Developing Effective Sampling Designs for Monitoring Natural Resources

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Outline

- Briefly review Fancy et al.'s (2009)* seven steps to developing an effective program for monitoring condition of natural resources

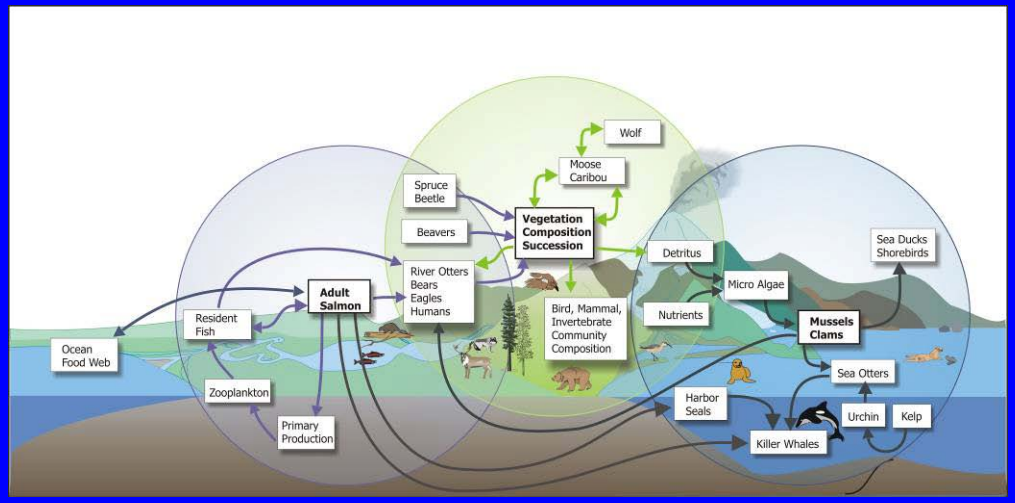
- Expand upon Step 5
  - iterative, 3-phased approach for developing sampling designs for resource monitoring
  - example: NPS-SWAN's vegetation monitoring protocol

- Concluding remarks

*Fancy et al. (2009), Environ. Monit. Assess. 151:161-174.

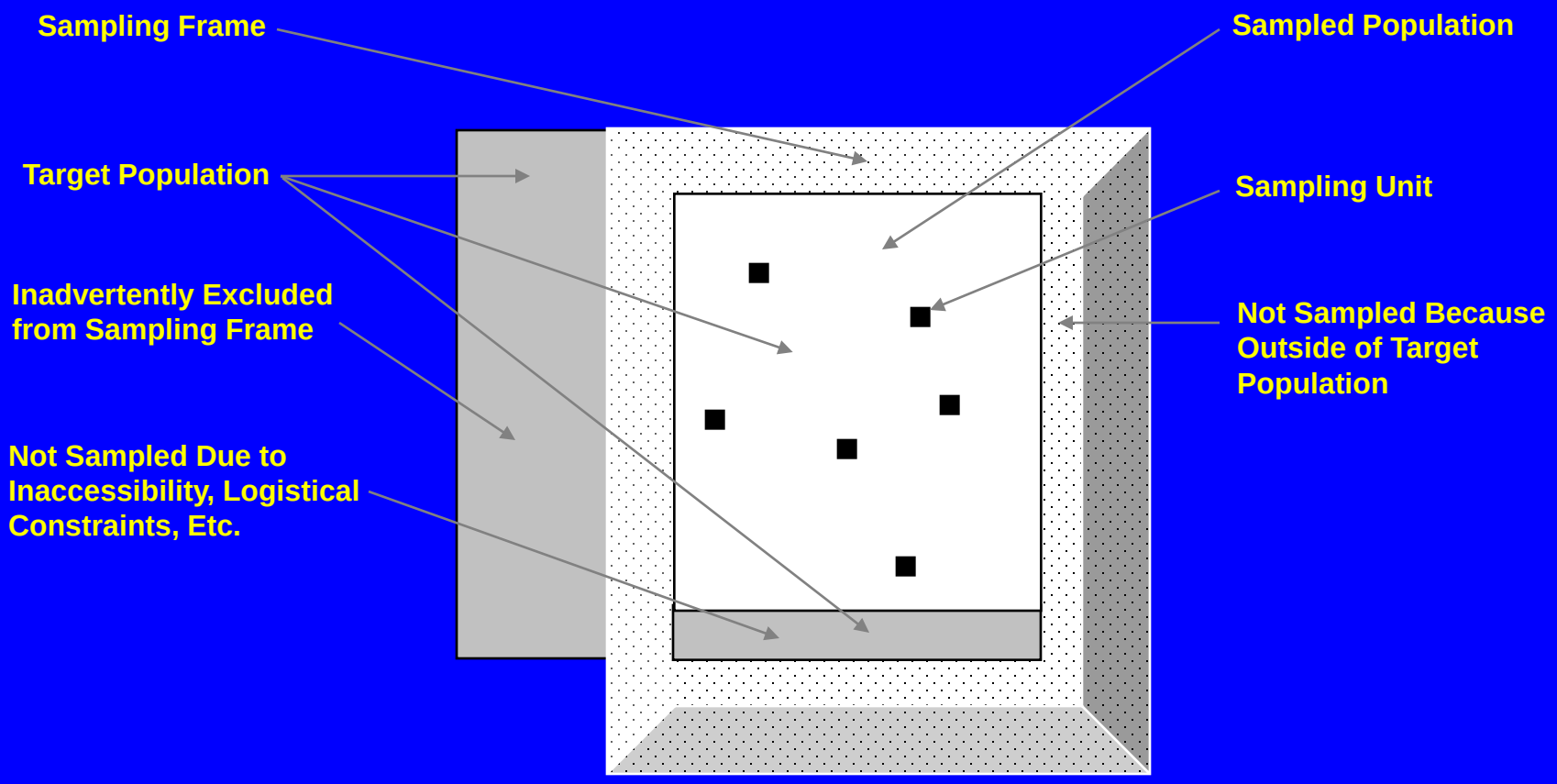
Seven Steps to Developing Effective Monitoring Programs

