Uncertainty in detection bias: Hidden management costs of index–based population monitoring

Clinton T. Moore
USGS Patuxent Wildlife Research Center, Warnell School of Forest Resources, University of Georgia, Athens, GA 30602

William L. Kendall
USGS Patuxent Wildlife Research Center, 12100 Beech Forest Road, Laurel, MD 20708

Abstract

Managers of wildlife populations commonly rely on simple counts of detected animals in making decisions regarding conservation, harvest, or control. The main appeal in using such indirect counts is their low material expense compared to methods that estimate the undetected population (and therefore the entire population). However, their correct use rests on the rarely–tested but often–assumed premise that they proportionately reflect population size, that is, that they constitute a population index. We investigated forest management for the endangered Red–cockaded Woodpecker (*Picoides borealis*) and the Wood Thrush (*Hylocichla mustelina*) at the Piedmont National Wildlife Refuge in central Georgia (USA). We derived optimal decision policies for a joint species objective under each of two alternative models of Wood Thrush population dynamics. We simulated the optimal policies under each model for three scenarios of bias for observed Wood Thrush densities: (1) unbiasedness, (2) consistent negative bias (i.e., a valid population index), and (3) habitat–dependent negative bias. Differences in simulation outcomes between biased and unbiased detection scenarios provided the expected loss in resource objectives (here, forest habitat and birds) through the basing of decisions on biased population counts. Under the models and objective function we used, expected losses were as great as 11%. For applications such as endangered species management, such a degree of loss may not be trivial and could be far greater under different model assumptions. Our analysis demonstrates that costs of uncertainty about the relationship between the population and its observation can be measured in units of the resource, costs which may offset apparent savings achieved by collecting uncorrected population counts.

Sponsors and Cooperators:

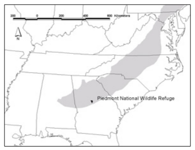
Region 4, U.S. Fish and Wildlife Service
Piedmont National Wildlife Refuge
USGS Cooperative Research Units Center
Georgia Cooperative Fish and Wildlife Research Unit
EPA STAR Fellowship Program
University of Georgia, Warnell School of Forest Resources
USGS Patuxent Wildlife Research Center

The Wildlife Management Institute

Introduction

Many monitoring programs for plants or animals yield incomplete counts of the target organism. These counts often serve as the basis for decision making in natural resource management because they are materially less expensive to collect than the ancillary data needed to estimate detection rate and therefore population size. Such uses of incomplete counts are entirely appropriate if they serve as valid "indices" of the population, that is, that they measure a constant proportion of the population in all sampling situations. In practice however, this assumption is almost never tested and is almost always taken on faith. Violation of this assumption is a form of partial system observability, which, if not addressed, can lead to highly suboptimal decision making. Is it possible then, that the material savings that one gains by relying unquestioningly on indirect counts for decision making are offset by conservation "opportunity" costs that may accrue from misdirected management? By how far can costs exceed savings? Our objective was to explore this tradeoff by simulating decision making under alternative assumptions about the relationship between the count and population size and by comparing these outcomes to known optimal values.

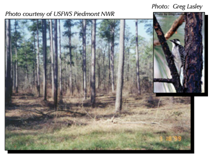
Study Area



The 14,136-ha Piedmont National Wildlife Refuge (PNWR) supports a second-growth mixed pine (*Pinus taeda*, *P. echinata*) and hardwood (*Quercus* spp., *Carya* spp.) forest that regenerated naturally on severely eroded farmland abandoned in the 1930s. Forest management is directed toward the maintenance of all native flora and fauna, sustenance of important ecosystems, and provision of public recreation, including wildlife viewing and sport harvest of some wildlife species. PNWR is also a designated recovery site for the Red-cockaded Woodpecker. For this reason, PNWR forest managers conduct aggressive regimes of thinning and regeneration cutting, prescribed burning, and mechanical vegetation removal to create and maintain the bird's preferred foraging and breeding habitat: pure, open stands of mature (≥80 yr) pine with a herbaceous understory and reduced hardwood midstory.

Photo: Greg Lasley

Photo courtesy of USFWS Piedmont NWR



Woodpecker habitat conditions ("F3" forest type)

Whereas reductions in the hardwood midstory and the overstory canopy are favorable for woodpeckers, a reasonable expectation is that the same conditions are unfavorable for the Wood Thrush, a neotropical migrant bird usually associated with dense understory and midstory conditions of closed-canopy forest interiors. But in fact, experimental work at PNWR has found no effect, either detrimental or beneficial, of refuge forest management on the Wood Thrush population (Powell et al. 2000). Nevertheless, refuge managers approach silvicultural actions targeted for the woodpecker under considerable uncertainty about their effects on the Wood Thrush and other nontarget organisms.

