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TO WHAT EXTENT CAN SIMULATION OPTIMIZATION BE USED IN WILDLIFE RESERVE DESIGN?

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ABSTRACT

Wildlife reserves serve as a critical tool for conserving wildlife species. The design of such reserves can be formulated as a simulation optimization problem, with the objective of minimizing conservation costs while satisfying species survival constraints. Our research explores this problem formulation and the relevant solution methods, with a particular focus on the Chance Constrained Selection of the Best algorithm. We formulate the problem using a deterministic objective function subject to a probabilistic constraint. To estimate the survival probability under various policies, we have developed a Gray Wolf (Canis lupus) model that simulates the wolves' dispersal, breeding, and death processes in discrete time steps. Our poster presents three scenarios that demonstrate the potential use of Simulation Optimization techniques in wildlife conservation.

1 RESERVE DESIGN PROBLEM

The International Union for Conservation of Nature (IUCN) reports that of the 150,300 evaluated species, over 42,100 are facing extinction (IUCN 2023). The establishment of nature reserves has become a key global strategy for conserving wildlife species. However, there are economic costs associated with establishing reserves. The need to balance the conservation effort and economic cost has led to the application of operational research (OR) methods in reserve design problems (RDP).

Much of the existing literature on solving RDP with OR methods uses mathematical optimization methods, such as integer programming (Camm et al. 1996). While effective in evaluating a broad range of policies, these methods often treat the problem deterministically. There is very little literature that approaches RDP as a Simulation Optimization (SO) problem, one such attempt is from Haight and Travis (2008). They formulated the RDP as a maximization problem with probabilistic species persistence objective and deterministic budget constraint. In our research, the RDP is formulated with a stochastic constraint to ensure that the final policy selected meets the minimum requirement for sustainable species survival.

2 SIMULATION MODEL AND PROBLEM FORMULATION

In our research, we used the Gray Wolf (Canis lupus) as an example of a wildlife species. Gray wolves are social and territorial carnivores that live in packs within specific territories. These packs are led by an alpha pair, which serves as the sole breeding pair. Average litter sizes are around six pups, and mature wolves typically disperse to find a mate or establish new territories.

We developed a wolf model based on the work of Haight et al. (1998). This model operates at the territorial level, simulating key events in individual wolves' life cycles - birth, growth, dispersal, and death - in discrete time steps. We extended the model to include a habitat-level perspective, drawing inspiration from Haight and Travis (2008). This extension enables our model to incorporate spatial elements at the habitat level, where "habitat" is defined as a larger area with geographical boundaries that contain multiple territories.

Our hypothetical problem aims to achieve optimal allocation of a given number of new territories while meeting a predefined conservation target for a large area with multiple habitats. The problem is mathematically formulated as follows:

$$\min_{i=1,2,...,I} \sum_{h=1}^{H} X_{hi}$$
$$s.t.\ Pr\{Y_i \geq N\} \geq 1-\gamma$$

The objective function is to minimize the total number of territories used across all H habitats, with X_{hi} denoting the number of territories added to habitat h under each policy i, which makes the objective deterministic. The limitation on budget territories naturally restricts the total number of solutions I, thereby making the solution space finite and combinatorial. The constraint ensures that the probability of the wolf population Y_i maintaining a certain level N is at least $1-\gamma$.

As for the solution method, we use the Chance Constrained Selection of the Best (CCSB) algorithm by Hong et al. (2015). This algorithm is specifically designed for probabilistic-constrained SO problems. It is a two-stage procedure that first identifies the feasible solutions and then uses a ranking and selection procedure to select the optimal. Given that our problem has a deterministic objective function, the feasible solution that uses the smallest number of territories will be the optimal solution. Essentially, the problem is a feasibility determination problem. Hence, we only use the feasibility check stage of the CCSB algorithm.

3 SCENARIOS

We applied CCSB to three scenarios to illustrate the extent to which SO can be used in RDP. Initially, we tackled a smaller problem with only 22 solutions, and compared CCSB's performance with a basic hypothesis testing method that uses Power Analysis for sample size determination. Results from 100 macro-replications indicate no statistically significant difference in the probability of correct selection between the two methods. However, the CCSB is more efficient. It saves approximately 1,300 runs per solution on average, compared to the 9,322 runs per solution required by PA under the same level of statistical confidence.

The second scenario examines a larger problem with 210 solutions. The aim of this scenario is to investigate the effect of excluding solutions based on performance dominance. This example aims to demonstrate how expert opinions in wildlife management can help identify dominance rules, thereby reducing the number of solutions to be considered.

The third scenario explores the potential of incorporating mathematical models to preemptively eliminate solutions that are unlikely to be feasible. The results for the second and third scenarios will be included in the poster.

REFERENCES

Camm, J. D., S. Polasky, A. Solow, and B. Csuti. 1996. "A Note On Optimal Algorithms For Reserve Site Selection". *Biological Conservation* 78:353–355.

Haight, R., and L. Travis. 2008. "Reserve Design to Maximize Species Persistence". *Environmental Modeling and Assessment* 13:243–253.

Haight, R. G., D. J. Mladenoff, and A. P. Wydeven. 1998. "Modeling Disjunct Gray Wolf Populations in Semi-Wild Landscapes". *Conservation Biology* 12:879–888.

Hong, L., J. Luo, and B. Nelson. 2015. "Chance Constrained Selection of the Best". *INFORMS Journal on Computing* 27:317–334.

IUCN 2023. "The IUCN Red List of Threatened Species. Version 2022-2.". https://www.iucnredlist.org, accessed 31.08.2023.