SUMMARY OF BUDWORM WORKSHOP

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A workshop was held at IIASA 14 to 16 January 1974 to develop a case study to explore the advantages of combining good ecological data, computer models and policy analysis in a coordinated whole. There are no examples available of this full combination,and the attempt to do it, therefore, forces modification and expansion of a considerable set of ecological, sampling, modelling, and policy techniques.

The particular focus was an insect pest, the spruce budworm, of the coniferous forests of eastern North America. It was chosen because there was an existing set of data collected using good statistical sampling procedures over the past 30 years in Canada. In addition, a simulation model was available which roughly captured some of the causal relations and more accurately represented the qualitative properties. What was missing was rigorous refinement and validation of the model, analysis of the effects of the stochastic behavior of weather and of the subprocesses and, most important, conceptualization and design of useable policy instruments. If these gaps could be effectively filled, then a valuable package of techniques would be available of broad applicability to any problem of single species management, whether of pests of crops or of man or of populations of fish or wildlife.

Feasibility research was initiated jointly by methodologists, hydrologists, and ecologists at IIASA in November. It quickly became clear that expansions were required of the existing techniques of optimization so that they could cope with what to the ecologists was a simple system, and to the methodologists a complex one (non-linear, large number of state variables, spatial pattern). Such expansions would be one step towards developing more broadly useful optimization techniques and at the same time would force a rigorous analysis of the ecological model and of relevant policy options. The result was a short intensive period of research in which the model was simplified to 4 state variables in 265 subregions, technical problems of the model were identified, data gaps were exposed, and a first phase dynamic programming model designed for optimization within one subregion. Most significantly, an alternate policy framework began to be conceived that was more qualitative, but richer in its ability to contain ecological and policy realities. We began to call this "Compressed Policy Analysis" and it showed promise of providing a policy framework which would furnish a coherent policy methodology useable by present policy makers.

With this feasibility study completed, we could see great profit in further exploring and integrating three themes: Model refinement and validation, Dynamic programming, and Compressed policy analysis. But to do so, it was essential to develop working contact with the scientific team which had been concentrating on this problem.

Hence the workshop, which expanded the interproject linkages developed within IIASA to link with an active working group in the Canadian Department of the Environment. The goals of this working session were:

(1) to define the objective functions and develop the framework for a dynamic programming model of a single subregion;

(2) to analyze, clarify, and modify the existing simulation model;

(3) to define future steps and goals for a short term cooperative effort which would be of value not just to the participants but broadly to those concerned with problems of single species management.

Each of these goals was achieved for the three themes.

Model Refinement, Testing and Analysis

The IIASA budworm workshop was able to answer some critical questions about the budworm system. Until these questions were answered, some of the avenues of investigation were blocked. The following steps and prerequisites for their completion were identified:

Model Refinement

-- The assumptions which went into the original model were clarified.

-- Procedures were established to correct the coding to more accurately portray the real world mechanisms.

-- New data were obtained which extend the range of several of the variables.

-- The model was restructured to incorporate within-time-period feedbacks of forest conditions on budworm survival.

Model Testing

-- The new model structure will be compared with various field measures of budworm dynamics.

-- New field data on forest and budworm conditions were obtained and will be coded as input to the model.

-- A real and simulated historical record since 1949 will be generated to allow comparison.

-- Measures of temporal and spatial outbreak patterns which capture their qualitative aspects will be developed for both the real and simulated data.

Model Analysis

-- The revisions and refinements developed in the workshop will be incorporated into the analysis of the model dynamics.

Dynamic Programming

The principal aim of the policy group was to determine the objective function for the optimization model and to develop the necessary data. This work was done in three stages:

(1) Determination of discount factor;

(2) Determination of yearly costs (or benefits)per site in terms of conditions in site and policy of that year;

(3) Determination of final value function.

(1) Discount factor

The choice of a discount factor is somehow arbitrary. It was felt that it should be between .04 and .10. A value of .05 was agreed upon as a reasonable value for the first tries.

(2) Costs (or benefits) per year

The costs incurred are those of spraying (adults or larvae) and the benefits come from wood production and wildlife/recreation.

(a) Spraying for adults

When spraying for adults we incur a cost of \$.30/acre.

(b) Spraying larvae

There is a fixed cost of \$.20/acre for spraying, plus and additional variable cost depending on the dosis, and which reflects the cost of the insecticide of \$1.25 per pound.

Hence,

$$C(S_\varepsilon) = \begin{cases} 0 \text{ if } S_\varepsilon = 0 & \text{i.e., no spraying} \\ .20 + .073 \times S & \text{where } S_\varepsilon \text{ ounces/}_{\text{acre}} \text{ is the insecticide dosis} \end{cases}$$

For a dosis of 3 ounces of insecticide per acre, this gives a cost of 43.4 cents/acre.

(c) Logging benefits

Only trees in age group 3 are logged. The benefits are obtained from the following information:

(i) one acre of age group 3 trees yields 20 cunits (1 cunit ≙ 100 cft) of wood.

(ii) The net benefits derived from the forest industry were $\$122.257 \times 10^6$ for 1972 in New Brunswick, with a total production of 2.2248×10^6 cunits. Hence a net benefit of $55 per cunit.

Hence we get a net benefit of 1100$/acre for trees in age group 3, whenever the total production is between $2. \times 10^6$ to $3. \times 10^6$ cunits.

