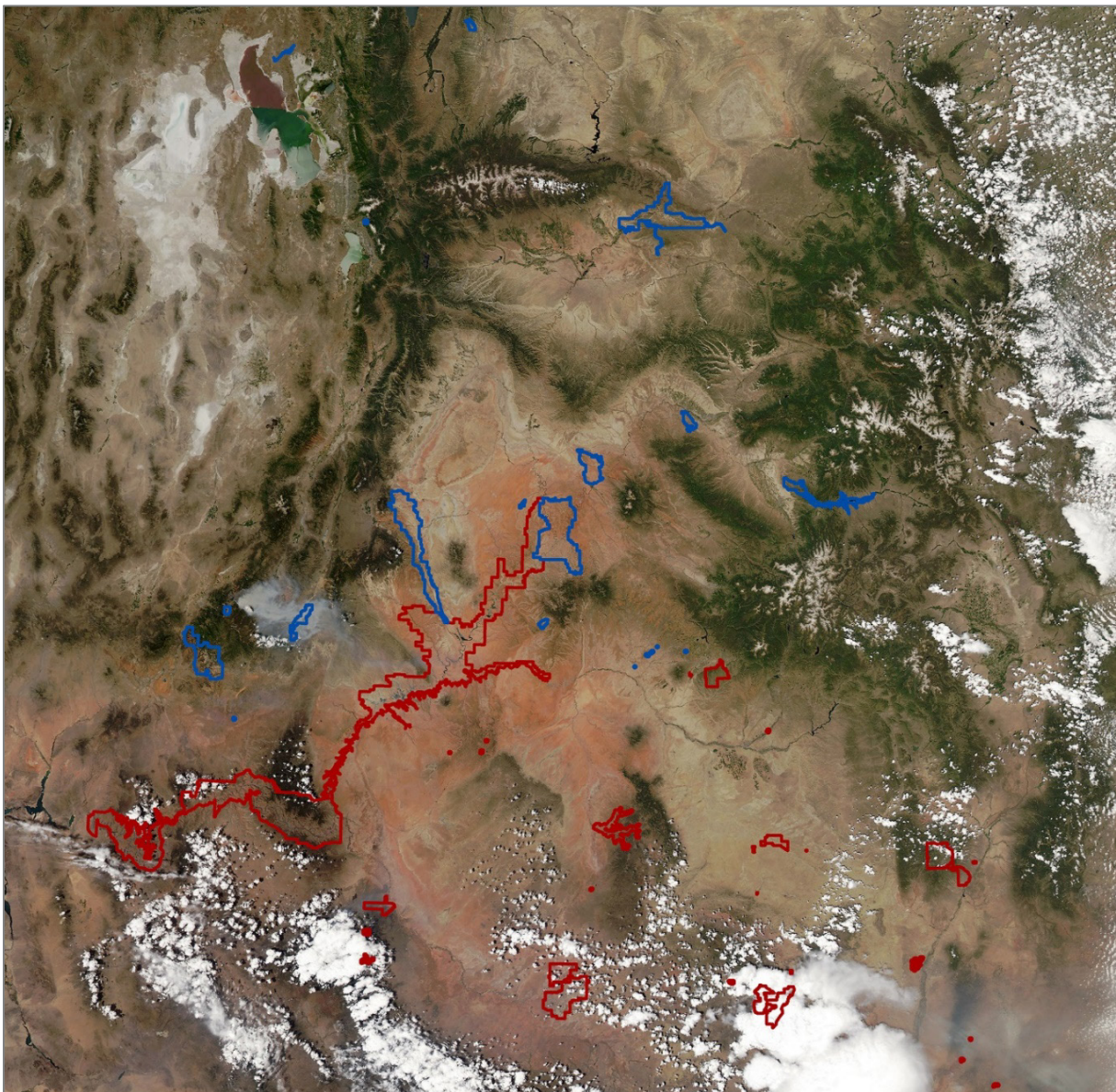




Northern Colorado Plateau Network Remote Sensing Protocol Science Review, 2023

A Summary of Reviewers' Responses and Recommendations



A satellite image from June 2017, illustrating how elevation shapes vegetation across the Northern Colorado Plateau Network (NCPN) parks.

NPS

Northern Colorado Plateau Network Remote Sensing Protocol Science Review, 2023: A Summary of Reviewers' Responses and Recommendations

Science Report NPS/SR—2026/436

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Abstract

A scientific protocol review of the Remote Sensing Monitoring Protocol for the Northern Colorado Plateau Network (NCPN) was conducted in 2023 as part of a larger review of multiple National Park Service (NPS) Inventory and Monitoring Network remote sensing programs. This comprehensive review included remote sensing programs in NCPN, the Southern Colorado Plateau Network, and the Southwest Alaska Network. Each program had completed a remote sensing trend report before the review, which was a prerequisite for the full protocol review. The Great Lakes Network and the North Coast and Cascades Network also participated to receive feedback on their current remote sensing operations but did not complete a full review. This document summarizes only the scientific protocol review for NCPN.

The review meeting was held February 28–March 2, 2023, in Tucson, Arizona. Staff from the five networks attended, along with peer reviewers. The overall goal was to evaluate current remote sensing efforts across these networks to maintain a program that is scientifically rigorous, relevant, sustainable, and impactful. The reviews specifically focused on assessing: 1) scientific integrity (i.e., credible, statistically valid analyses and conclusions), 2) management significance and impact to NPS parks, and 3) opportunities for collaboration, efficiency, standardization, and combining efforts across networks.

Overall, reviewers were impressed with the type of work and number of reports and publications derived from remote sensing work at NCPN. Moreover, they were impressed with the delivery of useful science on specific resources and their management to parks and noted that the number of analyses, sophistication of analyses, and amount of management-relevant information provided to parks had increased through time. Reviewers felt that protocol objectives were clearly being met and that analytical approaches employed by NCPN staff were sound and rigorous. With the sunsetting of the MODIS satellite, reviewers suggested NCPN adopt VIIRS satellite technology to continue their work, as it is the most congruent with the MODIS technology. Reviewers were pleased with the covariates being used in analyses and questions being addressed therein, which made the work more comprehensive and insightful. Reviewers also suggested using remote sensing data across larger landscapes to investigate larger-scale processes, and that standardizing imagery acquisition and analytical approaches across networks, while initially costly, would benefit multiple networks over time. In short, the NCPN remote-sensing work has been very successful in helping parks manage park resources and meeting the objectives of the Inventory and Monitoring Division's National Park science-support goals.

List of Abbreviations

GLKN: Great Lakes Network

I&M: Former abbreviation for the Inventory and Monitoring Division of the National Park Service

IMD: Inventory and Monitoring Division of the National Park Service

NCCN: North Coast and Cascades Network

NCPN: Northern Colorado Plateau Network

NOAA: National Oceanic and Atmospheric Administration

NPS: National Park Service

NRR: Natural Resource Report Series published from 2004 to 2024. This series was used to report information and analysis about natural resources on lands managed by the National Park Service.

NRTR: Natural Resource Technical Report Series published from 1996 to 2014. This series was used for reporting the results of studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission.

PI: Principal investigator

SCPN: Southern Colorado Plateau Network

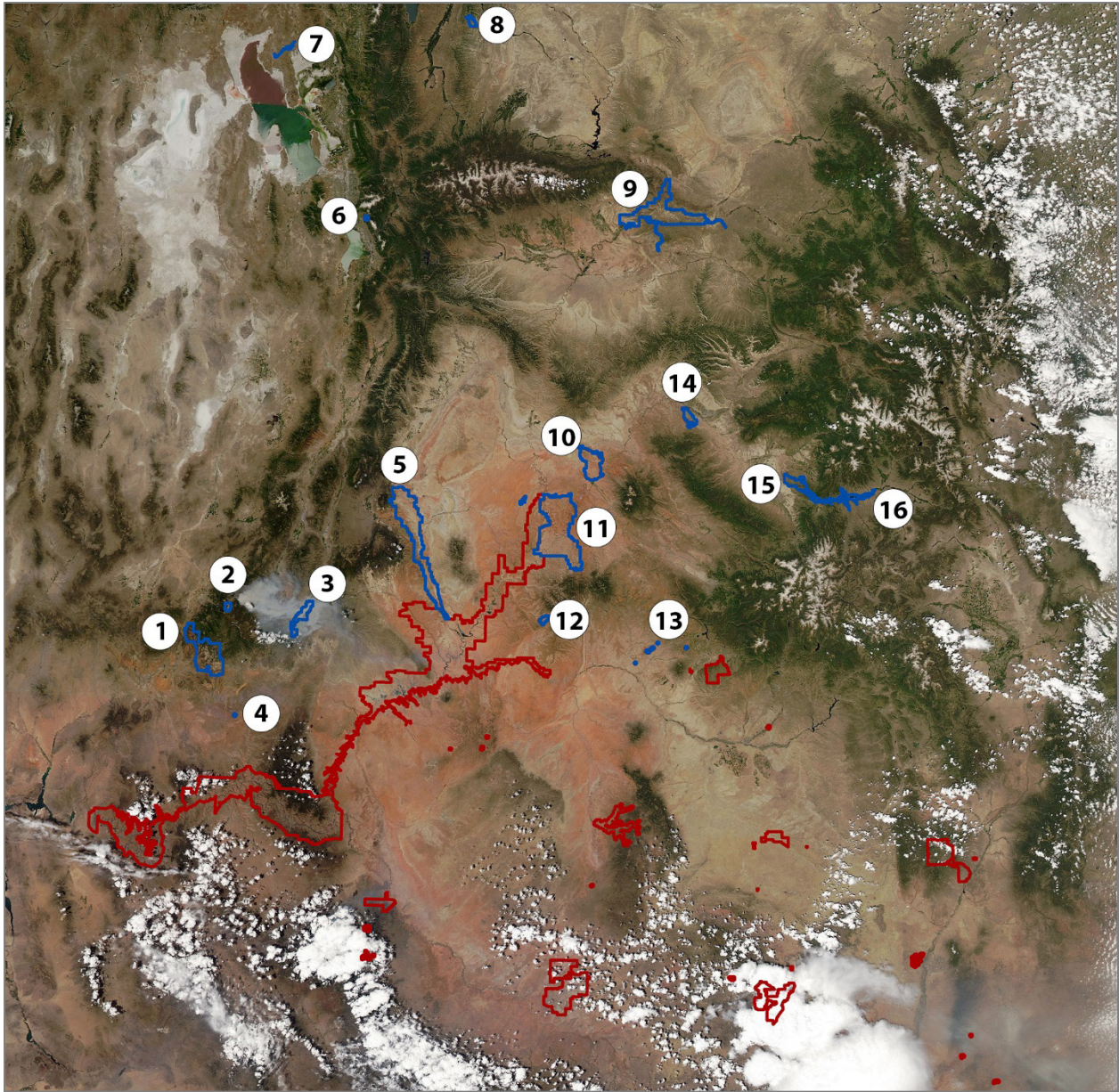
SWAN: Southwest Alaska Network

Acknowledgments

The Inventory and Monitoring Program began as part of the Natural Resource Challenge in 1998 (see [The Natural Resource Challenge: The National Park Service's Action Plan for Natural Resources](#)). From its inception through implementation, the dedication of early leaders—Mike Soukup, Gary Williams, Abby Miller, and Steve Fancy—helped turn this vision into reality by overcoming significant challenges to establish a long-term monitoring program that supports resource management in national parks and monuments.

