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EVALUATION OF RESEARCH AND DEVELOPMENT ACCOMPLISHMENTS: NORTHERN FORESTRY CENTRE

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Abstract: A retrospective, or hindsight, model was used to evaluate impacts and benefits of completed research and development (R&D) at the Northern Forestry Centre (NoFC) over a recent 10-year period. The evaluation included: (1) an inventory of R&D accomplishments in use with estimates of benefits; (2) client (forestry users) validation; (3) management rating of 62 accomplishments; (4) time and cost assessments; and, (5) quantified benefit compilations for a sample of six accomplishments. A conservative three-to-one benefit-to-cost ratio, over the *entire* NoFC R&D program costs (including services), for the 10-year period has been identified for the sample alone. The most successful R&D was client-driven, with emphasis on applied R&D and technology transfer.

Résumé: C'est par une étude rétrospective que l'on a évalué les effets et les profits du programme de la recherche et du développement (R & D) mené récemment sur une période de 10 ans au Centre de Foresterie du Nord. L'évaluation comprenait: (1) Les projets de R & D mis en oeuvre ont été utilisés pour calculer les profits; (2) Validation du client (utilisateurs de la foresterie); (3) Evaluation par la direction de 62 projects mis en oeuvre; (4) Estimation du temps et des coûts; (5) Compilations quantifiées de profits pour un échantillonnage de six projects mis en oeuvre. On a retenu, pour l'échantillonnage seulement et sur une période de dix ans, une faible proportion de trois contre un des profits et dépenses de la totalité des coûts (services compris) du programme R & D du CFN. Le programme R & D ciblant le client, mettant l'accent sur la R & D appliquée et le transfert de technologie a donné les meilleurs résultats.

The forest industry is one of the most important industries in Canada; yet it lags behind other world-scale industries in relating its research and development (R&D) to increases in productivity. The forestry R&D community is increasingly required to evaluate its R&D contributions to society. This is particularly evident in government-

sponsored R&D associated with management of the resource. Research managers must now be aware of the value (i.e., impacts, benefits, etc.) of the R&D activities for which they are responsible, as well as the costs of that R&D.

The Northern Forestry Centre (NoFC) of Forestry Canada is responsible for fulfilling the federal role in forestry research, regional development, and technology transfer in Alberta, Saskatchewan, Manitoba, and the Northwest Territories (i.e., the Northwest Region). One of six regional centers, two national forestry institutes, and a headquarters unit, NoFC is located in Edmonton, Alberta, and has district offices in Prince Albert, Saskatchewan, and Winnipeg, Manitoba. The main objectives of NoFC are research and regional development in support of improved forest management for the economic, environmental, and social benefit of all Canadians. The main clients of NoFC are forest land managers (i.e., federal/provincial/territorial agencies) and forest industries. Any assessment of NoFC productivity must consider the multiplicity of research objectives of a federal mandate and the nature of economic analyses.

> Uncertainty is perhaps the defining feature of R&D activities; uncertainty is also one of the greatest obstacles to economic analysis. The techniques developed by operations research specialists to conduct economic analyses under uncertainty are conceptually interesting and often applied to R&D in abstract academic papers. But to practically use the techniques of uncertainty analysis, one must be able to quantify, or subjectively estimate probability distributions for key variables, a process that is difficult for many R&D activities (McDaniels Research and Quantalytics, 1986). Thus the smaller the uncertainty for a given R&D effort, the more accurate and easier will be any economic analysis. This suggests that *ex post* evaluations, undertaken once R&D efforts are completed, will exhibit less uncertainty about their results than *ex ante* evaluations. (McDaniels, 1988)

A realistic forestry R&D evaluation methodology has been developed for the U.S. Forest Service and tested with a U.S. regional center (Callaham & Hubbard, 1984); the methodology might be adapted for a Forestry Canada center.

