

Methods note · Observation and data

What sentinel sites can and cannot represent

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Fictional author and institute · Editorial demonstration, not peer reviewed

ABSTRACT

Sites selected for sensitivity or continuity can provide excellent process evidence without representing a region. This methods note combines primary preferential-sampling research, EPA probability-survey guidance, and climate-observing sources to examine that distinction. A fictional catchment census shows how a sentinel network concentrated in sensitive terrain can yield a site fraction far above the regional proportion. The analysis separates population targets, weighting, purposeful selection, probability sampling, and conditional model-based expansion. It considers hybrid networks, transfer-oriented evaluation, changing representativeness, and protected selection records. No actual regional condition or optimal site list is estimated. The implication is to retain detailed sentinel findings and separately justified regional estimates as complementary products, rather than treating repeated measurements at informative sites as a cure for missing population coverage.

Keywords: sentinel sites · selection bias · probability sampling · regional inference

A source-based editorial text, not a report of original Still North research. Examples and imagery are illustrative.

An early signal and a regional estimate are different products

A sentinel site is often chosen because it is especially informative: a sensitive transition zone, a well-understood reference location, or a place where repeated observation is feasible. That can be excellent design for detecting a mechanism or an emerging change. It does not automatically make the site representative of the wider landscape. A record can be accurate, continuous, and scientifically valuable while answering a narrower question than its public map suggests.

This methods note examines the boundary between purposeful sentinel observation and population inference. It draws on an original study of preferential sampling in species-distribution models, the US Environmental Protection Agency's explanation of probability surveys, and climate-observing guidance. A fictional catchment example makes the distinction numerical. It does not describe a real network, propose a representative Arctic site list, or assess the condition of actual waterways.

Write the target before selecting the site

The target might be the proportion of catchments showing a defined change, the mean change across land area, or the behaviour of a particular sensitive process. These require different units and weights. Counting lakes equally answers a different question from weighting by lake area. Sampling stream reaches and weighting them

by represented length differs from counting catchments. A network should not switch among these targets because one produces a more striking number.

Purposeful site selection can serve a mechanism question well. A location near a known environmental boundary may reveal responses that would be rare in an equal-probability sample. A long reference record may clarify seasonal processes even if its site type occupies little regional area. The scientific mistake is not choosing such a site. It is allowing the reason for choosing it to disappear from the interpretation.

The GCOS principles give priority to data-poor regions, poorly observed parameters, and regions sensitive to change. These are substantive observing priorities, not a claim that every resulting network is a random sample. Networks can be designed for multiple objectives, but inference must remain attached to the objective and design that support it.

Fictional worked case: sensitive catchments

Imagine an invented region with 100 catchments, each given equal weight for a particular question. Twenty belong to a highly sensitive terrain class, and 80 to a less sensitive class. Suppose a complete census, available only within this teaching example, would find a specified change in 12 sensitive catchments and eight others. The regional proportion is 20 out of 100, or 20%.

Invented class	Catchments in the region	Catchments with the defined change	Class proportion
Highly sensitive terrain	20	12	60%
Other terrain	80	8	10%
Whole region	100	20	20%

Now suppose a ten-site sentinel network deliberately samples only sensitive terrain and records the change at six sites. Its observed fraction is 60%. That can be a useful description of those ten sites. Calling it the percentage of all regional catchments affected would overstate the fictional regional proportion threefold. Taking more measurements at those same ten sites would reduce some temporal uncertainty without repairing the missing terrain coverage.

If the class proportions were estimated from suitable samples within both classes, a regional estimate could weight them by regional class shares: $0.2 \times 0.6 + 0.8 \times 0.1$ equals 0.2. In the sentinel-only design, however, the 0.1 for the unsampled class is unknown. The calculation cannot be rescued by borrowing the teaching census as if it were available field evidence. Weighting requires information, not just a formula.

