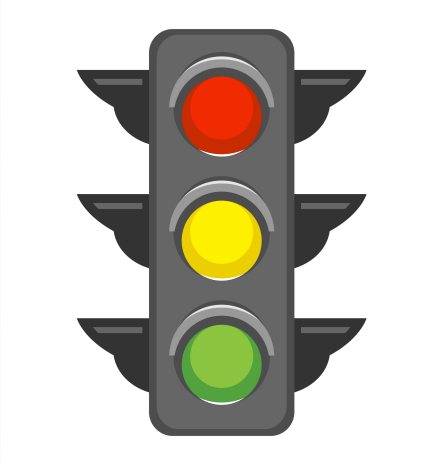
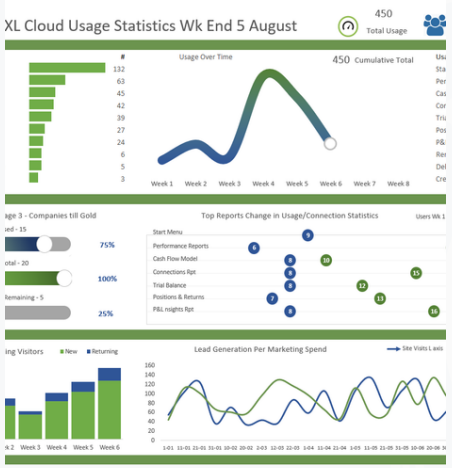
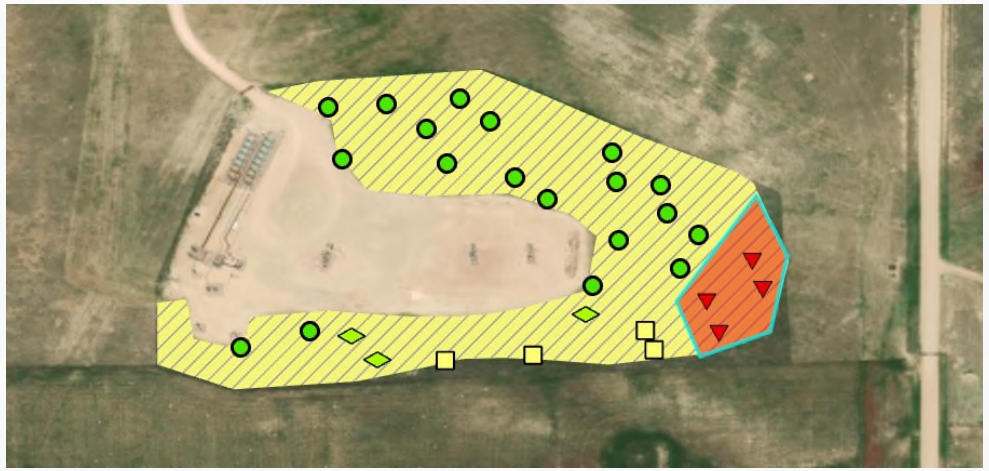






Reclamation Monitoring and Management: Metrics, Key Performance Indicators, and Dashboards for Projects Across their Life Spans

Michael Curran – Abnova Ecological Solutions

Joe Schroeder – Tetra Tech

Jesse Dillon – Cedar Creek

Tim Robinson – University of Wyoming

Blair Robertson – University of Canterbury

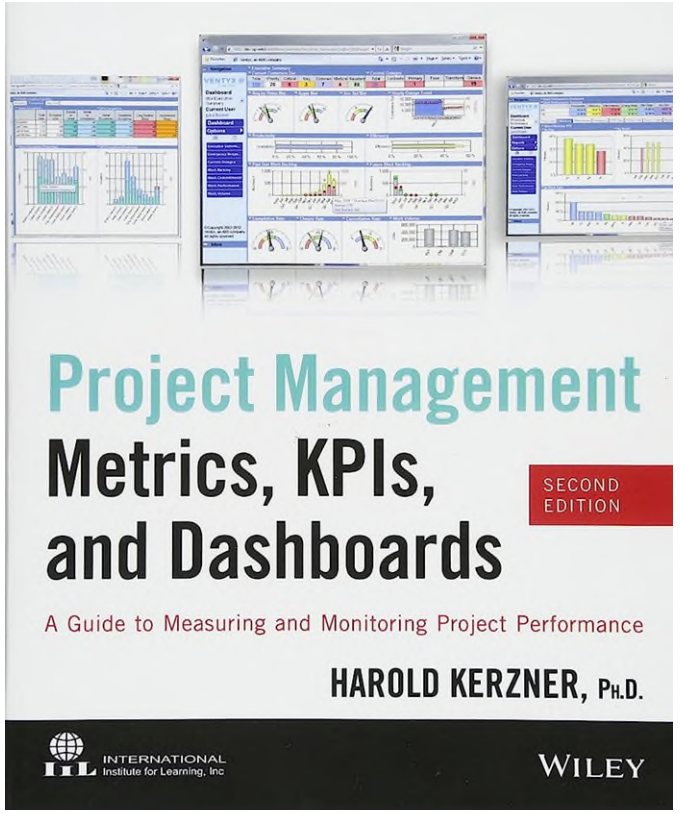
Steve Bower – Abnova Ecological Solutions

"The ultimate purpose of metrics (what we measure) and dashboards (presentation of measurements) is *not* to provide more information but to provide the right information, to the right person at the right time, using the correct media and in a cost-effective manner."

"Today, everyone seems concerned about information overload. Unfortunately, the real issue is non-information overload. In other words, there are too many useless reports that cannot easily be read and that provide readers with too much information, much of which may have no relevance… it simply distracts us from the real issues"

"Insufficient or ineffective metrics prevent us from understanding what decisions really need to be made."

"The 3 most important words to a stakeholder's vocabulary: The 3 most important words to a stakeholder's vocabulary:"Making Informed Decisions."

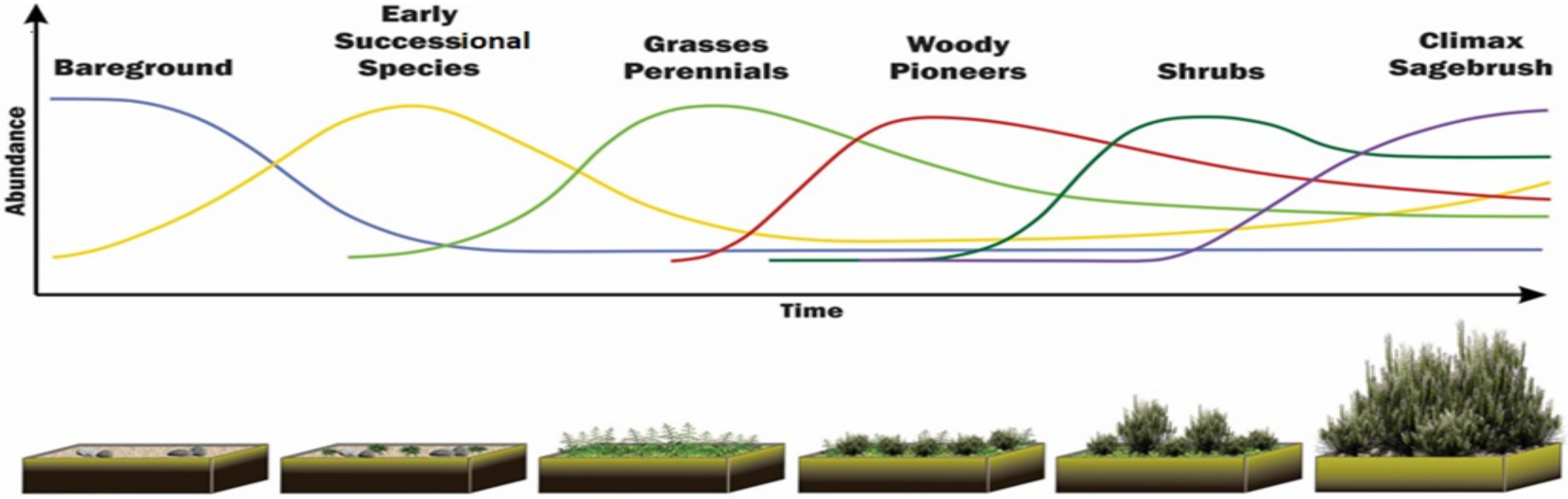


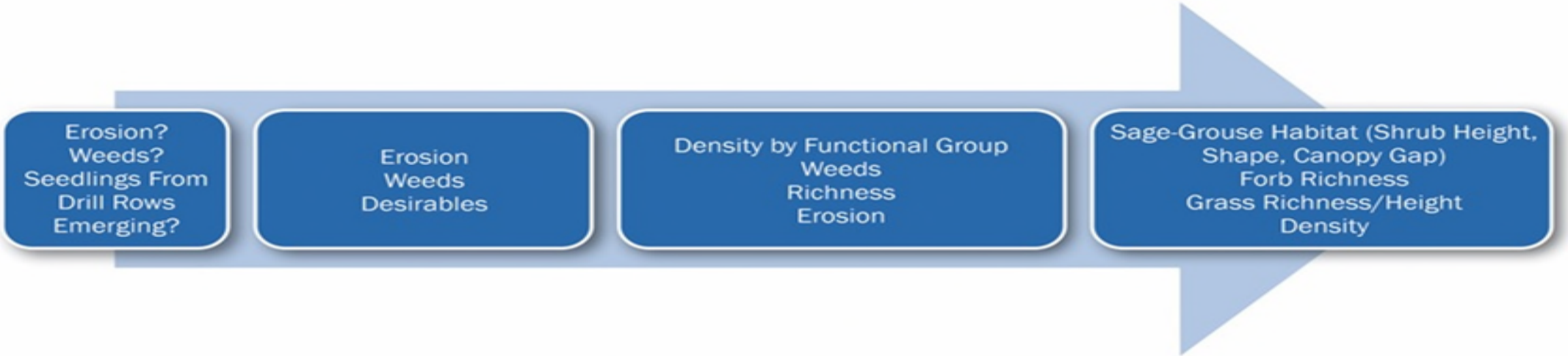
Reclamation as a Process

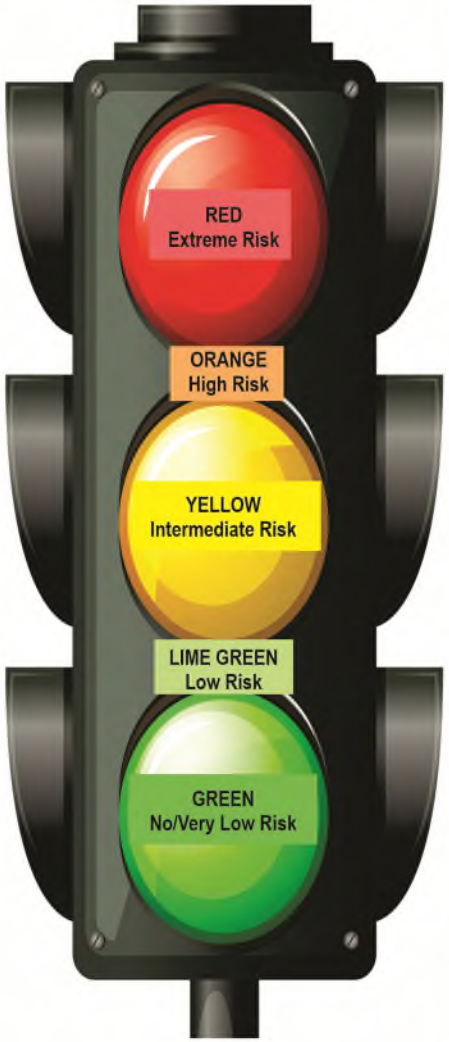
3 Phases (Hobbs and Norton 1996, Tischew et al. 2010, Curran & Stahl 2015, Nilsson et al. 2016)

- Planning
  - Identify Stakeholders
  - Identify Regulatory Criteria
  - Define Success
  - Select Reclamation Inputs
- Implementation
- Monitoring
  - Are goals being met?
  - Can we be adaptive?
  - What to measure? When to measure? How to measure? Who will measure? How to report information?

