Developing Effective Sampling Designs for Monitoring Natural Resources

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Integrating science, education, and resource protection though monitoring

Abstract

Fancy et al. (2009) discussed seven steps to developing an effective program for monitoring condition of natural resources: (1) defining goals and objectives, (2) compiling and summarizing existing information, (3) developing conceptual models, (4) prioritizing and selecting indicators, (5) creating an overall sampling design, (6) developing monitoring protocols, and (7) implementing data management, analysis, and reporting procedures. We expand upon step 5 by describing an iterative, three-phased process of developing sampling designs for resource monitoring. The first phase generates a sample frame that encompasses the resource(s) and area of interest, and then identifies those portions of the frame where resource condition(s) could be effectively monitored by remote imagery, aerial surveys, or ground sampling. The second phase uses existing information, pilot data, and/or simulations to identify the size and configuration of the sampling units and how they are chosen. The third phase uses simulations and empirical data for evaluating minimum sample size and sample frequency required for detecting a meaningful change or trend in a given resource with a stated level of statistical confidence during the time period of interest. The process iterates through the three phases as necessary until either a feasible design has been developed or all reasonable design options have been rigorously evaluated. We provide examples from monitoring programs being developed for national parks in southwest Alaska to illustrate our approach.

Developing Sampling Designs: Phase I

- Generate a sampling frame (Fig. 1) that encompasses the resource and area of interest
- Investigate whether existing programs and data can meet monitoring objectives (Fig. 2)
- Identify portions of the sampling frame that could effectively monitored via remote sensing, aerial surveys, or ground sampling
  - identify major technological, budgetary, and access constraints that could limit the type and scope of the sampling design
  - nonhabitat today may be habitat tomorrow (e.g., climate-induced changes), so should use broadest definition of sampling frame (Fig. 1)
- Examples from southwest AK network of parks (Fig. 3)
  - Brown bear
    - sampling frame: State Game Mgmt Unit(s) (national park contained within)
    - used existing aerial line-transect survey protocol developed by AK Dept. of Fish & Game for estimating abundance of brown bears
  - Vegetation
    - sampling frame: national park
    - used combination of satellite imagery and ground sampling
    - satellite imagery: sample entire park
    - ground sampling – changes that cannot be detected remotely; focused on vegetation communities (soil maps unavailable) thought most sensitive to change within 3 different elevational bands (Fig. 3B)

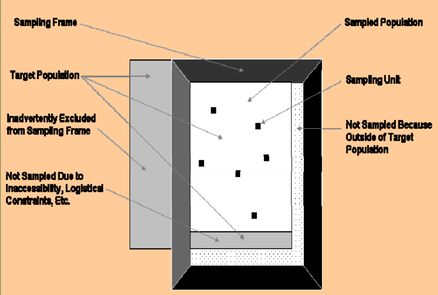


Figure 1. Sampling terminology. The combined gray and white areas portray the target population, the white area alone represents the sampled population, and the stippled white area is outside of the target population. (Adapted from A.R. Olsen [unpublished presentation] and Lohr [1999]).

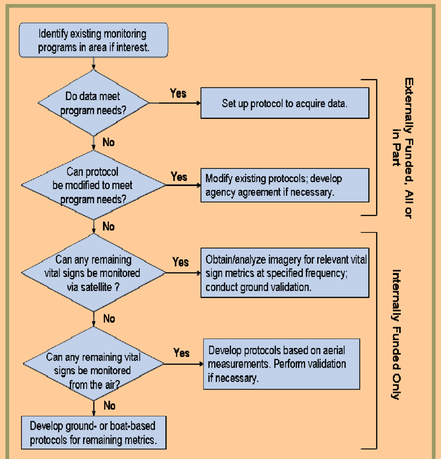
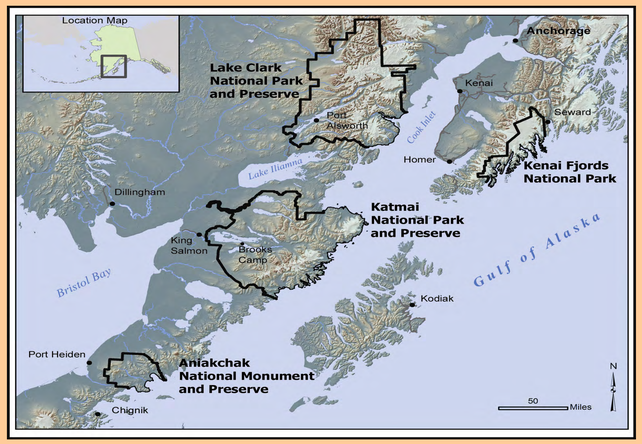
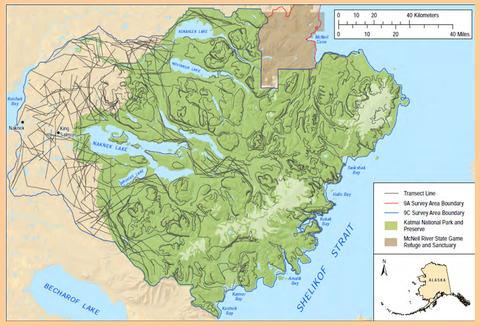


Figure 2. Initial steps in developing practical and effective sampling designs.



