FISH 507– Introduction to Structured Decision Making

Final Report

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Optimal monitoring and management of flowering rush in the Columbia River

**Problem:**

In the Columbia River, invasive species contribute to biodiversity loss and declines in native aquatic species such as Pacific salmon and other wildlife populations of cultural and economic importance. Invasive flowering rush is one example of an invasive species that is of significant concern in this region. Flowering rush is an aquatic invasive plant that can rapidly disperse, colonize, and produce dense stands of emergent and submerged growth that displace native vegetation and can provide habitat for invasive predator fish species that impact salmon populations. Dense stands of flowering rush can compromise irrigation systems by blocking water transport and affect water-related recreational activities.

The Columbia River Fish and Wildlife Conservation Office (CRFWCO) has recognized that flowering rush has been expanding its range within the Columbia River and CRFWCO is calling for a better understanding of the dynamics of flowering rush (e.g., dispersal rates and population growth) and methods to remove the invader. CRFWCO is eager to manage and monitor flowering rush for ten years to minimize overall presence and downstream spread of flowering rush. They are focusing their efforts within a 50km stretch of the river that represents the leading downstream edge of the invasion (Figure 1h). CRFWCO is constrained the number of management segments (i.e., discrete 1 km stretches of the river) on which they can conduct annual management and monitoring due to limited resources and intends minimize program cost.

This management problem is an information problem, dynamic problem, and multiple objective problem. It is an information problem because CRFWCO is interested in determining whether conducting additional monitoring data will improve management outcomes by potentially selecting locations to conduct management with more accuracy. Hence, a value of information analysis will be used for this problem. This problem is a dynamic and an adaptive management problem because it involves making iterative decisions with an emphasis on learning from management and monitoring outcomes. It is a multiple objective problem because it involves objectives of minimizing cost, minimizing overall flowering rush presence, and minimizing downstream spread of flowering rush.

**Objectives:**

In a workshop, six members of CRFWCO identified objectives for this decision problem. The strategic objective, or the ultimate objective of CRFWCO, is to maximize structure and function of aquatic resources of the Columbia River. They developed the following three fundamental objectives: 1) Minimize overall flowering rush presence after ten years, 2) Minimize downstream spread of flowering rush after ten years, and 3) Minimize cost. The attribute for the first objective is the invasion state averaged across the 50km section after 10 years. This is a value between 0 and 1, where 0 indicated the entire 50km area was empty from flowering rush and 1 indicated the entire invasion. The second objective’s attribute was calculated similarly but it represented the average invasion state in the most downstream 5km of the study area (or the easternmost 5km segments). The minimize cost objective was expressed as two means objectives, to minimize annual removal cost and minimize annual monitoring costs, with expenses informed by CRFWCO.

**Alternatives:**

Members of CRFWCO used a strategy table (Table 1) to organize potential alternatives. The group indicated that each year they could remove flowering rush at exactly 5, 1km segments. They decided that removal of flowering rush could either be conducted at segments that they believe represent the downstream edge of invasion or at randomly selected segments that they believe are invaded. CRFWCO decided they could collect detection/non-detection data once each year after the final removal occurred for that year at 0, 5, or 10 1km segments. The data could be collected at the next downstream segments, which are the segments that are upstream of the most upstream segment that just experienced removal, or this data could be collected at randomly selected locations where removal did not previously occur.

Table 1. Strategy table for the decision problem. The themes of the strategy table were removal location, detection/non-detection location, and number of detection/non-detection locations

|  |  |  |
| --- | --- | --- |
| **Removal Location** | **Detection/Non-detection Location** | **Number of detection/non-detection locations** |
| Downstream removal | Next downstream segments | 0 segments |
| Random removal | Randomly selected segments | 5 segments |
|  |  | 10 segments |

Six alternatives were identified from the strategy table.