Over the years, program staff across the country have ensured its continued relevance by providing science that informs management decisions nationwide. From coral reefs in the Caribbean to grasslands in the heartland, to deserts in the Southwest, to rainforests in the Pacific Northwest, and glaciers in Alaska, Inventory and Monitoring scientists apply their expertise to help parks use the best available science to protect resources for future generations.

We recognize and thank those early visionaries, as well as the more than 400 staff members who continue to uphold this commitment. Reviews such as this one honor their dedication to excellence and reinforce the value of science in guiding resource management decisions.



The cover and this page feature a satellite image from June 2017, illustrating how elevation shapes vegetation across the Northern Colorado Plateau Network (NCPN) parks. Greener areas show forested highlands, while lower elevations reveal sparse vegetation and exposed geology. Blue outlines mark NCPN park units, while red outlines indicate Southern Colorado Plateau Network (SCPN) units. For this report, numbered labels identify NCPN parks: 1) Zion NP (ZION), 2) Cedar Breaks NM (CEBR), 3) Bryce Canyon NP (BRCA), 4) Pipe Spring NM (PISP), 5) Capitol Reef NP (CARE), 6) Timpanogos Cave NM (TICA), 7) Golden Spike NHP (GOSP), 8) Fossil Butte NM (FOBU), 9) Dinosaur NM (DINO), 10) Arches NP (ARCH), 11) Canyonlands NP (CANY), 12) Natural Bridges NM (NABR), 13) Hovenweep NM (HOVE), 14) Colorado NM (COLM), 15) Black Canyon of the Gunnison NP (BLCA), and 16) Curecanti NRA (CURE).

NPS / ELIOT RENDLEMAN

Introduction

Periodic science reviews are essential components of all science programs. Reviews help ensure scientific integrity through rigorous peer review is maintained, allow for adjustments that integrate new technologies and analytical approaches, improve the relevance of science to better serve resource management staff, re-evaluate collaboration opportunities as new findings emerge, and ensure programs remain sustainable and relevant over time.

The periodic scientific review of National Park Service (NPS) monitoring protocols is also a requirement of the Inventory and Monitoring Division (Mitchell et al. 2018). This remote sensing protocol review is designed as a big-picture evaluation of study design, methods, data analysis, and interpretation and the delivery to our national parks and monuments of ongoing remote sensing monitoring at the Northern Colorado Plateau Network (NCPN), as well as insights gained from the program and its effectiveness in transferring information for use by land management agencies (see Figure 1 for an example of alliance group mapping using remote sensing at Arches National Park). This review critically examines the relevance of the work as a whole and the progress made toward each objective listed in the original protocol. Furthermore, it will assess overall constraints on the current program and recommend ways to improve its effectiveness. It should be noted that resource staff at each national park and monument selected the monitoring they felt would best help them manage resources in the park and answer their remotely sensed, landscape-level questions. This review was designed to ensure that scientific integrity was attained as well as the goal of integrating that information into park management. Multiple networks utilize remote sensing for long-term monitoring, so opportunities to collaborate more effectively and look at larger scale changes would increase the impact this monitoring has in helping parks manage resources.

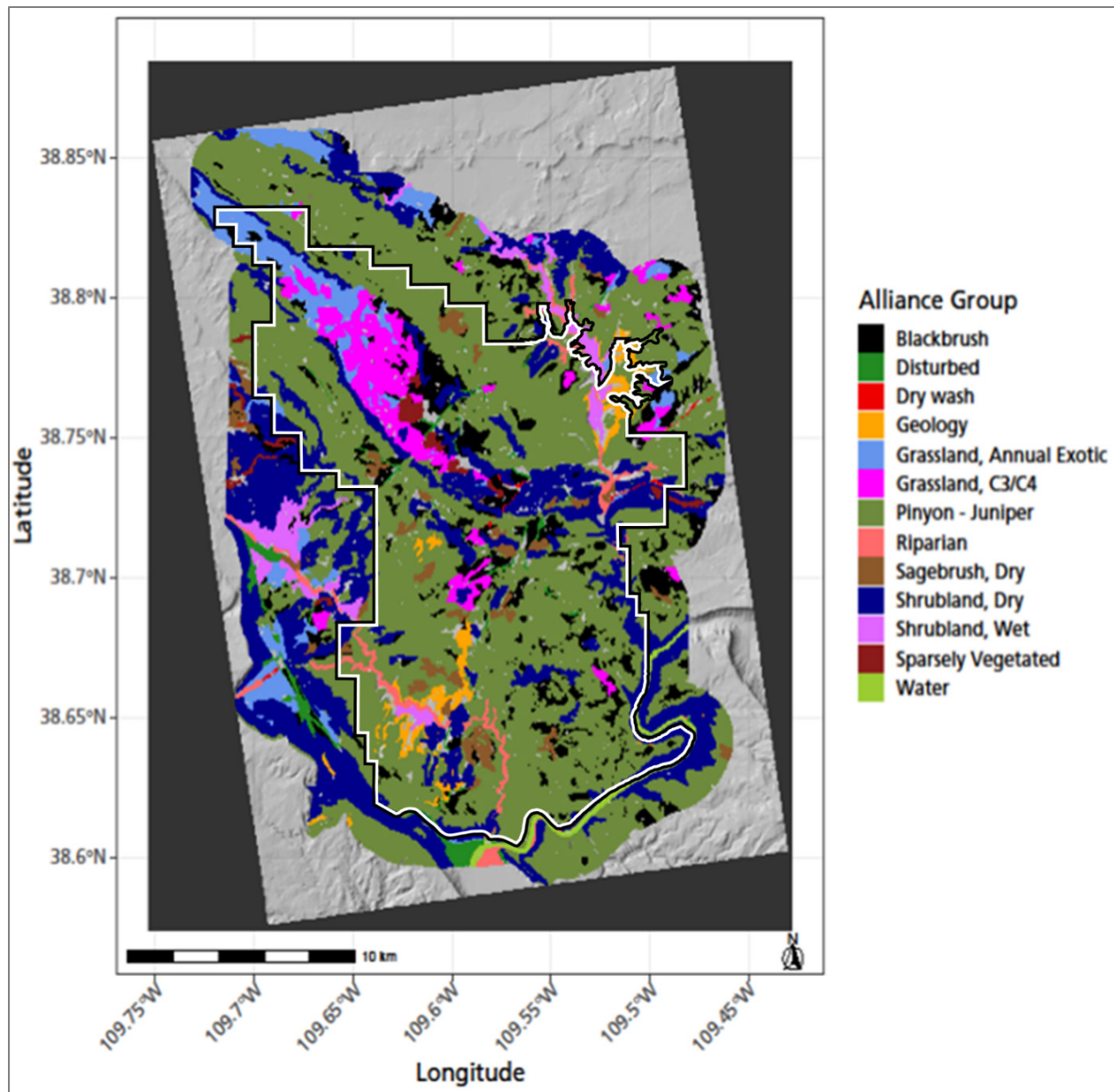


Figure 1. Example of an NCPN vegetation-mapping product that uses satellite imagery and field-verified classification to map vegetation alliance groups in Arches National Park. A highlighted boundary overlay indicates the extent of the park within the mapped vegetation area. Areas inside the boundary that appear uncolored represent alliance polygons smaller than the minimum mapping threshold (8.3 ha).

NPS / DAVID THOMA

Background

In 2023, Inventory and Monitoring staff from six networks—the Northern Colorado Plateau Network (NCPN), Southern Colorado Plateau Network (SCPN), Southwest Alaska Network (SWAN), Great Lakes Network (GLKN), and North Coast and Cascades Network (NCCN)—gathered in Tucson, Arizona, to have their remote sensing protocols reviewed. The impetus for the review was that many protocols within the Inventory and Monitoring Program had matured, accumulating enough information to conduct comprehensive trend analyses to determine whether the initial objectives were being met and whether the analyses and interpretations were valid.

During this process, one precondition for starting the in-depth portion of the scientific protocol review was that each network had to complete a peer-reviewed trend report for reviewers to evaluate. The overall goals of this review effort were:

1. to initiate scientific reviews of individual networks' remote sensing protocols to ensure the highest scientific standards for analysis and interpretation were upheld.
2. to assess the effective transfer of information to national parks and monuments for resource management needs, ensuring that the information is communicated effectively to parks and that they are using it.
3. to identify opportunities for collaboration.
4. to determine whether scaling up remote sensing monitoring is feasible and desirable across larger geographic areas using U.S. National Park Inventory and Monitoring Network efforts.

This review document focuses on the NCPN Remote Sensing protocol. For an example of a remote sensing product used in these reviews, see Figure 2.

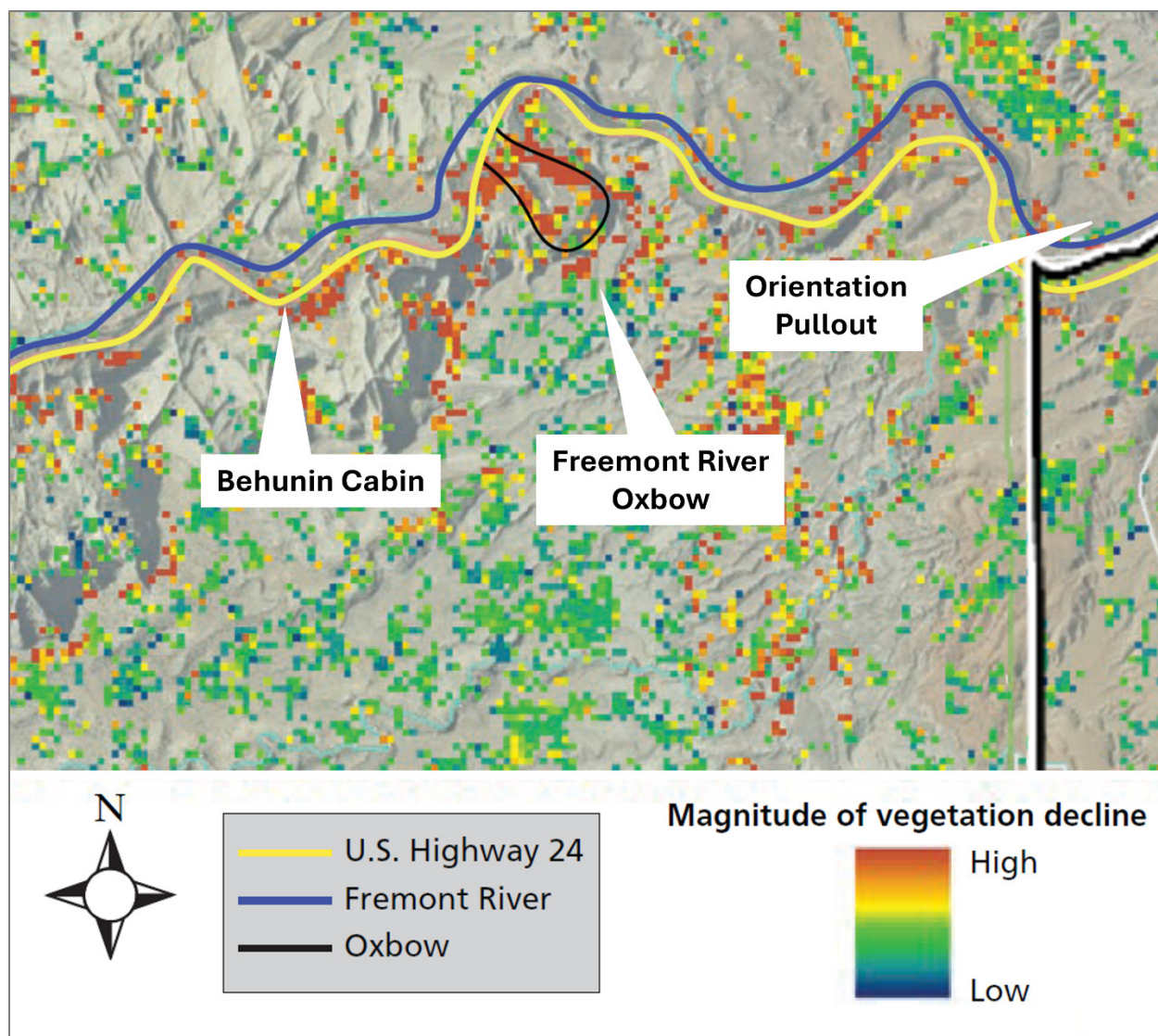


Figure 2. Example of an NCPN remote-sensing product illustrating Landsat-derived vegetation-change patterns for Capitol Reef National Park. This subset focuses on the area between Behunin Cabin and the Orientation Pullout, showing vegetation-change magnitude from 1986 to 2009. Pixel colors represent relative levels of change, and reference overlays identify U.S. Highway 24, the Fremont River, the Fremont River oxbow, and the portion of the park boundary visible within the mapped extent.

