Tried and True versus Experimental Methods for Eurasian Watermilfoil Control: An Economic Analysis

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Background

- Focus of IGERT Risk Analysis class
  - Risk Management Module
  - Ray Newman, David Ragsdale
- Effects of EWM
  - Reduces native plant diversity
  - Increases nutrient loading
  - Affects boating and swimming
- Problem in many lakes in MN and Wisconsin

Eurasian watermilfoil treatment options

1. Mechanical harvesting
2. Chemical treatments
   - Local
   - Whole lake
3. Biocontrol
   - Milfoil weevil
4. Water level manipulations
5. No control

Mechanical harvesting

- Out of pocket costs:
  - Per-hectare costs from $500 per hectare to over $2,500 per hectare (estimate for this presentation: $1000)
  - plants usually grow back in 4-6 weeks
- Fragments on the shoreline can be distasteful
- Mechanical harvesting may accelerate growth

Before mechanical harvesting

Photo: www.lakehopatcong.org/images

After mechanical harvesting

Photo: www.lakehopatcong.org/images

Biocontrol

- Milfoil weevil (native to Northern U.S.)
- Larvae feed on stems, plants collapse, stored energy is reduced, and health in subsequent years is compromised
- Commercial firm (EnviroScience) provides weevils and pre- and post-stocking assessments for $1000 per 1000 weevils (Madsen *et al.* 2000).
- Recommended density: 3000 weevils per hectare (Madsen *et al.* 2000, EnviroScience).
- Effectiveness enhanced by:
  - Self-sustaining weevil populations
    - Low predation by fish
    - Sufficient overwintering habitat
  - Healthy native plant communities to fill niche

Research Question

- Mechanical harvesting is a sure thing, and biocontrol is a risky strategy. Is it worth abandoning mechanical harvesting in favor of biocontrol?
- The two strategies are mutually exclusive because biocontrol agents live in the zone removed by mechanical harvesting.
- Basic idea can be applied to other management options that may be experimental.

Model

- Eurasian watermilfoil is a binary variable
  - S=1 (milfoil is a problem)
  - S=0 (milfoil is not a problem)
- Damage caused by watermilfoil is a linear function of S:
  - Damage Cost=d*S
- Control cost per hectare:
  - Mechanical harvesting=c_1*MH
    - MH=1 if mechanical harvesting is undertaken
  - Biocontrol: c_2*x
    - x is the stocking rate per square meter

Effects of Control Options

- Mechanical harvesting
  - Eliminates damage at a cost of c_1=\$2,000 per hectare per season
- Biocontrol
  - If a population establishes successfully, Eurasian watermilfoil is suppressed permanently.
  - Probability of Successful establishment and control of milfoil in the subsequent year, with *x* as the stocking rate:

$$P(S_{t+1}=0 \mid S_t=1, x_t, \alpha, \beta)=\frac{e^{\alpha+\beta x_t}}{1+e^{\alpha+\beta x_t}}$$

Dynamic Programming Approach

- Choose x_t (stocking rate) to minimize expected costs over time:

$$\min_{x_t} V(S_t, x_t) = \left[c_1 S_t + c_2 x_t\right] + \left[\frac{1}{1+r}\right]\Big(P(S_{t+1} = 0 \mid x_t, \ldots, S_t) * V(0, t+1)$$

$$+ P(S_{t+1} = 1 \mid x_t, \ldots, S_t) * V(1, t+1)\Big)$$

Parameter Values

- c_2=$1
- r=0.05
- d, α and β to be estimated
- d=$3,000
- α: Without stocking, what is the P(success)?
  - P(success)=0.1, α=-2.3
  - P(success)=0.5, α=0

Parameter Values

- β to be estimated
  - EnviroScience recommends 0.3 weevils/sq meter
- If $\alpha=-2.3$
  - If 0.3 weevils/sq meter is 29% effective, $\beta=4.62$
  - If 0.3 weevils/sq meter is 60% effective, $\beta=9$
  - If 0.3 weevils/sq meter is 80% effective, $\beta=12.3$
- If $\alpha=0$,
  - If 0.3 weevils/sq meter is 60% effective, $\beta=1.35$
  - If 0.3 weevils/sq meter is 80% effective, $\beta=4.62$

Solution Procedure

- Determine the date of the last decision, T
  - Final costs will be incurred in Period T+1
- Choose x_T to minimize costs in period T plus expected costs in period T+1. Calculate V(T), given that $S_T=1$. (V(T)=0 if $S_T=0$)
- Go back to period T-1, solve for the best x_{T-1}, calculate V(T-1), etc. Repeat.
- At some point, the decision date no longer matters and you have the solution for an infinite horizon problem.