The Southwest Alaska Network includes Katmai National Park and Preserve, Alagnak Wild River, Aniakchak National Monument and Preserve, Lake Clark National Park and Preserve and Kenai Fjords National Park. Collectively, these units comprise 9.4 million acres or 11.6 percent of the land managed by the National Park Service.

A



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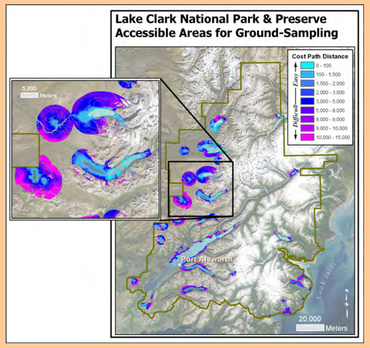

Figure 3. Sampling frames and sampled populations for monitoring brown bears in Katmai National Park and Preserve (3A; Olson and Putera 2007) and vegetation in Lake Clark National Park and Preserve (3B). The blue boundary line in 3A is the the State Game Management Unit (sampling frame) and the darker green is the non-glaciated, terrestrial areas of the park, within which a random sample of transects were selected to conduct aerial line-transect surveys (sampled population). The green boundary line in 3B is the park boundary (sampling frame) and the pink to light blue portions are areas accessible for ground sampling (sampled population) as determined by Path Distance Analysis in ArcGIS (Mortenson and Miller 2008).

Developing Sampling Designs: Phase II

- Identify size and configuration of sampling units and how they are chosen
  - Use existing information, pilot data, and/or simulations
  - Combination of spatially balanced random sampling and targeted nonrandom sampling of units often will be the most effective and realistic approach for collecting ground measurements
- Examples from sw AK network of parks
  - Brown bear: used existing sampling units (transects) and selection process (random sample along elevational contours; Fig. 3A) developed and field-tested by the AK Dept. of Fish and Game
  - Vegetation – ground sampling
    - Used simulation to evaluate a) best spatial configuration of plots (single points versus grid of points) and b) minimum frequency of occurrence of vegetation types that could be detected under a 20% and a 50% change over 2 points in time
    - Employed a generalized random-tessellation stratified (GRTS) design in simulations to select samples from existing landcover maps from Lake Clark National Park and Preserve

Developing Sampling Designs: Phase III

- Use simulations and empirical data for evaluating minimum sample size and sample frequency required for detecting a meaningful change or trend in a given resource with a stated level of statistical confidence during the time period of interest
  - Randomly generate time series (e.g., 1000) of values under a specified rate of decline (λ) and record the number of times that trends of various magnitudes are detected (i.e., upper 95% CIs do not contain the specified trend)
  - Include both sampling and temporal variation in the simulated time series
  - Meaningful change could be value outside natural range of variability as specified from pilot data, published articles, or other relevant sources
- Examples from sw AK network of parks
  - Brown bear
    - AK Dept. of Fish and Game had estimate of minimum number of transects required in a given year
    - Simulations indicated a maximum of 5-7 year intervals are necessary to have a ≥80% chance of detecting ≥20% total change with 95% confidence over 20 years
  - Vegetation – ground sampling
    - Concluded a minimum detectable change of 20% over 30 years was meaningful based on previous studies in these communities
    - Simulations indicated 12 plots per year every 5 years under a rotating panel design would have ≥80% chance of detecting a ≥20% total change, with 95% confidence, when the true total change was 40%

Discussion

Our approach to developing practical and effective sampling designs incorporates the logistical and budgetary constraints inherent in monitoring natural resources, especially in large and remote Alaskan national parks. A key step is subdividing the components of change or trend into those that can be adequately captured by remote sensing, by aerial surveys, and by ground sampling. The spatial scale of inference for each of these separate components will necessarily differ, ranging from parkwide (remote imagery) to accessible areas within a park (ground sampling). Simulations play a key role in determining what, where, and how often to sample. Moreover, using a minimum detectable (meaningful) change rather than a change (<0 for a decline; typical power analysis) as the benchmark comparison in simulations ensures both an ecologically interpretable quantity and a conservative estimate of sampling effort (i.e., more samples more often). That is, simulation models are approximations; we never know what the true change or trend is in reality so we cannot assume that a "statistically significant" change (e.g., <0) from actual data relates to the true change value used in simulations.

Literature Cited

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