OREGON STATE UNIVERSITY / ROBERT KENNEDY

Summaries, Conclusions, and Recommendations

Made by Michael Bozek, Inventory and Monitoring Program Manager–Intermountain Region.

Review Organizers

- Peter Kirchner, Southwest Alaska Network
- John Boetsch, North Coast and Cascades Network
- Jodi Norris, Southern Colorado Plateau Network

- Al Kirschbaum, Great Lakes Network
- Dusty Perkins, Inventory and Monitoring Program Manager–Northern Colorado Plateau Network
- Jim Lawler, Inventory and Monitoring Program Manager–Alaska Region
- Michael Bozek, Inventory and Monitoring Program Manager–Intermountain Region

Reviewers

For the NCPN portion of the review covered herein, three remote sensing experts from outside the network were recruited to participate and provide their findings:

- Andrew Bliss, Southwest Alaska Network, Inventory and Monitoring Division, National Park Service
- Yun Yang, Assistant Professor, Forest and Wildlife Research Center, Mississippi State University
- Parker Martyn, Inventory and Monitoring Division, Alaska Region (AKR), National Park Service

Background Material Sent to Reviewers

Program Overview

Fancy, S.G., and R.E. Bennetts. 2012. Institutionalizing an effective long-term monitoring program in the US National Park Service. Pages 481–497 in R.A. Gitzen, J.J. Millspaugh, A.B. Cooper, and D.S. Licht, editors. Design and analysis of long-term ecological monitoring studies. Cambridge University Press, Cambridge, United Kingdom.
<https://doi.org/10.1017/CBO9781139022422.029>

Protocol

Thoma, D., J. Norris, and P. Lauck. 2017. Satellite-based vegetation condition and phenology, and snow cover extent monitoring protocol for the Northern and Southern Colorado Plateau Networks. Natural Resource Technical Report NPS/SCPN/NRRR—2017/1533. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2246068>

Peer-Reviewed Trend Report

Thoma, D. 2022. Landscape phenology, vegetation condition, and relations with climate at Colorado National Monument, 2000–2019. Natural Resource Report. NPS/NCPN/NRR—2022/2384. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/nrr-2293476> [Summary [web article](#)]

Other Protocol-Related Remote Sensing Publications

Thoma, D.P., S.M. Munson, K.M. Irvine, D.L. Witwicki, and E.L. Bunting. 2016. Semi-arid vegetation response to antecedent climate and water balance windows. Applied Vegetation Science 19: 413–429. <https://doi.org/10.1111/avsc.12232> [Summary [web article](#)]

Thoma, D.P., S.M. Munson, and D.L. Witwicki. 2019. Landscape pivot points and responses to water balance in national parks of the southwest US. *Journal of Applied Ecology* 56: 157–167.
<https://doi.org/10.1111/1365-2664.13250> [Summary [web article](#)]

Reviewer Homework

Reviewers were sent background material to put this protocol into context, referred to as “Homework,” prior to the in-person Remote Sensing meeting. See Appendix C for the complete set of information provided.

Key Meetings

- February 3, 2023: Review Orientation and Pre-Meeting Overview. Review process outlined; leads from each protocol and reviewers in attendance; brief snapshot presentations of remote sensing work by each network.
- February 21, 2023: Overview of the Tucson review meeting and review process; I&M program managers and reviewers in attendance. One hour.
- February 28–March 2, 2023: NCPN, SCPN, SWAN Remote Sensing Protocol Review in Tucson, AZ. GLKN and NCCN participated.
- March 16, 2023: Post-Remote Sensing Protocol Review Meeting. Reviewers and protocol leads have discussions to elucidate any final questions reviewers have regarding information presented or in publications they were reviewing.

Final Review Process

Following the Remote Sensing Protocol Review, “snapshots” and protocol review presentations, and review of the reports and publications, reviewers provided their evaluations. These are summarized herein (narrative), with complete unedited responses included in the appendix.

Current Protocol Objectives and Rationale

Reviewers were informed of the objectives and rationale of the current remote sensing protocol as they are described in Thoma et al. (2017). Protocol objectives include the following:

1. Determine annual status, interannual variability, and long-term trends in the growing season as measured by NDVI (including peak spring and monsoon season dates and intensity; annual peak NDVI intensity and timing; and minimum NDVI) within select ecosystems.
2. Determine annual status, interannual variability, and long-term trends in the timing and duration of snow cover (e.g., establishment of snowpack, persistence, timing and rate of melt) within select ecosystems.

For an example of a remote sensing product that supports these protocol objectives, see Figure 3. In the remote sensing protocol, Thoma et al. ([2017, p. vii](#)) described the rationale as follows:

Vegetation phenology and condition have been identified as core vital signs for long-term monitoring in the Northern and Southern Colorado Plateau Networks [NCPN, SCPN]...The timing, intensity and duration of greenness provide important information about changes in vegetation condition and shifts in phenology...Monitoring the variability and trends in the timing and intensity of vegetation phenology, as well as snow cover extent may provide early indicators of climate change impacts that represent increased stress or vulnerability for plants and animals, or may presage gradual or sudden vegetation community shifts.

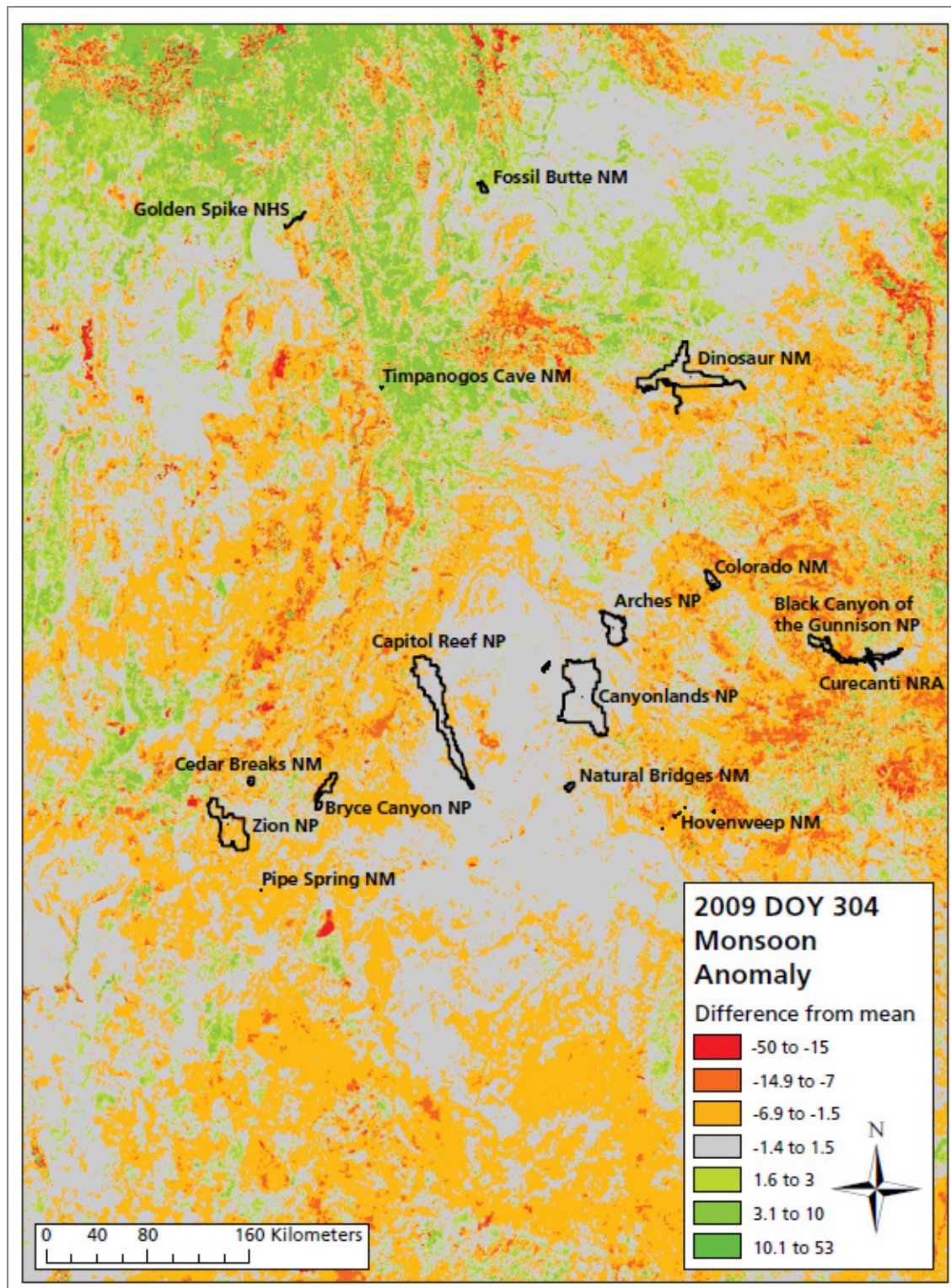


Figure 3. Example of an NCPN remote-sensing product showing the 2009 monsoon-season anomaly, mapped as the difference between Landsat-derived NDVI on Day of Year 304 (October 31) and the long-term average. This is included here to demonstrate how regional anomaly maps can be generated and visualized using time-series satellite imagery across NCPN parks.

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Review Questions

Two sets of questions were sent: one set to the protocol reviewers and a separate, more management-oriented set to resource chiefs and superintendents of NCPN parks.

Protocol Questions Sent to Reviewers

Reviewers were asked to respond to the following questions, which were designed to assess the scientific integrity of the monitoring design and its statistical rigor; opportunities to scale up analyses with proximal or regional efforts; the detectability of climate change effects and other covariates; the impacts of funding cuts or potential increases; and the validity of conclusions drawn.

1. Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?
2. Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?
3. Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?
4. Are the conclusions drawn from major findings appropriate?
5. Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?
6. What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?
7. How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?
8. Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?
9. How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?
10. Summary of thoughts and recommendations.

Management Questions Sent to Parks

1. Have you found the remote sensing monitoring data (NDVI productivity and phenology metrics, water balance, pivot points) to be useful to your park? In what ways?
2. How have you used remote sensing data (NDVI productivity and phenology metrics, water balance, pivot points) for specific management decisions or public education? Please elaborate.