This paper is based on a retrospective evaluation of R&D accomplishments at NoFC. The accomplishments evaluated were those made generally available and actually applied during the 10-year period of 1977-86 inclusive. The overall objectives were as follows:

1. to examine the utility of retrospective R&D evaluation as an in-house management tool for a Forestry Canada regional center using the methodology developed by the U.S. Forest Service;
2. to demonstrate to participating scientists that the value of their work is recognized by clients (i.e., direct beneficiaries of the R&D);
3. to provide NoFC managers with better information for program justification and technology transfer decisions; and
4. to give clients a better appreciation of the time and cost of forestry R&D towards solving their operational problems.

METHODOLOGY

Several R&D evaluation techniques were available. These have been categorized as retrospective evaluation of impact, evaluation of program management, and peer evaluation (Salasin et al., 1980). The latter two are already used on a regular basis by Forestry Canada. Hindsight studies are in the first category, and they should provide the additional accountability information required by research managers of public R&D organizations. This hindsight study of R&D accomplishments closely follows a U.S. Forest Service model by Dr. R.Z. Callaham (1981), based principally on his experience at the Pacific Southwest Forest and Range Experiment Station.

The NoFC Hindsight Study

There were five steps in this study. First, scientists created an inventory of their R&D accomplishments in use, with their estimates of benefits, for the 10-year period. Second, clients were asked to validate the scientist's claimed accomplishments and the benefits to the clients. Third, NoFC management reviewed the scientist claims and client validations for a final rating of the 62 accomplishments. Fourth, scientists provided time and cost data for each of the rated accomplishments. Fifth, detailed compilations of the benefits were completed for a sample of six of the most readily quantifiable accomplishments (i.e., about a 10% sample). These five steps are described below.

1. Scientists' Accomplishments. NoFC scientists itemized accomplishments in R&D that became generally available and operationally used during the 10-year study period. An accomplishment meant an improvement or a change in the costs, efficiency, condition, effectiveness or productivity of forestry management or activity. The emphasis was on R&D

applications, and not on pure science *per se*. Most NoFC scientists contributed. Each claimed accomplishment was classed as an invention, an innovation,[1] or a modification of an innovation,[2] as described by Callaham and Hubbard (1984). There were no inventions claimed. One hundred claims were accepted from NoFC scientists, including some from former staff, representing 19 innovations and 81 modifications of innovations. For instance, accomplishments included studies of: aspen biomass yield models; monitoring of granular herbicides in soils; a forest ecology field guide; a large-scale photo sampling system; and environmental impacts of northern pipelines. All claims were quantified through benefit ratings as described below.

Each accomplishment was allotted a perceived benefit, which could be improved income or employment, increased productivity or effectiveness, or reduced costs. The magnitude of the benefits were estimated by assigning a "double-plus" to "double-minus" scalar rating (i.e., a five-level rating with zero indicating no benefit or liability). These were applied to each of the 16 benefit categories as described by Moeller and Shafer (1981) and scored according to Mosteller (1981). A double-plus rating meant the innovation, or modification thereof, was perceived as an excellent improvement to the existing product, process, or technique. A zero rating meant there was no demonstrated gain, and a double-minus meant that the results were considerably worse than the product, process, or technique replaced. Single-plus/minus ratings, of course, fall between the scalar extremes and zero. Factors influencing innovation were also compiled as described by Callaham and Hubbard (1984).

2. *Client Validation.* Consolidated lists of claimed accomplishments (i.e., without ratings) were then forwarded to clients for their review and benefit ratings. The clients were requested to follow the same rating procedure (above) for each of the claimed accomplishments. At least one client response per claimed accomplishment was required, but most had two or more. Clients were also requested to provide, where possible, an estimate of the significance of the R&D application towards improving their operating method(s) or activities.

3. *Management Assessments.* The NoFC Management Committee reviewed and assessed the scientist and client ratings. A net rating was determined for each of the 16 benefit categories for each accomplishment claimed. These tended to reflect an average of the client benefit ratings, but the Committee did apply the scientists' or other ratings where it was felt the user failed to consider benefits to the federal mandate in particular. For instance, the prairie reforestation performance assessment

study more generally enhanced the Centre's federal role. Such raises in ratings did not happen often, however, because most client ratings exceeded those of the scientists. More ratings were reduced than augmented to determine a net rating. Other inputs to the Committee included data on factors influencing innovation and client feedback as to the effectiveness of the R&D in improving their activities.

