Monitoring Strategies for Reclamation Programs Involving Multiple Sites

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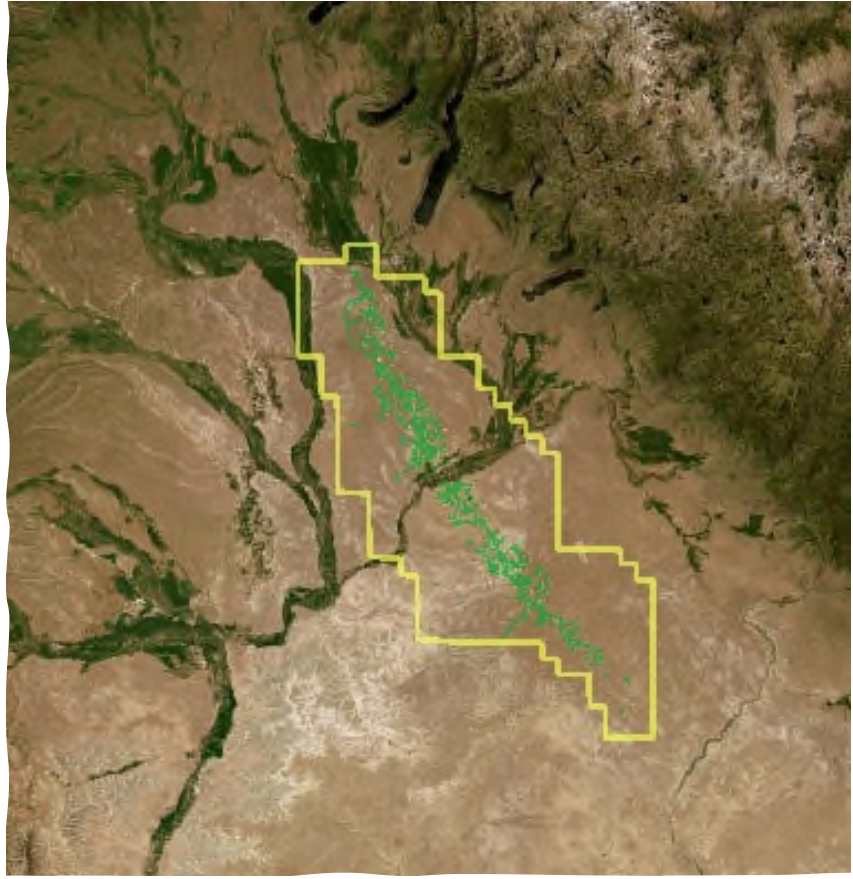
Reclamation Monitoring Programs

- Required for compliance
- Useful to gauge effectiveness of reclamation practices
- Assist with management decisions
- Help identify trends
- Not uncommon for a given company or agency to be responsible for large numbers of individual sites
  - Upstream oil and gas operators – hundreds or thousands of well pads
  - Midstream companies – miles of pipeline right-of-way
  - Abandoned Mine Land Programs – Hundreds/Thousands of Mines
  - Bureau of Land Management – Orphaned Well Program



Reclamation Monitoring Programs Over Space and Time

- Deciding on monitoring methods at given location based on a variety of factors
- For large programs, visiting every location on an annual basis may be challenging or impossible due to time, cost, and environmental factors
- Repeat visits to individual sites are necessary throughout the life cycle of a given reclamation program

Objectives of Surveys Over Space and Time (Duncan & Kalton 1987)

- To estimate population parameters at distinct time points
- To estimate population parameters averaged across a period of time
- To measure net change *
- To measure components of individual change *
- To aggregate data for individuals over time
- To measure frequency, timing, duration of events
- To accumulate samples over time

Spatial Coverage vs. Temporal Coverage

- Spatial replication – allows for inference about a spatial area
  - Important for compliance
  - Wildlife considerations
  - Geographic variation (performance on different soil types, slopes, etc.)
  - Land use goals (e.g., agriculture vs. rangeland)
- Temporal replication – allows for trend assessment
  - Year to year variation

Rotating Panel Design

- Panel – a group of population units that are always sampled during the same sampling occasion or time period (McDonald 2003)
- Revisit Design – the plan by which population units are visited and sampled through time (McDonald 2003)
- Membership Design – the way in which units of the population become members of the design (McDonald 2003)