3. We think that the remote sensing monitoring data (NDVI productivity and phenology metrics, water balance, pivot points) is underutilized and several other parks and NPS programs have used the data for management decisions. Are there significant hurdles that preclude you from using these data?
4. What has been the biggest benefit of having a remote sensing monitoring program?
5. What do you feel is the biggest value of the remote sensing monitoring program?
6. Are the remote sensing products you get from NCPN (reports, peer-reviewed papers, web articles) satisfactory to your needs?
7. What is the value of understanding relationships between primary production and climate in your park?
8. What do you wish the remote sensing data (NDVI productivity and phenology metrics, water balance, pivot points) could provide but currently does not?

Summarized Reviewer Responses

The following are the summarized review responses from Parker Martyn (PM), Yun Yang (YY), and Andrew Bliss (AB) regarding the Northern Colorado Plateau Remote Sensing Protocol Review. In the narrative that follows, summaries of reviewer comments are presented first, followed by portions of their specific answers to each question. The complete responses can be found in Appendix A.

General Review Synthesis

Reviewers were generally impressed with the protocol's study design and the body of work produced by NCPN. They noted the number and quality of reports as "high quality and impressive," and commented that the work clearly exceeded the original, narrower objectives of the protocol.

Where noted:

- PM = Parker Martyn
- YY = Yun Yang
- AB = Andrew Bliss

Question 1

Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?

The answer among all reviewers was an unequivocal "Yes" to both questions. PM in particular discussed at length the two versions of the protocol and how each one was meeting the protocol objectives. Moreover, PM also commented on how the lessons learned during implementation of the first 10 years of monitoring and analysis were used to improve the protocol in the second version. In particular, PM cited "1) vegetation was of more interest to staff than snow, 2) higher resolution spatial data was desired over parkwide summaries, 3) anomalies were more important to park staff than overall trends, and 4) results/findings need to be frequently conveyed in simple and concise formats in order to be useful to park staff." As a result, the adjustments made to the protocol following the initial 10 years increased the science communication transfer to park managers by: 1) utilization and presentation of water balance modeling, 2) identifying water balance windows, and 3) focusing on climate pivot points, which are the conditions in which vegetation communities shift.

Question 2

Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?

Reviewers felt that the analytical and data extraction methods being used for the objectives of the protocol were appropriate and that it was clear that the protocol lead demonstrated his awareness of alternative methods available. As a result, no alternative approaches were recommended by reviewers. PM indicated that the trends analyzed were appropriate but also commented that the

“water balance” metric is a derived value as opposed to a direct measurement. He didn’t indicate that it was a problem; just pointed it out and wondered the degree to which it was just another version of previously used metrics in this regard (i.e., duplicative). YY was pleased with the image processing and analytical methods used to meet the specific objectives of the protocol. She also found the pivot-point analysis to be inspiring, linking long-term remotely sensed data and the climate change impact. AB concurred with the other reviewers being impressed that the presentation and papers incorporated excellent statistical methods and was impressed that the network was aware of and using alternative remote sensing methods.

Question 3

Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?

Two reviewers offered insights into technological options moving forward that the network should consider. Both PM and YY pointed out that MODIS was ending and that this created incentives and opportunities for considering other remote sensing technologies. They both indicated the use of [VIIRS](#) satellite imagery (or similar technologies such as [Planet Fusion](#)) would be a likely next step in moving forward with image extraction and analysis. PM suggested their (i.e., these platforms’) greater spatial and temporal resolution would improve analyses, but felt those cadences of imagery collection would be more in line with climate/weather data. Moreover, PM felt that by using several approaches, issues such as cloud coverage, shadows, aerosols, smoke, water vapor and other visual hindrances could be better overcome. YY also suggested testing and incorporating Landsat and Sentinel 2 data, and the Harmonized Landsat and Sentinel (HLS) dataset published by NASA. Moreover, for water balance analyses, which NCPN uses extensively, YY suggested another dataset; the 30-m actual evapotranspiration dataset from OpenET project (<https://openetdata.org/>). One other suggestion by PM that would open up information transfer was his suggestion to develop a smart-phone app allowing park resource staff to more easily and readily access information.

Question 4

Are the conclusions drawn from major findings appropriate?

All three reviewers felt the conclusions drawn from the work were appropriate and accurate. PM commented that “appropriate” to him meant that conclusions/interpretations were not only accurate and realistic, but that they were also useful to park management activities. He particularly noted that water deficit and deficit pivot-point work linked to drought-stressed vegetation was an excellent example of this work helping managers predict how plant ecology overall was being impacted. AB noted the extent to which satellite data was being integrated with climate data, soil cores, and ground-truthed vegetation plot data.

Question 5

Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?

Two reviewers felt that all appropriate covariate data were being used in analyses (YY, AB) and complimented how various sources were being used and integrated into analyses. Similarly, PM complimented the work that has been done and indicated that while many covariates were being used, he suggested that additional value could be obtained by conducting larger scale, latitudinal/longitudinal analyses over broader geographic areas, and in particular, similar analyses among different parks beyond the network boundaries to infer larger scale processes and patterns. Moreover, he saw the value in work that was being done and especially indicated that there was an opportunity for other networks to benefit from the work already being pioneered in parks.

Question 6

What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?

All three reviewers responded by being in favor of merging remote sensing approaches and supported collaborating on projects among networks. PM provided the most insight: He indicated that much of the work in getting these protocols established has already been done, and any networks adopting these procedures will already have much of the development work done, such as the R coding being used in data extraction and analyses. Moreover, adopting pre-existing approaches allows for straightforward standardization and can be easily upscaled across larger landscapes. Phenology, for instance, could be compared to assess if different areas are following similar patterns and trends. PM felt that an additional benefit would be the larger pool of experts working on these analyses, where sharing code and analytical approaches would create efficiencies in producing scaleable products across multiple networks. PM also talked costs. Foremost was that any transition that would occur would result in the adjustments and training to get staff up-to-speed on new approaches. Workflows would need to be adjusted, and the issue of compatibility between older approaches and newer approaches and metrics would need to be worked out. In some cases, spatial or temporal resolution would differ, making some continuity problematic.

Question 7

How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?

All three reviewers felt that pivot point analyses that indicate when vegetation in a landscape will/can change due to changes in soil moisture were valuable uses of the work to date. YY suggested that integrating this information with Google Earth Engine and Landsat would yield very helpful information to parks. PM also provided a list of ways he saw the data being utilized regarding climate change as follows:

1. *Identify vegetation sensitivity to changes in weather variables and overall climate*
2. *Measure on-going vegetation production over time at various landscape scales*
3. *Identify pivot points for vegetation types, soil types, hydrographic regimes, and topographic settings*

4. *Forecasting phenology and production trends given various climatic scenarios*
5. *Inform management goal setting by using pivot points as triggers for management actions*
6. *Identify ecological sensitivities and conduct vulnerability assessments*
7. *Assist in park planning and climate-adaptation by informing and integrating with the planning process*
8. *Integrate data outputs into wildland fire forecasting activities*
9. *Collaborate with wildlife biologist and develop relationships to habitat, migration routes, and species distribution*
10. *Work with park infrastructure designers and planners to forecast environmental and landscape changes they can anticipate as a result of climate change*

Question 8

Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?

AB thought the collaborations to date were very productive and gave the program compliments for their work collaborating thus far, but did not make additional suggestions. PM saw value in NCPN working more closely with Alaska Inventory and Monitoring Networks; the region that he is located in. He again promoted collaboration as a more effective and efficient approach to product development and trouble-shooting. He further suggested that such collaborations would indeed improve the quality of the work already being done and that by having multiple networks collaborating, they could develop a more efficient workflow (i.e., data management, R-coding, Quantitative Ecology, science writing, etc.). YY thought it would be of great mutual benefit if NCPN would participate in Satellite Product Science Teams that consist of specialized, multidisciplinary groups of researchers, engineers, and application specialists from various government (NASA, USGS, NOAA), and other entities (e.g., universities and industry). She suggested that for MODIS, VIIRS and Landsat, there are science teams specifically aligned with those products and the scientists on these teams meet at least once per year.

Question 9

How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?

In short, all reviewers agreed that additional funding would result in significant benefits and increased science delivery information for parks. Benefits of additional staff being hired include increasing the analytical capabilities of the program in the form of hiring Quantitative Ecologists and Scientists in Parks interns, or providing additional funding for cooperators with specific capabilities, for instance, which would increase the workflow, help develop additional analytical tools, provide an opportunity to access additional satellite subscriptions such as Google Earth Engine, and allow more frequent meetings to exchange information with colleagues developing new approaches to using satellite imagery. Collaborations among colleagues dealing with specific questions regarding grazing

management, streamflow, fire danger and disease were among the specific examples given where collaboration could increase the impact of remote sensing work.

Conversely, reduced budget would promulgate reducing or simplifying analyses, reducing the numbers and types of report generated, and would clearly affect questions being asked and support provided to parks, thus reducing the output from this monitoring. Staff would need to prioritize the most important metrics and covariates and focus just on them, which would allow the most significant information to still be generated by the network. One idea was to reduce analyses related to snow that are not part of Water Balance modeling, which was an interesting suggestion, but additional thought would be required to understand the consequences and seeking park input would be paramount. Additional collaborations could stem some of the reduced output, although some of these efficiencies are already in place.

Question 10

Summary of thoughts and recommendations.

Actual verbatim summary statements from reviewers:

Yun Yang:

In summary, the objectives for the monitoring program are clear, relevant and achievable. The research and analyses from the NCPN's remote sensing program are very impressive. Appropriate data has been collected and analyzed. The analysis methods are straightforward and efficient. The conclusions are drawn based on the collected data and analysis.

Reaching out to the satellite science teams could gain help with understanding the satellite product and increase the impact of NPS remote sensing monitoring work. Reaching out to experts in related fields could be helpful to collaborate both inside and outside the NPS remote sensing monitoring group. Organizing webinars in related research topics would be a good way to start. Creating a working group could be helpful in organizing the webinars and starting the collaborations.

Parker Martyn:

I really like the concept of pivot points. Very easy to understand. Maybe it exists, and I just didn't see it, but it would be nice to see more example graphics that illustrate historical, best case, and worst case [forecasts] of various pivot point variables and scenarios. I'd also like to see the "backcasts" compared to historical data. Is that possible? If so how well do the backcasts line up with what actually happened? ([Thoma 2022, Figure 4-2, p. 47](#))

I also really like that the protocol relies on the USNVC. This allows for national level comparisons because it is a national standardized vegetation classification system.

Looking forward, I think new technology will open up many doors that are currently limiting access to data. For instance, becoming satellite agnostic will be very possible, in my opinion, because the volume of satellites being launched today is growing by leaps and bounds, and indexes like NDVI and SAVI will become more ubiquitous.

High spatial and temporal resolution satellite data (daily, <1 m pixels) is becoming the norm, so plan on metrics that are generated from such datastacks.

Information needs to be mobile, and mobile options to access and use outputs provided by this protocol should be provided to park staff.

Andrew Bliss:

No summary response.

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Appendix A: Complete Reviewer Comments

Text in square brackets indicates places where spelling and grammar corrections were made.

Responses to NCPN Protocol Review Questions

Responses from Parker Martyn (Alaska Inventory and Monitoring Program, NPS)

Question 1

Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?