Reclamation Evaluations: Adaptive Monitoring

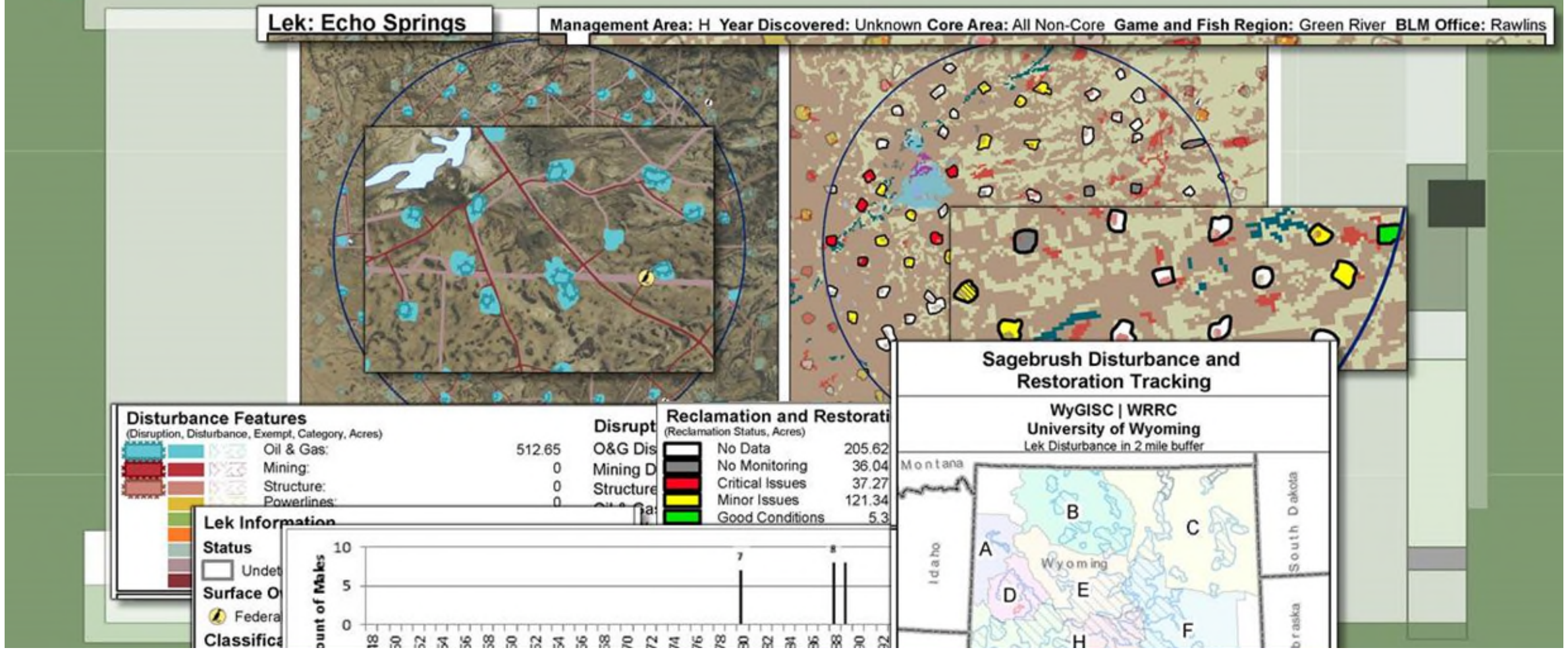






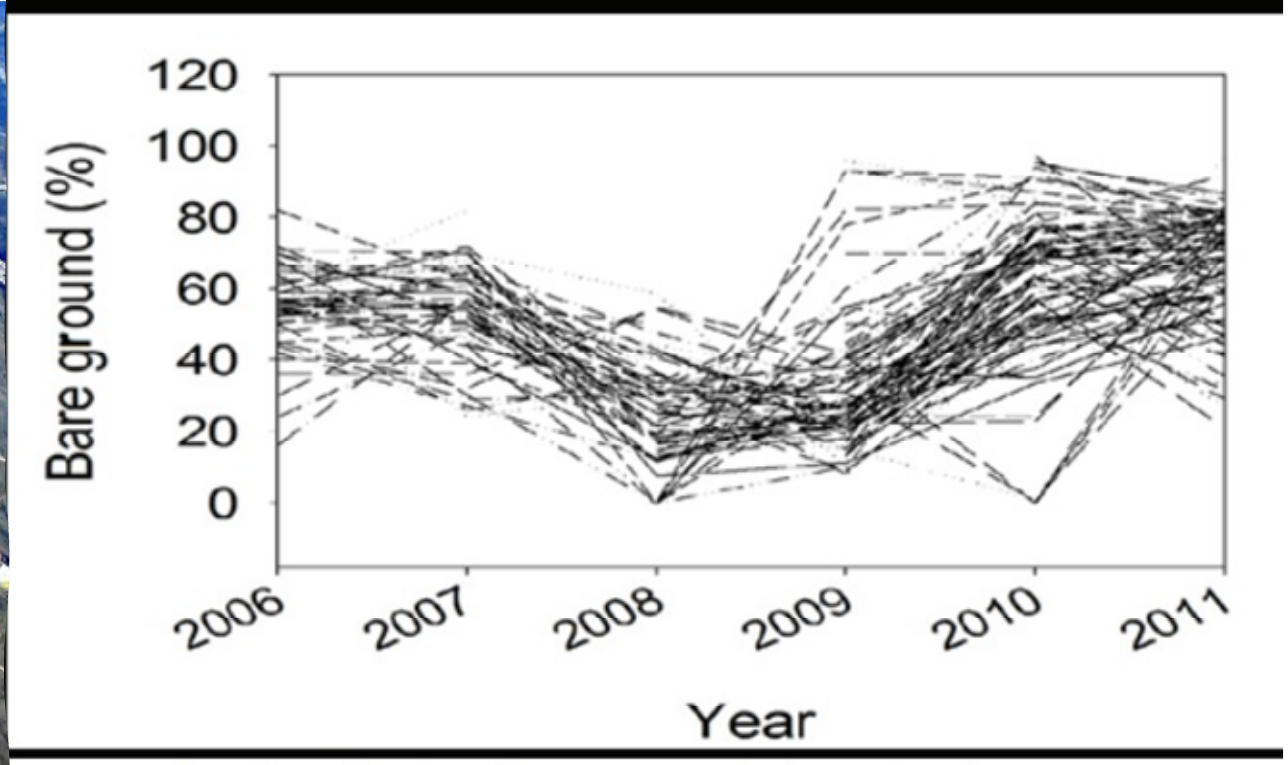
OVERALL SITE ASSESSMENT (Based on Supporting Category Assessments Below)	WEED STATUS	EROSION CONTROL STATUS	DESIRED VEGETATION COMMUNITY STATUS
Relevant monitoring data suggest site condition is poor to severe, with weed, erosion, bare ground, or desired species issues. For young and old sites, necessity for action is unequivocal and based on clear trends in site data.	Significant weed issues exist on site with, for example, noxious or invasive species present in high densities or - significant weed risk exists on site with, for example, any noxious/invasive weeds at a young site with low native plant cover or at a site (or portion of a site) planned for revegetation within a 2-year timeframe. The need for highly intense management actions(s) to reset site trajectory is certain.	Severe and widespread erosion features exist on site that have caused significant and widespread reclamation failure, and erosion potential is extreme because of very high slope gradients. The need for highly intense management action to reset site trajectory is certain.	For young sites, emergence of seeded species from drill rows is absent. For old sites, vegetation richness and density (or cover) is well below the expectations of the seed mix and vegetation standard (e.g., ESD, reference site), respectively. Reseeding or other management action is necessary.
Relevant monitoring data suggest site condition is marginal with combinations of weed, erosion, bare ground, or desired species issues. For young and old sites, necessary for action is likely and based on professional judgement, careful evaluation of and corroborating trends in site data, and consultation (if necessary).	Many weed issues exist on site, with, for example, moderate densities of noxious or invasive species with an adjacent native plant community(s) at high risk of being overtaken by invasive weeds. Management actions(s) is likely.	Erosion features exist on site that have caused or are likely to cause reclamation failure without management action, and erosion potential is high because of high slope gradients.	For young sites, emergence of seeded species from drill rows is apparent but absent from >50% of drill rows. For old sites, vegetation richness and density (or cover) is well below expectations from the seed mix and vegetation standard (e.g., ESD, reference site), respectively, with one or two dominant species throughout the site.
Relevant monitoring data suggest site conditions are moderate, with singular or combinations of weed, erosion, bare ground, or desired species issues. The necessity for management action is uncertain and based on professional judgement, careful evaluation of ambiguous or conflicting trends in site data, and consultation(s).	Moderate invasive weed issues exist on site, with, for example, low density or few individual plants of invasive species or larger quantities of non-invasive weeds species, and a resilient adjacent native plant community(s). Professional judgement, careful data review, and consultation are required to determine management action or no action.	Erosion features exist on site that have the potential to cause reclamation failure, and erosion potential is moderate because of moderate slope gradients. Professional judgement, careful data review and consultation are required to determine whether management action is warranted.	For young sites, emergence of seeded species from drill rows is apparent but absent from 33 to 50% of drill rows. For old sites, vegetation richness and density (or cover) is below the seed mix or vegetation and vegetation standard) e.g., ESD, reference site), respectively, with several species dominating.
Relevant monitoring data suggest site condition is good, with very minor weed, erosion, bare ground, and desired species issues. Management actions are unnecessary or very minor. For old sites, consider site certification, one-year additional-monitoring at minimum, or continued monitoring for young sites.	Successional/non-invasive weeds exist on young sites or non-native weeds with low invasion potential and density exist on old sites and a resilient adjacent native plant community(s) (where invasive species are absent or rare). Example: Russian thistle present on a site 1-2 years after initial reclamation efforts.	Erosion features exist on site but are very minor, and erosion potential is low to moderate because of gentle to moderate slope gradients.	For young sites, emergence of seeded species from drill rows is evident but notably absent from drill rows. For old sites, vegetation richness and density (or cover) is near expectations from the seed mix and vegetation standard) e.g., ESD, reference site), respectively, without dominance by any specific species.
Relevant monitoring data suggest site condition is good, with no weed, erosion, bare ground, or desired species issues. No management actions are necessary. For old sites (3+ years since reclamation), consider site certification or continue monitoring for young sites (0-2 years since reclamation).	Weeds do not exist on site.	Erosion features do not exist on site, and erosion potential is low because of	For young sites, emergence of seeded species from drill rows is evident and uninterrupted. For old sites, vegetation richness and density (or cover) is meeting, or exceeding expectations based on reference site or ESD characterization.

Surface Mapping and Restoration Tracking



Commonly Used Monitoring Techniques

- Ocular estimates
- Daubenmire frames
- Line-point intercept (along transect)
- Step-point



