Sampling, fast and slow: Examining trade-offs in survey designs of low-density populations

Jake Ferguson, John Fieberg

Sampling populations

Surveying plant and animal populations to estimate density is a fundamental task of many management and conservation organizations. While there are many different approaches designed to estimate densities, there is no existing framework to study how searcher behavior influences the quality of estimates. Here, we incorporate ideas from foraging theory into the design of surveys of zebra mussels in recently invaded lakes in Minnesota.

Diver settiing up a transect.

Sampling tradeoffs

Typically, survey designs are chosen assuming the number of sampling units is fixed before conducting the survey. In many conservation applications, we are faced with a set amount of time or money, then survey until we run out of resources. With a fixed resource budget, search time becomes a quantity we can tune. Here we ask, should we go fast and have poor detection but cover a large area or go slowly? The below figure is an experiment designed to highlight the trade-off between search speed and detectability.

Trade-off between the amount of time spent searching and the probability of detection in an experimental context.

We compared two different sampling strategies under a fixed amount of time:
• Quadrat surveys, which are slow but have perfect detection
• Distance surveys, which are faster but have imperfect detection that must be accounted for.
These two designs represent a continuum of diver behavior and a trade-off between improving detection but surveying less area. We tested these designs across a range of densities in Minnesota lakes, each lake had a fixed time, two days, for each survey type.

We partition the uncertainty of the density into two components. The first is the underlying counts, while the second is the uncertainty in the probability of making a detection. Going slow will increase your likelihood of making a detection in your sampling unit, but you will cover less sampling units in a fixed amount of time.

How we expect the uncertainty in density to change as a function of searcher speed.

Empirical results

We found that the strategy that minimized estimator uncertainty was dependent on the density. At low densities distance surveys had the smallest variance in the density estimate while at high densities quadrat surveys had the smaller variance.

Density estimates (points) with uncertainty (bars) in three Minnesota lakes.

Furthermore, we examined the amount of time spent setting up transects and the amount of time spent surveying to understand the cause of the optimal strategy change. We used this information to build a behavioral search model to explore how set up and survey time affected the optimal survey strategies.

The time taken to setup the transects and search the transects for the two different survey methods.
We see that the setup of the distance survey is faster than quadrats, but the average total search time of distance surveys is slower. This difference in the temporal cost of making detections is the underlying reason that the efficiency of the two methods changes with density.

Theoretical results

We can combine sampling theory with foraging ecology to determine which strategy works better as a function of density and overdispersion, a measure of the clumpiness of the search targets. We see that at low densities and no overdispersion going fast using Distance surveys is better. As densities and clumpiness increase, going slower with quadrat surveys is better.

The optimal regimes for distance and quadrat surveys. This calculation assumes that searchers have the search and handling times estimated from our data.

We can also use foraging theory to tune the behavior of a searcher conducting distance surveys. Below we show the optimal amount of time for a transect search when conducting a distance survey.

This gives the optimal time spent searching under a distance survey.
At low levels of overdispersion the optimal search time changes slowly, but at high levels of overdispersion we get a linear increase in search time with densities. Thus when high levels of overdispersion are present the survey approach can be highly tuned to be optimal.

Zebra mussels

Zebra mussels are highly invasive freshwater bivalves that have rapidly invaded the eastern and midwestern United States. They have the ability to reach high densities (> 10,000 individuals/m^2), affect water treatment and power plant intake pipes, hydropower facilities, as well as impact recreation, tourism, and lakefront property. At these high densities, they can remove high volumes of planktonic organisms. Zebra mussels in Lake Michigan have led to dramatically higher water clarity (detectable from space!) potentially influencing the trophic dynamics of this emblematic lake.

Cluster of zebra mussels in Lake Burgan, MN. Photo courtesy of Naomi Blinick.

Resources

This video was produced by our research group and details how to conduct the sampling techniques presented in this poster.

We also have a tutorial on estimating density including code and data, located at: https://zebramusselsurveys.netlify.com/tutorial

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contact me: jakeferg@hawaii.edu