Some common examples – “4,8,4” “$(1\text{-}5)^3$” “0-3-1-2”

Examples of Revisit Panel Plans (Urquhart & Kincaid 1999)

Table 1. Schematic Specification for Five Planned Revisit Panel Plans

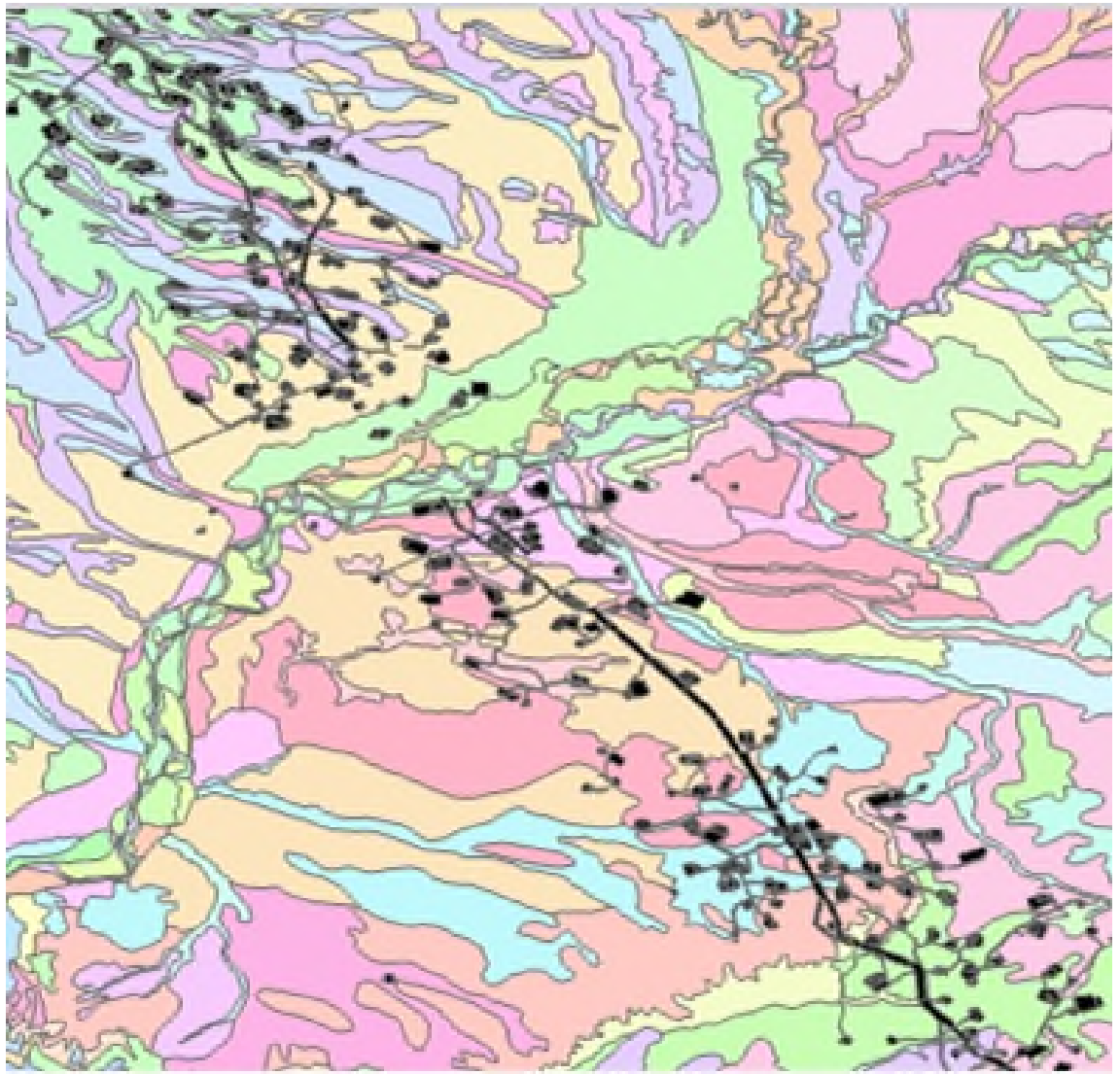
Panel	Size	Time periods (= years) 1	2	3	4	5	6	7	8	9	10	11	12	...
Design 1 = Always Revisit = Same Sites (= Stream Segments)														
1	60	X	X	X	X	X	X	X	X	X	X	X	X	...
Design 2 = Never Revisit = New Sites (= Stream Segments)														
1	60	X												
2	60		X											
3	60			X										
4	60				X									
5	60					X								
6	60						X							
7	60							X						
8	60								X					
9	60									X				
10	60										X			
11	60											X		
12	60												X	
⋮	⋮													⋱
Design 3 = Rotating Panel (= NASS)														
−3	12	X												
−2	12	X	X											
−1	12	X	X	X										
0	12	X	X	X	X									
1	12	X	X	X	X	X								
2	12		X	X	X	X	X							
3	12			X	X	X	X	X						
4	12				X	X	X	X	X					
⋮	⋮					⋱	⋱	⋱	⋱	⋱				
Design 4 = Augmented Serially Alternating														
1	50	X				X					X			...
2	50		X				X					X		...
3	50			X				X					X	...
4	50				X				X					X ...
Common	10	X	X	X	X	X	X	X	X	X	X	X	X	...
Design 5 = Partially Augmented Serially Alternating														
1	35	X				X					X			...
2	35		X				X					X		...
3	35			X				X					X	...
4	40				X				X					X ...
1A	5	X	X			X					X			...
2A	5		X	X			X					X		...
⋮	⋮													⋮
1B	5	X				X	X				X			...
⋮	⋮													⋮
1C	5	X				X					X	X		...
⋮	⋮													⋮