The 100 accomplishments claimed were consequently reduced to 62 by the Management Committee. Some were recategorized as useful only in science or service functions, others were aggregated with similar R&D accomplishments, and still others were deemed "not in use" in the 1977-86 period. The importance of accomplishments was defined as improvement or change in efficiency, condition, effectiveness, productivity, or costs. There is a difference in scale between studies of the box elder twig borer, for example, and the development and implementation of ecological land classification mapping for the mountain national parks. The Committee, therefore, further rated the net benefits by classifying each of the verified 62 innovations or modifications of innovations into one of the following four improvement classes:

1. permits 10% or less improvement in the situation or way of doing business (this "improvement" can be in the form of increased efficiency, cost savings, improved production, or reduced environmental degradation);
2. permits 11-30% improvement;
3. permits 31-50% improvement; or
4. permits 51% or more improvement.

4. R&D Expenditures. It was essential to estimate how long it took to realize the accomplishments and to determine the costs. An internal breakdown of costs was conducted to be consistent with external contributions to R&D. Scientists first identified the chronology of significant events. These were the authority, funding, publication, demonstration, etc., events between the preconception, conception, direct program, and post-innovation periods of R&D projects as described by Callaham and Hubbard (1984). External support (e.g., special funding programs) and in-kind support (e.g., client-provided flight time) were considered separate from internal activities. Internal activities were accounted for in "Scientist Years" (SY). An SY was a person-year plus the proportional costs of operations and maintenance, support staff, capital funding, etc., for the entire NoFC R&D and applications program. This also included contributions to science, unidentified accomplishments, incomplete R&D, and a diversity of NoFC service functions (e.g., demonstrations, workshops, etc.).

The costs of rated accomplishments were determined from NoFC financial records. Only innovations, or modifications thereof, reaching general availability (i.e., application) during the 1977-86 inclusive study period were considered. Several of these had costs attributed to them prior to this "window" of assessment. The average cost per SY for the entire NoFC R&D program in 1986/87 was $98,300, and this was used for the 1982-86 inclusive time period. Likewise, the 1981/82 average of $46,000 per SY was used for the 1977-81 time period. The 1976/77 average cost per SY of $34,500 was used for several of the accomplishments that showed activity prior to 1977. The appropriate amounts were summed by accomplishment to determine the internal costs.

5. NoFC R&D Benefits. The benefits of NoFC R&D were substantial, but were more difficult to quantify than expenditures. The results of R&D were openly disseminated with few restrictions or requirements for copyrights, royalties, or patents. There was not always complete feedback to NoFC. As in the U.S. studies, no effort was made to analyze the magnitude of benefits or to determine internal rates of return on investments. The data do not lend themselves to statistical analysis, but have value as descriptive information reflecting the best recall by scientists (Callaham & Hubbard, 1984).

RESULTS AND DISCUSSION

This retrospective study of NoFC R&D applications accomplishments had very positive results. The most immediate result appeared to be enhanced three-way communications between scientists in very specialized and diverse activities and their clients and management. At least one provincial authority has subsequently used the format of this study for its own reporting purposes. The benefits for six accomplishments (i.e., about a 10% sample) with relatively immediate, identifiable benefits were calculated based on the best information available. Summaries of significant results for decision making and discussions of factors influencing innovation and benefit/cost examples will follow.

