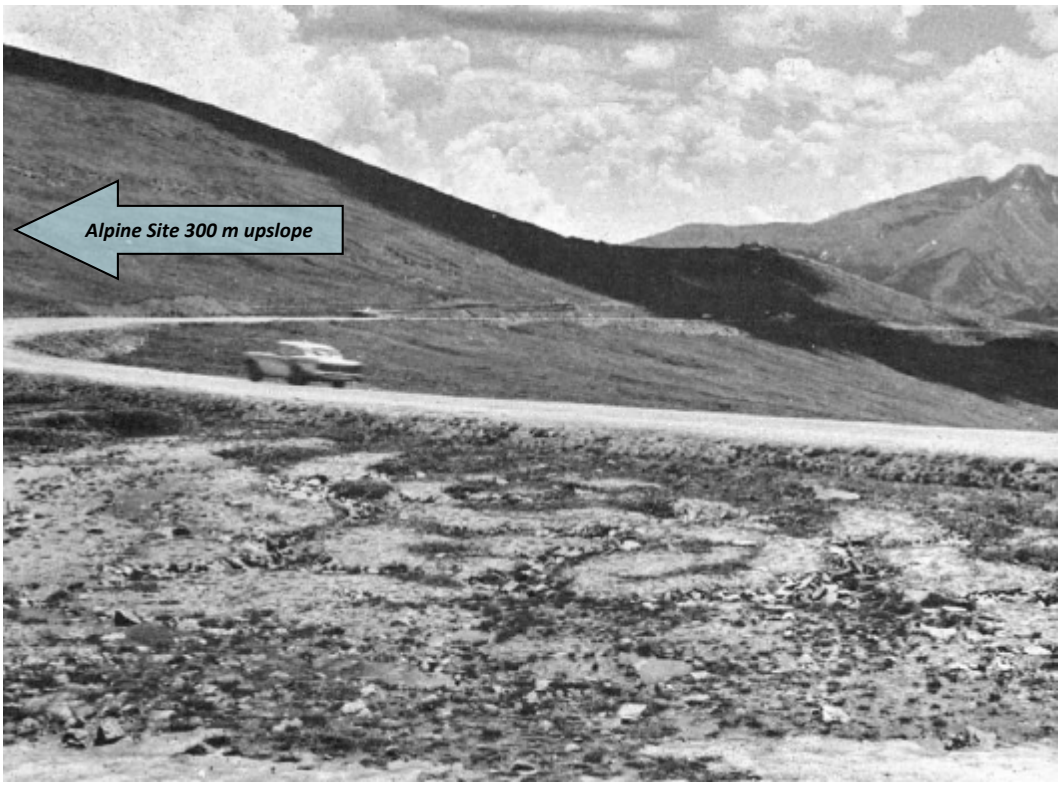


Figure B7. Photo of section of Trail Ridge road traversing tundra—part of B. Willard's study area (Willard and Marr 1970). The Alpine sentinel complex is approximately 300 m to the left of the road at the photo edge. NPS photo

Kawuneeche Valley

General Site Description

Kawuneeche Valley is a large willow dominated riparian wetland surrounding the headwaters of the Colorado River. Kawuneeche Valley stretches approximately 24 km from south of the Western Entrance Portal to north of the Colorado River trailhead. The Never Summer mountains rise over the

valley to the west and it is bounded to the east by the lower slopes of peaks along the Continental Divide. This area has a long history of human use, including ranching, homesteading, mining, and water diversion, most notably the Grand Ditch trans-basin canal, still in use, traversing the Never Summer Mountains 300 m above the valley floor. Kawuneeche Valley is large, with multiple water sources, and cannot be adequately monitored in entirety using our methods. Therefore, a smaller, representative section of the valley was selected as the Kawuneeche Valley sentinel site. The sentinel site transects the valley from east to west between Beaver Ponds picnic area and Timber Creek Campground, near the convergence of Timber Creek and the Colorado River (Figure B8). It is an approximately 1 km by 1 km area located around several groundwater monitoring well transects installed by previous researchers. This section of Kawuneeche Valley sits at approximately 2700 m in elevation and is dominated by common willow species and sedges. Willows in this area are currently in decline and current research suggests that a number of factors, such as disease epidemics and altered hydrologic regimes, may be negatively affecting willow health.

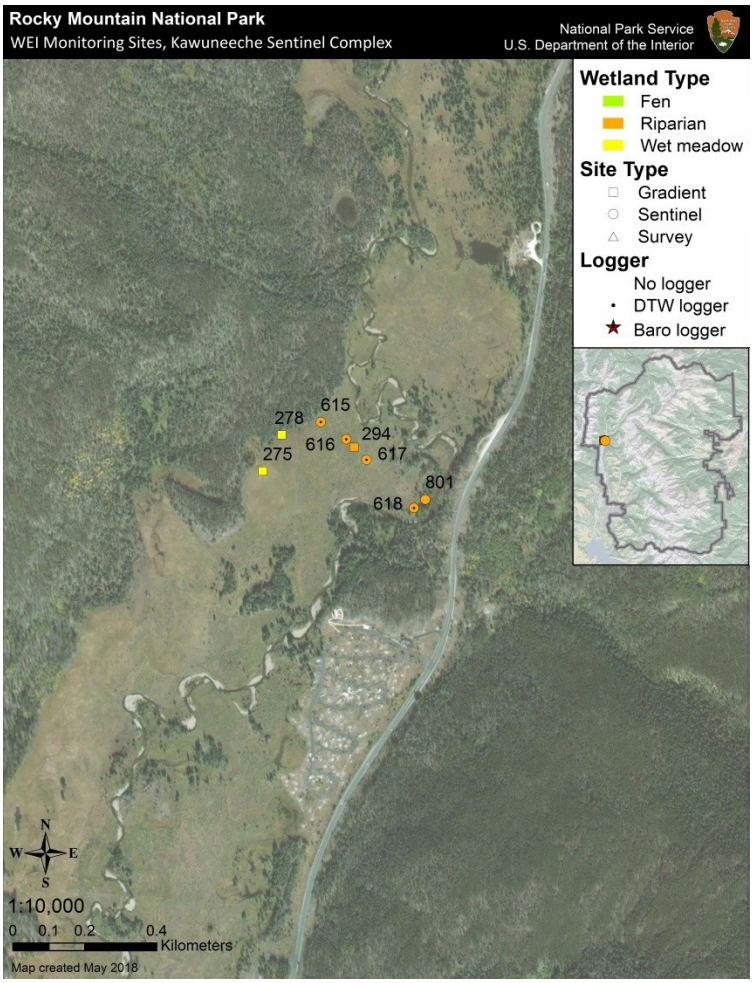


Figure B8. Aerial view of the Kawuneeche Valley complex sentinel site, showing four Rocky Mountain Network wetland ecological integrity (WEI) sites established as of 2009.

The complex was selected as a Rocky Mountain Network wetland ecological integrity sentinel site for monitoring because of its size and importance to Rocky Mountain National Park. It is the largest riparian wetland in the park and contains the headwaters of the Colorado River. The valley is also affected by several anthropogenic and natural disturbances that may affect the condition of the wetland. These disturbances include water diversion from the Grand Ditch, as well as the effects of the Grand Ditch breach in 2003, historical and current human use, the presence of invasive plant species, the decline and death of willow communities, herbivore overpopulation and beaver extirpation, and the extensive tree death (on slopes above the valley) from the pine bark beetle (*Dendroctonus ponderosae*).