Mechanical Harvesting Costs

- What is the present value of incurring the cost of mechanical harvesting for the relevant time horizon?
- PV(mechanical harvesting)=

$$\sum_{t=i}^{T+1} \frac{c_1}{(1+r)^{t-i}}$$

Results

- With: $\alpha=-2.3$, $\beta=4.63$ (so that P(success)=29% if x=.3)

Time	V(t)	x*(t)	c*x*(t)	P(success/x=x*(t))	PV(mech harvesting)
T	$10,744	0.558	$ 5,579	0.569	$3,905

- At date T, it's better to continue with mechanical harvesting because the expected present value of the cost of biocontrol ($10,744) exceeds the cost of mechanical harvesting ($3,905).

Results: α=–2.3, β=4.63

Time	V(t)	x*(t)	c*x*(t)	P(success/x=x*(t))	PV(mech harvesting)
T	$ 10,744	0.558	$ 5,579	0.569	$ 3,905
T-1	$ 13,505	0.834	$ 8,341	0.825	$ 5,719
T-2	$ 14,000	0.884	$ 8,836	0.856	$ 7,446
T-3	$ 14,078	0.891	$ 8,914	0.860	$ 9,092
T-4	$ 14,090	0.893	$ 8,926	0.861	$ 10,659
T-5	$ 14,092	0.893	$ 8,927	0.861	$ 12,151
T-6	**$ 14,092**	**0.893**	**$ 8,928**	**0.861**	**$ 13,573**
T-7	**$ 14,092**	**0.893**	**$ 8,928**	**0.861**	**$ 14,926**
T-8	$ 14,092	0.893	$ 8,926	0.861	$ 16,216

- With 6-7 years in the planning horizon, it becomes optimal to try biocontrol.
- At t=T-5, optimal solution becomes invariant to remaining time

Results: $\alpha=-2.3$, $\beta=9$

Probability of Success if $x=0.3$ is 0.6

Time	V(t)	x*(t)	c*x*(t)	P(success/x=x*(t))	PV(mech harvesting)
T	$ 8,135	0.473	$ 4,732	0.876	$ 3,905
T-1	$ 8,824	0.471	$ 4,713	0.875	$ 5,719
T-2	$ 8,915	0.480	$ 4,804	0.883	$ 7,446
T-3	$ 8,926	0.482	$ 4,815	0.884	$ 9,092
T-4	$ 8,928	0.482	$ 4,816	0.884	$ 10,659
T-5	$ 8,928	0.482	$ 4,817	0.884	$ 12,151

Results: $\alpha=-2.3$, $\beta=12.3$

Probability of Success if x=0.3 is 0.8

Time	V(t)	x*(t)	c*x*(t)	P(success/x=x*(t))	PV (mech harvesting)
T	$ 6,705	0.289	$ 2,892	0.778	$ 3,905
T-1	**$ 7,359**	**0.355**	**$ 3,546**	**0.887**	$ 5,719
T-2	**$ 7,434**	**0.362**	**$ 3,621**	**0.896**	$ 7,446
T-3	$ 7,443	0.363	$ 3,630	0.897	$ 9,092
T-4	$ 7,443	0.363	$ 3,630	0.897	$ 10,659
T-5	$ 7,444	0.363	$ 3,631	0.897	$ 12,151

Discussion

- Biocontrol becomes attractive relative to mechanical harvesting with a long time horizon.
  - Property owners may have to endure several seasons of milfoil effects for eventual eradication of the population.
  - Biocontrol offers the promise of permanent control, while mechanical harvesting guarantees that property owners will incur ongoing costs.

Discussion

- As β becomes smaller, a longer time horizon is required for biocontrol to be compare favorably to mechanical harvesting.
- A higher β leads to a lower optimal stocking rate, x, and a higher optimal probability of success in any particular try.
- Existing milfoil weevil populations may control Eurasian watermilfoil. A higher probability of control from existing populations (α) leads to lower optimal stocking rates

Model Refinements

- Learn about other factors influencing success
  - Temperature
  - Habitat
  - Predators
  - Availability of native plants

$$P(S_{t+1}=0 \mid S_t=1, x_t, \beta) = \frac{e^{\beta x_t}}{1+e^{\beta x_t}}$$

- Include in the vector, *x*
- Learn about other parameters, e.g. damage per hectare from willingness to pay studies (e.g., studies done in Wisconsin, Florida)