Selection can depend on the anticipated response

Accessibility is one selection process. Preferential sampling is a more specific problem: locations are chosen partly because the response of interest is expected to be high or low. Fishers seek productive grounds, observers revisit likely sightings, and investigators may choose unusually changed sites. The selection then contains information about the response that a standard model may ignore.

Pennino and colleagues' original study analyses this problem using simulation and Mediterranean fishery data. Their joint models represent both sampling locations and measured abundance, rather than treating locations as uninformative. The study demonstrates consequences of ignoring preferential sampling in that setting. Its particular model and empirical results are not a ready-made correction for an Arctic catchment network.

Not every non-random design has the same bias, and purposeful selection need not always exaggerate change. A network concentrated on stable reference sites could understate regional change. The direction depends on why sites were chosen, how the response varies, and what population is being inferred. Declaring a network "biased" without naming those relationships is less useful than stating precisely which comparisons it supports.

What probability sampling adds

The EPA's National Aquatic Resource Surveys explanation describes random site selection in which each sampled site represents a defined portion of the resource. Known inclusion probabilities support design-based inference to a specified population. They do not guarantee perfect measurements, complete participation, or suitability of every outcome definition. The sampling frame and treatment of inaccessible or ineligible sites still matter.

A practical design may combine permanent sentinel sites with a rotating probability sample. The sentinels provide temporal detail and process understanding; the probability component supports broader condition estimates. Their data can inform each other, but they should not be pooled with equal weights simply because their columns match. The analysis needs to retain which design generated each observation and what it represents.

In a stratified design, rare but important terrain can be sampled more heavily than its area share, then weighted appropriately for a regional target. That is different from pretending the sample is spatially uniform. Deliberate oversampling can increase knowledge where it is needed while preserving a coherent population estimate, provided inclusion probabilities and other design information are retained.

Model-based expansion remains conditional

Where probability sampling is infeasible, a model may predict unobserved locations using terrain, climate, or remotely sensed covariates. Its usefulness depends on whether observed sites cover the relationships needed elsewhere. If no sentinel represents a particular combination of conditions, a smooth regional map may conceal extrapolation. A narrow interval generated by the model is not evidence that the unsupported region is well observed.

Evaluation should challenge transfer, not only interpolation among neighbours. Holding out whole sites or environmental classes may reveal weaknesses that random row-level cross-validation misses. Even that cannot fully test predictions in conditions absent from all observations. Report the target population, sampled domain, covariate coverage, and assumptions connecting them. A map of model support can be more informative than a single overall accuracy score.

Selection records help future analysts: why each site entered, which alternatives were considered, what prevented access, and whether a replacement followed an observed change. Those records may contain sensitive locations or governance information and need appropriate protection. Public documentation can describe selection mechanisms without disclosing restricted details. A technically useful sampling frame does not override the authority needed to observe or publish.

A fixed network can still change its meaning

Longitudinal consistency is valuable, but following the same sites does not freeze representativeness. A terrain class can expand, a shoreline can move, or the monitored footprint can become atypical of a changing region. Conversely, replacing damaged sites with convenient alternatives can introduce artificial trends. Keep site-specific change, network composition, and changing regional weights distinguishable.

The 2025 Arctic observing-network assessment documents spatial and seasonal gaps and limited field validation across several indicators. Its own methods also acknowledge that the included topics favour systems already capable of supporting strong assessments. That candid selection limit is instructive: even an assessment of observing capability must say which observing questions were able to enter it.

Limits and implication

The fictional example assumes perfect classification, equal catchment weights, and known population structure. Real studies face measurement error, uncertain boundaries, non-response, spatial dependence, and changing access. Neither a probability sample nor a joint

spatial model eliminates all those problems. No universal mixture of sentinel and regional sites follows from this note.

The useful implication is to preserve two honest products rather than force one into the other: a detailed account of change at selected informative sites, and a separately justified estimate of regional condition. Sentinels need not represent everything to matter. Their strongest contribution comes when the reason they were chosen remains part of the evidence.

References

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