Membership Design

- Often flawed due to ‘haphazard’ or ‘judgement’ sampling
  - Haphazard Samples – Collected without a defined protocol or directed effort (McDonald 2003)
  - Judgement Samples – ‘Hand-picked’ by researchers, often referred to as subjective sampling
  - Both techniques are non-probability samples (absence of randomization) and require a lot of assumptions to make inference about the population at large
  - Non-probability sampling makes quantifying uncertainty difficult
- Probability sampling techniques
  - Simple random sampling
  - Systematic sampling
  - Spatially balanced sampling

Example from the Pinedale Anticline

- Auxiliary variables obtained for each location
  - Seeding year (s)
  - Seed mix used
  - Other reclamation inputs
  - Ecological Site Descriptions
- Well pads and linear divisions separated
  - N = number of well pads owned by operator
  - N = sections of pipeline which are distinctly different
- Sites broken into panels accordingly



Spatially Balanced Selection of Panels

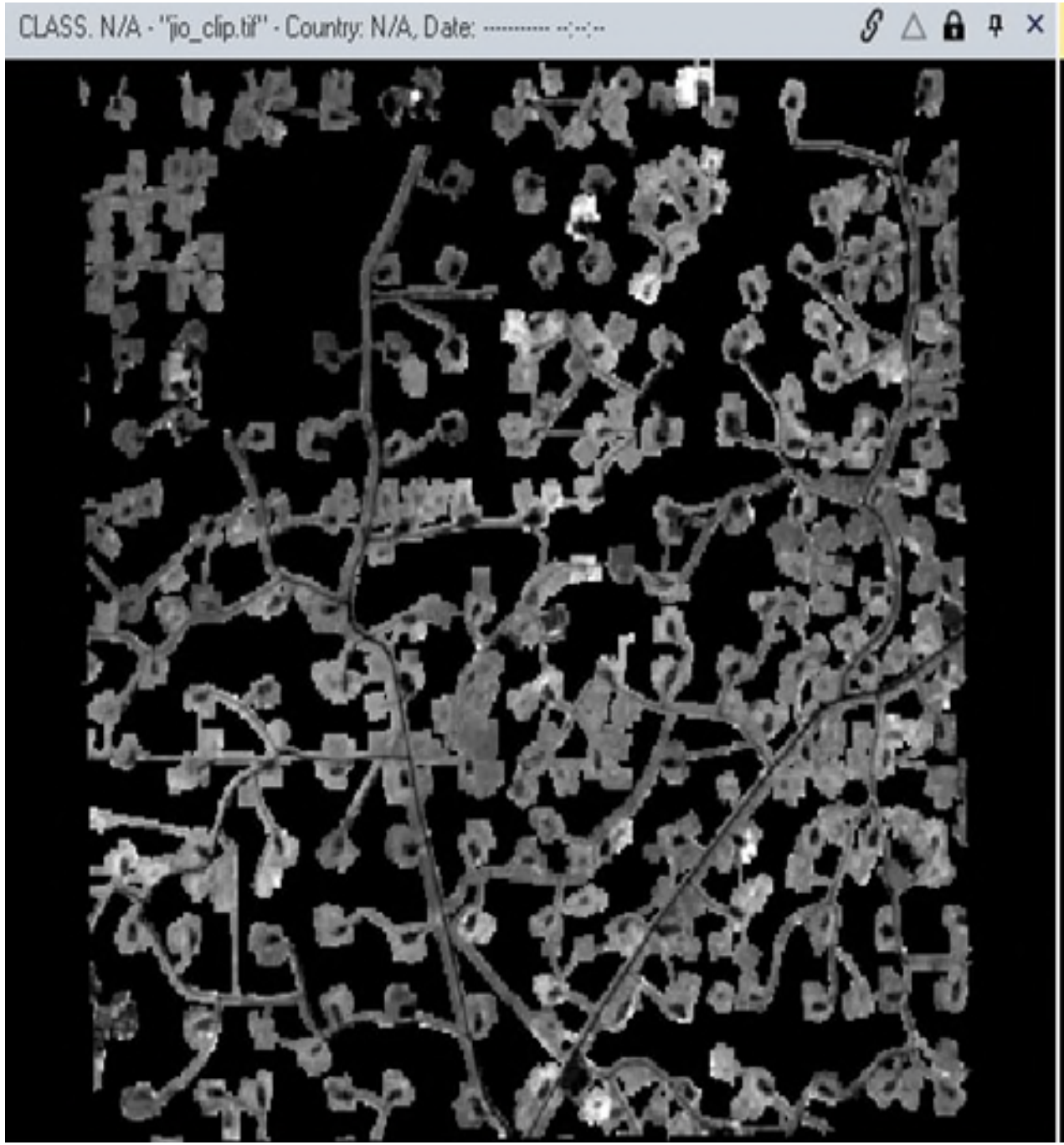
- Let U = {1,2, ..., N} be a population of N units. A representative sample is a scaled-down version of the entire population, where the sample reflects the population in as many ways as possible. Let B(i,r) be a ball with centre i and radius r > 0, with 0 <= N* <= N being the number of population units in B(i,r). A sample s is considered representative if n* approx (n/N) N* for all r, where n* is the number of units from s in B(i,r). For equal probability sampling (which is what we have been doing), spatially balanced samples are representative.
- Each panel is a representative sample - a spatially balanced sample. Hence, precise estimates of population characteristics can be made from each panel. But we can do even better than that. We can ensure the union of successive panels is representative and that the union of all panels is representative. We can achieve this using spatially balanced methods (BAS for continuous resources).

Union of Successive Panels

- Let s = {1,2, ..., 3n} be a spatially balanced (SB) sample. If s is a BAS sample, all contiguous subsets of units are also SB. Hence, for a BAS sample of size 3n, we can define three panels using p1 = {1,2, ..., n}, p2 = {n+1, n+2, ..., 2n} and p3 = {2n+1, 2n+2, ..., 3n}. Each panel is SB, p1 u p2 is SB, p2 u p3 is SB and p1 u p2 u p3 is SB. You can also allow for overlap between panels.