Yes. During the first 10-years of the protocol vegetation and snow monitoring objectives were clearly met, and achieved. Metrics for vegetation annual status, interannual variability, long-term trends in growing season, key seasonal phenology dates, and duration of growing season metrics were all measured and adequately summarized. Snow metrics for annual snow status, interannual variability, long-term trends in timing and duration were all achieved, and clearly summarized within select ecosystems. While objectives of the first [iteration] of the protocol were mostly met, several lessons were learned: 1) vegetation was of more interest to staff than snow, 2) higher resolution spatial data was desired over parkwide summaries, 3) anomalies were more important to park staff than overall trends, and 4) results/findings need to be frequently conveyed in simple and concise formats in order to be useful to park staff.

Version 2 of the protocol also achieved several of the objectives, but it took from the lessons learned in version 1 and expanded on more useful observations that could be better understood by park managers. This meant advancing the protocol in three areas: 1) utilization of water balance modeling, 2) identification of water balance windows, and 3) focusing on climate pivot points. By advancing the protocol in these three areas the vital signs monitoring effort has been able to determine several key indicators with regards vegetation: annual status of vegetation, identify long-term trends in growing season production, monitor start, end, peak of season dates and measure the duration and intensity of growing season. Snow monitoring has now been replaced by snow modeling within the water balance model, and thus determination of annual snow status, interannual snow variability and long-term assessment of trends of snow monitoring objectives are not being performed in the new version of the protocol. Although snow has been identified as a covariate in production and phenology analysis by I&M staff, it is unclear to me [whether] this statement refers to modeled snow within the water balance model, or actual measured snow.

Nevertheless, the objectives for this monitoring program are still clear, relevant, and achievable. And despite identifying some hurdles related to limited access to experts for [esoteric] questions, and limitations of time on both science staff and park managers to tune and use the protocol models and outputs, there are still clear goals being set and next steps being taken to continue producing [relevant] and useful products that aid in park management. Even with influences such as climate change that continue to shift demands of data and product requirements, NCPN staff are attempting to build and deliver ecological forecasts across scales for vegetation that are applicable to grazing

management, stream flow and temperature relationships, for fire danger and drought monitoring, and identification of forest diseases. To do this, NCPN staff are embracing the use of powerful technology such as Google Earth Engine, R, and responding as much as possible to park needs.

Question 2

Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?

Yes. Although the results of the protocol are not explicitly “factual”, so to speak, the analysis within the protocol is heavily based on modeled metrics that have been shown to correlate well with factual measured values (e.g., daily and monthly discharge flows, seasonal importance of water balance terms related to precipitation levels, etc.) and can be used as proxies for fact-based mensuration. Image processing and analytical methods are used appropriately, too. For instance, image analysis of regional patterns of drought stressed vegetation at NABR visitor center is a good example that shows statistical relationships of wet and dry landscape [conditions] derived from imagery to convey areas of modeled water deficits.

With regards to alternative methods that could be considered I only have one comment and it is related to the protocol’s water deficits modeling. As I heard the description of this [analysis] at our workgroup meeting, I wondered if the protocol was re-inventing development of drought indices? I wondered how well the NCPN model matched off-the-shelf indices like the PDSI, or NFDRS, or NDWI, etc., and whether they could/should be used instead.

Question 3

Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?

The use of Google Earth Engine and R code appears to be very efficient and is a powerful way [to] process the different components of the protocol. I suppose it is possible that additional satellite observations by using satellites with more frequent cadences, or simply using additional satellite sensors could allow for more and improved viewing opportunities, and therefore near real-time calculations of phenology and productivity. Although MODIS is being used I believe the platform is aging and a replacement will soon be needed to provide protocol continuity. [Planet Fusion](#) or [VIIRS](#) satellite imagery may offer the next evolutionary step in creating phenology records that would be of higher resolution, in both spatial and temporal resolution. Their daily cadences and higher spatial resolution may also align better with climate/weather point data being used. I also wonder if using more than one satellite dataset would help, by performing data fusion. For instance, is it possible that VIIRS and/or Synthetic Aperture Radar (e.g., Sentinel-1, or equivalent), could help eliminate issues with clouds, shadows, aerosols, smoke, water vapor, and/or other general poor viewing issues? In short, perhaps the addition of such fused products could increase the number of high-quality viewing opportunities of the phenology products.

Because NDVI, SAVI, and similar [indexes] are calculated equations based on sensor wavelength (band combinations), I would suggest the protocol should strive towards becoming satellite agnostic. Perhaps focus on using the best available sensor datasets, and not be beholden to a specific dataset, if possible. There are any number of satellites that have sensors on-board which are capable of creating the calculated metrics such as NDVI, or SAVI. Of course, there would be a need for calibration and validation of such fused datasets, and new workflows to be created. But I am sure there are plenty of commercial vendors and/or university affiliates with the computing resources willing and able to perform these tasks. In turn, this would allow numerous more viewing windows to open up which would increase availability of high quality data. My take-home message is “Use more satellite data”– there are many more opportunities available today than when this protocol was first implemented, and the list is getting longer every day, so be more agile.

Also, as mentioned in the workshop meeting, I think development of an App that park staff can use on their smart-phones would be an excellent way to distribute the reports and science data. This could replace the weekly emails, and slick sheets that are being generated, and provide more real-time information access by park managers. I could also see how it might allow for more place-based and fine-scale analysis and reporting if results could be generated on the fly, say for a set of metrics at a given location as compared to the 30-year average for that same point, i.e., point based deviation from the norms.

Question 4

Are the conclusions drawn from major findings appropriate?

Yes. The term “appropriate” to me means that the findings represent realistic conclusions and interpretations of what is taking place on the ground, and that the findings are useful to park management activities. The vital signs monitoring protocol findings have identified plant/water requirements relationships very well. For instance, drought stressed vegetation has been clearly linked to measured water deficits, and these water deficit pivot points provide indications of drought tolerances of various vegetation types. In short, the protocol shows that vegetation can be used as an environmental sensor for park managers to predict how park ecology (plants, soils, water bodies, wildlife, etc.) may be affected given anticipated climate changes (i.e., changes in temperature and precipitation, etc.). As an example, by monitoring changes and trends in weather variables, and how such changes relate to vegetative productivity, park managers can anticipate where disturbances in vegetation may occur within their parks given multiple climate scenarios.

Question 5

Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?

My statistical background is not very strong, so I don’t feel qualified to dive deep into this question. But from what I can tell, yes, many appropriate covariates are used and studied within the protocol. Although there are multiple examples of spatial distribution and patterns of pivot points related to vegetation, precipitation, soil properties, etc. within the provided reading material and the workshop

presentation, I did not notice a discussion of how geographic position, specifically latitude and longitude, as covariates may influence results or trends. It may be implied, or the geographic extent may not be great enough to make a difference. But I am thinking if these methods are someday applied in other networks (i.e., Alaska networks) it may be helpful to better understand the relationships these two covariates [latitude/longitude] have with vegetation and snow phenology, their associated patterns, and variability, when looking at large expanses or making comparisons across multiple parks and/or networks.

Question 6

What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?

Costs: There would be a variety of learning curves network staff would need to overcome, which would add to the cost of on-going monitoring efforts. New data stacks and code will need to be developed for workflows not currently being used by the adopting networks. In some cases, where there may be workflows or metrics that are currently being produced and are in common across networks, the way to achieve those metrics may differ. Once calculated by new methods the new results may differ from the old metrics, causing a diversion that would create a period of transition, troubleshooting, and calibration to identify the best and most appropriate method of generating the needed results. This will also mean existing workflows and method that took considerable amounts of time to develop may be abandoned. Additionally, in some cases, datasets may not exist or may not be available at appropriate temporal or spatial resolution, and work-arounds to fill in data gaps may need to be developed.

Benefits:

- With regard to applying this protocol's workflows to other networks, much of the legwork (approximately 20 years' worth!) for generating the initial metrics has already been done, which is a huge lift and benefit if it is applied across networks. Computer code and workflows have already been produced and ported to GEE and/or developed in R, which means they can be leveraged and modified by other Networks as needed, without the need to start from scratch. Plus, if multiple networks utilize the protocol, there will be a consistency and standardization of methods that will result in similar metrics that will provide an ability for cross-network, and potentially service-wide, trend reporting related to vegetation and snow phenology as key indicators of climate change. This will allow parks and networks across the country to identify and compare pivot points, monitor and forecast impacts related to climate change, and/or prepare for and respond to such changes in coordination with each other. Or, better yet, the protocol could be applied to all appropriate networks and centralized (i.e., one network or office runs metrics for all networks).
- Merging other Network protocols with NCPN's has added benefits that will allow the network to possibly address some of its current hurdles. For instance, by increasing cross-[network] collaborative efforts NCPN could deepen its pool of experts which could help answer some of the more esoteric questions within the protocol. It may also provide help in

developing new code and/or enhancements or workflows by increasing available staff that are working towards common goals. It could also reduce the silo effect that many network activities experience.

Question 7

How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?

What follows is a list of ways this protocol could be used to address climate change and integrate the information with other efforts to maximize utility of the data for managing conservation at multiple scales:

1. Identify vegetation sensitivity to changes in weather variables and overall climate
2. Measure on-going vegetation production over time at various landscape scales
3. Identify pivot points for vegetation types, soil types, hydrographic regimes, and topographic settings.
4. Forecasting phenology and production trends given various climatic scenarios
5. Inform management goal setting by using pivot points as triggers for management actions
6. Identify ecological [sensitivities] and conduct vulnerability assessments
7. Assist in park planning and climate-adaptation by informing and integrating with the planning process.
8. Integrate data outputs into wildland fire forecasting activities
9. Collaborate with wildlife biologist and develop relationships to habitat, migration routes, and species distribution.
10. Work with park infrastructure designers and planners to forecast environmental and landscape changes they can anticipate as a result of climate change.

Question 8

Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?

Yes. I think Alaska Networks in particular could benefit from at least investigating if this protocol could be adopted and/or enhanced for application to the Alaska Region. It would be interesting to know if required data inputs for the modeling efforts are available and/or the same caliber for Alaska as they are for NCPN. Another thought would be to spread protocol implementation functions (i.e., data management, R-Coding, QE, science writing, etc.) across multiple networks so the burden of producing output products doesn't fall on each network, or doesn't fall on one particular network (e.g., division of labor). Finally, with more SMEs participating in the implementation of the protocol,

chances are the outcomes will be of higher quality because [there] will be more people scrutinizing the development of the protocol.

Question 9

How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?

Increase in Budget: Numerous benefits could result from an increase in budget. Point source location information and an App for smartphones would help managers understand specific conditions for any (most) places within their parks if they had access to it on their cell phone. Additional personnel in the form of Quantitative Ecologists (QE), Scientist in the Park (SIP), temporary details, or university cooperators could help in data collection, data management, code development, data analysis, and more. Additional funding may also allow for the purchase of data subscriptions for additional commercial satellite data (i.e., [Planet Data](#), SAR Data) or software that currently may not be available for free. Additional funds could provide opportunities for holding annual interagency workshops on vegetation and snow phenology that may help build partnerships and tap into new subject matter expertise. For instance, such workshops could increase collaborations related to calibrating response relationships to grazing management, stream flow and temperature, fire danger, [and] forest disease.