(d) Wildlife/recreation benefits

The wildlife/recreation benefits are estimated to be $1000 per square mile per year when the forest composition is uniform over age, and very low when there is only one tree age. The following function is proposed:

$$WLB = 3.7 \times 10^4 \min(\alpha_1, .15) \times \min(\alpha_2, .30) \times \alpha_3 \ \$/\text{yr (mile)}^2$$

(3) Final Value Function

It was agreed that the final value function should be the present value (at time T) of all future benefits due to the forest. This way, if at time T there is no outbreak (I = 0, small egg density), its value will depend mainly on α_3. If there is an outbreak, then the benefits from α_3 should be reduced by a factor g(I)

$$g(I) = \begin{cases} 1 & \text{if } I = 0 \\ .5 & \text{at value of } I \text{ where trees start dying} \\ 0 & \text{at 30 units over value at which trees start dying} \\ & \text{and the linear interpolation value for other Is.} \end{cases}$$

Besides that, we should subtract the value of spraying insecticide to reduce the larvae to a density equivalent to that of a normal period.

Hence,

$$P_{T+1}(\alpha_1,\alpha_3,E,I) = a_1\alpha_1+a_2(1-\alpha_1-\alpha_3)-f(E)+a_3\alpha_3.g(I)$$

where $g(I)$ is as given above and $f(E)$, a_1, a_2 and a_3 can be calculated from the economic information available and the discount factor. Also $a_1 \ll a_2 \ll a_3$.

Compressed Policy Analysis

Extensive use of the simulation model is contemplated in order to test a range of policy options. Several modes of operation will be developed, all based on systematic generation of weather at many locations in the province.

(1) The work essential to generate extensive traces of "raw data" at 10 sites, and to convert these to biologically relevant weather states (1, 2, 3) at 265 plots, has been allocated. These reconstituted data will preserve the temporal and spatial correlations inherent in the observed sequences.

(2) Using the model with a single long synthetic trace, we will generate regression equations relating egg density (dependent) to previous density, deriving separate relationships for each of a small number of weather patterns. Departure from trendline estimates can be attributed to stand conditions and stress index; the cumulative effect of these will be measured by the residual variance in the regressions. This will give an initial approximation to the magnitude of the smear or cloud of data points in the prototype.

(3) The full model will be used to generate transition matrices over 1 year; the states will include food, eggs, weather and stress index. Nine states are visualized:

1 - Threat (food $\geq$ S), weather pattern 1
2 - Threat weather pattern 2
3 - Threat weather pattern 3
4 - Threat weather pattern 4
5 - Endemic level; no threat; food < S
6 - Decline of outbreak
7 - Outbreak;stress index 1
8 - Outbreak; stress index 2
9 - Outbreak; stress index 3

Long traces will be run to investigate the transition probabilitities for a variety of strategies.

(4) Full scale weather models will be used to test spatial policy effects.

A research schedule was then agreed to (summarized in Table 1) which would lead to a final report by 30 May 1974.. In order to achieve this, responsibilities for specific tasks were defined:

(1) By 1 February, detailed information on past management policies using insecticides (size of blocks sprayed, dose, hazard trigger by year by area in the form of a write up and maps).

Action: Miller

(2) By 1 February, detailed information on management policies by tree cutting by sub-region in 5 or 10 year periods (maps).

Action: Baskerville

(3) By 15 February, weather records of raw data from 10 stations over 60 years punched for a complete rectangular array, together with a map locating weather stations and contiguous regions associated with each.

Action: Miller

(4) By 15 February, data provided on egg densities and forest condition by 265 sub-regions for each year from 1948.

Action: Baskerville & Miller

(5) By 28 February, mapping of above data and validation runs using these data.

Action: Jones

(6) By 28 February description and data justification for weather index.

Action: Miller

(7) On or about 30 March, a return visit by Miller at D.O.E. expense to help define realistic policy sets.

(8) By 30 May, a brief summary of dynamic programming for the practitioner using insect pests as the example.

Action: Dantzig

Additional Plans

By 30 May, therefore, there should be a completed report emphasizing a combination of expanded ecological, modelling and policy techniques as illuminated by this specific example of management of a pest within an ecosystem. But there will still be missing elements:

(1) informing and involving groups with similar problems in other countries;

(2) the full decision process in the real world involves as well the techniques of identifying alternate objectives in our society and of rationalizing often conflicting ones. Such techniques cannot possibly be well designed in isolation from the actual decision-makers and those who are affected by the decisions.

Steps have already been initiated to identify interested groups in other countries, particularly USSR, FRG, GDR, France, Poland, and USA. But the exact pattern of involvement of these people will depend on the results of this case study. And that is even more true of any future move into the realities of decision making in a specific problem.

CSH

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Table 1. Research Schedule - Budworm Project

b-Area Responsibility)	Completion Dates for Stages						
	16 Jan.	1 Feb.	28 Feb.	15 March	30 March	30 April	30 May
Simulation Model (Jones)	Resolve technical, conceptual and data problems	rewrite Simulation model; design output indicators reflecting spatial pattern	collate 1948-1970 data by year and 265 subregions; validate runs of model	final model revision; preparation of figures; complete analytics of model	FINAL REPORT		
Dynamic Programming (C.Winkler)	Define objective function (for subregion)				standard optimization model complete and run	conceptualization of inter-site optimization scheme & identification of problems	FINAL REPORT
Compressed Policy Analysis (Fiering)	Conceptualize technique	define min. states of the system in terms of budworm food threshold, budworm density thresholds and relevant weather patterns	weather data from 10 stations for 60 years punched and analyzed; stochastic model of weather completed	simulation runs coupling weather model with ecological simulation model for tests of sensitivity; test runs to identify alt. mgmt. options & useful output indicators required for policy assessment.	define reasonable policy sets and alternate actions	production runs	develop graphic packages for decision makers; FINAL REPORT