Decision Model

We expressed dynamics of the forest and the Wood Thrush population in simple deterministic models. We used a stage-based matrix model to represent annual transitions among three forest seral stages: pine regeneration (F1, age 0-20), mature mixed pine-hardwood (F2, age 20-90), and open pine forest suitable for woodpecker utilization (F3, age 20-90). The model (Fig. 1) projects the future stage composition of the forest in response to current composition, imposed silvicultural actions (d_{ij}), and growth/mortality processes (τ_{ij}). Decision variables reflect regeneration amounts taken from F2 and F3 (d_{12} and d_{13} respectively) or amounts of F2 and F3 forest to treat (through thinning and burning) to convert into or retain as F3 forest (d_{23} and d_{32}, respectively). Entry of forest into class F3 (woodpecker habitat) from F2 is accomplished only through management (Fig. 1, panel B); in the absence of management, all forest in class F3 eventually reverts to F2 or is regenerated (Fig. 1, panel A).

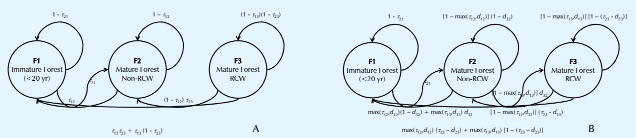


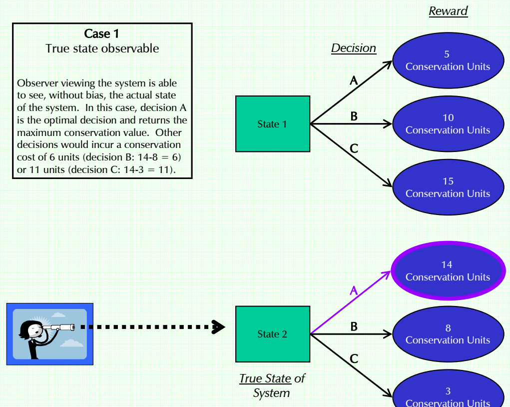
***Fig 1.** Model of dynamics among regeneration (F1), mature untreated (F2), and mature forest treated for Red-cockaded Woodpecker use (F3) at PNWR. Portions of the mature forest naturally regenerate every year, and mature classes are augmented by recruitment from the regeneration class. In the absence of management (A), the treated stage F3 reverts back to the F2 stage and ultimately disappears. However, management (B) can reduce this attrition either through treatment of F2 forest or re–treatment of F3 forest. Furthermore, regeneration rate can be increased by cutting from the mature classes.*

Photo courtesy of Larkin Powell

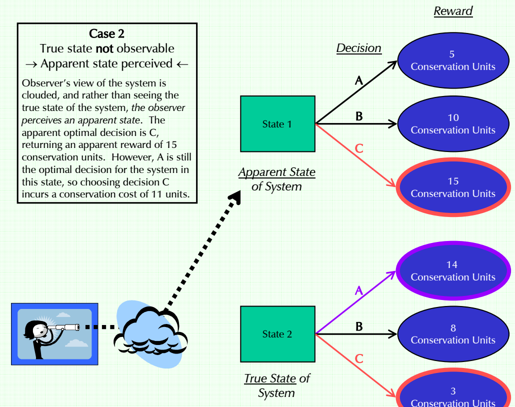
We modeled Wood Thrush population growth in the F2 and F3 habitats (we assumed Wood Thrush did not make use of stage F1) using an exponential growth model with habitat-specific growth rate (λ). Given uncertainty about Wood Thrush population dynamics relative to forest management, we constructed two models. In the first (M1 - the "conventional" model), λ was >1.0 in F2 habitat (net positive population growth) and <1.0 in F3 (net negative growth); λ value assignments were reversed in the second model (M2 - the "counterintuitive" model). We used estimated values of λ reported by Powell et al. (2000).

At any time t, the state of the modeled system is described by the amount of forest in each seral stage and by the density of Wood Thrushes in types F2 and F3. Given a selection of one of the population models, the steps of the model were as follows:

(1) obtain the current forest and Wood Thrush states;
(2) obtain the optimal forest management decisions d_{ij} for those states;
(3) project the state of the forest to the next decision period, given the d_{ij};
(4) calculate bird densities at next decision period, given future forest state;
(5) move to next decision period, repeat 1-5.



Decision A is optimal with reward of 14 conservation units and 0 conservation cost.



Decision C is apparently optimal but highly suboptimal for the unknown true state of the system. The conservation cost of decision C is 11 units.

What do we mean by "conservation cost" of decision making for a system that is hard to observe?

Because each state of a managed system is associated with an optimal decision that returns a maximum conservation reward, at least some of the other decision alternatives for the state are suboptimal. The choice of any suboptimal decision represents a lost opportunity for conservation management, i.e., the choice incurs a "conservation cost". There are many circumstances that lead to suboptimal decision making, but partial system observability (inability to directly or accurately measure the state of the system) is a common situation that results in the true state of the system to be perceived as a different state. If the perceived state is incorrectly taken as truth, and if the optimal decision for the perceived state differs from that for the true state, then a suboptimal management decision will be made, and a conservation cost will be incurred.