1. Define goals and objectives
2. Compile and summarize existing information
3. Develop conceptual models
4. Prioritize and select indicators
5. ***Develop an overall sampling design***
6. Develop monitoring protocols
7. Implement data management, analysis, and reporting procedures



Develop Sampling Designs – Phase I

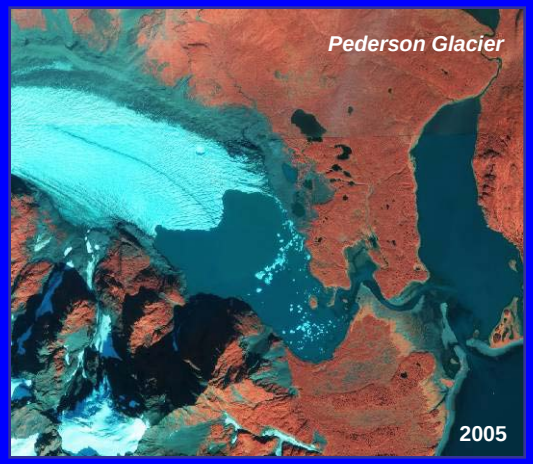
- Define a sampling frame that encompasses the area and resource of interest

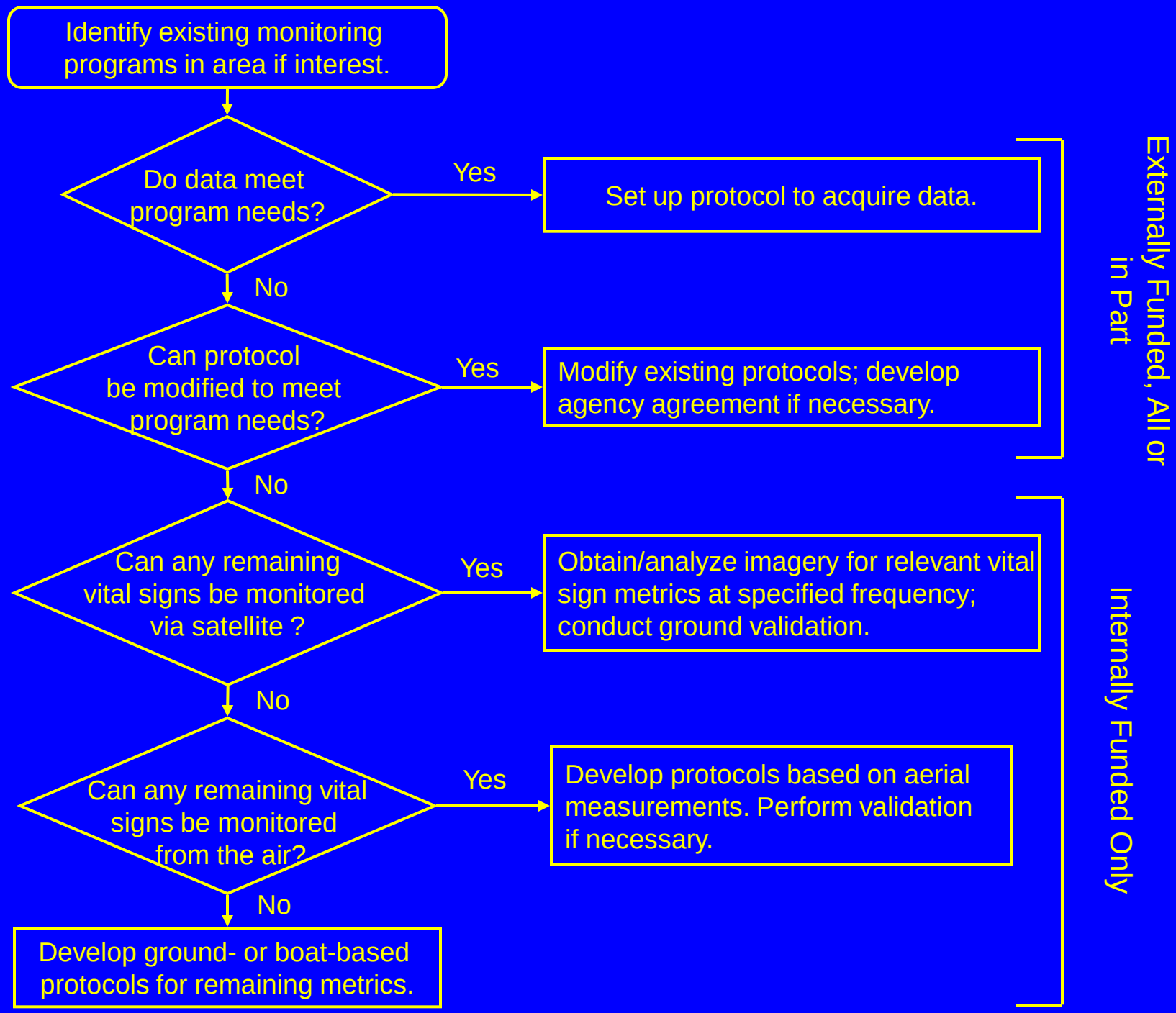


Adapted from A. R. Olsen (unpubl.) and Lohr (1999)

Develop Sampling Designs – Phase I