1. Downstream removal and detection/non-detection at 10 next downstream observations
2. Downstream removal and detection/non-detection at 5 next downstream observations
3. Downstream removal and no observations
4. Random removal and detection/non-detection at 10 random observations
5. Random removal and detection/non-detection at 5 random observations
6. Random removal and no observations

**Consequences:**

CRFWCO is unable to experiment with the different monitoring and management alternatives prior to making the decision and relied on a dynamic occupancy model to simulate flowering rush population dynamics and evaluate potential monitoring and management alternatives within the context of a forward simulation adaptive management framework. The framework involved four steps: 1) Under each alternative, simulate realistic population dynamics of flowering rush using a generating model with parameter distributions representing the current state of knowledge, 2) Gather simulated monitoring and management data from the generating model, 3) Analyze monitoring and management data using an estimation model and informed priors generated through Bayesian updating, then predict population dynamics, and 4) based on estimated model predictions, update management allocation, which subsequently influences realistic dynamics in the generating model. Each alternative was simulated ten times in this framework. The generating and estimation models were dynamic occupancy models. The process model had empty and invaded states with transition parameters including invasion probability, written as a function of the number of neighboring invaded segments, and eradication probability. The observation model included not observed and observed states with a detection probability parameter. The group assumed that the initial state of the most upstream 5kms was invaded. In the generating model, the rest of the river was initially uninvaded and the estimation model had uncertainty in the states of the rest of the river.

Using the framework, the group calculated invasion states at the end of 10 years at each 1km river segment for each alternative (Figure 1a-g). They also represented each objective against each alternative in a consequence table (Table 2)

Chart, line chart

Description automatically generated

Figure 1. a-f) True invasion states at the end of 10 years at each 1km river segment within the 50km study area. The state at each segment represents the mean final invasion state across all 10 simulations of the generating model for each alternative. Figures a-f represents true invasion states for alternatives 1-6, respectively. g) The legend for figures a-f. A value of 1 indicates that under all simulations, the segment was invaded, values less than 1 represent that some simulations resulted in different invaded and not invaded states after 10 years. h) Inset map of the study area (black box).

Table 2. Consequence table. Alternatives are displayed in the first column and objectives are shown in the final three columns. Elements in the table represent the performance of each alternative for each objective

|  |  |  |  |
| --- | --- | --- | --- |
| Alternative | 1. Average state  (Between [0,1]) | 2. Average downstream state  (Between [0,1]) | 3. Monitoring cost  ($/year) |
| 1. Downstream removal &  10 observations | 0.948 | 0.82 | $10,000 |
| 2. Downstream removal &  5 observations | 0.944 | 0.68 | $5,000 |
| 3. Downstream removal &  No observations | 0.944 | 0.78 | $0 |
| 4. Random removal &  10 observations | 0.936 | 0.98 | $10,000 |
| 5. Random removal &  5 observations | 0.934 | 0.94 | $5,000 |
| 6. Random removal &  No observations | 0.938 | 0.88 | $0 |

**Tradeoffs:**

CRFWCO removed the means objective to minimize removal cost because all alternatives had the same removal effort, hence this cost would be the same across all alternatives. When CRFWCO analyzed the consequence table, they decided that objective 1 was irrelevant because they believed there was not a significant difference between alternatives in this objective. With the remaining two objectives, CRFWCO removed all of the alternatives except alternatives 2 and 3 because all other alternatives were dominated.

CRFWCO noticed these two alternatives represent the same removal location but differ in the number of detection/non-detection data collected. CRFWCO calculated the expected value of sample information as the difference between the expected value with information (0.68) and the expected value without information (0.78), which was -0.10 which represents a 0.10 reduction in overall downstream states from the invaded state. In other words, a difference between 0.78 and 0.68 is a 12.8% decrease in invasion at the downstream segments.

However, this decrease would come at an additional cost of $5,000/ year. Given this tradeoff Brielle Thompson, the director of CRFWCO, was involved in a swing weighting exercise that resulted weights on objectives 2 and 3 to be 0.71 and 0.29. Using a standardized consequence table, the weighted preference was 0.71 and 0.29 for alternatives 2 and 3 respectively. Hence, alternative 2 was selected.

*\*all material for the final project can be found at* [*https://github.com/briellekwarta19/SDM\_finalproject*](https://github.com/briellekwarta19/SDM_finalproject)