Optimization

The objective of optimization was a composite measure of woodpecker habitat (amount of F3) and Wood Thrush reward value expected at the next time period. The Wood Thrush reward value simply assigned a value scaled between 0 and 1 for expected bird densities between acceptance limits of 0.05 and 2.0 pairs/ha. The composite objective measure was the geometric mean of the F3 habitat amount and Wood Thrush reward values. For each Wood Thrush growth model, we used dynamic programming to find a policy of stationary, state-specific decisions for the goal of maximizing the accumulated composite objective value over an infinite time frame.

Expected Opportunity Costs

We wanted to assess the outcome of decision making based on observed states of the system (Wood Thrush densities inferred from unadjusted counts) that may or may not correspond to unobservable true states. We looked at four scenarios of the relationship between observed and true densities of Wood Thrush: (D1) birds are perfectly detectable in F2 and F3 habitats (detection rate = 1.0), (D2) birds are equally but imperfectly detectable (detection rate = 0.5) in F2 and F3 habitats, (D3) birds are more detectable in F3 habitat (detection rate = 0.7) than in F2 habitat (0.3), and (D4) birds are less detectable in F3 habitat (detection rate = 0.3) than in F2 habitat (0.7).

We simulated each of the Wood Thrush population models over a 100-year time period, starting from each of five initial forest states and from an initial state of 0.5 pairs/ha of Wood Thrush in F2 and F3 habitats. We accumulated 100-year values of the composite objective value for each biological model, each detection scenario, and each initial forest state. Differences in values among the detection scenarios led to the computation of a partial opportunity cost ("conservation cost") incurred in either resource component (woodpecker habitat or Wood Thrush density) under suboptimal management.

Results

The conservation cost of managing under incomplete detectability differed among biological models, initial forest state, and detection relationship. Under the "counterintuitive" model of Wood Thrush response, management under incomplete detectability was slightly suboptimal (3-6% less than optimal value, depending on initial forest state) when birds were more difficult to detect in the favorable F3 habitat than in unfavorable F2. Under uncertainty with respect to all three alternative models of imperfect detection, expected conservation cost for the "counterintuitive" model ranged 1-3% depending on initial forest state.

In contrast, management under incomplete detectability was notably suboptimal – as great as 11% – under the "conventional" model of Wood Thrush response. Under uncertainty with respect to all three models of imperfect detection, the range of expected conservation cost was 2-6%, depending on initial forest state.

Implications for Conservation Management

Recent intensive debate has centered on the issue of whether unadjusted counts constitute reliable indicators of wildlife population abundance. Perhaps one reason that the arguments persist is that the extra costs associated with collecting the ancillary data to estimate detection rate are tangible and easy to perceive, whereas consequences of decision making based on faulty detectability assumptions are not. As long as this "invisible cost" of misled management is ignored or assumed to be negligible, there may continue to be a complacency toward the problem of unmeasured detection biases. Our analysis of a very simple population model under quite reasonable alternative patterns of detection bias demonstrates that uncertainty with respect to detectability results in some degree of opportunity cost that is measurable in units of the resource (Moore and Kendall 2004).

Whereas a conservation cost of 11% may be tolerable in many situations, we note that this outcome is dependent on choice of the model and objective function. We found that costs increased to 24% when we manipulated one of the detection rate parameters. We also note that there are many applications – endangered species management in particular – where a conservation cost of 11% is intolerable. In our application, if F2 forest provides favorable habitat and yields greater detectability of Wood Thrushes than does F3 forest, then woodpecker habitat could be needlessly sacrificed if management is based on the erroneous assumption that Wood Thrushes are equally detectable in both habitats.

We recommend the use of models to explore the implications of management when there is uncertainty about the relationship between population status and the monitoring data upon which decisions are based (Moore and Kendall 2004). Our results suggest that the full cost of a monitoring program is the cost of collecting the data plus the expected conservation cost of management under the degree of observability offered by the data. When conservation costs are accounted for, monitoring programs that estimate detection rate may be more economical than ones that rely solely on uncorrected counts, despite their greater material cost. Even when the conservation cost of using uncorrected counts is not expected to be great, the relationship between the count and true density should at least occasionally be monitored.

References

Moore, C. T., and W. L. Kendall. 2004. Costs of detection bias in index-based population monitoring. Animal Biodiversity and Conservation 27(1):287-296.

Powell, L. A., Lang, J. D., Conroy, M. J. & Krementz, D. G., 2000. Effects of forest management on density, survival, and population growth of wood thrushes. Journal of Wildlife Management, 64:11–23.