Assumptions in Model

- Well pads or stretches of pipeline which were treated with the same reclamation inputs and are in the same ecological site description (ESD) unit will perform similarly to each other
  - Need mechanisms to capture this to assess validity of panels
  - Good record keeping
  - Good monitoring information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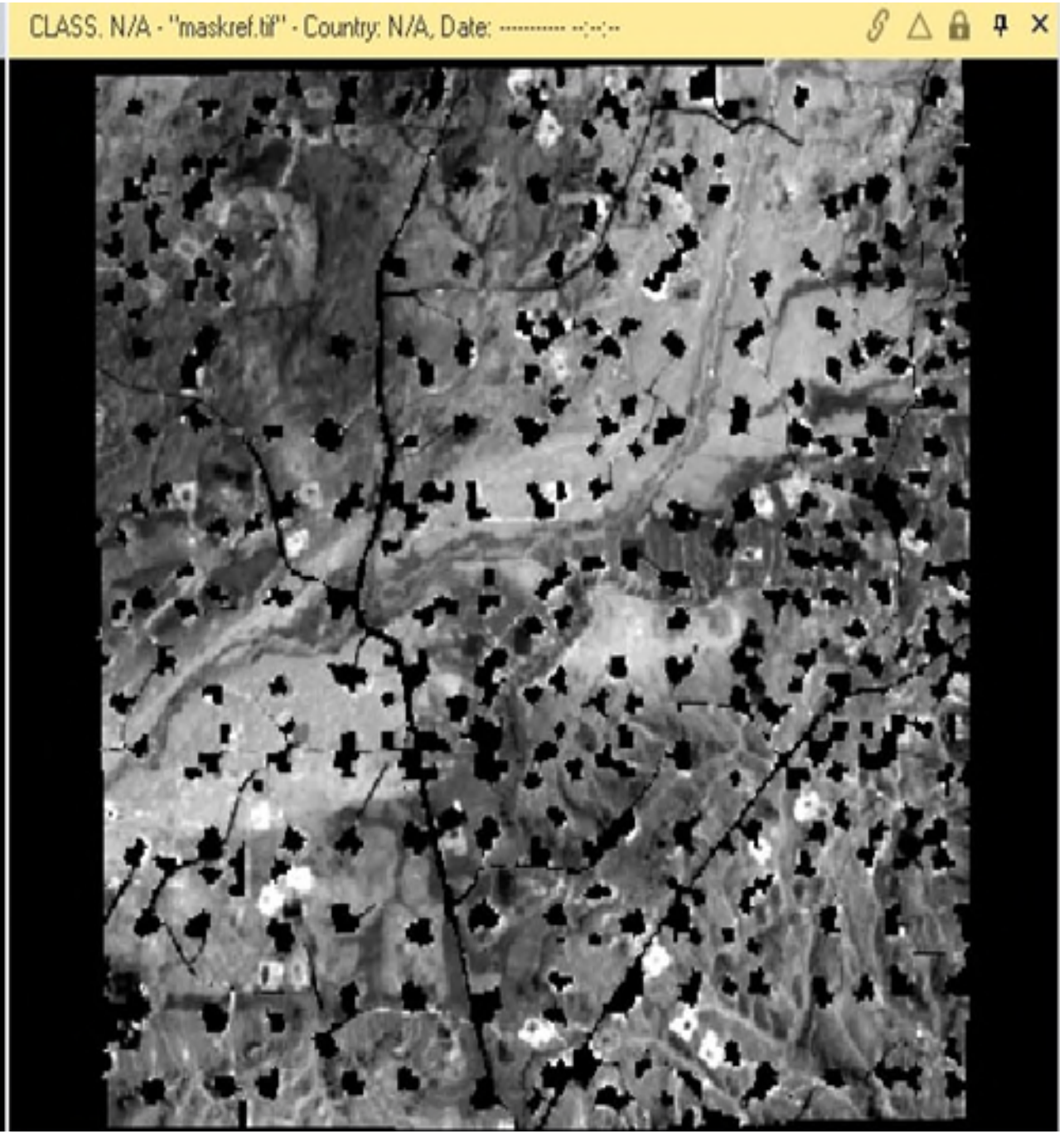
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Eliminating Anomalies from a Panel

1. allow each panel to have an over-sample and replace discarded units with units in the over-sample (this affects overall spatial balance)
2. move all the units after the discarded one down one position in the ordered list (this keeps the overall spatial spread but means some units will change panels).

Conclusions

- Rotating panel designs are likely a useful improvement over current techniques for monitoring programs involving a large number of sites
- Coupled with sound site-specific monitoring plans, rotating panel designs should result in time and cost savings while still providing robust datasets useful for informed decision making
- A troublesome assumption is that trend of all sites follows regional trend
    - Rapid site assessment may help here

Thank You

- Co-authors
- PureWest
- MPLX