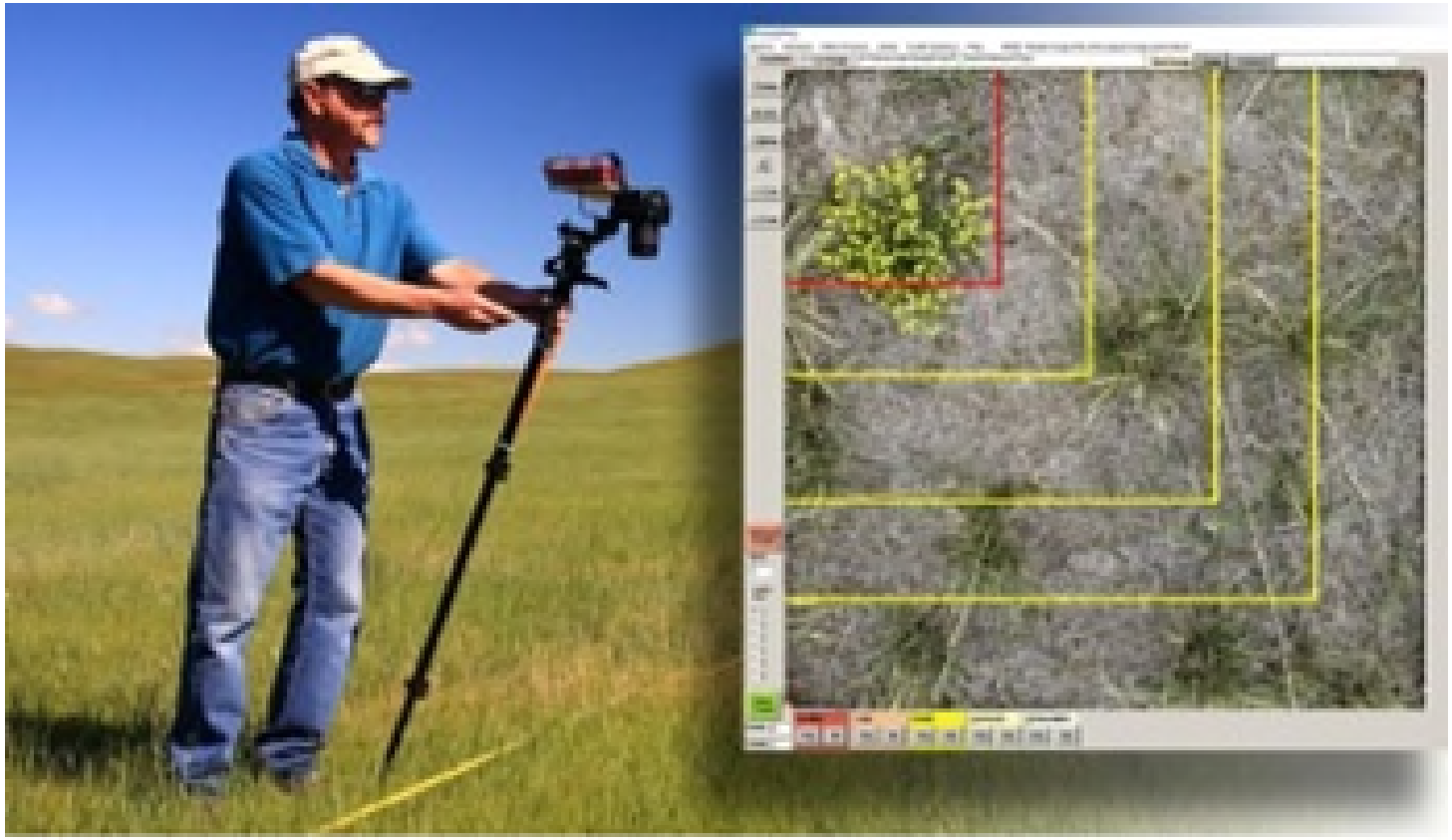
Curran, M. F., & Stahl, P. D. (2015). Database management for large scale reclamation projects in Wyor Developing better data acquisition, monitoring, and models for application to future projects. *Journal Environmental Solutions for Oil, Gas, and Mining,* 1(2), 31-43.

Will adopting new methods ruin our ability to assess trends?

- Commonly used methods not doing a good job at accurately assessing trends
- Technicians and techniques inconsistent
- Monitoring metrics inconsistent
- Timing varies from year to year

Image based monitoring

- Faster than LPI
- Less biased than LPI to wind, bright colors, moving pointing devices
- Permanent records
- Ability for multiple people to analyze
- As technology advances, so can image analysis



Cox, S. E., Booth, D. T., & Berryman, R. D. (2021). Measuring nested frequency of plants from digital images with SampleFreq. *Ecological Indicators*, *121*, 106946.

Cagney, J., Cox, S. E., & Booth, D. T. (2011). Comparison of point intercept and image analysis for monitoring rangeland transects. *Rangeland Ecology & Management*, *64*(3), 309-315.

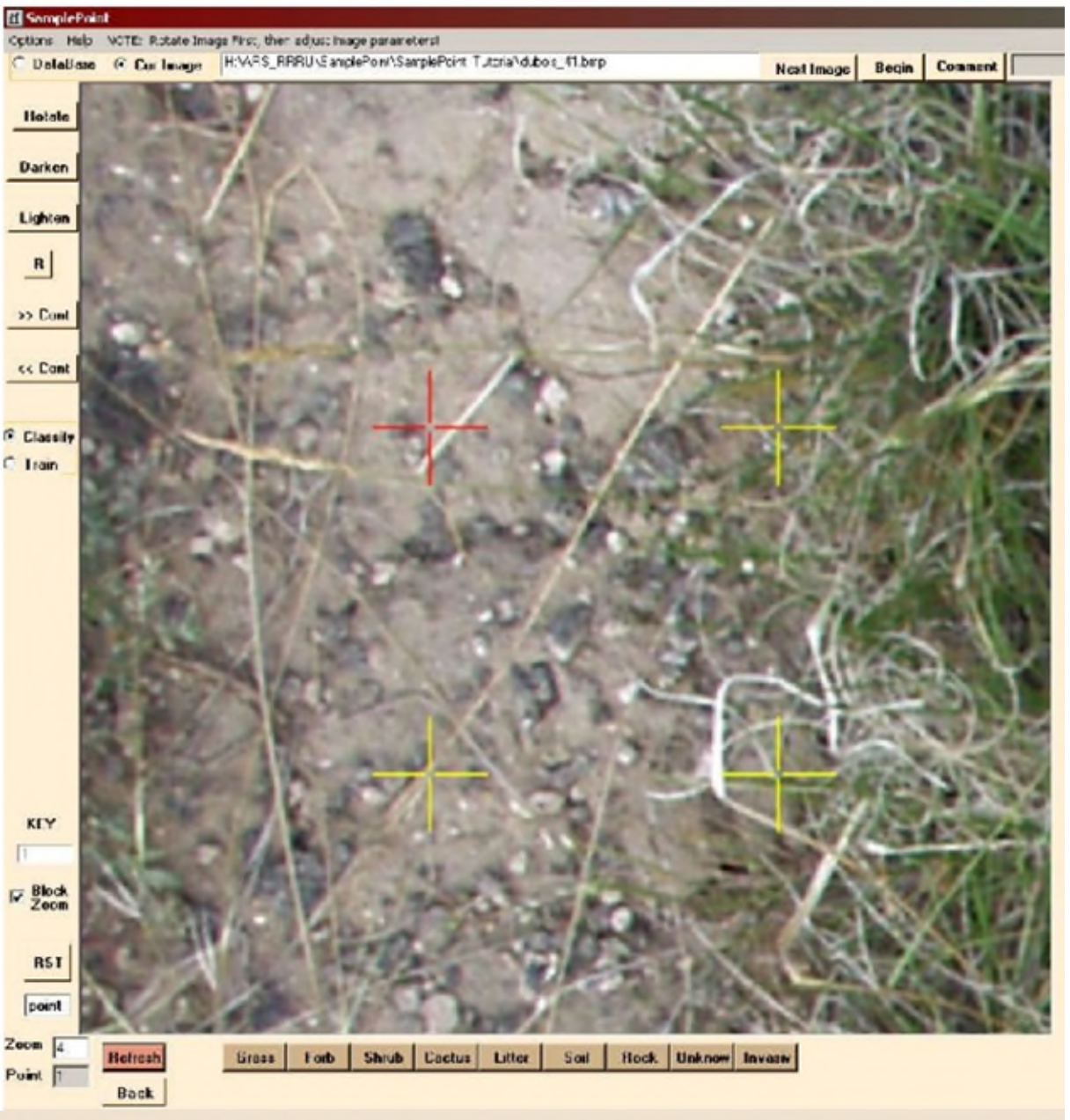
Ground Sample Distance

- Distance between the centers of two adjacent pixels measured on the ground
- Lower GSD results in:
  - Higher accuracy
  - More data
  - More image detail

H	|	height in meters
ImW	|	image width in pixels
GSD	|	ground sampling distance in centimeters/pixels
F	|	focal length in millimeters
SW	|	sensor width in millimeters

SamplePoint

- Free ImageAnalysis Software
  - www.SamplePoint.org
- Pixel Classification
  - Functional Group or Species
- Time Savings
- Reports Automatically Generated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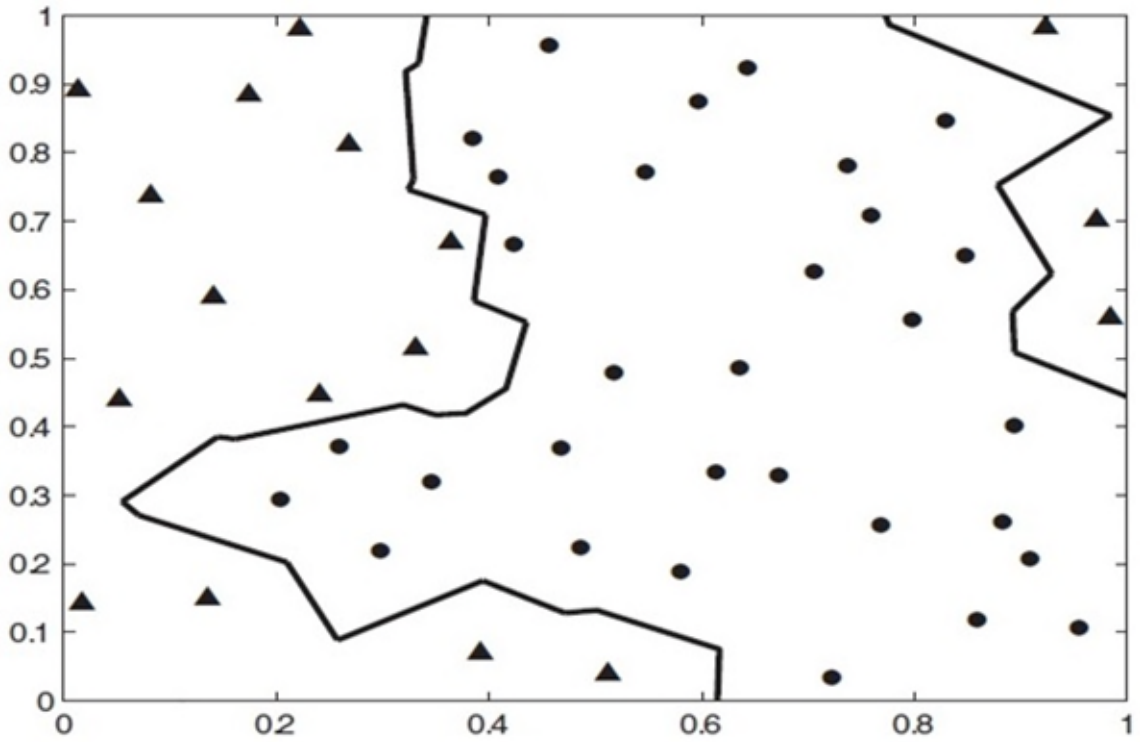
Invasiv

Balanced Acceptance Sampling (BAS)

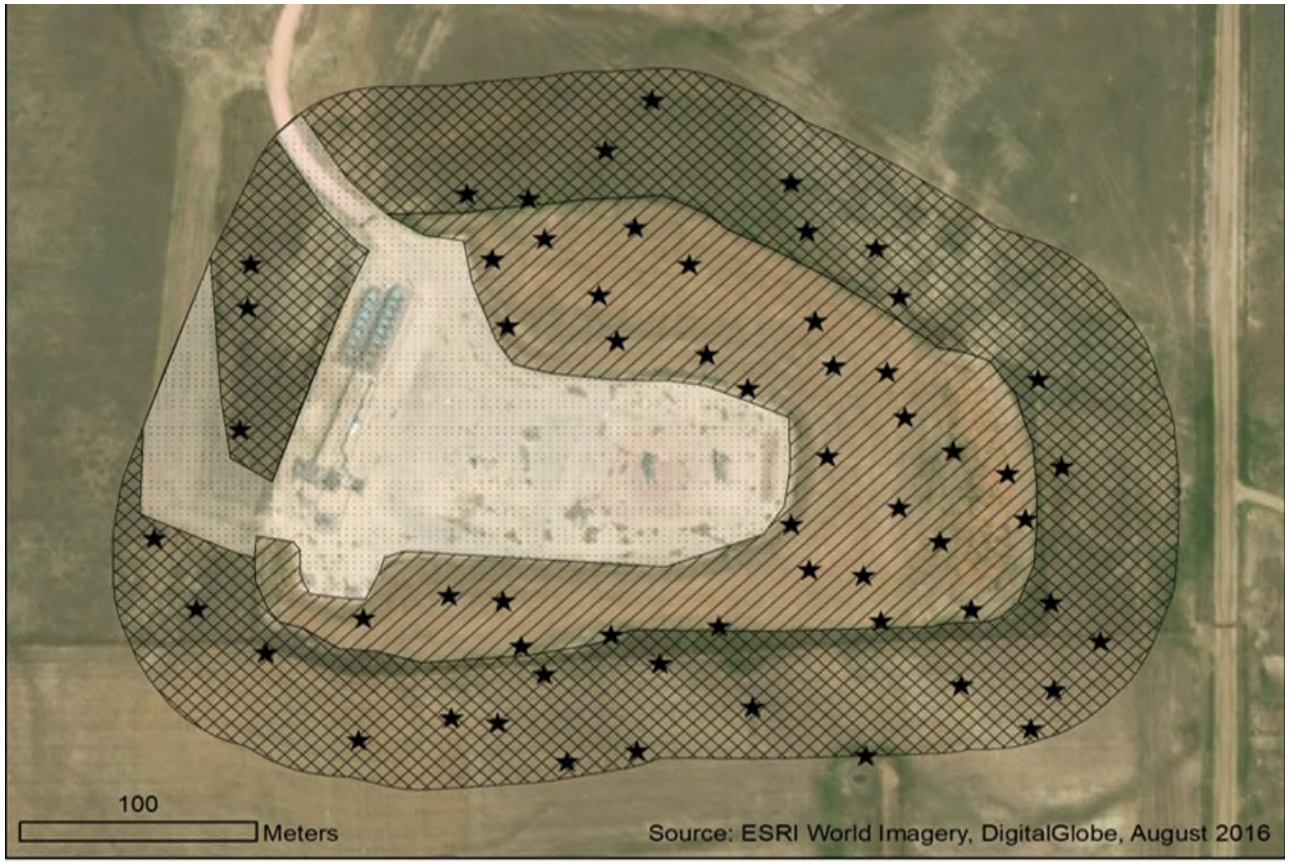
- Spatially balanced sampling design
  - Well suited for natural resource sampling
    - Nearby units similar due to environmental and management inputs
  - Sample well spread across study area
  - Allows for strong estimates of population
- Quasi random
- Computationally efficient
- Allows for over sample
  - Accounts for unsafe or impractical locations