Site History

Early settlers of Kawuneeche Valley arrived prospecting for silver and gold during the height of the gold rush, in the 1870s and 1880s. Three mining towns were established on the valley floor, Lulu City, Gaskill, and Dutchtown, which boomed briefly before disappearing when prospectors realized the Colorado mineral belt did not extend to this area. The mining boom was followed by an equally unsuccessful homesteading and ranching period. In the early 1900s several homesteaders established Holzwarth Trout Lodge and Hotel de Hardscrabble, both primitive but successful dude ranches. These were later replaced by the Never Summer Ranch (Figure B9) and Phantom Valley Ranch, respectively, which hosted guests until the 1970s. Hunting, fishing and trapping, along with increases in human populations and subsequent species reintroductions, may have contributed to changes in animal populations that persist today (Ziegenfuss et al. 2002). Homesteaders also modified the land by building roads, trails, and structures, many of which still remain in various states of repair throughout the valley.

Some of these early settlers realized that the richness of the area, if not in gold or ranching, was in the water. Undertaken in 1895 and finished 1935, the Grand Ditch canal was excavated by hand along a 27 km mile stretch of the Never Summer Mountains. It was built to bring water from the "wetter" western slope across La Poudre Pass to Long Draw Reservoir and down the Cache la Poudre drainage to the eastern plains for agricultural use. This structure diverts 20–40% of the total water produced in this segment of the Never Summer range. The ditch transects 13 tributaries to the Colorado River, has a drainage area of approximately 20 miles, and can reduce peak flows and summer base flows by up to 50% (Woods and Cooper 2005). The cooperative that owns the Grand Ditch is one of the only entities to have water rights preceding those of the park and is still in operation today.

The Grand Ditch ecologically impacts the valley, including the section chosen as the sentinel site, by decreasing incidence of flooding of the Colorado River and lowering groundwater tables in fens. Lower water tables have been shown to negatively affect plant and animal populations, cause the decomposition of organic soils, and aid the establishment of exotic species (Chimner and Cooper 2003b, Westbrook et al. 2006, Woods and Cooper 2005, Woods et al. 2006), while a decrease in flooding regimes can alter willow establishment patterns and rates (Woods and Cooper 2005, Cooper et al. 2006). In 2003, the bank of the Grand Ditch breached, sending water and 36,700 cubic meters of sediment cascading 300 meters into LuLu Creek and the headwaters of the Colorado River. The

breach directly affected 2.4 km of riparian wetland above Kawuneeche Valley by scouring the channel, depositing sediment, and changing stream patterns (Clayton and Westbrook 2008). Research into the long-term effects of the Grand Ditch breach and a restoration project are ongoing.



Figure B9. Never Summer Ranch, circa 1920s. NPS/ROCKY MOUNTAIN NATIONAL PARK.

Starting in 2004–2005, lodgepole pine death from the pine bark beetle infestation reached the edge of the park near the mouth of the Kawuneeche Valley. By 2010, >50% of the lodgepole pines around and above Kawuneeche Valley had been killed by the beetle, with expected future mortality rates close to 98%. This species constitutes one of the dominant forest trees in Rocky Mountain National Park at montane elevations and extensive tree death up slope from Kawuneeche Valley and in its contributing watersheds may cause changing conditions in the valley bottom. Based on evidence from neighboring counties, possible effects of high tree mortality include increased groundwater and surface water flows, increased sediment, and topsoil movement.

Previous Wetland Research/Monitoring

Research in Kawuneeche Valley began in the 1990s when D. Cooper, L. MacDonald, and several graduate students began studying the valley hydrology by installing groundwater monitoring wells in different areas of the wetland, several of which are currently being used by the Rocky Mountain Network to monitor hydrology in the sentinel site. In 1996, C. Westbrook created an extensive network of well transects bisecting the valley from east to west for several kilometers in riparian

wetland with current and historical beaver ponds. This area included the sentinel site and was chosen to study the effect of beaver and beaver dams on the hydrology of the wetland. Westbrook found that beaver dams and ponds greatly enhanced the depth, extent, and duration of inundation associated with floods, raised groundwater levels during both high and low stream flows (during the entire growing season), and that the main effect of the dams occurred downstream, not in the immediate area surrounding the beaver pond (Westbrook et al. 2006, 2011). This research suggested that in Kawuneeche Valley, beaver are important for creating and maintaining hydrologic regimes suitable for the formation and persistence of the riparian wetland and highlights concerns over current low beaver population levels (as compared to historical levels). More recent work by Cooper et al. (2006) used Kawuneeche Valley as a study area to examine regional willow decline in context of climate change. This study found that climate change, specifically increased temperatures and shifts in the seasonality of precipitation, will lower opportunities for willow establishment and likely contribute to willow decline.

Several studies focused on the impacts of the Grand Ditch diversion. Woods and Cooper (2005) found that the diversion lowered soil water content by up to 15% and decreased willow seedling survival rates along the stream. A second study by Woods described the hydrology of a sloping wetland affected by the Grand Ditch and found, consistent with other studies, that groundwater levels were greatly reduced in some areas of the wetland (Woods et al. 2006). Peat accumulation and decomposition rates were modeled in fens affected and unaffected by the Grand Ditch water diversion and researchers found that some fen water tables are lowered by the diversion, resulting in increased carbon emissions and causing affected fens to become carbon sources to the atmosphere (Chimner and Cooper 2003a, b). A recent study focusing on the Grand Ditch breach compared benthic invertebrate communities before and after and found that there were almost 2.5 times more benthic insects before the flooding and stream scouring (Clayton and Westbrook 2008).

Research on elk overabundance and the effect on willows in the park are also relevant to the Kawuneeche Valley and sentinel site monitoring. Studies have confirmed that current elk populations are larger than historical levels and winter ranges have been altered due to development of lower valleys and temperature increases caused by climate change (Singer and Zeingenfuss 2002). This increased browsing pressure has adversely affected willow communities by decreasing willow biomass and height (Wang et al. 2002) and adding additional strain to plants that may already be water stressed. There is also some evidence that herbivore overpopulation and excessive browsing of willow stems may negatively affect beaver populations and contribute to beaver extirpation (D. Cooper pers. comm.).

There are several current, ongoing research projects in Kawuneeche Valley that are relevant to WEI monitoring.

Appendix C: Quality Assurance and Quality Control Overview

The Rocky Mountain Network wetland ecological integrity (WEI) protocol and associated SOPs (Schweiger et al. 2015) include various quality assurance and quality control (QAQC) procedures. The table in this appendix lists the various steps associated with the protocol to ensure data quality and assurance throughout the data lifecycle (Table C1).

Table C1. The following table summarizes quality control and quality assurance procedures for wetland monitoring by the Rocky Mountain Network at Rocky Mountain National Park.

Core QA and QC measure	Description of the action
Documentation	Documentation via protocol, SOPs, methodology, etc., readily accessible
Training	Pre-season training of field crew
Field datasheets	Datasheets include standardized codes, precision guidelines for measured values, and clearly documented methodology to complete the form
Field oversight	Crew leader/protocol lead oversight during the field season and or periodically during data collection
Field datasheet review	End of the day or end of week quality assurance review of field datasheets for completeness, recording errors, and legible handwriting
Data entry quality control	Data entry quality control measures, including electronic data collection devices, to eliminate misspellings, to standardize entry, and reduce errors (drop down menus, value range, limited lists, check boxes, and species lists)
Quality assurance post-data entry	Quality assurance review following SOP Data Management Quality Assurance and Quality Control Queries are applied to the data post-data entry to isolate errors. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance.
Quality assurance post-analyses	Quality assurance tests for derived data prior to uploading to the database. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance.
Quality assurance queries for data recorded by a digital device	Data collected with electronic equipment must undergo tests using QA software, queries in MS Access, or graphical review in MS Excel for outliers and missing data. Assessment points must be developed for accepting or omitting data. All tests and procedures should be documented in SOP SEI: Quality Control and Quality Assurance
Lab data quality control	Protocol methodology establishes quality control pertaining to the sample collection. Rocky Mountain Network assumes contract labs maintain a level of quality control that is tractable internally.
Lab data quality assurance	Chain of custody forms are crosswalked with lab sample results for completeness. Data results are reviewed by the Protocol lead for outliers and missing data prior to uploading to the database.
Species lists	At the end of the field season, the species list, with additions from the current year, are crosswalked and updated with code and names as listed in NPSpecies, ITIS, CNHP, Weber, and USDA Plants. Database is updated prior to data entry.