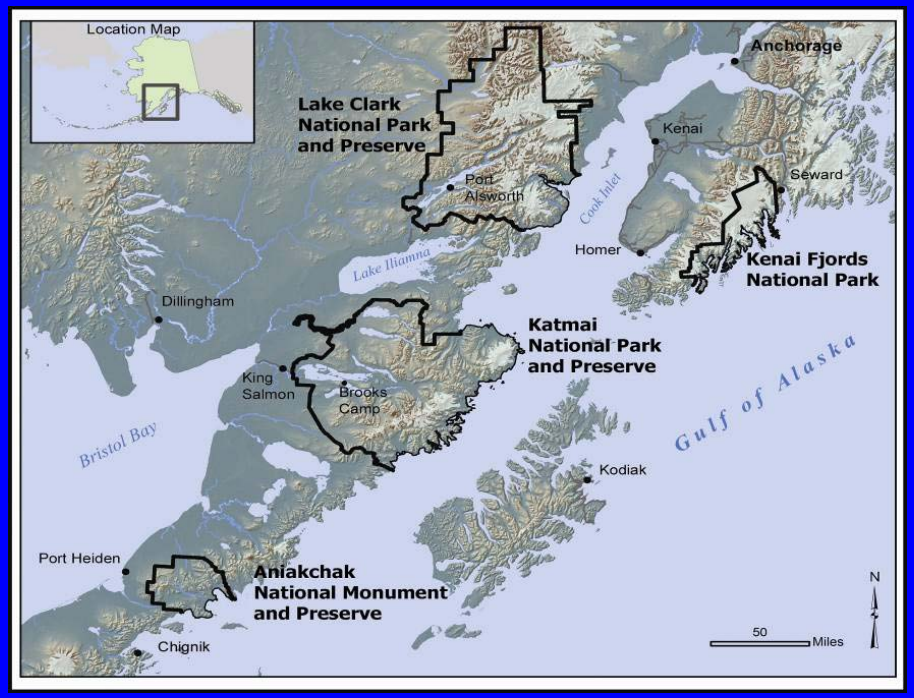
- Investigate whether existing programs can meet objectives
- Identify portion of the target population within the sampling frame that can be effectively monitored via remote imagery, aerial surveys, and/or ground sampling (define sampled population[s])
  - identify technological, budgetary, and access constraints that limit type and scope of the sampling design
  - subdivide components of change or trend into those that can be adequately captured by satellite imagery, then by aerial surveys, and finally by ground sampling (only)