Robertson, B.L. et al. 2013. BAS: Balanced Acceptance Sampling of Natural Resources. *Bioinformatics.*

Spatially balanced sampling and ground-level imagery for vegetation monitoring on reclaimed well pads

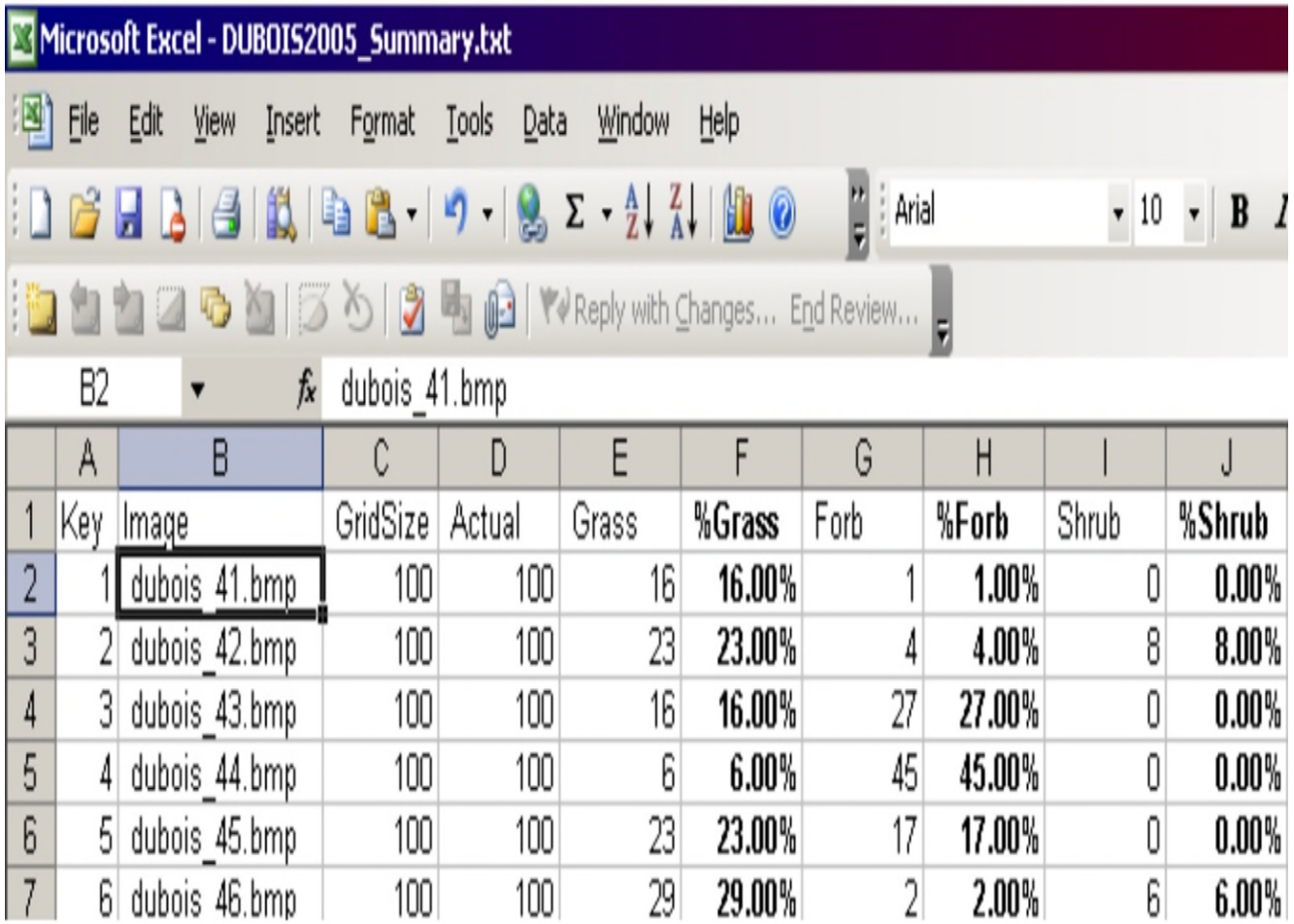
- Spatial verification method introduced
- 7-10x faster than LPI techniques
- Increased statistical power
- One-time data collection satisfies all existing regulatory criteria
  - Jonah Interagency Office
  - WY DEQ – Stormwater Pollution Prevention Plan (SWPPP)
  - WY Sage-grouse Executive Order
- Species specific report allows for seed mix assessment
- Spatially explicit weed information
- Increased variability in reference area accounted for
- Allows for spatially-explicit dashboard systems to be created (Curran et al. 2018 – *One Steppe*)



Curran, M. F., Cox, S. E., Robinson, T. J., Robertson, B. L., Rogers, K. J., Sherman, Z. A., Adams, T.A., Strom, C.F. & Stahl, P. D. (2019). Spatially balanced sampling and ground-level imagery for vegetation monitoring on reclaimed well pads. *Restoration Ecology*, 27(5), 974-980.

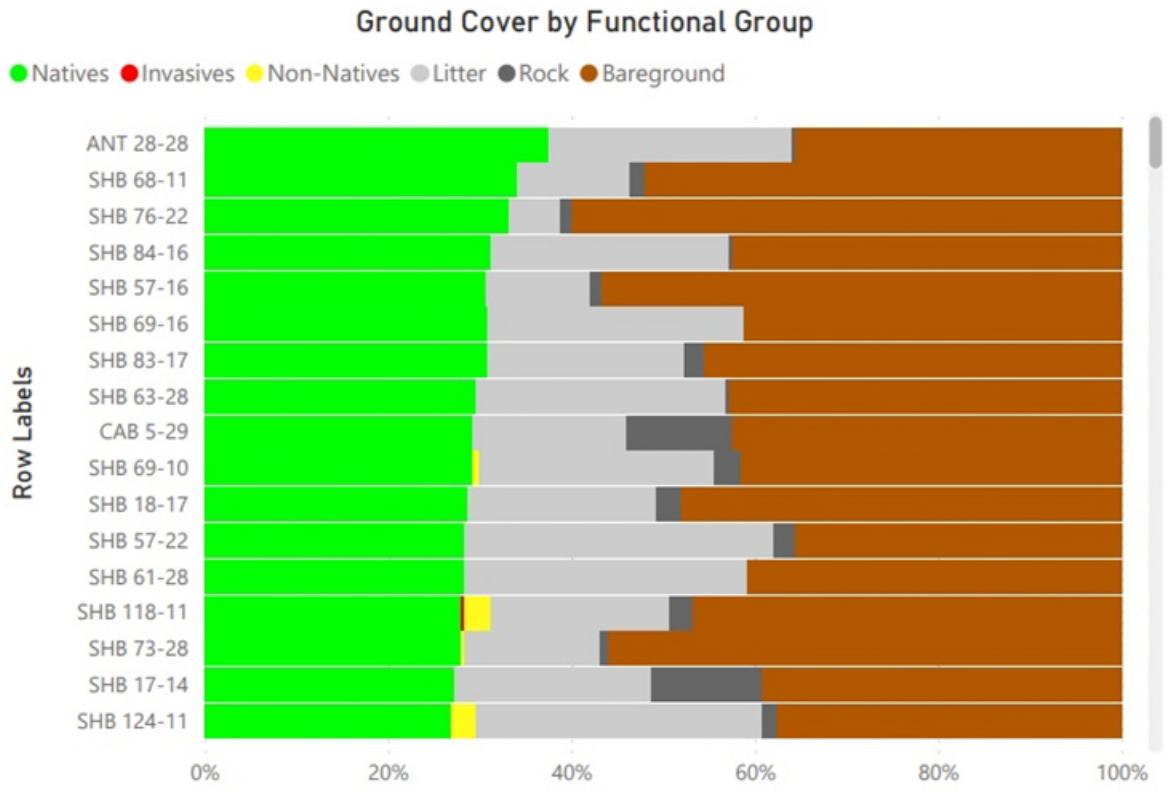
SamplePoint Report

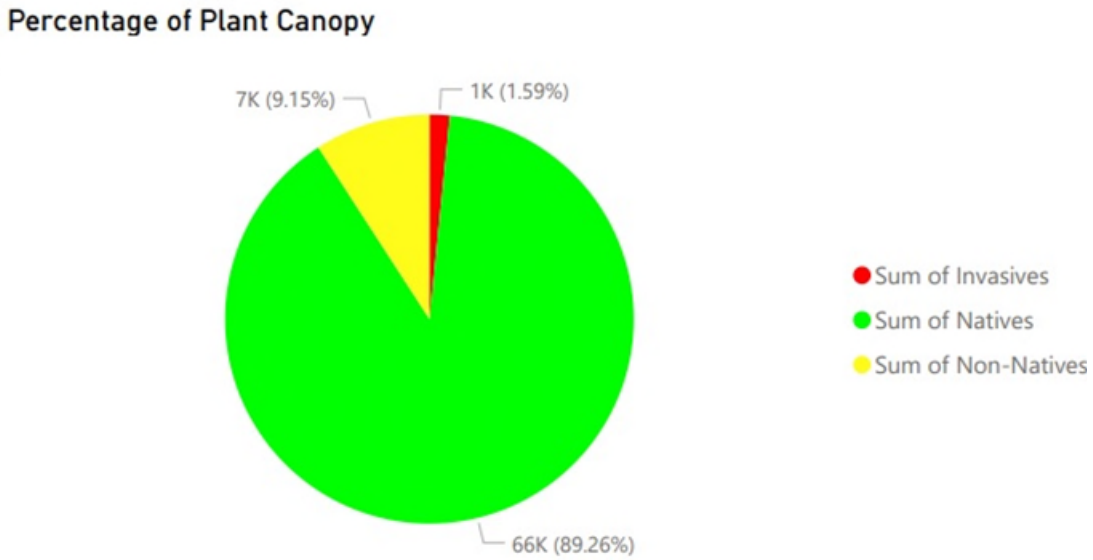
- .csv spreadsheet autogenerated
- Total ‘clicks’ per image
- Percent cover by group
  - Functional group
  - Species specific
- Allows for percent cover variance to be estimated
- Species richness