All collection and measurement procedures were standardized among all field crews. Field protocols and other activities were documented in peer reviewed SOPs. All field crew personnel participated in a standardized field training session. Field trainers were experienced NPS Rocky Mountain Network staff. Each training session was 1–2 days, and included lectures, field demonstrations, and at least one practice field exercise. The field operations manual served as the basis for the field training program. Field crews often had experienced network staff or collaborators as core members. Field crews were offered an opportunity at the end of each year to suggest improvements to the field operations manual and other aspects of field operations. Systematic errors were minimized by using validated methodologies and standardized procedures.

A draft Rocky Mountain Network Quality Assurance Project Plan (QAPP) presents details on Measurement Quality Objectives. These objectives are intended to demonstrate how the network monitoring generates data of known and documented quality, resulting in complete, accurate, and transferable information. Data credibility necessary for the intended uses will be achieved when data are:

- consistent over time and consistent between staff members
- collected and analyzed using standardized and acceptable techniques
- comparable to data collected in other assessments using the same methods
- used appropriately to make decisions based on sound statistics

The network QAPP also provides a summary of Data Quality Objectives or quantitative and qualitative terms that describe how good data need to be in order to meet project objectives. Data Quality Objectives for measurement data (or data quality indicators) are discussed in detail below but should also meet NPS Water Resources Division standards regarding:

- Target population
- Sensitivity
- Representativeness
- Completeness
- Data comparability
- Measurement sensitivity and detection limits
- Measurement precision as repeatability (accuracy)
- Measurement systematic error/bias

All of the various data components of the WEI protocol were managed at the network offices. Completed field forms were reviewed and entered into a database, with several internal QAQC checks. At least 10% of the forms were randomly selected and all data were confirmed. Any systematic errors were evaluated to assess if there was a persistent error with a need for a global correction. Data were reviewed and validated to be sufficiently representative, accurate, precise, and complete.

A key statistic used as part of our QAQC is the ratio of the “signal” to “noise” (S:N) in a response measure (Kaufmann et al. 1999). We present S:N results in the main narrative of this report.

For references in this appendix please see the literature cited section that follows the main narrative.

Appendix D: Remotely Sensed Estimates of Wetland Extent

Appendix D presents estimates of wetland extent at Rocky Mountain National Park based on remotely sensed data (Table D1, Table D2). We crosswalked the data to Ecological System and Cowardin types using an evaluation of plot level floristics (D. Cooper and Chris Lee, pers. comm.). Ecological Systems are very similar to Rocky Mountain Network wetland types, and had we crosswalked the Rocky Mountain National Park vegetation map (VegMap) data to network types, the results would have likely been similar. The National Wetland Inventory (NWI) data suggest there were about 3800 ha of wetland in the park, comprising about 3.52% of total park area. The vast majority of the wetland in the NWI data was various palustrine types, difficult to crosswalk to either network types or Ecological Systems. The NWI data are dated and collected at a large scale, with high errors of omission, especially for small patches of wetland. While NWI data are an important resource for the park, we do not use them in any analytical way in the network's wetland ecological integrity (WEI) protocol. The VegMap data suggested there were about 16,050 ha of wetland in the park, comprising about 15% of total park area. Wetland type was about 15% fen, with the remaining 85% split between wet meadows and riparian wetland. VegMap data are recent, high quality, and of sufficient resolution to accurately capture useful results. However, analyses conducted by the VegMap program on the park data suggested that errors of commission were an issue. In general, wetland was overmapped; many areas that looked like wetland in imagery were actually not entirely wetland when species composition and other ground truthing data were included. Wetlands in Rocky Mountain National Park are often small and embedded in upland settings. The VegMap sometimes did not distinguish among the wetland and upland polygons and instead lumped them into one contiguous wetland patch. Therefore, it is probable that the VegMap estimate of wetland extent is high.

For references in this appendix please see the literature cited section that follows the main narrative.

Table D1. Rocky Mountain National Park wetland types derived from the National Wetland Inventory (NWI) data (USFWS 1991):

Wetland type (Generalized NWI)	Count	Mean patch size (ha)	Total area (ha)	Percent of park wetland	Percent of park area
Lacustrine Littoral	4	1.73	6.94	0.18	0.0064
Palustrine Emergent	65	6.37	413.82	10.89	0.3834
Palustrine Forested	19	6.35	120.59	3.17	0.1117
Palustrine Scrub Shrub Emergent	732	4.45	3259.44	85.75	3.0197
Palustrine Semipermanently Flooded	2	0.21	0.42	0.01	0.0004
Total from National Wetland Inventory		**NA**	**3801.20**	**NA**	**3.52%**

Table D2. Rocky Mountain National Park wetland types derived from the Rocky Mountain National Park Vegetation Map (Salas et al. 2005):

Wetland type (VegMap MapUnit)	Wetland type (Ecological System)	Wetland type (Generalized NWI)	Count	Mean patch size (ha)	Total area (ha)	Percent of park wetland	Percent of park area
Herbaceous Wetland SubAlpine / Alpine - Alpine Meadow	Rocky Mountain Alpine-Montane Wet Meadow	Palustrine Emergent	1056	6.75	7123.91	44.36	6.5999
Herbaceous Wetland Cross Zone - Wetland	Rocky Mountain Subalpine-Montane Fen	Palustrine Emergent	1495	1.45	2162.66	13.47	2.0036
Herbaceous Wetland Cross Zone - Marsh	North American Arid West Emergent Marsh	Palustrine Emergent / Lacustrine Littoral / Palustrine Aquatic Bed	26	0.58	15.11	0.09	0.0140
Riparian Lower Montane Mixed Conifer <8500 ft	Rocky Mountain Lower Montane Riparian Woodland and Shrubland	Palustrine Forested	41	1.91	78.38	0.49	0.0726

Table D2 (continued). Rocky Mountain National Park wetland types derived from the Rocky Mountain National Park Vegetation Map (Salas et al. 2005):

Wetland type (VegMap MapUnit)	Wetland type (Ecological System)	Wetland type (Generalized NWI)	Count	Mean patch size (ha)	Total area (ha)	Percent of park wetland	Percent of park area
Riparian Upper Montane Mixed Conifer >8500 ft	Rocky Mountain Subalpine-Montane Riparian Woodland	Palustrine Forested	536	5.02	2692.34	16.77	2.4943
Shrub Riparian Cross Zone <9600 ft	Rocky Mountain Subalpine-Montane Riparian Shrubland	Palustrine Scrub Shrub Emergent	290	3.31	960.73	5.98	0.8901
Shrub Riparian Cross Zone >9600 ft	Rocky Mountain Subalpine-Montane Riparian Shrubland	Palustrine Scrub Shrub Emergent	401	3.49	1400.08	8.72	1.2971
Shrub Upland Alpine	Rocky Mountain Subalpine-Montane Riparian Shrubland	Palustrine Scrub Shrub Emergent	641	2.54	1625.72	10.12	1.5061
Total from Rocky Mountain National Park Vegetation Map			**NA**	**NA**	**16058.92**	**–**	**14.88%**

Appendix E: Vegetation Metrics

For vegetation monitored by the Rocky Mountain Network wetland ecological integrity protocol at Rocky Mountain National Park, we generated 206 metrics classified into 11 groups: floristic quality (conservatism), duration, ground cover, life form composition, degree of invasion, endemism (perhaps better thought of as "conservation value"), noxiousness, taxonomic diversity, taxonomic composition, wetland status and salt tolerance. In this appendix, we present calculation details for the seven metrics we focus on in the body of this report and then summarize 28 out of these by wetland type (Table E1). All 206 are available on the NPS Integrated Resources Management Applications portal (IRMA), in this tabular dataset labeled, Rocky Mountain NP WEI Metric Summary 20180523_StandAlone.xlsx, at this link:

https://irma.nps.gov/DataStore/Reference/Profile/2259529

Table E1. Calculation details for seven focal metrics in this report.