Decrease in Budget: Not knowing all the expenses related to the implementation of the [protocol] it is difficult to answer this portion of the question. As such, I offer the following ideas for consideration should the budget need to be trimmed. For instance, fewer metrics could be generated. Since snow was identified as being less useful to park staff, consider dropping any metrics and reporting related to snow that are not part of the water balance modeling efforts. Consider reducing travel, and/or fieldwork, and increase the use of freely available remotely sensed datasets collected by others. Try producing products as much as possible through office and desktop efforts, rather than directly collecting field data and observations. Consider reducing the number of reports that are produced which do not have direct application to management actions. Increase collaborations with other agencies and cooperators to leverage project funds and use other people's money to get the job done as much as possible. And finally, partner with other agencies on similar efforts to reduce overhead costs and increase economies of scale.

Question 10

Summary of thoughts and recommendations.

1. I really like the concept of pivot points. Very easy to understand. Maybe it exists, and I just didn't see it, but it would be nice to see more example graphics that illustrate historical, best case, and worst case [forecasts] of various pivot point variables and scenarios. I'd also like to see the "backcasts" compared to historical data. Is that possible? If so how well do the backcasts line up with what actually [happened]? i.e., Figure 4-2, page 47, NRR 2022/2384.
2. I also really like that the protocol relies on the USNVC. This allows for national level comparisons because it is a national standardized vegetation classification system.

3. Looking forward, I think new technology will open up many doors that are currently limiting access to data. For instance, becoming satellite agnostic will be very possible, in my opinion, because the volume of satellites being launched today is growing by leaps and bounds, and indexes like NDVI and SAVI will become more ubiquitous.
4. High spatial and temporal resolution satellite data (daily, <1m pixels) is becoming the norm, so plan on metrics that are generated from such datastacks.
5. Information needs to be mobile, and [mobile] options to access and use outputs provided by this protocol should be provided to park staff.

Responses from Yun Yang (Assistant Professor, Department of Forestry, Mississippi State University, MS)

Question 1

Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?

Yes, the objectives for the monitoring program are clear, relevant, and achievable. These objectives have been adequately met in the reports and published papers supplied to me. The reported results are in high quality and very impressive.

Question 2

Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?

The statistical trends analyses are appropriate, and conclusions are drawn based on the data analyses. The image processing and analytical methods are appropriate to meet the specific objectives of the protocol. The pivot point analysis is very inspiring and provide the link between long-term remotely sensed data and the climate change impact.

Question 3

Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?

The main data source used in the current analysis is from MODIS, which is the medium resolution that ranging from 500m to 1km. It is nice to see that there are already plans to integrate [VIIRS data](#) into the analysis, since MODIS data will be discontinued in about one year. I would also recommend to test Landsat and Sentinel 2 data, also the Harmonized Landsat and Sentinel (HLS) dataset published by NASA. Sentinel 2 data is in 10-m spatial resolution and Landsat and HLS data are in 30-m spatial resolution. Comparing with the 500m–1km spatial resolution from MODIS, HLS data can capture more spatial patterns, especially for the more heterogenous area. Although the Landsat-scale data is not in daily time-step (16 days for one Landsat and 8 days for combination of Landsat 8

and Landsat 9), it might still provide the time series data at required accuracy. Especially for vegetation indices, there might not be that much variation in an 8–16 days' time period.

The water balance analysis method is very interesting, that is sensitive to the park conditions in NCPN. Another dataset that could be useful in the water balance analysis is the 30-m actual evapotranspiration dataset from OpenET project (<https://openetdata.org/>).

Question 4

Are the conclusions drawn from major findings appropriate?

Yes, the conclusions drawn from major findings are appropriate.

Question 5

Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?

Yes, all appropriate covariate data are being collected and they are used in the analyses.

Question 6

What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?

I am not familiar with the structures of NPS networks, but I think collaboration is always a good option that could benefit all the members across the networks.

Question 7

How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?

The pivot point analysis is a good example of how to link the data with climate change. It could be helpful to get this analysis integrated into Google Earth Engine, that can be shared inside the network and with park managers. Also, including Landsat data with relatively fine spatial resolution can be beneficial for studying heterogeneous area. On GEE, it is easier to share the findings. This might create more opportunities to effectively interact with park managers.

Question 8

Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?

Reaching out the satellite product science teams would be helpful to gain insights and get help directly from sciences who produced these products. For MODIS, VIIRS and Landsat, there are science teams and the scientists in the science team meet at least once per year. The Landsat science team meeting is normally hold twice per year, which are in summer and winter respectively.

Presenting to the science team could be a way to share the findings and increase the impact of the work from our NPS remote sensing monitoring group.

Question 9

How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?

If there is a 10% increase, I think [investing] some of the budget in GEE related activities and research would be a good way to explore the potential of using high resolution data with cloud computing.

Question 10

Summary of thoughts and recommendations.

In summary, the objectives for the monitoring program are clear, relevant and achievable. The research and analyses from the NCPN's remote sensing program are very impressive. Appropriate data has been collected and analyzed. The analysis methods are straightforward and efficient. The conclusions are drawn based on the collected data and analysis.

Reaching out to the satellite science teams could gain help with understanding the satellite product and increase the impact of NPS remote sensing monitoring work. Reaching out to experts in related fields could be helpful to collaborate both inside and outside the NPS remote sensing monitoring group. Organizing webinars in related research topics would be a good way to start. Creating a working group could be helpful in organizing the webinars and starting the collaborations.

Responses from Andrew Bliss (Southwest Alaska Network, Inventory and Monitoring Program, NPS)

Question 1

Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?

Yes and yes. The objectives are narrower than the actual work the network is doing. On some level, that is a good thing (exceeding objectives is better than not meeting them), but as part of the review and any updates to the protocol, ideally the objectives would match the work.

Question 2

Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?

Yes, the presentation and papers included great statistics. It seems like the network is aware of alternative methods (e.g., to migrate from MODIS to VIIRS, and take advantage of other products available in Google Earth Engine).

Question 3

Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?

It seems like the network is on top of, and/or leading the way on new techniques. As with almost any study, additional field data could enhance the conclusions, specifically in translating from the small scale (field plots) to the large scale (satellite images). Covering a larger percentage of a satellite pixel with field plots may yield stronger conclusions or a better process understanding of the landscape (but there's a \$ cost).

Question 4

Are the conclusions drawn from major findings appropriate?

Yes, and the conclusions seem to be presented at relevant scales (e.g., limiting conclusions to similar environments rather than trying to generalize across dissimilar conditions).

Question 5

Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?

Yes—the network does a great job integrating satellite data with climate data, soil cores, and vegetation plot data. It is clear that staff has thought carefully about how the various data sources complement each other, while simultaneously being aware of their limitations. Analyses include all relevant data (as far as I can tell).

Question 6

What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?

These protocols are already shared across networks in similar environments. It seems to me like this is a model for how to do that, with good collaborations among a variety of staff. Meetings like the Tucson 2023 remote sensing gathering foster collaborations across networks and benefit participants and their networks alike.

Question 7

How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?

Again, this program is a model for using IMD data to address climate change problems in an integrative way. Staff has published work and given talks on climate projections, pivot points, and the idea of using trends over climate rather than trends over time. They have also integrated results from the work into management decisions in parks.

Question 8

Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?

The network has collaborations and outreach with/via: USGS, Climate Analyzer, Climate-Smart conservation, park outreach materials, and journal articles. Already on track, just keep going!

Question 9

How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?

A budget increase could be applied to increasing staff time for data analysis. Someone else at the meeting had the idea of sabbaticals to visit other networks which could benefit both networks.

With a decrease, maintain focus on NDVI and reduce work on covariates.

Question 10

Summary of thoughts and recommendations.

No summary response from reviewer.

Appendix B: Remote Sensing Protocol Review

Agenda

February 28 to March 2, 2023, 9:00 AM to 4:00 PM MST

UA campus, Tucson, Arizona

Goals of the Review Meeting

- Review NCPN, SCPN, and SWAN's remote sensing programs (Day 1–Day 2)
- Provide feedback for NCCN, GLKN, and SEAN's remote sensing programs (Day 2–Day 3)
- Evaluate current strategies for a scientifically robust and sustainable monitoring program that is relevant, impactful, and informs decisions for the next 10 years (Day 3)

Objectives

- Provide reviewers the information and data needed to complete a peer review of NCPN, SCPN and SWAN's remote sensing protocols for an NRSS report
- Provide feedback on NCCN, GLKN, and SEAN's existing programs and a roadmap for their future reviews
- Identify a resource management-relevant set of metrics (variables) that participating networks can continue to provide, monitor and adapt to evolving technology and analytic capacity associated with remote sensing science
- Determine areas of redundancy, conflict and potential collaboration between networks, other agencies, and researchers in our respective remote sensing programs
- Identify and consider the impact of emerging technologies and analytic methods on our programs regionally and nationally

Day 1, February 28, 2023

Programatic Overview

8:30–8:45: Overview of Requirements for this Review and the I&M Division (Michael Bozek, Jim Lawler)

Goal: Provide some understanding of basic process, products and utility

8:45–9:30: Overview of SCPN's Remote Sensing Program (Jodi Norris)

Outline for Presentations

1. Quick refresher of existing recorded presentation
2. Integration of data with others—within network, parks, outside partners
3. Potential for data uses in park management

4. How to make resource managers aware of potential of phenological data
5. How we will make data easily available in useful form
6. Existing science or methods questions that your network wants to look into
7. Hurdles—what is preventing your remotely sensed data from being published/analyzed/reported
8. What are you planning to do next?

The objectives of the SCPN remote sensing program are listed in Table 1.

Table 1. Objectives of the SCPN remote sensing program from Thoma et al. (2017), “Satellite-based Vegetation Condition and Phenology, and Snow Cover Extent Monitoring Protocol for the Northern and Southern Colorado Plateau Networks.”

Objective	Description
Objective 1	Determine annual status, interannual variability, and long-term trends in growing season as measured in NDVI (peak of spring and monsoon season dates and intensity; annual peak NDVI intensity and timing; and minimum NDVI) within select ecosystems.
Objective 2	Determine annual status, interannual variability, and long-term trends in the timing and duration of snow cover (establishment of snowpack, persistence, time and rate of melt) within select ecosystems.

9:30–9:45: Break

9:45–11:30: SCPN Reviewer Discussion

Open discussion starting with Network-specific reviewers (SCPN) commenting on review questions, then opening the discussion with all other reviewers contributing. This will be followed with a general discussion.

1. Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?
2. Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?
3. Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?
4. Are the conclusions drawn from major findings appropriate?
5. Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?

6. What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?
7. How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?
8. Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?
9. How might you expand or contract this work with a 10% increase or decrease in budget (SCPN budget is approximately \$144,000 annually)?
10. Summary of thoughts and recommendations.

11:30–1:00: Lunch

1:00–2:30: Overview of SWAN's Remote Sensing Program (Michael Hannam, Peter Kirchner)

Outline for Presentations

1. Objectives
2. Methods
3. Analyses/results
4. Key findings
5. Integration of data with others—within network, parks, outside partners
6. Data uses in park management
7. Existing science or methods questions that your network wants to look into
8. Hurdles—What is preventing your data from being published, analyzed, reported, or advanced to the next step
9. Retrospective view from David Swanson
10. What are you planning to do next?

The objectives of the SWAN remote sensing program are listed in Table 2.

Table 2. Objectives of the SWAN remote sensing program from Reed et al. (2006), "Satellite-Derived Measures of Landscape Processes Monitoring Protocol for the Southwest Alaska Network." This report can be accessed at <https://irma.nps.gov/DataStore/Reference/Profile/2224962>.