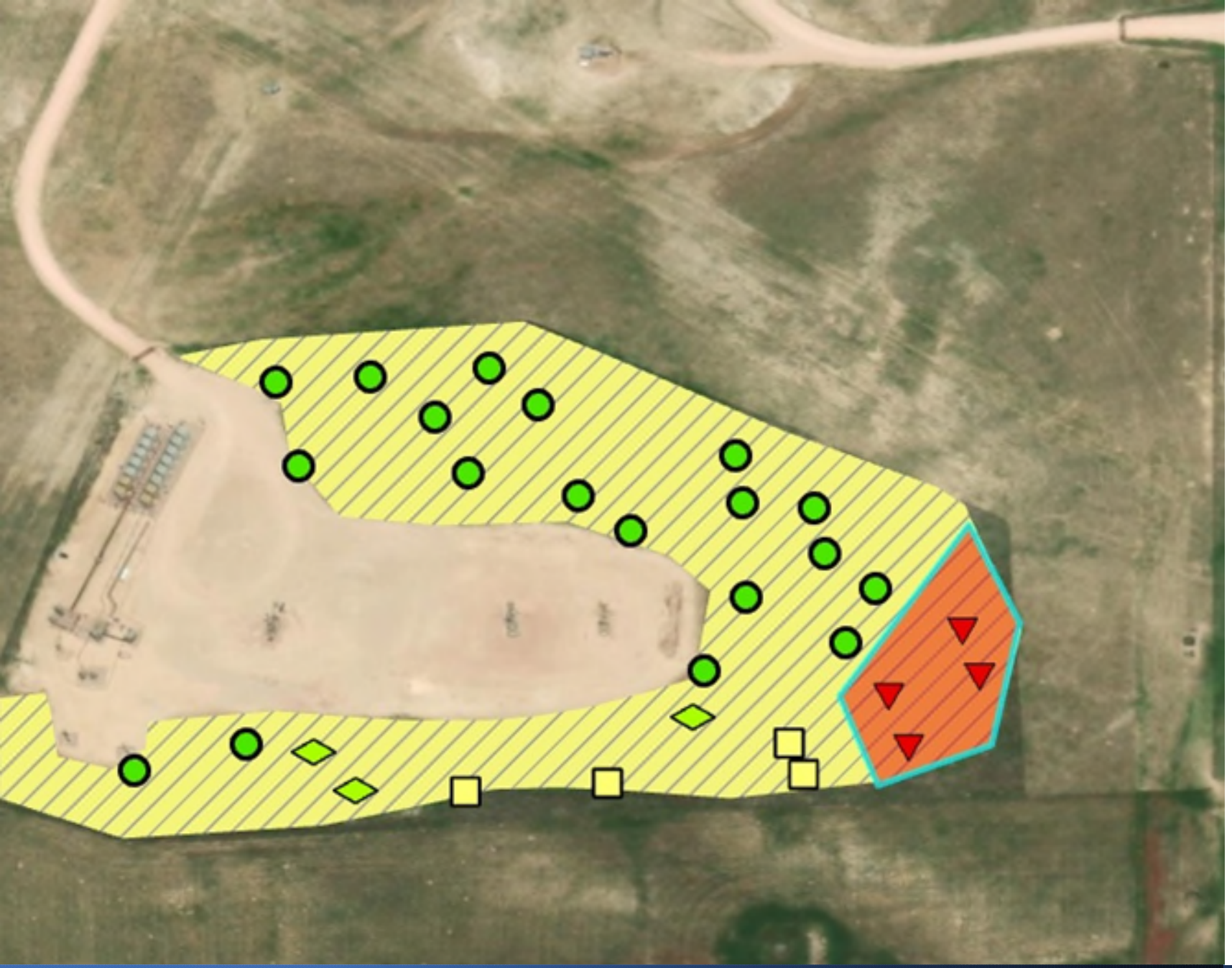


	A	B	C	D	E	F	G	H	I	J
1	Key	Image	GridSize	Actual	Grass	%Grass	Forb	%Forb	Shrub	%Shrub
2	1	dubois_41.bmp	100	100	16	16.00%	1	1.00%	0	0.00%
3	2	dubois_42.bmp	100	100	23	23.00%	4	4.00%	8	8.00%
4	3	dubois_43.bmp	100	100	16	16.00%	27	27.00%	0	0.00%
5	4	dubois_44.bmp	100	100	6	6.00%	45	45.00%	0	0.00%
6	5	dubois_45.bmp	100	100	23	23.00%	17	17.00%	0	0.00%
7	6	dubois_46.bmp	100	100	29	29.00%	2	2.00%	6	6.00%

Example of a dashboard from Jonah (200 sites)







Legend

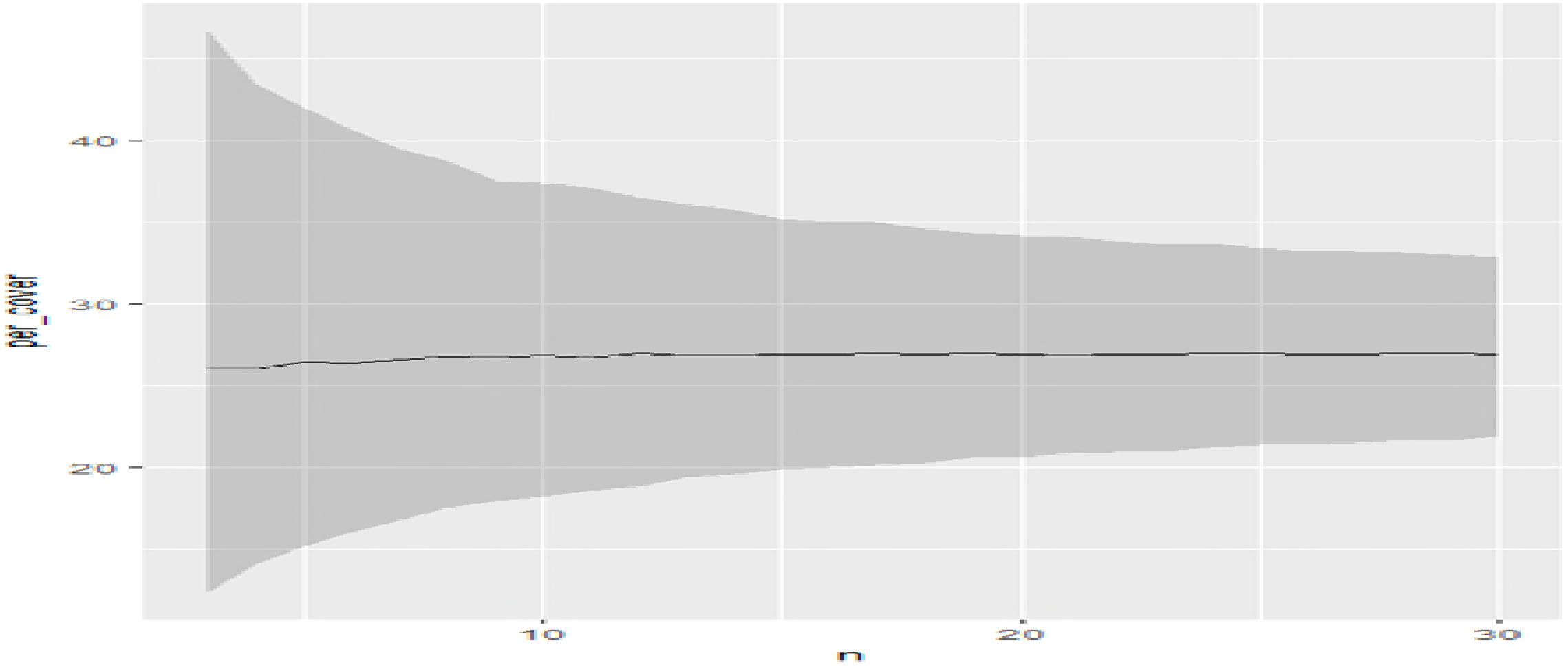
Native Vegetation

Native/Non-Native Mix

Non-Native Vegetation

Invasive Vegetation

What is the optimal sample size?

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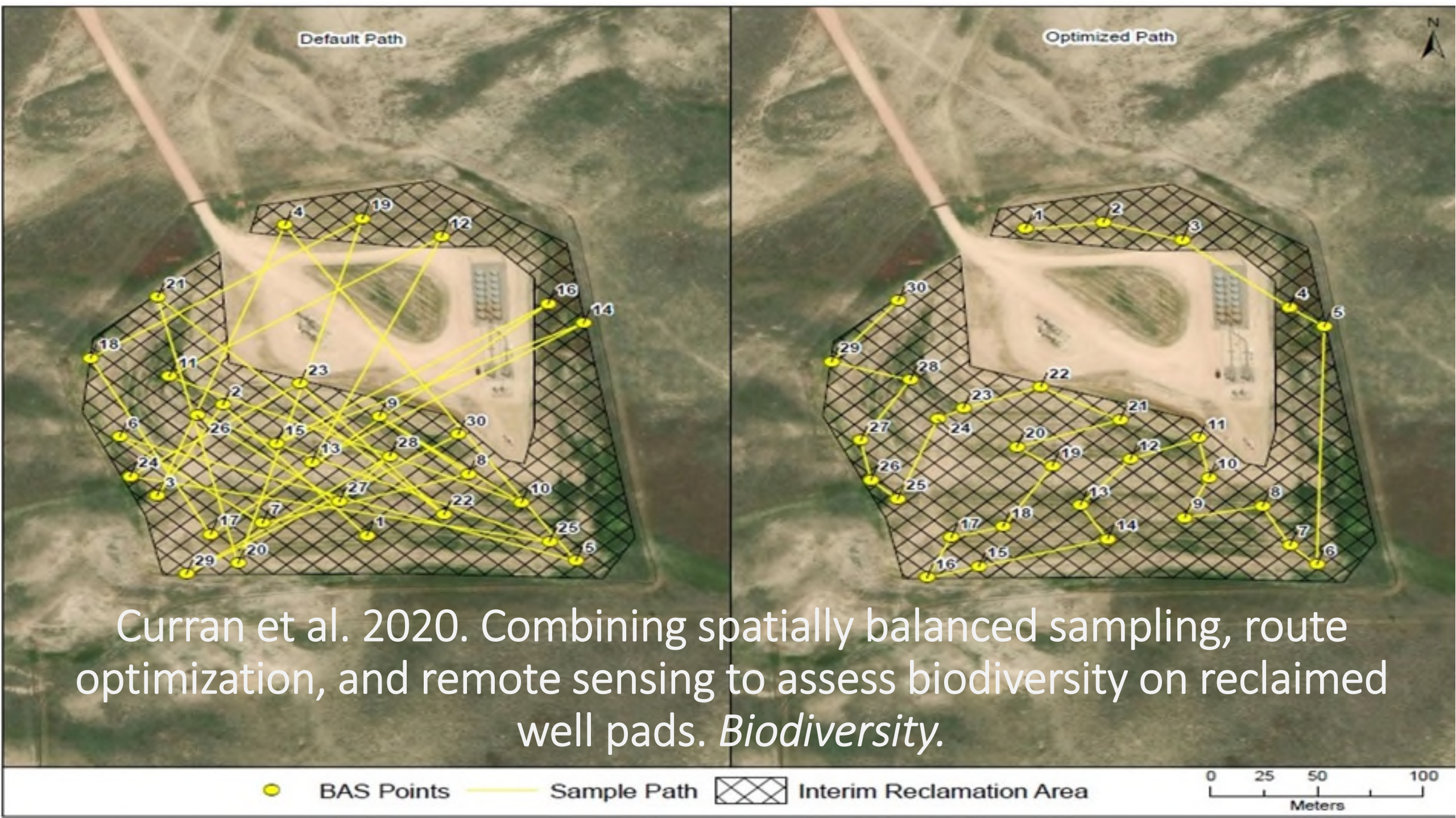
Combining spatially balanced sampling, route optimization and remote sensing to assess biodiversity on reclaimed well pads

- Solved travelling salesman problem to connect BAS points with shortest path
- Flew drone 25 ft (7.6 m) above ground level
  - Handheld – 12.1 megapixel
    - 0.2 mm GSD
  - Drone – 16 megapixel
    - ~2 mm GSD
- Compared drone imagery with handheld imagery
  - Time analysis
  - Vegetation agreement



Curran et al. 2020. Combining spatially balanced sampling, route optimization, and remote sensing to assess biodiversity on reclaimed well pads. *Biodiversity.*