Metric	Formula	Notes
Absolute Cover Salicaceae & Betulaceae	$\sum(Absolute\ cover\ S\qquad\ \&\ Betulaceae)$	Can be over 100
Absolute Native Forb Cover	$\sum(Absolute\ cover\ na\qquad fo\quad)$	Can be over 100
Cover Weighted Native Forb Richness	$\sum(Naitve\ fo\quad *relative\ cover)$	–
Degree of invasion index 1	$\sum(Ir\qquad *Cover)\ /\ Total\ species\ count$	–
Degree of invasion index 2	$\sum(Ir\qquad *(Count\ invasive/Total\ species\ count)\ /\ Total\ species\ count$	–
Mean Conservatism	$\frac{\sum(C\ score)}{Total\ count\ with\ C\ scores}$	–
Wetland Affinity Native Cover Weighted	–	–

For references in this appendix please see the literature cited section that follows the main narrative.

Table E2 presents baseline parkwide summary statistics for 28 wetland ecological integrity metrics for fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. Estimates are derived from a baseline of 'best' events at each site from 2007 to 2011 (with most in 2008). Parkwide scale values are derived from randomly selected sites using design-based inference (Stevens 1997) and are statistically unbiased estimates for wetland condition in the park.

Table E2. Summary statistics for baseline parkwide wetland ecological integrity for fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. [a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Fen	Absolute Cover Intolerant	33	19.49	3.12	13.38	25.61
Mdw	Absolute Cover Intolerant	40	24.45	5.54	13.60	35.30
Rip	Absolute Cover Intolerant	20	13.04	5.37	2.51	23.56
Wetland	Absolute Cover Intolerant	93	21.51	3.58	14.50	28.52
Fen	Absolute Cover Salicaceae and Betulaceae	33	11.85	5.48	1.10	22.59
Mdw	Absolute Cover Salicaceae and Betulaceae	40	13.76	6.15	1.70	25.82
Rip	Absolute Cover Salicaceae and Betulaceae	20	13.63	4.85	4.13	23.13
Wetland	Absolute Cover Salicaceae and Betulaceae	93	13.07	4.11	5.01	21.12
Fen	Absolute Cover Woody	33	21.51	9.51	2.88	40.14
Mdw	Absolute Cover Woody	40	19.35	7.24	5.17	33.54
Rip	Absolute Cover Woody	20	53.30	7.67	38.26	68.34
Wetland	Absolute Cover Woody	93	23.62	5.66	12.53	34.71
Fen	Absolute Native Forb Cover	33	14.21	1.91	10.47	17.95
Mdw	Absolute Native Forb Cover	40	29.47	5.28	19.13	39.81
Rip	Absolute Native Forb Cover	20	33.49	6.77	20.21	46.76
Wetland	Absolute Native Forb Cover	93	24.47	3.64	17.34	31.59
Fen	Bare Ground	33	4.94	2.01	1.00	8.87
Mdw	Bare Ground	40	11.20	3.22	4.88	17.51
Rip	Bare Ground	20	14.10	3.78	6.69	21.50
Wetland	Bare Ground	93	9.27	2.31	4.75	13.79
Fen	Cover Weighted Mean Conservatism	33	6.27	0.16	5.95	6.59
Mdw	Cover Weighted Mean Conservatism	40	5.96	0.32	5.33	6.58
Rip	Cover Weighted Mean Conservatism	20	5.48	0.38	4.74	6.23
Wetland	Cover Weighted Mean Conservatism	93	6.02	0.19	5.64	6.39
Fen	Cover Weighted Native Forb Richness	33	0.15	0.02	0.12	0.19
Mdw	Cover Weighted Native Forb Richness	40	0.29	0.07	0.16	0.42
Rip	Cover Weighted Native Forb Richness	20	0.29	0.04	0.21	0.37
Wetland	Cover Weighted Native Forb Richness	93	0.24	0.04	0.16	0.33

[a] SE = standard error, SD = standard deviation, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Table E2 (continued). Summary statistics for baseline parkwide wetland ecological integrity for fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. [a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Fen	Degree of invasion index 1	33	0.29	0.25	0.00	0.77
Mdw	Degree of invasion index 1	40	1.25	0.52	0.23	2.27
Rip	Degree of invasion index 1	20	3.15	0.66	1.85	4.44
Wetland	Degree of invasion index 1	93	1.10	0.34	0.43	1.78
Fen	Degree of invasion index 2	33	0.00	0.00	0.00	0.01
Mdw	Degree of invasion index 2	40	0.02	0.01	0.00	0.04
Rip	Degree of invasion index 2	20	0.25	0.20	0.00	0.64
Wetland	Degree of invasion index 2	93	0.04	0.03	0.00	0.09
Fen	Element occurrence score	33	1.14	0.05	1.04	1.24
Mdw	Element occurrence score	40	1.17	0.03	1.11	1.24
Rip	Element occurrence score	20	1.14	0.04	1.06	1.23
Wetland	Element occurrence score	93	1.16	0.03	1.10	1.22
Fen	Floristic Quality Index	33	29.53	1.43	26.73	32.32
Mdw	Floristic Quality Index	40	32.35	2.63	27.18	37.51
Rip	Floristic Quality Index	20	35.12	1.29	32.60	37.65
Wetland	Floristic Quality Index	93	31.63	1.55	28.60	34.66
Fen	Floristic Quality Index Cover Weighted	33	25.78	1.73	22.38	29.18
Mdw	Floristic Quality Index Cover Weighted	40	27.44	2.77	22.00	32.88
Rip	Floristic Quality Index Cover Weighted	20	29.25	1.82	25.68	32.82
Wetland	Floristic Quality Index Cover Weighted	93	27.04	1.61	23.88	30.20
Fen	Floristic Quality Index Native	33	29.68	1.48	26.78	32.59
Mdw	Floristic Quality Index Native	40	33.19	2.44	28.41	37.97
Rip	Floristic Quality Index Native	20	37.11	0.95	35.24	38.97
Wetland	Floristic Quality Index Native	93	32.35	1.48	29.44	35.25
Fen	Invasive Richness	33	0.11	0.09	0.00	0.30
Mdw	Invasive Richness	40	0.65	0.27	0.13	1.18
Rip	Invasive Richness	20	1.88	0.82	0.28	3.48
Wetland	Invasive Richness	93	0.59	0.21	0.18	0.99