Identify existing monitoring programs in area if interest.
Do data meet program needs?
Yes
Set up protocol to acquire data.
No
Can protocol be modified to meet program needs?
Yes
Modify existing protocols; develop agency agreement if necessary.
No
Can any remaining vital signs be monitored via satellite ?
Yes
Obtain/analyze imagery for relevant vital sign metrics at specified frequency; conduct ground validation.
No
Can any remaining vital signs be monitored from the air?
Yes
Develop protocols based on aerial measurements. Perform validation if necessary.
No
Develop ground- or boat-based protocols for remaining metrics.
Externally Funded, All or in Part
Internally Funded Only

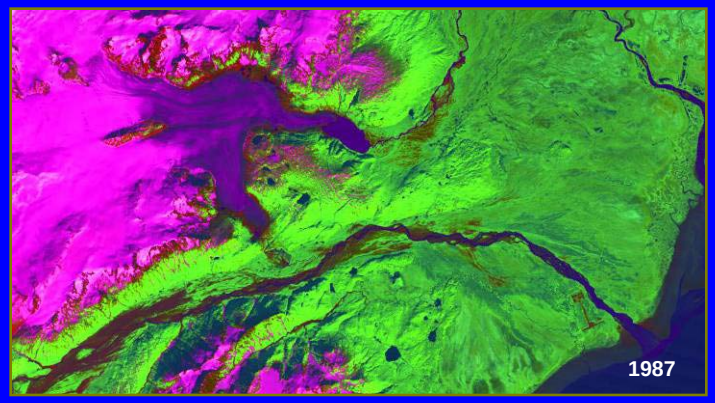
Develop Sampling Designs – Phase I

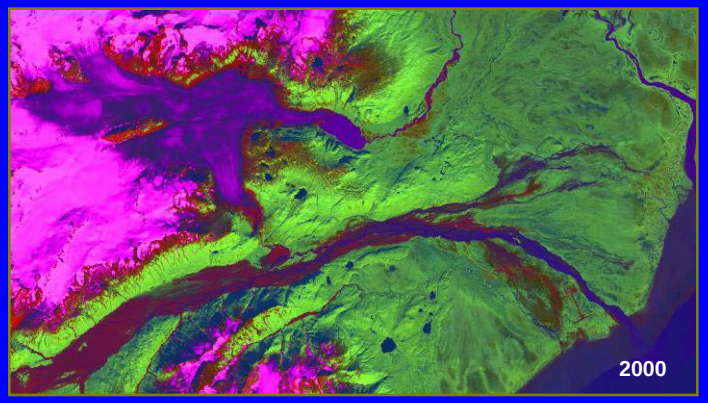
- Example: SWAN's vegetation monitoring protocol
- SWAN's 5 park units comprise 9.4 million acres or 11.6% of lands managed by NPS
  - largely remote wilderness areas
  - large portions of parks only accessible by plane, helicopter or boat (or on foot)



Develop Sampling Designs – Phase I

- SWAN's vegetation monitoring protocol (e.g., Lake Clark NPP)
- Sampling frame = Lake Clark NPP
- Combination of remote imagery and ground sampling
  - remote imagery: sampled population = entire park
  - ground sampling: initial sampled populations = reasonably accessible vegetated areas within 3 elevational bands in park
  - most of the park is inaccessible due to steep terrain, glaciers, and a limited number of entry points