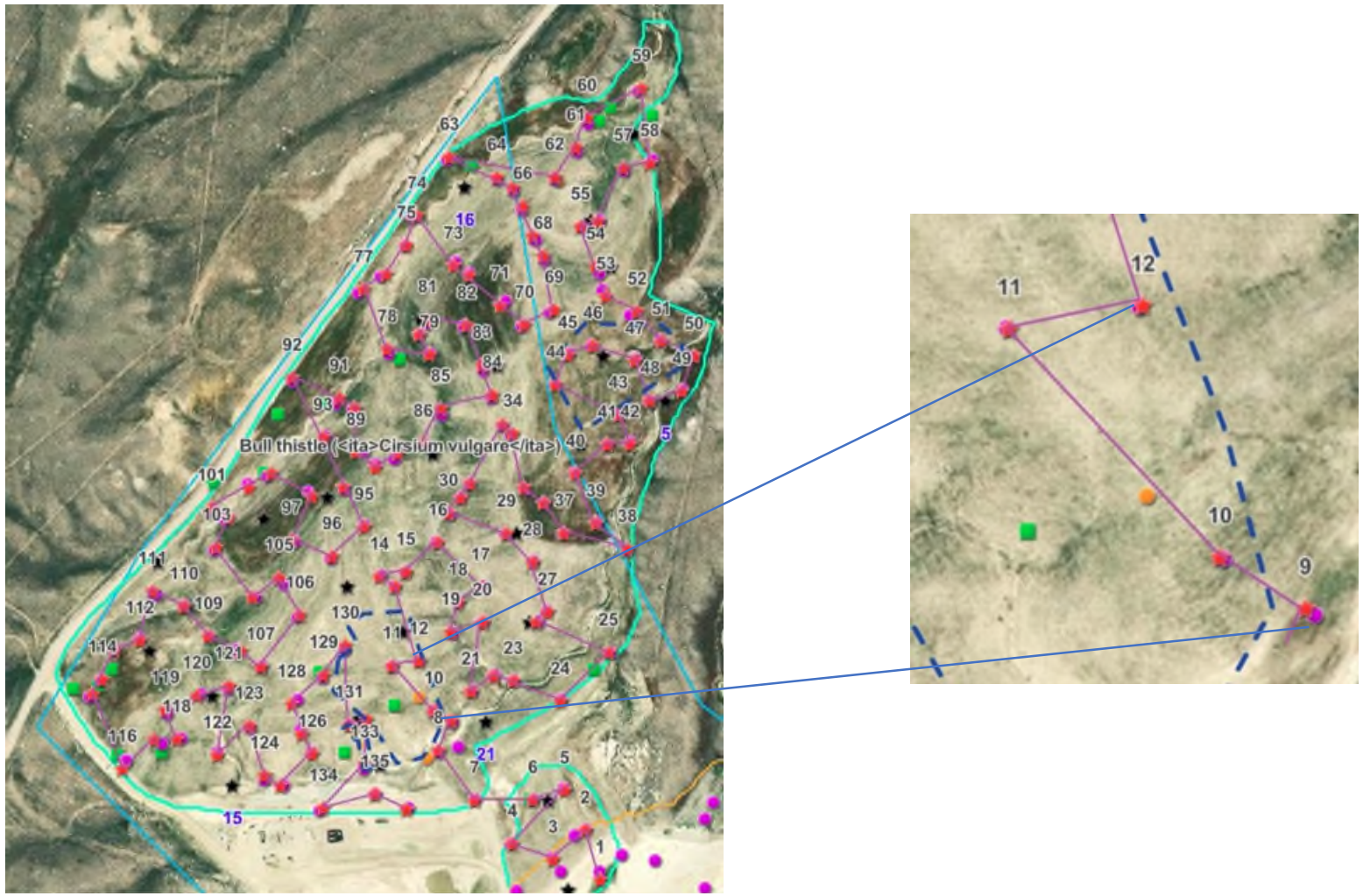
Conclusions

- Drone imagery and handheld imagery performed similarly for percent cover of bare ground and vegetation based on functional groups
  - GSD with drone made grass ID to species difficult
  - Drone saved average of 22.1 minutes per well pad compared to handheld imagery
  - Drone 25-42x faster than traditional (LPI) methods
- Flight height restrictions and infrastructure must be taken into account

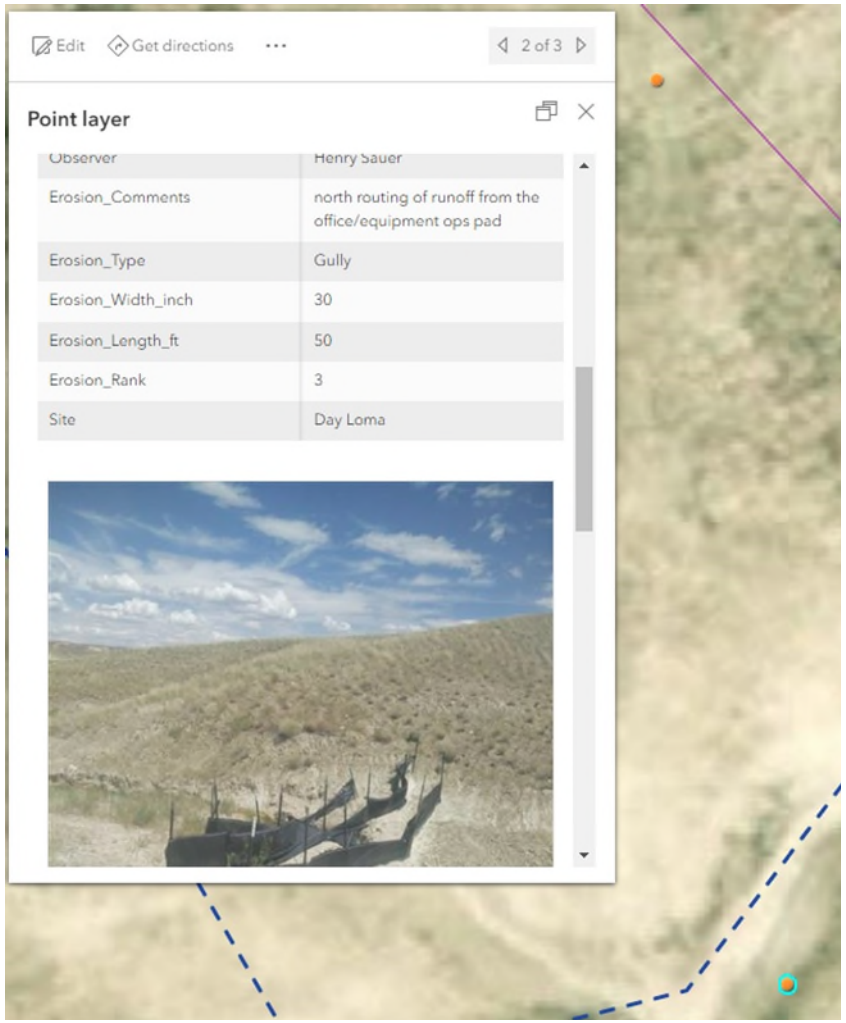
Pipeline Example

- 2.5 Mile Pipeline
- ~70 Acres (~28 hectares)
- Requires 168 photo locations
- BAS Points with Optimized Route
  ~ 4 Mile line
- Drone at 20 mph completes
  survey in ~17.5 minutes

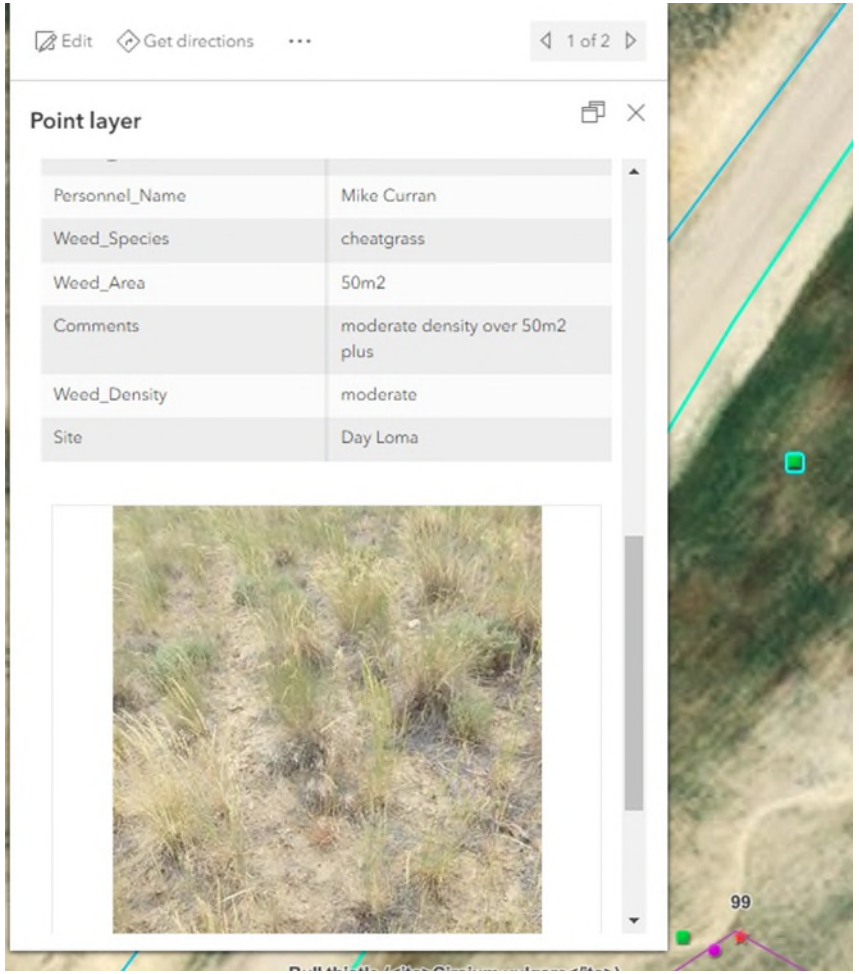
Abandoned Mine Land – Cell Phone Collection