[a] SE = standard error, SD = standard deviation, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Table E2 (continued). Summary statistics for baseline parkwide wetland ecological integrity for fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. [a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Fen	Mean Conservatism	33	6.89	0.06	6.76	7.01
Mdw	Mean Conservatism	40	6.59	0.25	6.11	7.07
Rip	Mean Conservatism	20	6.13	0.22	5.71	6.56
Wetland	Mean Conservatism	93	6.65	0.15	6.36	6.94
Fen	NonVascular GroundCover	33	33.33	7.00	19.61	47.05
Mdw	NonVascular GroundCover	40	14.74	6.89	1.25	28.24
Rip	NonVascular GroundCover	20	6.40	2.41	1.67	11.12
Wetland	NonVascular GroundCover	93	20.48	4.96	10.77	30.20
Fen	Percent Invasive	33	0.04	0.05	0.00	0.14
Mdw	Percent Invasive	40	0.42	0.26	0.00	0.93
Rip	Percent Invasive	20	4.99	3.96	0.00	12.76
Wetland	Percent Invasive	93	0.76	0.51	0.00	1.76
Fen	Relative Importance Natives	33	52.07	0.24	51.60	52.53
Mdw	Relative Importance Natives	40	51.43	0.72	50.02	52.83
Rip	Relative Importance Natives	20	48.87	1.26	46.40	51.34
Wetland	Relative Importance Natives	93	51.39	0.45	50.52	52.26
Fen	Richness All	33	18.90	1.79	15.40	22.39
Mdw	Richness All	40	25.32	2.75	19.93	30.72
Rip	Richness All	20	35.32	2.46	30.50	40.15
Wetland	Richness All	93	24.07	1.83	20.48	27.66
Fen	Richness NonVascular	33	3.92	0.38	3.17	4.67
Mdw	Richness NonVascular	40	2.53	0.33	1.89	3.18
Rip	Richness NonVascular	20	4.49	0.77	2.99	6.00
Wetland	Richness NonVascular	93	3.23	0.29	2.67	3.79
Fen	Shannon Weiner Native Diversity	33	1.35	0.06	1.24	1.46
Mdw	Shannon Weiner Native Diversity	40	1.74	0.12	1.51	1.97
Rip	Shannon Weiner Native Diversity	20	1.98	0.16	1.66	2.31
Wetland	Shannon Weiner Native Diversity	93	1.63	0.09	1.45	1.80

[a] SE = standard error, SD = standard deviation, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Table E2 (continued). Summary statistics for baseline parkwide wetland ecological integrity for fens, wet meadows, riparian wetland, and all wetland in Rocky Mountain National Park. [a]

Wetland type	Indicator	N	Mean	SE	LCB	UCB
Fen	Simpson Diversity	33	0.73	0.02	0.70	0.76
Mdw	Simpson Diversity	40	0.77	0.04	0.69	0.85
Rip	Simpson Diversity	20	0.84	0.02	0.79	0.88
Wetland	Simpson Diversity	93	0.76	0.02	0.72	0.81
Fen	Simpson Diversity Native	33	0.73	0.02	0.70	0.76
Mdw	Simpson Diversity Native	40	0.77	0.04	0.69	0.85
Rip	Simpson Diversity Native	20	0.83	0.03	0.78	0.88
Wetland	Simpson Diversity Native	93	0.76	0.02	0.71	0.81
Fen	Tolerant to Intolerant Absolute Cover	33	0.00	0.00	0.00	0.01
Mdw	Tolerant to Intolerant Absolute Cover	39	0.09	0.05	0.00	0.18
Rip	Tolerant to Intolerant Absolute Cover	20	0.28	0.11	0.06	0.49
Wetland	Tolerant to Intolerant Absolute Cover	92	0.08	0.03	0.01	0.14
Fen	Total Litter	33	46.92	4.13	38.83	55.02
Mdw	Total Litter	40	59.36	3.63	52.24	66.47
Rip	Total Litter	20	57.54	5.43	46.89	68.19
Wetland	Total Litter	93	54.75	2.85	49.16	60.34
Fen	Wetland Affinity Native Cover Weighted	33	4.53	0.10	4.33	4.73
Fen	Wetland Affinity Native Cover Weighted	33	4.53	0.10	4.33	4.73
Mdw	Wetland Affinity Native Cover Weighted	40	4.12	0.13	3.88	4.37
Mdw	Wetland Affinity Native Cover Weighted	40	4.12	0.13	3.88	4.37
Rip	Wetland Affinity Native Cover Weighted	20	3.37	0.16	3.06	3.69
Rip	Wetland Affinity Native Cover Weighted	20	3.37	0.16	3.06	3.69
Wetland	Wetland Affinity Native Cover Weighted	93	4.19	0.08	4.03	4.35
Wetland	Wetland Affinity Native Cover Weighted	93	4.19	0.08	4.03	4.35
Fen	Wetland Affinity Native Richness	33	12.85	1.21	10.48	15.22
Mdw	Wetland Affinity Native Richness	40	13.69	1.77	10.21	17.16
Rip	Wetland Affinity Native Richness	20	14.20	1.19	11.87	16.53
Wetland	Wetland Affinity Native Richness	93	13.44	1.01	11.46	15.43

[a] SE = standard error, SD = standard deviation, LCB and UCB = lower and upper bounds on a 95% confidence interval. Note that a negative LCB is reported as 0.

Appendix F: Groundwater Depth Metrics

For groundwater monitoring by the Rocky Mountain Network wetland ecological integrity protocol, we generated 12 site-scale summary statistics from continuously logged depth to water from ground surface (DTW, cm) for sentinel wetlands in Rocky Mountain National Park (Table F1). Values are averaged to daily means from hourly readings on snow free days (spring through early fall) as collected by all data loggers in each sentinel site. Note that the number of days included varies from 31 to 194 days due to variable snow free periods, logger installation, and download timing. Logs shorter than 30 days are omitted.

Table F1. Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Number of days logged	Alpine	2007	–	–	–	–
	Alpine	2008	42	–	–	–
	Alpine	2009	110	0.50	109.45	111.05
	Alpine	2010	89	31.82	9.63	167.70
	Alpine	2011	82	30.41	-191.68	354.68
	Alpine	2012	118	10.61	22.20	212.80
	Alpine	2013	73	18.38	-92.18	238.18
	Alpine	2014	77	–	–	–
	Big Meadows	2007	96	–	–	–
	Big Meadows	2008	73	17.39	29.47	115.86
	Big Meadows	2009	137	85.58	-75.93	349.26
	Big Meadows	2010	86	53.82	-48.02	219.36
	Big Meadows	2011	145	–	–	–
	Big Meadows	2012	184	6.36	126.32	240.68
	Big Meadows	2013	142	0.71	135.15	147.85
	Big Meadows	2014	87	–	–	–
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	132	–	–	–
	Kawuneeche	2010	43	18.50	-3.30	88.63
	Kawuneeche	2011	103	–	–	–
	Kawuneeche	2012	194	20.51	9.26	377.74