Objective	Description
Objective 1	Estimate variability and long-term trends in the timing and duration of snow cover in the Alaska region (establishment of snowpack; snowmelt).
Objective 2	Estimate variability and long-term trends in growing season NDVI in the Alaska region (start and end of season dates; duration of growing season; maximum NDVI).

2:30–2:45: Break

2:45–4:30: SWAN Reviewer Discussion

Start with comments from the specific reviewers on these topics. Then general discussion.

1. What products being produced and available (e.g., by EROS, NASA, ESA) can mesh with our current data and be a sustainable solution into the future? Could we be relying upon others to produce these metrics?
2. Are there hybrid products on the horizon (e.g., SNODAS) that will be nationally available and meet our needs? Who (what agencies research groups, or scientists) is working on these?
3. If we transition to VIIRS are there any others that have successfully cross-walked MODIS growing season (e.g., NDVI) and snow metrics (e.g., NDSI)?
4. How can we distinguish spectrally or algorithmically between a start of season/green-up signal produced by loss of snow cover/high reflectance and an SOS signal produced by increasing productivity/NDVI? Are SOS products currently available or emerging that resolve the confusion around start of season (snow off/green-up) date?
5. What is the state of the art in dealing with evergreen forest, and snow cover under forest canopy? Evergreen canopies presumably have a lower seasonal amplitude in VI values. Are some VIs or algorithms more suitable for phenology estimation in these vegetation types?
6. How should we best account for disturbance (e.g., fire, beetle kill) in our analyses of vegetation phenology? We currently do not account for this, but the change in vegetation type resulting from disturbance could yield a different phenology for that location, complicating the estimation and interpretation of trends.
7. Aside from a daily analysis, what are the best data reductive methods (e.g., metrics) for analyzing high latitude annual snow cover variability?

Day 2, March 1, 2023

8:30–9:15: Overview of NCPN's Remote Sensing Program (David Thoma)

Outline for Presentations

1. Objectives
2. Methods
3. Analyses/results
4. Key findings
5. Integration of data with others—within network, parks, outside partners
6. Data uses in park management
7. Existing science or methods questions that your network wants to look into

8. Hurdles—what is preventing your data from being published/analyzed/reported
9. What are you planning to do next?

The objectives of the NCPN remote sensing program are listed in Tables 3 and 4.

Table 3. Objectives of the NCPN remote sensing program from Thoma et al. (2017), “Satellite-based Vegetation Condition and Phenology, and Snow Cover Extent Monitoring Protocol for the Northern and Southern Colorado Plateau Networks.”

Objective	Description
Objective 1	Determine annual status, interannual variability, and long-term trends in growing season as measured in NDVI (start, end, and peak of season dates; duration and intensity of growing season) within select ecosystems.
Objective 2	Determine annual status, interannual variability, and long-term trends in the timing and duration of snow cover (establishment of snowpack, persistence, time and rate of melt) within select ecosystems.

Table 4. Objectives of the NCPN remote sensing program from Thoma (2016), “Application of Landsat Imagery for Landscape-Scale Change Detection and Trend Analysis in the Northern Colorado Plateau Network.” This report can be accessed at <https://irma.nps.gov/DataStore/Reference/Profile/2229777>.

Objective	Description
Objective 1	Determine the start, end, duration, and rate of disturbance, as well as the magnitude of disturbance and recovery. ^A

^A Due to rapidly changing technology, we did not develop specific objectives, but rather “NCPN plans to implement LandTrendr on a project basis to address management-relevant questions appropriate to the tools, as described below.” This approach was approved by Bruce Bingham on 4/12/12. The closest thing to an objective for this protocol was taken from the narrative.

9:15–9:30: Break

9:30–11:15: NCPN Reviewer Discussion

Open discussion starting with Network-specific reviewers (NCPN) commenting on review questions, then opening the discussion with all other reviewers contributing. This will be followed with a general discussion.

1. Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?
2. Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?

3. Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?
4. Are the conclusions drawn from major findings appropriate?
5. Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?
6. What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we've already done?
7. How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?
8. Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?
9. How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?
10. Summary of thoughts and recommendations.

11:15–1:00: Lunch

1:00–1:50: Overview of GLKN and NCCN Remote Sensing Programs

Presentation (~50 minutes):

1. Objectives
2. Methods
3. Analyses and preliminary results
4. Key findings and relation to other network and park information streams
5. Challenges and hurdles
6. Next steps, science and methods questions to look into

2:00–2:50: Discussion of GLKN and NCCN Remote Sensing Programs (~50 minutes)

1. Challenges distinguishing disturbance type categories—are these sufficiently distinct and representative of meaningful ecological patterns? Should we consider different ways of splitting/grouping?
2. Minimum mapping unit decisions—set to a higher threshold to reduce tiny patches for a reasonable/manageable workload and to accommodate complex terrain/canopy. Reasonable? Different approach suggested? Net benefit to reducing size in certain areas (e.g., riparian corridors)?

3. Manual versus automated labeling—is there another way forward that would provide a reasonable compromise between accuracy and efficiency?
4. What alternative technologies and data streams should we be considering? NAIP, C-CAP, LCMAP, or even snowpack & phenology in high-elevation areas (e.g., tie-in with subalpine vegetation, landbirds, and mountain lakes)?
5. Approaches to consider when analyzing low-frequency events across the time series?
6. How to characterize change patterns and deal with the episodic nature of regional climate (ENSO/PDO)?
7. Do we need to take steps to address unequal disturbance event detection probabilities across the time series? (Due to patch size, terrain, image quality/resolution, and disturbance type.)

3:00–3:50: Overview and discussion of SEAN’s Remote Sensing Program (Andy Bliss)

1. Background: SEAN’s glacier dynamics vital sign has been deferred, but is now actively being developed. Initial focus is outlining tidewater glacier termini from Landsat, but also looking at glacier velocities, and surface elevations.
2. Do other networks have suggestions/examples of data management and visualizations for geospatial data? Ideas on how to bridge the disconnect between IRMA, Story Maps, and network or park websites? Coordination with NPS GIS Council (coordinators and workgroups)?
3. Our landcover and landform vital sign has also been deferred. Are there any remote sensing workflows we could adopt that would give interesting data to parks without a painful ramp-up? Ideally, we’d like to be able to notice rapid, medium-to-large scale changes to the landscape (e.g., landslides, glacier disintegrations) from remote sensing.

Day 3, March 2, 2023

Goal: Identify commonalities for remote sensing across networks in order to co-create strategies for a scientifically robust and sustainable monitoring program (collaboratively or individually) that is relevant, impactful, and informs decisions for the next 10 years.

Outcomes

- A matrix that describes the use of remote sensing across networks (information collected prior to the meeting and refined at the meeting). Identified areas of strength and areas needing improvement or new direction.
- Identified commonalities and ways networks can work together more effectively.
- Identified potential for centralized or shared efforts.
- Tangible next steps for moving discussions and outcomes further after the meeting.

8:30: Remote sensing in context: Commonalities across networks (Jodi Norris)

Overview of the way remote sensing is used in the NPS I&M program. Presentation of matrix results and identified common themes.

9:00: Reviewer comments and questions

This is the time for reviewers to ask any remaining clarifying questions, provide additional feedback or thoughts, and for networks to ask final questions that have not been resolved.

10:45: Break

11:00: Using remote sensing analyses to support conservation outcomes

What can we do to provide better information to support climate-smart planning processes and decision making? (David Thoma to lead the discussion.)

12:00: Lunch

1:00: Using remote sensing analyses to support conservation outcomes (*continued*)

Remote sensing products, how they are used, and how to make products more effective. (David Thoma to lead the discussion.)

2:45: Break

3:00: Next Steps

Identify next steps to act on the outcomes of the meeting.

4:30: Wrap up and adjourn (Michael Bozek and Jim Lawler)

Final close-out.

Appendix C: Reviewer Homework

NCPN Protocol Overview: Vegetation Phenology, Condition and Snow Cover Extent Protocol

Reviewers were asked to review the information in this appendix in advance of the NCPN remote sensing protocol review meeting.

Protocol Background

National parks face resource challenges at multiple spatiotemporal scales that result from land use, disturbance and climate change. Many challenges in semiarid parks are related to water availability and the role that water plays supporting basic ecological functions like primary production and stream flow. Impacts of water shortage are episodic, with periods of recovery, nested within longer-term chronic changes resulting from monotonic (rising temperatures) climate changes. Vegetation indexes derived from this protocol track the ecological response to these variations and trends. Semiarid vegetation responds dynamically to variation in weather, so vegetation condition and climate are investigated together in this protocol: <https://www.nps.gov/im/ncpn/phenology.htm>.

Like summarizing vegetation indexes in many ways, climate can be reported in many ways. The first version of this protocol focused solely on trends in metrics derived from vegetation indexes. Since then, advances now include trends in vegetation production and climate, as well as the quantitative relationships between them. Specifically, the development of pivot points and response relationships indicate critical water needs for vegetation as well as expected change in vegetation production per unit change in a climate variable. This enables near-term as well as long-range forecasts of vegetation condition using only weather (short term) and climate (long-term) data.

Why Water Balance

A water balance approach has been adopted to explore vegetation/climate relationships from the perspective of climate variables like soil moisture (water supply), deficit (unmet water need) and evapotranspiration (water used). These variables are typically more strongly correlated with vegetation production than with temperature and precipitation because they better represent the environmental conditions experienced by plants.

Scientific Value

Water balance variables explain more of the variation in vegetation production than temperature and precipitation because they are more proximal to the mechanisms of plant water use and need. Appreciating this, we soon realized that many of the water balance variables also explained response in other vital signs better than temperature and precipitation. Since 2016 we have published more than 20 papers using the NCPN water balance with several more in preparation. We refer to water balance here as “NCPN water balance” due to the numerous improvements we have made to the code that was sourced with permission from a physical hydrology textbook. Additionally, we collaborate closely with the NPS Climate Change Response Program (CCRP) and Mike Tercek to continue developing applications and to support a CONUS water balance grid for use in vital signs reporting and scenario planning. The CONUS gridded products were approved by NASA for hosting by the

USGS Land Processes Digital Active Archive Center (LPDAAC) on the [AppEEARS](#) portal adjacent to Landsat and MODIS products. This will make the products easily accessible by NPS scientists, managers, academics and the general public. The product coverage does not include Alaska, but it has been shown to work well for modeling stream flow at selected locations in Alaska.

Information for Parks

The information generated from this protocol has been used by parks for many applications. Examples include providing content in NPS Natural Resource Stewardship and Science planning documents that describes change over time in vegetation communities, contributions to sensitivity and vulnerability assessments used in climate smart conservation planning workshops, and implications of climate change on potable water supply, stream flows, and infrastructure planning. One of the most important applications was development of pivot points that characterize the critical water need and drought stress tolerance of native vegetation at landscape scales. This is the only place-based, wall-to-wall quantitative landscape scale vulnerability information available to parks for climate adaptation planning.

Integration with Climate Adaptation Programs

The wide array of ecological and physical processes affected by water movement through the environment that is characterized by water balance variables created many opportunities for engaging park managers in understanding and dealing with a changing climate. One of the most useful ways to organize this engagement is via the Climate Smart Conservation framework. In this framework our science supports the assessment of plausible climate impacts, evaluation of management options and development of reasonable management goals. Placing our science in the Climate Smart Conservation framework has garnered a great deal of interest from park staff, because when we do this, they understand the implications of our findings. Since 2016 we have hosted seven Climate Adaptation workshops in the Rocky Mountains, Desert Southwest and in Yosemite, typically in collaboration with park staff and colleagues in the NPS Climate Change Response Program (CCRP) and other academics.