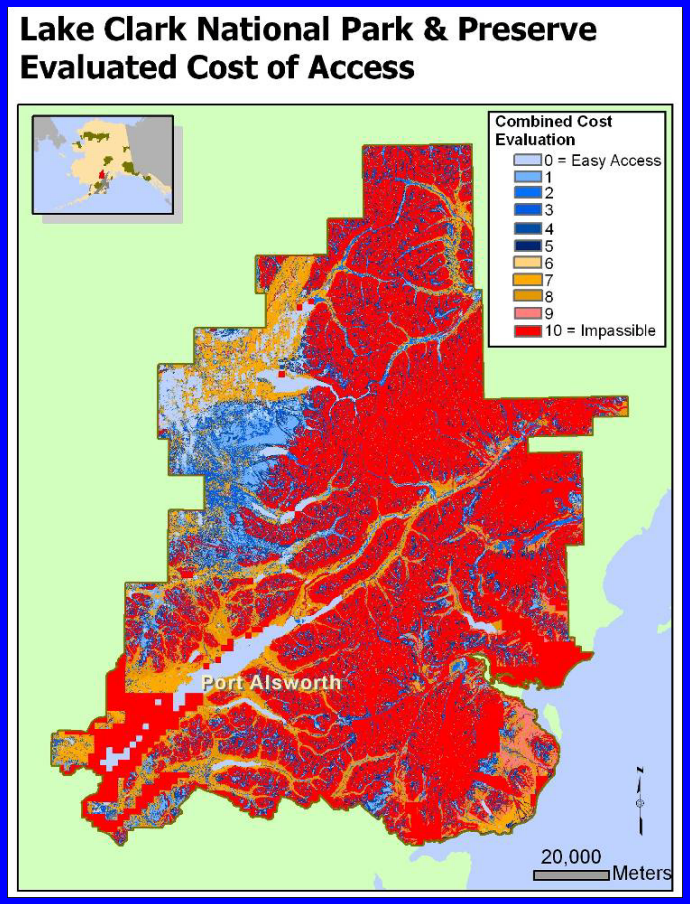
Landsat images showing changes in channel morphology and vegetation cover following the 1989-1990 eruption of Mt. Redoubt, Lake Clark NPP.

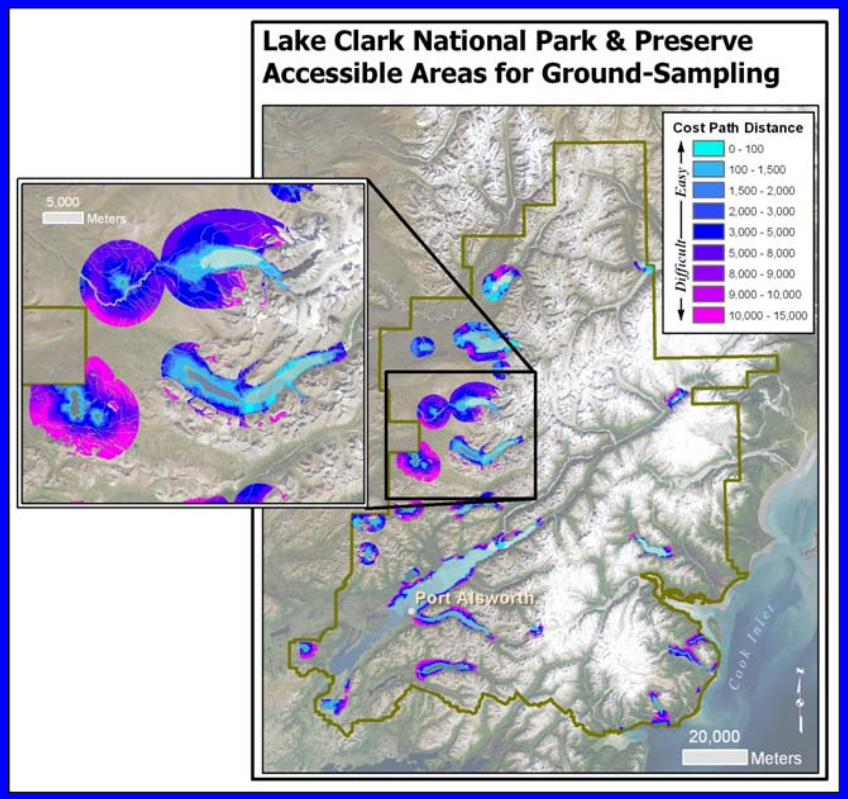
Develop Sampling Designs – Phase I

- Used ArcGIS 9.2 to perform a Path Distance analysis to estimate accessibility for ground sampling
  - calculated the minimum cumulative travel cost from a source point to surrounding locations within a specified area
  - used horizontal (distance, vegetation type) and vertical (elevation) factors to adjust travel cost
  - input layers to estimate travel cost: areas accessible by aircraft, boat, or foot; land cover classification; slope derived from elevation; and walking distance
  - input layers representing inhibitors to travel: glaciers, large rivers, steep slopes, non-NPS lands
  - classified selected GIS layers for 0-10 (0=easy, 10=impassable) to quantify cost of travel
  - 5km buffer around access points (maximum travel distance)
- Details available in Mortenson and Miller (2008; NRTR 2008/126):