Significant Results

The "Benefit Categories" listed in Table 1 were those developed for the U.S. Forest Service (Callaham & Hubbard, 1984), and were used for rating all the R&D accomplishments at NoFC. The "Percent" column in Table 1 was used to rank the benefit categories for NoFC. These values include, directly or indirectly, the net benefit ratings of scientists, clients

Table 1
R&D Accomplishment Ranking at NoFC

Rank	Benefit Category	Percent
1	Increased efficiency or reduced costs through improved processes	75.1
2	Reduced costs or increased efficiency of managing resources (clients)	68.2
3	Improved methods for planning and evaluating alternative investments	47.2
4	Resulted in new and improved products	45.0
5	Improved scientific methods/theory	39.4
6	Increased resource productivity or quality	38.3
7	Improved quality of physical/biological environment	32.1
8	Improved visual environment and related amenities	19.3
9	Generated income or employment in industry or regional economy	14.5
10	Increased utilization of natural resources	13.7
11	Enhanced health and safety	12.0
12	Enhanced public involvement in decision making	7.3
13	Lowered prices or costs to consumers (not clients)	5.3
14	Improved cultural/historical/geological environment	5.3
15	Improved social enviroment	4.7
16	Raised quality, lowered cost of housing	0.6

Note: The percent column includes the product of the improvement class (1 to 4) multiplied by the net scalar rating (i.e., number of +s).

and the Committee, as well as the improvement class assigned to each accomplishment by the Committee. The ranking is a good indication of the functional priorities of NoFC. This is not to be confused with the functional priorities of all of Forestry Canada. For instance, the lowest ranking, "Raised quality, lowered cost of housing," is last because this type of R&D is carried out by organizations other than NoFC. In addition, scientists cited a number of factors influencing the innovative process for their R&D accomplishments. Factors such as adaptation of available techniques, technology or equipment (84%) and the development of adequate theory for applied research (79%) were highly rated. The development of special techniques (60%) was less frequently cited. Cooperation with provincial, territorial or local government (87%), and to a lesser extent with industry (56%), was also important. Personal contacts with users (87%), publication of intermediate results (74%), and feasibility (58%) and technology, equipment or process (69%) demonstrations were factors most often cited for success in technology transfer. To a lesser extent, significant outside financial support (50%) and multifunctional approaches to research (34%) were also contributing

factors. Surprisingly, factors such as reacting to changes in legislation or policy (18%), environmental law/standards (8%), or cooperation with national parks or Indian reserves (15%) and international affairs (15%) scored comparatively low. Client adoption of R&D was dependent on formal and informal contacts, demonstrations and various modes of technology transfer.

Discussion of Benefit/Cost

Quantification of all benefits attributed to all NoFC R&D to the same extent that all costs are documented is an ideal that will probably never be met. For instance, the results of extensive fieldwork and software development for the effects of tree harvesting on water yield have been widely disseminated and used. Nevertheless, a complete forest crop rotation (i.e., 80–100 years) would be required for a completely accurate assessment of benefit(s). There is evidence, however, that *benefits of just six of 62 rated R&D accomplishments significantly exceeded the entire NoFC R&D budget for the ten-year study period.* Outside economic evaluations were used for these examples whenever possible (e.g., Agriculture Canada, 1988), and they are discussed below.

Fire Behavior Prediction (FBP) System. This component of the Canadian Forest Fire Danger Rating System (CFFDRS) has been developed partially as a result of the fire behavior research conducted at NoFC. About $750 million in benefits have been attributed to the CFFDRS nationwide from 1971 to 1982 (Agriculture Canada, 1988). Although only half of that time period overlaps the period of this study, the first half was assumed to be extensive development and implementation of CFFDRS; whereas, the 1983-86 period most likely produced even greater benefits. The documented 1971-82 benefits, therefore, were roughly equivalent to actual benefits for the study period. About 35% of this benefit can be attributed to the FBP in preventing major forest fire losses. This amounts to approximately $262.5 million. About 25% of the development of the FBP was due to R&D at NoFC. The financial benefit attributed to R&D at NoFC, therefore, is about $65.6 million over the course of the development of the FBP system as an integral part of the CFFDRS.

Fertilizer Regime for Containerized Seedlings. The audit (Agriculture Canada, 1988) also noted that published guidelines, from R&D at NoFC, for rearing conifer tree seedlings in containers saved between $3.5 million and $10.4 million from 1978 to 1986 in the prairie provinces alone. For the purpose of this study, a median value of $7 million has been adopted as a net benefit.