Goals

The [Northern Colorado Plateau Network](#) (NCPN) identified vegetation phenology and condition, as well as snow cover extent, as important park vital signs. The first park-scale trend report was completed in 2011. The protocol has evolved since then due to significant advances in satellite data processing approaches and with the inclusion of water balance covariates in analyses. Collectively, the analysis of high-frequency observations of vegetation with climate and water balance provides a means to understand climate as a driver of vegetation condition.

Objectives

Monitoring vegetation condition and climate in NCPN is designed around the pervasive influence of climate on biological systems. Climate affects primary production which affects flows of nutrients, energy and water through ecosystems. Specific objectives are to:

1. determine annual status, interannual variability, and long-term trends in growing season as measured in NDVI (start, end, and peak of season dates; duration and intensity of growing season) within select ecosystems; and
2. determine annual status, interannual variability, and long-term trends in the timing and duration of snow cover (establishment of snowpack, persistence, time and rate of melt) within select ecosystems

Status and Analyses

A first-decade [trend report](#) was completed in 2011 for the period 2000–2010 evaluating NDVI and water balance trends. This analysis was done at the “park scale” where all pixels within a park unit were averaged at each time step. Phenology was determined for bimodal growing seasons using the [TimeSat](#) algorithms. Snow cover extent and melt rates were determined using customized methods. The second-generation reporting (https://www.nps.gov/articles/000/ncpn_remote-sensing-and-climate-change-planning-at-colorado-monument.htm) uses vegetation alliance map units as targets (aggregated from park vegetation maps).

The water balance approach is a major development in the interpretation of vegetation condition and trend. It has been so successful in vegetation condition modeling that it has become a covariate suite routinely used in other vital signs analyses in NCPN and more broadly by other networks and nationwide by the CCRP program to explain the effects of climate change on NPS resources.

Management Use of Protocol

1. *Informing vegetation condition, trends and management*
 - a. Pivot points determine the critical water need of vegetation (like 8 glasses of water per day for people), as well as the sensitivity of vegetation to changes in water or heat needed for growth. Pivot points and associated workflows have been used for many applications:
 - i. Vulnerability assessments for grasslands in Southern Utah parks that informed planning and management options developed in climate adaptation workshops 2016–2019
 - i. Protocol R code was borrowed by scientists for a USGS Grazing/Climate study at Dinosaur National Monument to quantify climate/production relations on Yampa Bench, 2022
 - ii. Pivot points were used in the Capitol Reef N.P. Resource Stewardship Strategy workshop to identify climate sensitive vegetation, 2022
 - iii. At Capitol Reef N.P. vegetation condition nowcast and forecast alerts are automatically sent to park managers on Friday afternoons and posted on-line [here](#), since 2017
 - b. Soil moisture relationships with [saguaro cactus blooms](#) in Saguaro N. P., 2021

- c. Trends in NDVI and relations with climate reported in Natural Resource Condition Assessment for [Bryce Canyon N.P., 2018](#)
- d. Trends in NDVI and relations with climate reported in Natural Resource Condition Assessment for [Cedar Breaks N.M., 2018](#)
- e. Using water balance and biophysical limits to identify white bark pine refugia for out-planting seedlings that increase likelihood of survival until reproductive age (~80–100 years)

2. *Informing water supply and river flow*

- a. River flow vulnerability to climate change was determined for a major tributary to the Fremont River in Capitol Reef to inform the Resource Stewardship Strategy planning, 2022
- b. A river flow model for the [Yellowstone river is being used to build a flood alert system](#), 2023
- c. Climate/flow model completed for scenario planning in National Capitol Region parks (Rock Creek and Antietam) shared with CCRP and regional program manager, 2021
- d. Merced River flow projections for climate smart conservation training at Yosemite, 2019
- e. Medano creek [flow forecast](#) at Great Sand Dunes N.P.
- f. [Implications of climate change](#) for the water supply of the Chisos Mountains developed area, Big Bend National Park, 2019
- g. Stream flow vulnerability analysis [Wet Beaver Creek](#), AZ, 2021
- h. River flow model developed for aquatic working group, Lake Clark and Kijik, Alaska, 2021

3. *Tools for real time resource condition assessment*

- a. Climate and resource condition dashboard for [Northern Colorado Plateau Parks](#)
- b. Climate and resource condition dashboard for [Yellowstone and Grand Teton](#)
- c. [Yellowstone fire prediction tool](#), online since 2018
- d. Great Sand Dunes online [fire danger alert system](#), since 2020
- e. Earth Engine biomass estimation tool for cattle grazing management in Capitol Reef N.P.
- f. Earth Engine vegetation anomaly difference from long-term average NDVI by pixel for assessing drought stress on vegetation at regional and local scales. Includes time series charts that illustrate forest disease or other disturbance.

- g. Earth Engine trend over time in NDVI by pixel for assessing long-term trends in vegetation condition and early warning of chronic change
- h. Earth Engine growing degree day mapper for real time assessment of pine beetle development in forests of the Greater Yellowstone region (in progress)

Review Publications (i.e., Peer Reviewer Homework)

Please review these documents prior to the meeting. Please respond to the questions at the end of this document after the Tucson meeting by March 31, 2023.

Peer-Reviewed Trend Report

Thoma, D. 2022. Landscape Phenology, Vegetation Condition, and Relations With Climate at Colorado National Monument, 2000–2019. Natural Resource Report NPS/NCPN/NRR—2022/2384. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/nrr-2293476>

Other NCPN Remote Sensing Publications to Review

Thoma, D.P., S.M. Munson, and D.L. Witwicksi. 2018. Landscape Pivot Points and Responses to Water Balance in National Parks of the Southwest U.S. *Journal of Applied Ecology*. <https://doi.org/10.1111/1365-2664.13250>. Summary [web article](#)

Thoma, D.P., S.M. Munson, K.M. Irvine, D.L. Witwicksi, and E.L. Bunting. 2016. Semi-Arid Vegetation Response to Antecedent Climate and Water Balance Windows. *Applied Vegetation Science* 19: 413–429. <https://doi.org/10.1111/avsc.12232>. Summary [web article](#)

Protocol

Thoma, D.P., J. Norris, and P. Lauck. 2017. Satellite-Based Vegetation Condition and Phenology, and Snow Cover Extent Monitoring Protocol for the Northern and Southern Colorado Plateau Networks. Natural Resource Report NPS/SCPN/NRR—2017/1533. National Park Service, Fort Collins, Colorado. <https://irma.nps.gov/DataStore/Reference/Profile/2246068>

Inventory and Monitoring Program Overview

Fancy, S.G., and R.E. Bennetts. 2012. Institutionalizing an Effective Long-Term Monitoring Program in the U.S. National Park Service. Pages 481–497 in R.A. Gitzen, J.J. Millspaugh, A.B. Cooper, and D.S. Licht, editors. *Design and Analysis of Long-Term Ecological Monitoring Studies*. Cambridge University Press, Cambridge, United Kingdom. <https://doi.org/10.1017/CBO9781139022422.029>

Review Questions

The objectives of the NCPN remote sensing protocol presented in Table 5.

Table 5. Objectives from the NCPN remote sensing protocol “Satellite-based Vegetation Condition and Phenology, and Snow Cover Extent Monitoring Protocol for the Northern and Southern Colorado Plateau Networks,” by Thoma et al. (2017).

Objective	Description
Objective 1	Determine annual status, interannual variability, and long-term trends in growing season as measured in NDVI (start, end, and peak of season dates; duration and intensity of growing season) within select ecosystems.
Objective 2	Determine annual status, interannual variability, and long-term trends in the timing and duration of snow cover (establishment of snowpack, persistence, time and rate of melt) within select ecosystems.

Specific Questions to Be Addressed by Peer Reviewers for the NCPN Protocol

1. Are the objectives for the monitoring program still clear, relevant, and achievable? Have the objectives adequately been met in reports and published papers supplied to you?
2. Were statistical trends analyzed appropriately and conclusions drawn factually based on the data analyses used? Were the image processing and analytical methods used appropriate to meet the specific objectives of the protocol? Are there alternative methods to consider?
3. Are there technological improvements that improve the data workflow from collection through analysis? Are there any recommended changes to procedures that would enhance the overall quality and usefulness of the data being gathered?
4. Are the conclusions drawn from major findings appropriate?
5. Are all appropriate covariate data being collected? Are the covariate data currently collected being used in analyses?
6. What do you see as the costs and benefits to merging approaches across networks, and how might we achieve that without losing what we’ve already done?
7. How can we use the information generated from this protocol to address climate change and integrate with other information and efforts to maximize its utility in managing for conservation at multiple scales?
8. Are there additional collaborations the network could take advantage of to share data and findings and increase the impact of their work?
9. How might you expand or contract this work with a 10% increase or decrease in budget (NCPN budget is approximately \$70,000 annually)?

Additional Publications from This Protocol

Peer-Reviewed Publications

Brice, E.M., M. Halabisky, and A.M. Ray. 2022. Making the Leap from Ponds to Landscapes: Integrating Field-Based Monitoring of Amphibians and Wetlands with Satellite Observations. *Ecological Indicators* 135: 108559. <https://doi.org/10.1016/j.ecolind.2022.108559>

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- Ray, A.M., W.R. Gould, B.R. Hossack, A.J. Sepulveda, D.P. Thoma, D.A. Patla, and R. Al-Chokhachy. 2016. Influence of Climate Drivers on Colonization and Extinction Dynamics of Wetland-Dependent Species. *Ecosphere* 7(7): 1–21. <https://doi.org/10.1002/ecs2.1409>
- Ray, A.M., A.J. Sepulveda, K.M. Irvine, S.K.C. Wilmoth, D.P. Thoma, and D.A. Patla. 2019. Wetland Drying Linked to Variations in Snowmelt Runoff Across Grand Teton and Yellowstone National Parks. *Science of the Total Environment* 666: 1188–1197. <https://doi.org/10.1016/j.scitotenv.2019.02.296>
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- Shanahan, E., K.M. Irvine, D. Thoma, S. Wilmoth, A. Ray, K. Legg, and H. Shovic. 2016. Whitebark Pine Mortality Related to White Pine Blister Rust, Mountain Pine Beetle Outbreak, and Water Availability. *Ecosphere* 7(12): e01610. <https://doi.org/10.1002/ecs2.1610>
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- Tercek, M.T., J.E. Gross, and D.P. Thoma. 2023. Robust Projections and Consequences of an Expanding Bimodal Growing Season in the Western United States. *Ecosphere* 14(5): e4530. <https://doi.org/10.1002/ecs2.4530>

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- Thoma, D. 2020. Climate Change in the Tetons: Science Spotlight. Page 36 in U.S. Department of Interior, National Park Service, Grand Teton National Park & John D. Rockefeller, Jr. Memorial Parkway: Resource Report 2020. Moose, Wyoming.
- Thoma, D. 2022. Landscape Phenology, Vegetation Condition, and Relations With Climate at Colorado National Monument, 2000–2019. Natural Resource Report NPS/NCPN/NRR—2022/2384. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/nrr-2293476>
- Web Articles**
- Daw, S., D. Thoma, and B. Schweiger. 2020. Water Balance Underlies Natural Resource Conditions at Great Sand Dunes National Park and Preserve. Rocky Mountain Network, National Park Service. <https://www.nps.gov/articles/000/water-balance-underlies-natural-resource-conditions-at-great-sand-dunes-national-park-and-preserve.htm>
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