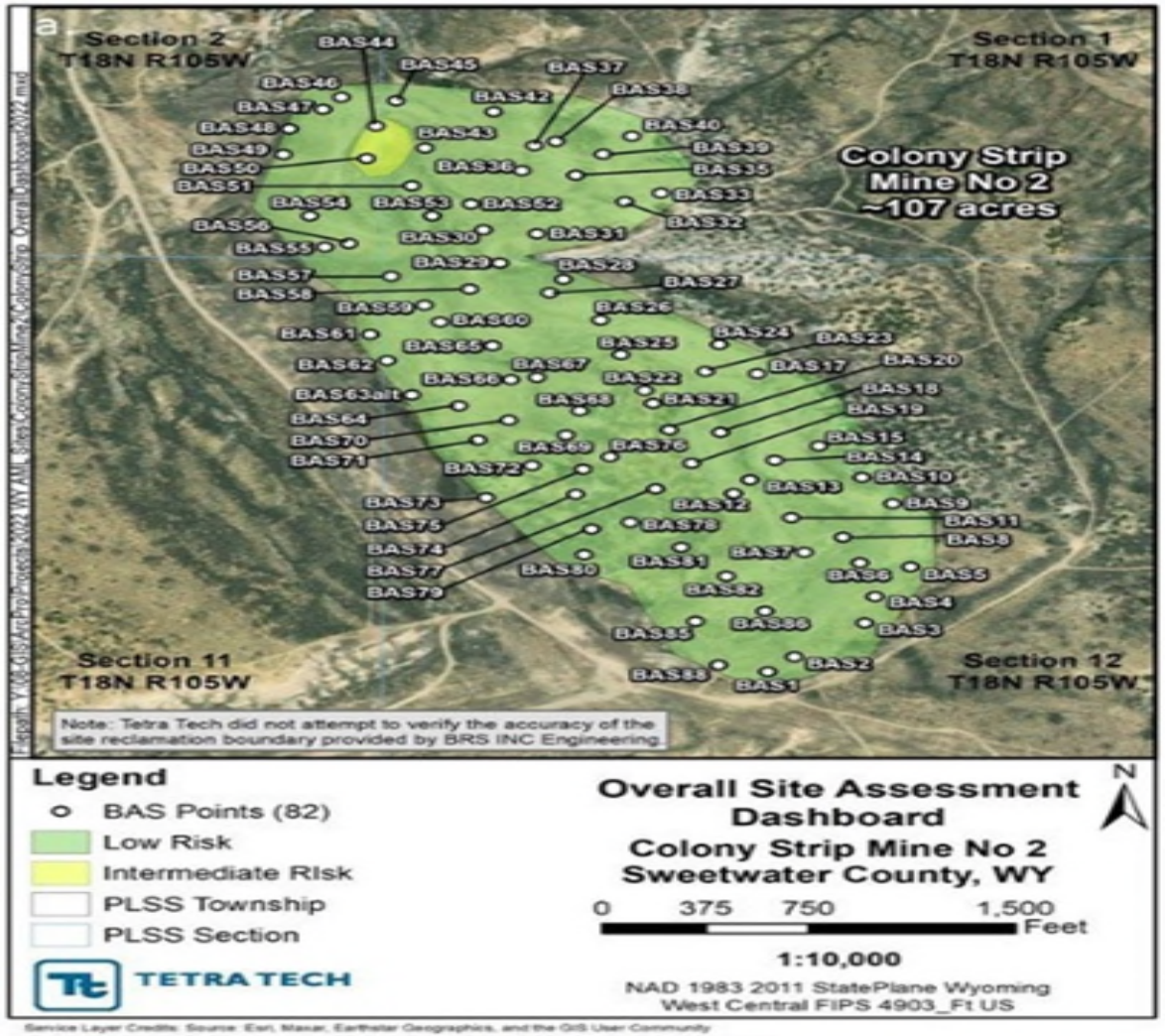
Abandoned Mine Land – Erosion Example

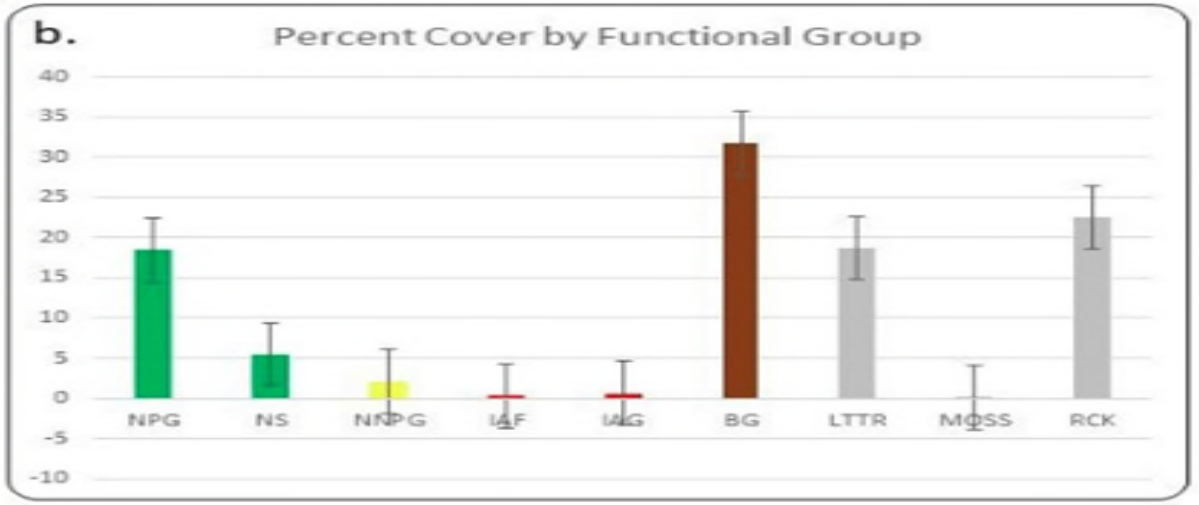


Abandoned Mine Land – Weed Example



Colony Strip – Overall Dashboard





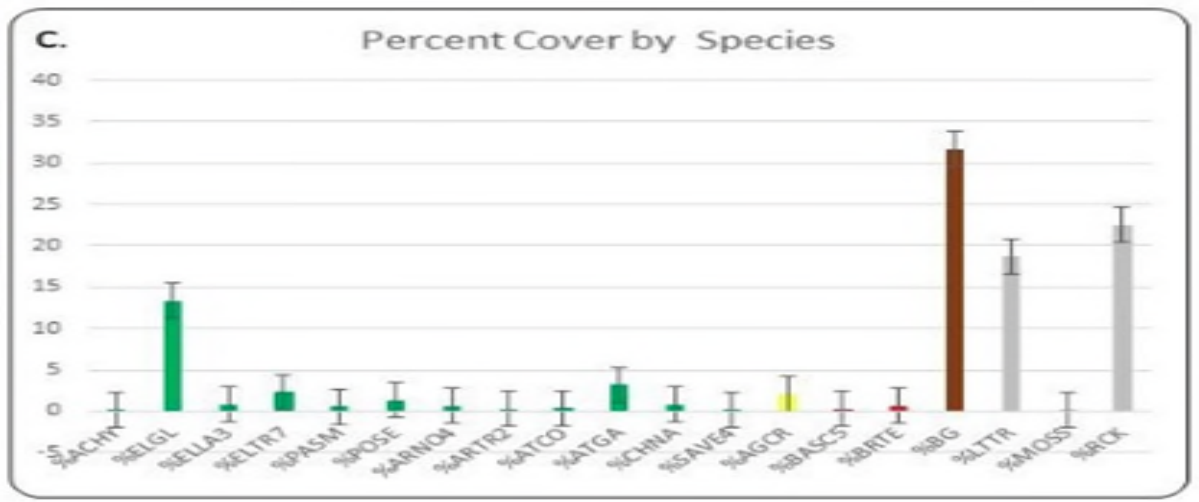
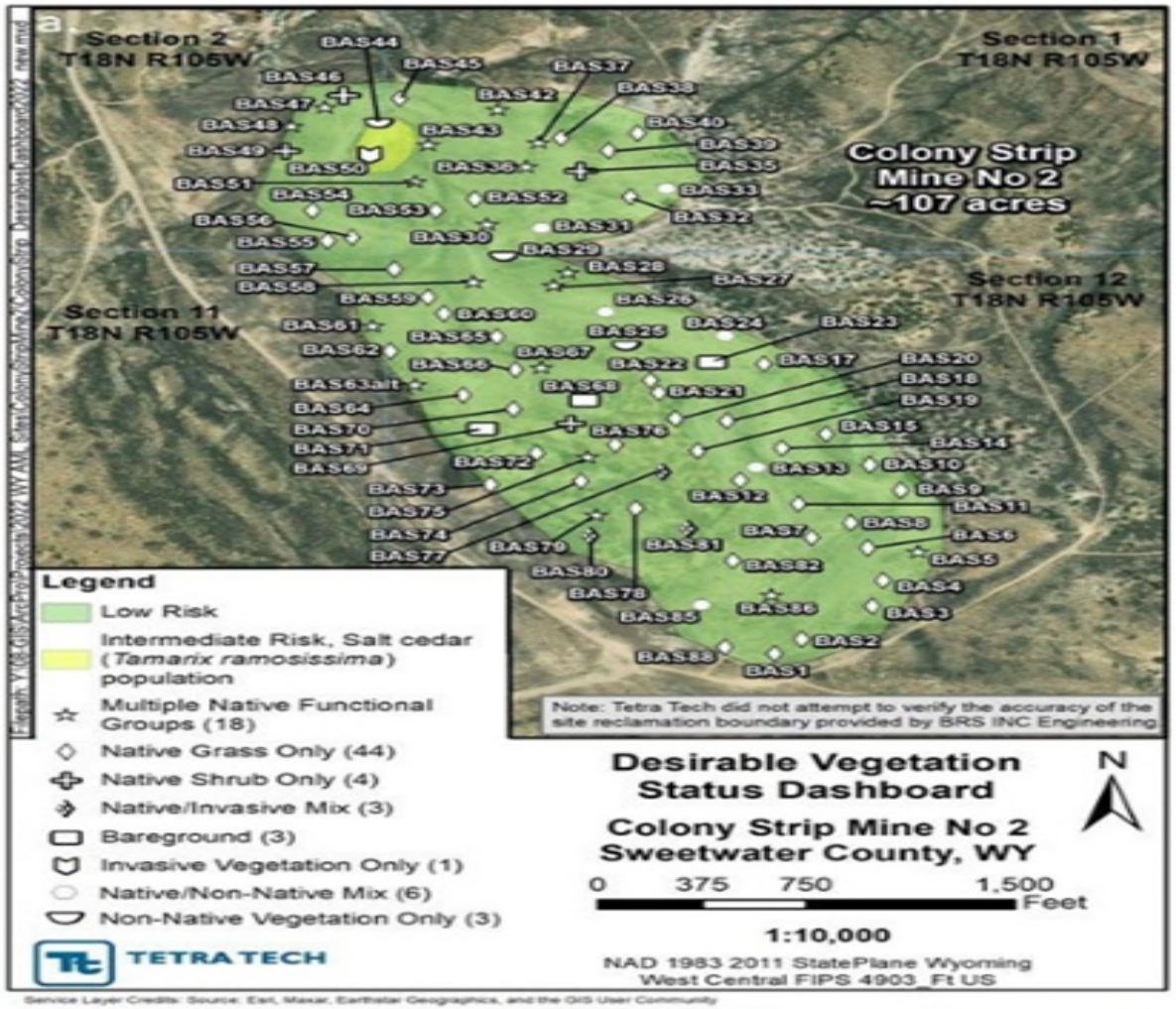


Figure 2. Overall Status Dashboard for Portion of the Colony Strip No. 2 Mine Reclaimed by AML.
Note: The functional group and symbol (or abbreviation) for each plant species observed on Site are presented in Appendix B.

Colony Strip – Desirable Species Management



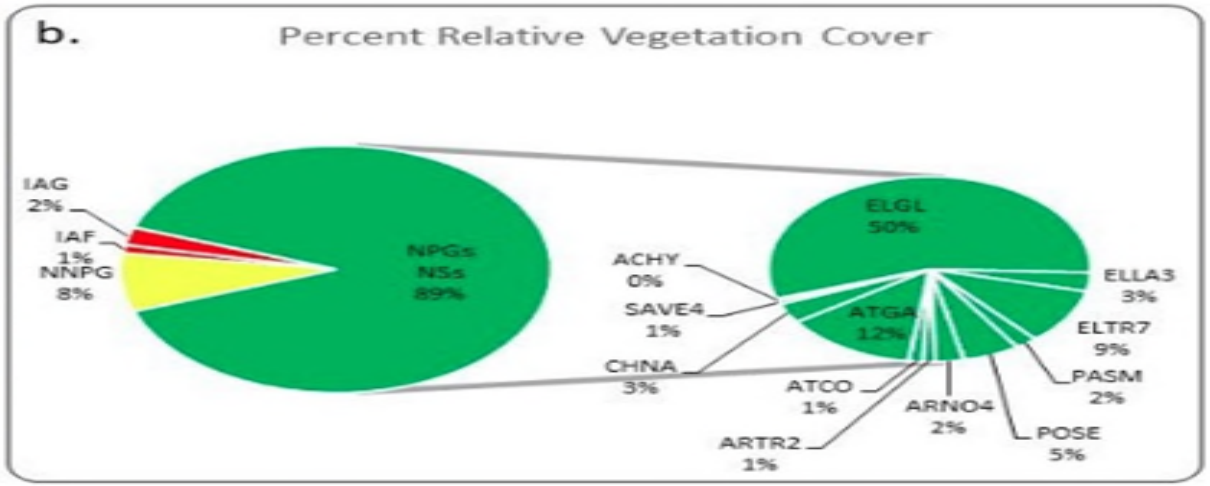
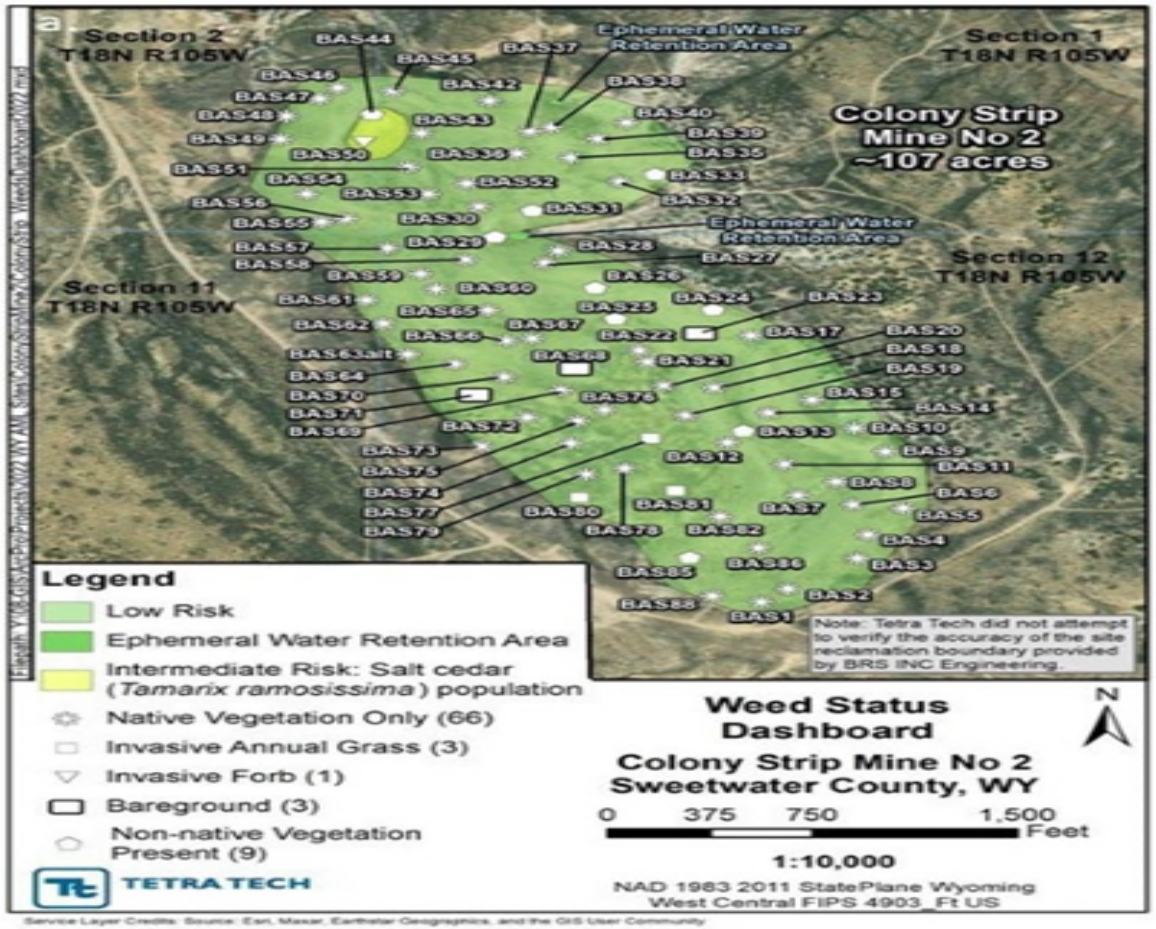