Nursery Salinity, Irrigation and Fertilizer Investigations. Plot experiments indicated the optimum amount, type and form of fertilizers, as well as the application timing, required for individual nursery seedbeds across the Region. Client savings accrued to both bareroot and containerized stock production, but only the bareroot stock operations are considered here. Less land and seed are required as a direct result of these prescriptions, and the weeding costs and seedling culls are reduced. Nurserymen have estimated savings of $250,000 in Alberta, $200,000 in Saskatchewan, and $150,000 in Manitoba.

Handheld Infrared Scanner. It has been conservatively estimated, by forest protection personnel of the Alberta Forest Service, that the NoFC innovation of handheld infrared scanners in fire control has resulted in savings of about $14.4 million nationwide in fire mop-up costs during the 10-year study period. These scanners were used to detect small heat sources such as holdover fires. The benefit is derived from an estimate of direct financial savings as a result of early release of fire crews during mop-up operations. Untold further savings could potentially be attributed to the prevention of timber losses and additional direct suppression costs. In addition, these scanners were used each spring, particularly in Alberta, to detect upwards of 200 holdover fires from brush pile burning on seismic, logging, road building and other land clearing operations. It has been estimated that up to 50 of these heat sources, left undetected, could potentially have resulted in wildfire ignitions. Again, the resultant direct suppression costs would have amounted to additional millions of dollars.

Forest Depletions Mapping. Landsat satellite imagery interpretation techniques were developed over a period of years, and this experience was applied with the Procom-2 Image Transfer System. This cost-effective technology was transferred to provincial and territorial forest management agencies through workshops and demonstrations. The Alberta Forest Service has operationally tested the system for mapping forest depletions due to clear-cuts and fires, and has demonstrated savings of about $100,000 per year over traditional aerial survey techniques. Such information is critical for annual allowable cut estimates and the licensing of new forest product mill capacity. In addition, the Landsat/Procom system was selected and is being used by the Government of the Northwest Territories, principally for its mapping accuracy over helicopter sketch-mapping, for mapping burned forest land. The annual cost savings are about $35,000. The Landsat/Procom system has also been evaluated and recommended for forest cut-block and wildlife habitat mapping, as well as for use in other jurisdictions. But the already "in use" operations represent over one-half-million dollars in savings for each 5-year map update cycle.

Water Thickeners. One NoFC accomplishment concerns calcium carbonate water hardness effects on water thickeners formerly used in conjunction with water bomber operations in forest fire suppression. The cessation of use of costly water thickening compounds (i.e., short-term retardants) by regional fire control agencies resulted in about $2 million in post-innovation savings. The net benefit attributable to NoFC, based on conducting about 60% of the R&D that led to these savings, was determined to be $1.2 million.

The total of the foregoing six benefit determinations, attributable to NoFC, is about $89.3 million. This is a conservatively estimated three-to-one benefit-to-cost ratio over the *entire* NoFC R&D program for the study period.

CONCLUSION

A retrospective evaluation based on a specific U.S. Forest Service model was a useful in-house management tool for a regional center of Forestry Canada. Substantial accountability information was made available to research managers, and has already been used for planning purposes. Dollar benefits are not always appropriate measures of R&D impacts within a federal department mandate, but the dollar benefits of selected accomplishments in this study exceeded the costs of overall R&D by large margins. Forestry land managers and industrial clients endorsed the R&D effort by NoFC, as shown by their contribution to this study.

NoFC scientists were impressed and satisfied with the feedback from the clients. The study did not provide a base for detailed statistical or economic analyses *per se*, but it did provide some valuable information for decision making related to the uncertainty of R&D. It also showed that the most successful R&D applications were completed in cooperation with clients.

NOTES

1. An innovation is a fully developed new or useful product, process, or technique that is accepted and in use. It must meet one of three criteria: be a completely new function (e.g., balloon logging); provide a totally new way to perform a function (e.g., aerial spraying of microbial pesticides); or establish improvements for time/cost/safety advantages.
2. A modification of an innovation extends the use of an innovation to new geographic areas, species or problems, as well as refining innovations or making them more cost-effective.

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