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Number of days logged (continued)	Kawuneeche	2013	142	1.41	129.29	154.71
	Kawuneeche	2014	99	22.63	-104.30	302.30
	Moraine Park	2007	117	–	–	–
	Moraine Park	2008	98	48.03	-21.32	217.32
	Moraine Park	2009	146	22.27	90.68	201.32
	Moraine Park	2010	110	11.53	81.35	138.65
	Moraine Park	2011	164	30.92	114.29	212.71
	Moraine Park	2012	172	8.38	158.41	185.09
	Moraine Park	2013	171	33.23	117.87	223.63
	Moraine Park	2014	82	9.00	67.18	95.82
	All Years	2007-2014	116	46.50	105.17	126.72
Minimum DTW	Alpine	2007	–	–	–	–
	Alpine	2008	-16.50	12.85	-131.99	98.99
	Alpine	2009	-33.09	15.58	-57.89	-8.30
	Alpine	2010	-59.89	26.17	-124.91	5.12
	Alpine	2011	-33.47	43.91	-428.02	361.09
	Alpine	2012	-39.07	38.96	-389.14	311.00
	Alpine	2013	-92.55	10.42	-186.21	1.12
	Alpine	2014	-36.66	17.23	-191.44	118.12
	Big Meadows	2007	-29.50	–	–	–
	Big Meadows	2008	-36.44	24.40	-97.05	24.17
	Big Meadows	2009	-30.33	9.62	-54.22	-6.45
	Big Meadows	2010	-23.40	24.20	-83.51	36.72
	Big Meadows	2011	-14.34	14.86	-147.88	119.20
	Big Meadows	2012	-39.48	7.02	-102.54	23.59
	Big Meadows	2013	-20.65	8.17	-94.03	52.72
	Big Meadows	2014	-14.06	21.00	-202.75	174.62
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Minimum DTW (continued)	Kawuneeche	2009	-124.79	45.12	-530.20	280.61
	Kawuneeche	2010	-74.85	13.69	-108.85	-40.85
	Kawuneeche	2011	-56.17	32.01	-343.76	231.41
	Kawuneeche	2012	-74.19	8.37	-149.43	1.04
	Kawuneeche	2013	-57.60	5.60	-107.95	-7.25
	Kawuneeche	2014	-36.51	0.24	-38.67	-34.35
	Moraine Park	2007	-54.90	–	–	–
	Moraine Park	2008	-47.03	35.27	-134.65	40.59
	Moraine Park	2009	-56.72	40.63	-157.65	44.21
	Moraine Park	2010	-37.66	14.83	-74.50	-0.82
	Moraine Park	2011	-41.06	10.58	-57.90	-24.22
	Moraine Park	2012	-40.98	27.96	-85.47	3.51
	Moraine Park	2013	-25.29	26.00	-66.65	16.08
	Moraine Park	2014	-21.41	19.04	-51.71	8.88
	All Years	2007-2014	-42.47	29.22	-49.24	-35.70
Maximum DTW	Alpine	2007	–	–	–	–
	Alpine	2008	0.76	3.08	-26.88	28.40
	Alpine	2009	6.99	3.32	1.70	12.28
	Alpine	2010	-1.98	6.19	-17.35	13.38
	Alpine	2011	9.11	7.22	-55.78	74.01
	Alpine	2012	4.08	3.16	-24.33	32.50
	Alpine	2013	13.48	11.92	-93.60	120.57
	Alpine	2014	46.13	6.96	-16.42	108.68
	Big Meadows	2007	-1.70	–	–	–
	Big Meadows	2008	-0.57	2.87	-7.69	6.55
	Big Meadows	2009	2.54	1.38	-0.88	5.97
	Big Meadows	2010	30.77	30.74	-45.59	107.13
	Big Meadows	2011	6.84	2.70	-17.45	31.12
	Big Meadows	2012	6.69	0.11	5.72	7.65

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Maximum DTW (continued)	Big Meadows	2013	9.38	4.65	-32.44	51.21
	Big Meadows	2014	8.03	8.03	-64.15	80.20
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	-36.85	36.38	-363.73	290.02
	Kawuneeche	2010	-14.28	10.84	-41.20	12.64
	Kawuneeche	2011	4.08	8.35	-70.94	79.11
	Kawuneeche	2012	-36.00	54.26	-523.48	451.48
	Kawuneeche	2013	17.22	31.30	-263.98	298.41
	Kawuneeche	2014	27.45	17.81	-132.60	187.49
	Moraine Park	2007	-11.88	–	–	–
	Moraine Park	2008	1.45	10.81	-25.40	28.30
	Moraine Park	2009	0.32	10.87	-26.69	27.33
	Moraine Park	2010	-2.92	5.44	-16.43	10.59
	Moraine Park	2011	3.90	2.86	-0.64	8.45
	Moraine Park	2012	-2.05	7.51	-13.99	9.89
	Moraine Park	2013	11.32	7.24	-0.19	22.84
	Moraine Park	2014	4.55	5.32	-3.92	13.01
	All Years	2007-2014	3.95	18.63	-0.37	8.26
Mean DTW	Alpine	2007	–	–	–	–
	Alpine	2008	-6.83	3.68	-39.87	26.22
	Alpine	2009	-9.82	11.33	-27.85	8.21
	Alpine	2010	-28.21	27.52	-96.58	40.16
	Alpine	2011	-12.04	20.04	-192.10	168.02
	Alpine	2012	-17.86	26.09	-252.25	216.54
	Alpine	2013	-15.60	2.07	-34.17	2.97
	Alpine	2014	-5.87	7.46	-72.85	61.12
	Big Meadows	2007	-15.02	–	–	–
	Big Meadows	2008	-17.90	14.98	-55.11	19.31

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Mean DTW (continued)	Big Meadows	2009	-12.32	3.12	-20.07	-4.57
	Big Meadows	2010	-2.75	20.06	-52.57	47.07
	Big Meadows	2011	-3.54	6.09	-58.28	51.20
	Big Meadows	2012	-15.33	1.90	-32.40	1.74
	Big Meadows	2013	-3.74	10.83	-101.02	93.55
	Big Meadows	2014	-3.87	11.12	-103.74	96.01
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	-101.34	21.03	-290.33	87.65
	Kawuneeche	2010	-43.17	12.26	-73.62	-12.72
	Kawuneeche	2011	-44.30	41.86	-420.39	331.78
	Kawuneeche	2012	-61.81	20.94	-249.94	126.33
	Kawuneeche	2013	-26.61	1.17	-37.16	-16.05
	Kawuneeche	2014	-6.43	6.30	-63.00	50.13
	Moraine Park	2007	-29.04	–	–	–
	Moraine Park	2008	-21.35	18.25	-66.68	23.97
	Moraine Park	2009	-34.37	25.18	-96.92	28.17
	Moraine Park	2010	-12.58	10.35	-38.29	13.13
	Moraine Park	2011	-10.95	11.44	-29.15	7.24
	Moraine Park	2012	-14.85	19.18	-45.37	15.67
	Moraine Park	2013	-11.32	14.70	-34.71	12.08
	Moraine Park	2014	-7.68	8.35	-20.97	5.61
	All Years	2007-2014	-19.34	22.97	-24.66	-14.01
Mean maximum DTW	Alpine	2007	–	–	–	–
	Alpine	2008	-4.96	2.39	-26.42	16.50
	Alpine	2009	-8.06	10.37	-24.56	8.44
	Alpine	2010	-25.84	26.68	-92.12	40.44
	Alpine	2011	-10.31	18.48	-176.37	155.74
	Alpine	2012	-15.60	24.86	-238.97	207.77

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Mean maximum DTW (continued)	Alpine	2013	-5.54	4.24	-43.62	32.55
	Alpine	2014	13.78	7.45	-53.13	80.70
	Big Meadows	2007	-13.89	–	–	–
	Big Meadows	2008	-15.83	14.04	-50.70	19.04
	Big Meadows	2009	-11.11	3.24	-19.17	-3.06
	Big Meadows	2010	-1.44	19.55	-50.00	47.12
	Big Meadows	2011	-2.59	5.73	-54.04	48.86
	Big Meadows	2012	-13.50	1.66	-28.44	1.45
	Big Meadows	2013	-2.51	10.28	-94.86	89.84
	Big Meadows	2014	-2.70	10.57	-97.71	92.31
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	-100.14	20.69	-286.03	85.75
	Kawuneeche	2010	-41.26	12.89	-73.28	-9.24
	Kawuneeche	2011	-42.90	42.63	-425.89	340.09
	Kawuneeche	2012	-60.74	21.50	-253.91	132.43
	Kawuneeche	2013	-24.58	1.32	-36.47	-12.69
	Kawuneeche	2014	-4.47	5.43	-53.28	44.33
	Moraine Park	2007	-24.96	–	–	–
	Moraine Park	2008	-18.41	16.57	-59.58	22.75
	Moraine Park	2009	-31.75	23.26	-89.54	26.04
	Moraine Park	2010	-10.91	9.12	-33.57	11.75
	Moraine Park	2011	-9.22	10.58	-26.04	7.61
	Moraine Park	2012	-13.39	18.33	-42.56	15.78
	Moraine Park	2013	-9.63	13.45	-31.03	11.76
	Moraine Park	2014	-5.66	6.91	-16.66	5.34
	All Years	2007-2014	-16.84	23.22	-22.22	-11.46
Mean minimum DTW	Alpine	2007	–	–	–	–
	Alpine	2008	-8.72	4.73	-51.19	33.75