Figure 3. Desirable Species Status Dashboard for Portion of the Colony Strip No. 2 Mine Reclaimed by AML

Colony Strip – Weed Management Dashboard



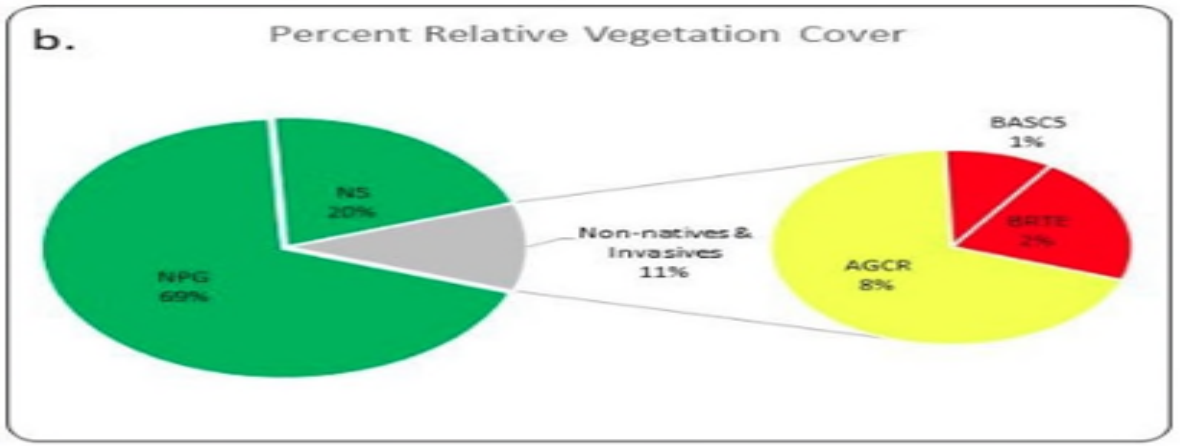
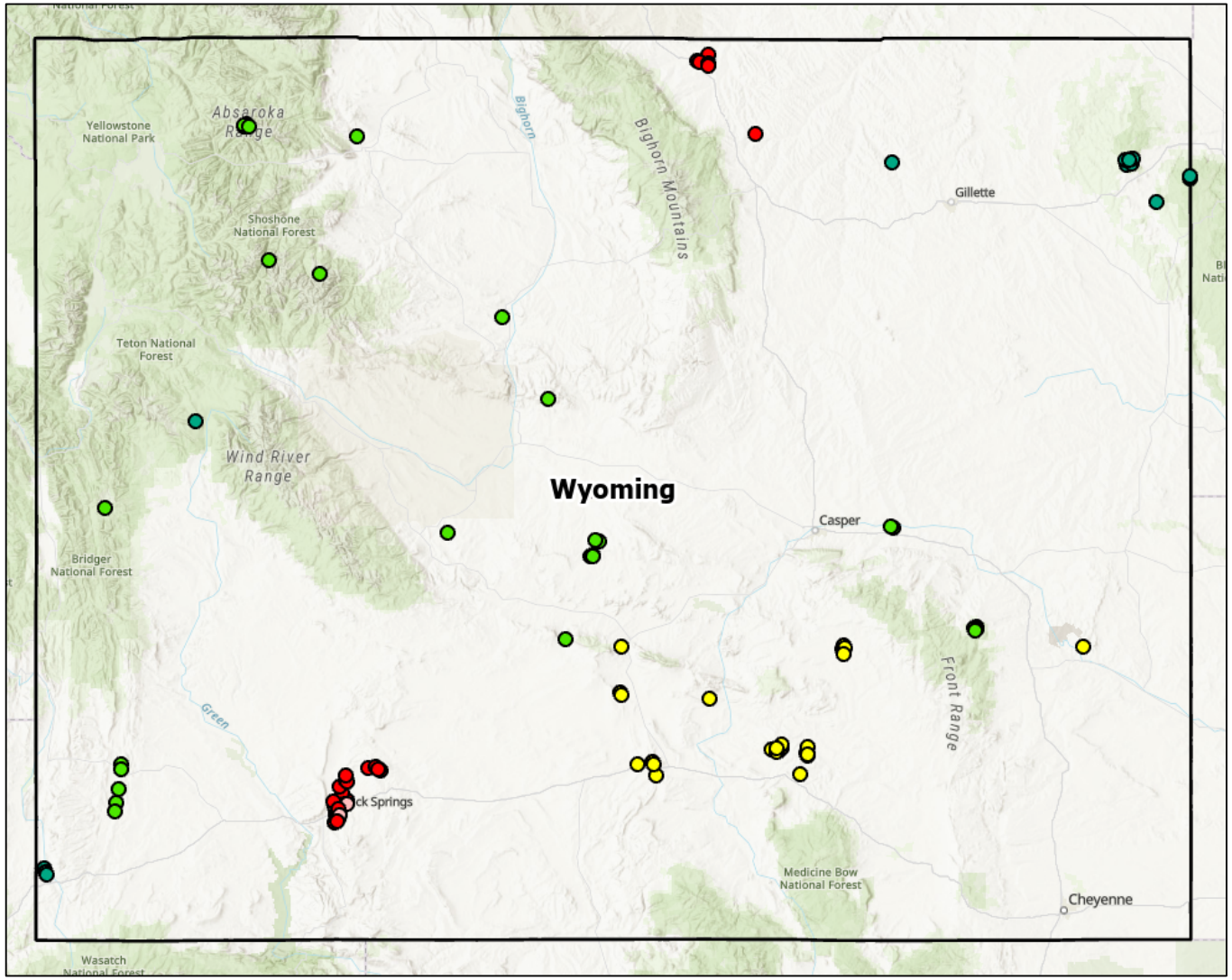


Figure 4. Weed Status Dashboard for Portion of the Colony Strip No. 2 Mine Reclaimed by AML

Statewide Dashboarding

- Each monitored and classified Site can then be ported to a state-wide map and/or dashboard system for quick administrative reference.
- Each point could be hyperlinked to the Dashboard reports, along with any other desired supporting information.
- The system could be used for administrative purposes and as a communication tool for interagency collaborations.

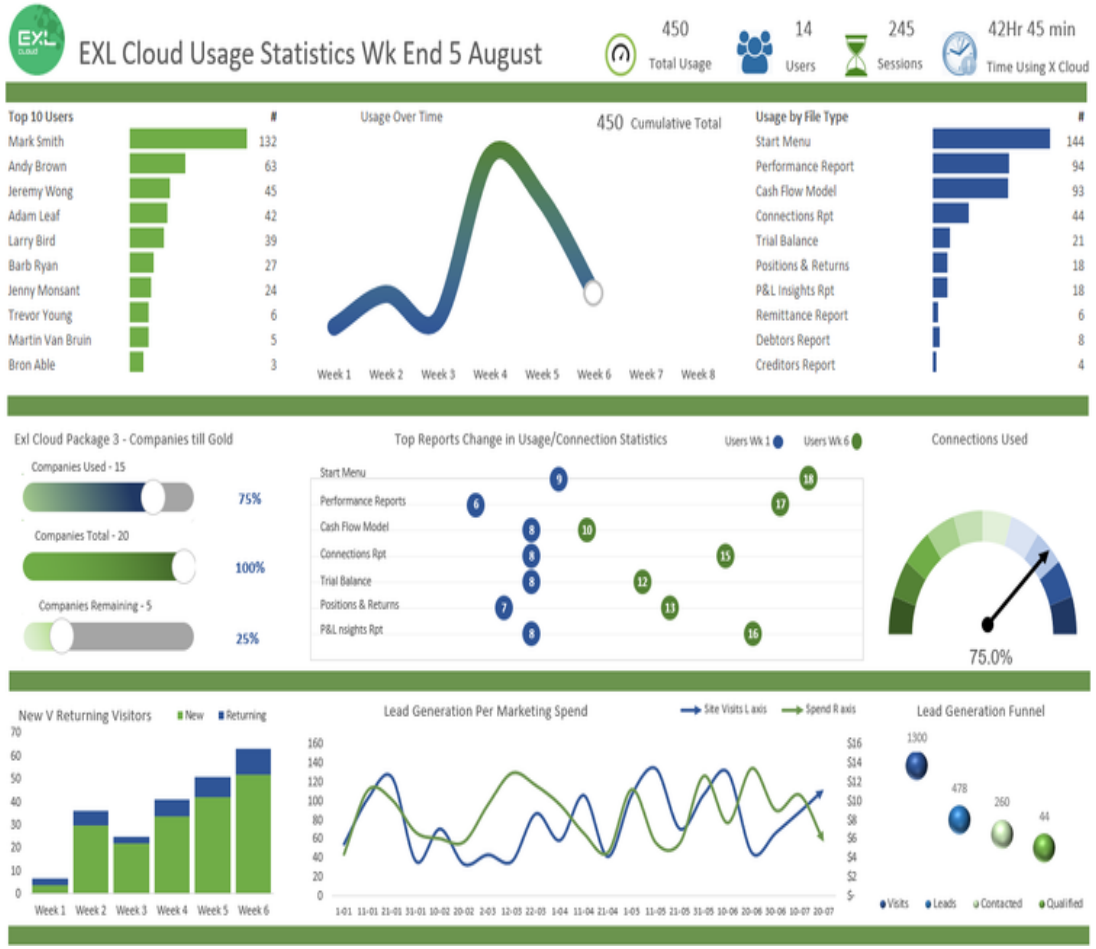


Overall Conclusions

- Image-based monitoring allows for significantly faster data collection in field than traditional techniques
- More data is collected, covering larger areas
- Quantitative data from images can be used to satisfy all existing regulatory criteria
- Data can also be used to inform weed management, test (and improve) seed mixes, for trend analysis, and for rapid report generation (adaptive management)
- Ultimately, since data is spatially explicit, a spatially explicit dashboard system can be used for reporting (resulting in easy to interpret, visual reports rather than cumbersome written documents)
- Cost savings in field data collection become amplified when used to inform management decisions

Next Steps

- Continue Refining Metrics, KPIs, Dashboards
  - Operator and Agency Cooperation
- Couple Site Specific Plans with Rotating Panel Design



Acknowledgements

- Co-authors
- Jonah Energy
- Anadarko Petroleum Corporation
- WY Abandoned Mine Lands