http://www.nature.nps.gov/publications/NRPM/nrtr.cfm#2008

Develop Sampling Designs – Phase I





Evaluated cost of access (left) and accessible areas after Path Distance analysis (right).

Path Distance analysis is more than simply overlaying GIS layers (overlaying would generate isolated areas that met sampling criteria but were inaccessible by ground).

Develop Sampling Designs – Phase II

- Identify size and configuration of sampling units and how they are chosen
  - use existing information/protocols, pilot data, and/or simulations
  - applies mainly to aerial and ground sampling
  - ground sampling = combination of spatially balanced random sampling and targeted nonrandom sampling often will be the most effective and realistic approach
- Example = ground sampling of vegetation in Lake Clark NPP

Develop Sampling Designs – Phase II

Ground-based Vegetation Sampling in Lake Clark NPP

- Used a sampling frame that was conceptually similar to one used by North Coast and Cascades I&M Network and a plot configuration employed by Central Alaska I&M Network (CAKN)
- Simulations evaluated:
  - best spatial configuration of plots (single vs. grids of plots [CAKN])
  - minimum frequency of occurrence of a vegetation type required for detecting 20% and 50% changes in this type over 2 time points when all vegetation types are sampled
- Simulation set-up
  - generated a grid of points 30m apart within accessible areas of Lake Clark NPP; each point was assigned an elevation and landcover class code from existing data
  - randomly chose either 20% or 50% of points to change within a certain vegetation type and elevation
  - used generalized random-tessellation stratified (GRTS) design to select up to 50 points, 2 x 2 point grids, and 3 x 3 point grids from accessible areas

Develop Sampling Designs – Phase II

Ground-based Vegetation Sampling in Lake Clark NPP

- Simulation results summary
  - single points better at detecting trend than sampling equivalent number of points in 2 x 2 and 3 x 3 grids (more variation among than within)
  - vegetation type experiencing a 50% change must occupy at least 45% of sampled population to have at least an 80% chance of detecting a 5% change
  - unrealistically large sample size required to detect even a 2.5% change for a vegetation type actually experiencing a 20% change that occupies 60% of the sampled population

- Take-home message: use single points and limit ground sampling to vegetation types most sensitive to change, by elevation band
  - needle in haystack if trying to detect a reasonable level of change in a vegetation type that comprises less than ~2/3 of sampled population
  - soil maps are unavailable for Lake Clark NPP so we cannot use them as surrogates for vegetation in our ground sampling

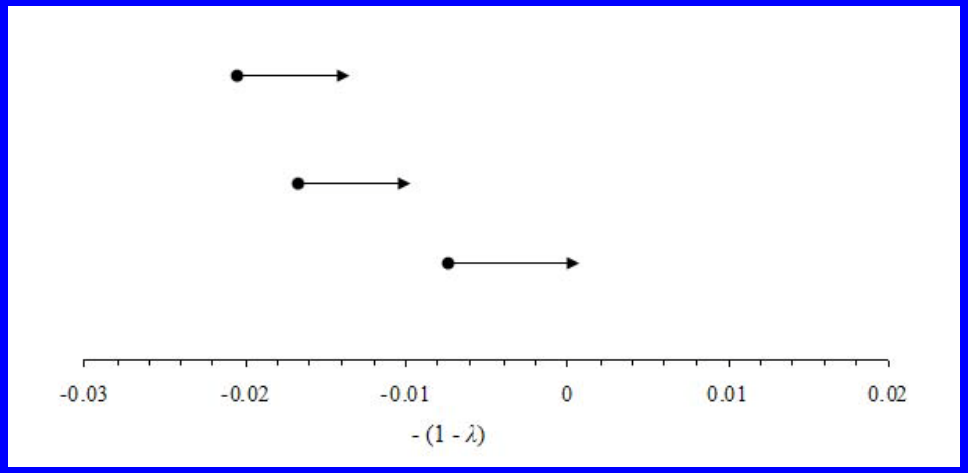
Develop Sampling Designs – Phase III

- Use simulations and empirical data to determine sample size and sampling frequency to detect a meaningful trend or total change
  - randomly generate time series (e.g., 1000) of values for a specified rate of decline (λ) for each scenario
  - incorporate both sampling and temporal variation into randomly generated time series
  - record the number of times (say, out of 1000) that total changes or trends of various magnitudes are detected for each sample size and level of sampling variability (CV) combination under a specified sampling frequency (panel design)