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Mean minimum DTW (continued)	Alpine	2009	-11.48	12.20	-30.89	7.93
	Alpine	2010	-30.64	28.45	-101.32	40.04
	Alpine	2011	-13.39	21.14	-203.30	176.53
	Alpine	2012	-21.20	27.53	-268.51	226.10
	Alpine	2013	-23.15	4.90	-67.20	20.90
	Alpine	2014	-17.94	7.77	-87.76	51.88
	Big Meadows	2007	-15.98	–	–	–
	Big Meadows	2008	-20.19	15.29	-58.18	17.80
	Big Meadows	2009	-13.41	3.08	-21.07	-5.76
	Big Meadows	2010	-3.93	20.46	-54.75	46.88
	Big Meadows	2011	-4.43	6.44	-62.28	53.42
	Big Meadows	2012	-16.92	2.04	-35.21	1.37
	Big Meadows	2013	-5.00	11.33	-106.82	96.82
	Big Meadows	2014	-4.97	11.62	-109.39	99.46
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	-102.53	21.42	-294.93	89.88
	Kawuneeche	2010	-44.97	11.83	-74.35	-15.59
	Kawuneeche	2011	-45.65	41.12	-415.09	323.78
	Kawuneeche	2012	-62.78	20.41	-246.13	120.57
	Kawuneeche	2013	-28.45	0.83	-35.87	-21.03
	Kawuneeche	2014	-8.09	6.88	-69.94	53.76
	Moraine Park	2007	-34.42	–	–	–
	Moraine Park	2008	-24.65	20.07	-74.51	25.20
	Moraine Park	2009	-37.05	27.05	-104.24	30.14
	Moraine Park	2010	-14.55	11.05	-42.01	12.91
	Moraine Park	2011	-12.66	12.07	-31.87	6.56
	Moraine Park	2012	-16.40	19.62	-47.61	14.82
	Moraine Park	2013	-12.74	15.65	-37.64	12.17

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Mean minimum DTW (continued)	Moraine Park	2014	-9.38	9.52	-24.53	5.78
	All Years	2007-2014	-21.56	23.18	-26.93	-16.19
Median DTW	Alpine	2007	–	–	–	–
	Alpine	2008	-6.29	3.10	-34.17	21.60
	Alpine	2009	-8.16	10.73	-25.24	8.91
	Alpine	2010	-26.09	28.80	-97.62	45.45
	Alpine	2011	-9.53	15.76	-151.14	132.08
	Alpine	2012	-22.05	33.36	-321.81	277.72
	Alpine	2013	-10.56	2.75	-35.24	14.13
	Alpine	2014	-3.76	4.99	-48.59	41.06
	Big Meadows	2007	-14.25	–	–	–
	Big Meadows	2008	-17.19	13.80	-51.47	17.09
	Big Meadows	2009	-10.53	2.83	-17.56	-3.51
	Big Meadows	2010	-9.39	15.12	-46.94	28.17
	Big Meadows	2011	-3.51	4.45	-43.47	36.46
	Big Meadows	2012	-15.58	3.29	-45.13	13.98
	Big Meadows	2013	-2.84	12.88	-118.54	112.85
	Big Meadows	2014	-4.72	11.02	-103.72	94.28
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	-112.92	32.82	-407.83	181.98
	Kawuneeche	2010	-46.98	18.20	-92.18	-1.78
	Kawuneeche	2011	-47.02	42.85	-432.04	338.00
	Kawuneeche	2012	-67.21	12.57	-180.18	45.76
	Kawuneeche	2013	-24.95	0.19	-26.61	-23.28
	Kawuneeche	2014	-13.17	3.00	-40.14	13.81
	Moraine Park	2007	-29.38	–	–	–
	Moraine Park	2008	-22.73	18.29	-68.16	22.70
	Moraine Park	2009	-41.37	29.65	-115.02	32.28

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Median DTW (continued)	Moraine Park	2010	-12.62	10.57	-38.89	13.64
	Moraine Park	2011	-11.92	14.78	-35.44	11.60
	Moraine Park	2012	-14.17	18.60	-43.77	15.43
	Moraine Park	2013	-13.63	17.50	-41.47	14.22
	Moraine Park	2014	-6.50	6.77	-17.27	4.27
	All Years	2007-2014	-20.41	25.22	-26.25	-14.56
Proportion dry days (DTW < -40 cm)	Alpine	2007	–	–	–	–
	Alpine	2008	0.00	–	–	–
	Alpine	2009	0.11	0.22	-0.24	0.46
	Alpine	2010	0.36	0.45	-0.76	1.48
	Alpine	2011	0.18	0.25	-2.10	2.46
	Alpine	2012	0.28	0.40	-3.32	3.89
	Alpine	2013	0.15	0.19	-1.59	1.89
	Alpine	2014	0.10	0.14	-1.14	1.34
	Big Meadows	2007	0.00	–	–	–
	Big Meadows	2008	0.14	0.23	-0.45	0.72
	Big Meadows	2009	0.00	–	–	–
	Big Meadows	2010	0.01	0.01	-0.02	0.04
	Big Meadows	2011	0.00	–	–	–
	Big Meadows	2012	0.03	0.04	-0.36	0.42
	Big Meadows	2013	0.00	–	–	–
	Big Meadows	2014	0.00	–	–	–
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	0.95	0.07	0.33	1.58
	Kawuneeche	2010	0.58	0.27	-0.09	1.25
	Kawuneeche	2011	0.49	0.69	-5.68	6.65
	Kawuneeche	2012	0.86	0.19	-0.88	2.60
	Kawuneeche	2013	0.26	0.00	0.24	0.28

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Proportion dry days (DTW < -40 cm) (continued)	Kawuneeche	2014	0.00	–	–	–
	Moraine Park	2007	0.32	–	–	–
	Moraine Park	2008	0.34	0.31	-0.44	1.12
	Moraine Park	2009	0.47	0.42	-0.58	1.52
	Moraine Park	2010	0.03	0.03	-0.05	0.11
	Moraine Park	2011	0.07	0.10	-0.08	0.22
	Moraine Park	2012	0.15	0.22	-0.20	0.50
	Moraine Park	2013	0.10	0.13	-0.10	0.30
	Moraine Park	2014	0.00	–	–	–
	All Years	2007-2014	0.19	0.30	0.12	0.26
Proportion saturated days (DTW > -5 cm)	Alpine	2007	–	–	–	–
	Alpine	2008	0.70	0.42	-3.08	4.48
	Alpine	2009	0.55	0.39	-0.08	1.18
	Alpine	2010	0.32	0.51	-0.95	1.58
	Alpine	2011	0.66	0.48	-3.66	4.98
	Alpine	2012	0.62	0.51	-3.94	5.18
	Alpine	2013	0.52	0.14	-0.75	1.78
	Alpine	2014	0.84	0.17	-0.64	2.33
	Big Meadows	2007	0.01	–	–	–
	Big Meadows	2008	0.27	0.37	-0.65	1.19
	Big Meadows	2009	0.27	0.15	-0.11	0.65
	Big Meadows	2010	0.55	0.39	-0.43	1.53
	Big Meadows	2011	0.72	0.39	-2.78	4.23
	Big Meadows	2012	0.23	0.09	-0.61	1.06
	Big Meadows	2013	0.64	0.42	-3.16	4.44
	Big Meadows	2014	0.64	0.50	-3.88	5.17
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	0.00	–	–	–