- Meaningful trend or total change could be a value outside of natural range of variability as indicated by historical data, published articles or other relevant sources

Develop Sampling Designs – Phase III

Simple Example: Using simulation to estimate chance of detecting a total change or trend of some size



- One-sided 95% CIs of the annual change estimate (-[1-λ])
- generated from 3 simulated 31-year time series subjected to a -50% true change (λ = 0.978 or annual change estimate = -0.022)
- Typical power analysis approach = use 0 as benchmark
- Our approach = use minimum detectable total change as benchmark

Develop Sampling Designs – Phase III

Ground-based Vegetation Sampling in Lake Clark NPP

- Simulations evaluated different sample sizes of plots (*n* = 6, 8, 12, 24) measured in a given year at two different sampling frequencies (5 and 10 years) under a rotating panel design for different levels of true total change (30%, 40%, and 50%)
  - preliminary fieldwork indicated a maximum of 24 random plots could be feasibly sampled during any given year
  - concluded a minimum detectable total change of 20% over 31 years was meaningful

	Year																													
Panel design	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5 panels	X					X					X					X					X					X					X
sampled		X					X					X					X					X					X				
every 5			X					X					X					X					X					X			
years				X					X					X					X					X					X		
					X					X					X					X					X					X	
5 panels	X										X										X										X
sampled		X										X										X									
every 10			X										X										X								
years				X										X										X							
					X										X										X						
10 panels	X										X										X										X
sampled		X										X										X									
every 10			X										X										X								
years				X										X										X							
					X										X										X						
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Panel designs investigated in simulations (panel = group of plots always sampled during the same year).

Develop Sampling Designs – Phase III

Ground-based Vegetation Sampling in Lake Clark NPP

- Simulation results for ≥80% chance of detecting ≥20% decline, with 95% confidence, given a true 40% decline over 31 years
  - sample CVs ≤30%
  - 12 plots per vegetation type × elevation band × park combination (total = 24 plots per year) every 5 years under a rotating panel design
  - supplement with 2-4 more accessible, nonrandom plots collocated with weather stations (sampled 2 consecutive years beginning every 5th year)
  - same sampling effort and confidence level associate with detecting ≥30% decline given a true 50% decline

	Year																				
Panel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	X					X					X					X					
2		X					X					X					X				
3			X					X					X					X			
4				X					X					X					X		
5					X					X					X					X	
6	\				X	X				X	X				X	X				X	X

Proposed panel design for ground sampling of vegetation.

Concluding Remarks

- Developing effective sampling designs requires striking a balance between statistical rigor and feasibility/sustainability
  - logistical and budgetary constraints inherent in monitoring natural resources
  - access also an issue in lower 48 (private land ownership)
- Key step: subdividing the components of change or trend into those adequately captured by remote sensing, by aerial surveys, and by ground sampling
  - ground sampling has the most restricted spatial scale of inference
    - for vegetation sampling, focus on types most sensitive to change
    - assume extensive, fine-scale changes will be detectable by remote imagery
  - nonhabitat today may be habitat tomorrow or vice versa; large-scale changes best captured by remote imagery because it covers the entire sampling frame

Concluding Remarks

- Simulations can play an important role in determining what, where, and when to sample
  - parameterize with actual data when available
  - the closer the simulation model mimics reality, the more useful its results
- Recommend a minimum detectable (meaningful) change instead of a change (<0 for a decline) as the benchmark in simulations for estimating chance of detecting a trend or change
  - ecologically interpretable quantity
  - conservative estimate of sampling effort (better to oversample than to undersample)
    - never know the true trend or change in reality so we cannot assume a "statistically significant" result (e.g., <0) from actual data exactly corresponds to the true trend or change value used in the simulation
    - using the <0 benchmark in our simulations indicated half the number of plots would need to be sampled