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Proportion saturated days (DTW > -5 cm) (continued)	Kawuneeche	2010	0.01	0.01	-0.02	0.03
	Kawuneeche	2011	0.13	0.16	-1.29	1.55
	Kawuneeche	2012	0.03	0.04	-0.34	0.40
	Kawuneeche	2013	0.03	0.03	-0.28	0.34
	Kawuneeche	2014	0.43	0.08	-0.33	1.20
	Moraine Park	2007	0.00	–	–	–
	Moraine Park	2008	0.48	0.50	-0.75	1.71
	Moraine Park	2009	0.10	0.17	-0.32	0.52
	Moraine Park	2010	0.35	0.56	-1.04	1.75
	Moraine Park	2011	0.58	0.42	-0.08	1.25
	Moraine Park	2012	0.51	0.56	-0.39	1.41
	Moraine Park	2013	0.60	0.47	-0.15	1.34
	Moraine Park	2014	0.68	0.39	0.05	1.30
	All Years	2007-2014	0.42	0.39	0.33	0.51
Range DTW	Alpine	2007	–	–	–	–
	Alpine	2008	17.26	15.93	-125.87	160.39
	Alpine	2009	40.08	13.87	18.01	62.15
	Alpine	2010	57.91	19.99	8.26	107.56
	Alpine	2011	42.58	36.69	-287.07	372.24
	Alpine	2012	43.15	35.80	-278.50	364.81
	Alpine	2013	100.97	29.50	-164.04	365.98
	Alpine	2014	82.79	10.26	-9.44	175.02
	Big Meadows	2007	27.80			
	Big Meadows	2008	35.87	22.49	-20.01	91.74
	Big Meadows	2009	32.88	8.61	11.48	54.27
	Big Meadows	2010	54.17	13.15	21.51	86.83
	Big Meadows	2011	21.18	12.16	-88.08	130.43
	Big Meadows	2012	46.16	7.13	-17.87	110.19
	Big Meadows	2013	30.04	3.51	-1.52	61.59

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Range DTW (continued)	Big Meadows	2014	22.09	12.97	-94.42	138.60
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	87.94	81.50	-644.33	820.22
	Kawuneeche	2010	60.57	3.02	53.07	68.07
	Kawuneeche	2011	60.26	23.66	-152.30	272.82
	Kawuneeche	2012	38.20	45.88	-374.05	450.44
	Kawuneeche	2013	74.82	36.90	-256.73	406.37
	Kawuneeche	2014	63.95	18.05	-98.25	226.16
	Moraine Park	2007	43.02	–	–	–
	Moraine Park	2008	48.48	35.88	-40.65	137.62
	Moraine Park	2009	57.04	44.74	-54.09	168.17
	Moraine Park	2010	34.74	20.24	-15.54	85.02
	Moraine Park	2011	44.96	13.22	23.92	66.01
	Moraine Park	2012	38.93	23.08	2.21	75.66
	Moraine Park	2013	36.61	31.03	-12.77	85.99
	Moraine Park	2014	25.96	22.89	-10.46	62.38
	All Years	2007-2014	46.28	28.01	39.79	52.77
Standard Deviation DTW	Alpine	2007	–	–	–	–
	Alpine	2008	2.81	3.11	-25.12	30.73
	Alpine	2009	9.74	8.02	-3.03	22.50
	Alpine	2010	13.17	4.70	1.51	24.84
	Alpine	2011	12.21	14.57	-118.73	143.15
	Alpine	2012	13.43	15.09	-122.15	149.00
	Alpine	2013	16.54	6.18	-39.01	72.08
	Alpine	2014	9.91	5.84	-42.57	62.38
	Big Meadows	2007	5.86	–	–	–
	Big Meadows	2008	7.47	7.15	-10.29	25.23
	Big Meadows	2009	8.36	2.01	3.37	13.36

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Standard Deviation DTW (continued)	Big Meadows	2010	15.82	2.64	9.27	22.38
	Big Meadows	2011	5.02	3.22	-23.95	33.99
	Big Meadows	2012	11.17	3.60	-21.17	43.51
	Big Meadows	2013	6.86	1.75	-8.89	22.60
	Big Meadows	2014	5.27	4.03	-30.97	41.52
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	24.77	24.68	-197.00	246.53
	Kawuneeche	2010	16.36	3.51	7.64	25.09
	Kawuneeche	2011	12.42	1.28	0.89	23.95
	Kawuneeche	2012	11.57	14.97	-122.94	146.08
	Kawuneeche	2013	14.08	1.08	4.40	23.76
	Kawuneeche	2014	22.98	14.92	-111.11	157.07
	Moraine Park	2007	8.37	–	–	–
	Moraine Park	2008	13.82	11.70	-15.24	42.89
	Moraine Park	2009	16.54	14.72	-20.03	53.11
	Moraine Park	2010	4.07	4.40	-6.86	14.99
	Moraine Park	2011	8.76	7.63	-3.38	20.90
	Moraine Park	2012	5.83	5.86	-3.50	15.15
	Moraine Park	2013	8.17	8.15	-4.80	21.13
	Moraine Park	2014	5.96	5.92	-3.46	15.37
	All Years	2007-2014	10.72	8.44	8.76	12.67
Wettest day	Alpine	2007	–	–	–	–
	Alpine	2008	8/26/2008	–	–	–
	Alpine	2009	6/4/2009	0.50	154.95	156.55
	Alpine	2010	6/13/2010	10.69	137.77	190.90
	Alpine	2011	6/28/2011	–	–	–
	Alpine	2012	6/13/2012	1.41	152.29	177.71
	Alpine	2013	6/9/2013	4.24	121.88	198.12

Table F1 (continued). Site scale summary statistics for groundwater monitoring at Rocky Mountain National Park.

Indicator	Sentinel complex	Year	Mean	SD	LCB	UCB
Wettest day (continued)	Alpine	2014	6/13/2014	–	–	–
	Big Meadows	2007	6/22/2007	–	–	–
	Big Meadows	2008	6/16/2008	16.17	128.51	208.82
	Big Meadows	2009	7/13/2009	25.42	131.51	257.82
	Big Meadows	2010	5/23/2010	10.15	117.79	168.21
	Big Meadows	2011	6/9/2011	–	–	–
	Big Meadows	2012	4/14/2012	7.07	41.47	168.53
	Big Meadows	2013	5/23/2013	–	–	–
	Big Meadows	2014	5/24/2014	–	–	–
	Kawuneeche	2007	–	–	–	–
	Kawuneeche	2008	–	–	–	–
	Kawuneeche	2009	6/16/2009	–	–	–
	Kawuneeche	2010	6/1/2010	18.48	106.77	198.56
	Kawuneeche	2011	7/21/2011	–	–	–
	Kawuneeche	2012	4/19/2012	–	–	–
	Kawuneeche	2013	5/23/2013	–	–	–
	Kawuneeche	2014	5/24/2014	–	–	–
	Moraine Park	2007	6/19/2007	–	–	–
	Moraine Park	2008	6/22/2008	8.66	152.49	195.51
	Moraine Park	2009	5/17/2009	10.44	111.06	162.94
	Moraine Park	2010	6/18/2010	–	–	–
	Moraine Park	2011	5/9/2011	24.58	90.14	168.36
	Moraine Park	2012	5/1/2012	13.86	99.95	144.05
	Moraine Park	2013	5/13/2013	11.55	114.63	151.37
	Moraine Park	2014	5/18/2014	6.93	126.98	149.02
	All Years	2007-2014	6/3	27.72	147.83	160.68

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

NPS 121/151290, April 2019



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525