Evaluating tradeoffs in regional forest planning

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Summary

Initiated in 1995 under auspices of national forest policy and completed in 2001, Australia's Regional Forest Agreement (RFA) program sought to resolve major conflicts relating to the use and management of key public native forests. Comprehensive Regional Assessments (CRAs) of environmental, heritage, social and economic values were undertaken as part of the program to achieve outcomes balanced between competing forest uses, and long-term agreements for forest management. Implementation of each RFA is to be reviewed after 5 y and each agreement after 20 y.

The paper outlines a planning model for multiple resources that explains the development of RFAs, and discusses examples of software used to evaluate competing conservation and timber interests. Limitations of the planning model and software applications are briefly discussed, along with proposals for improving them. The improved model is not only relevant for evaluation and review for RFAs; it also has potential application in other natural resources planning and management situations.

Keywords: land use; multiple land use; planning; natural resources; forest policy; environmental policy; resource management; sustainability; models; information systems; decision making; Australia

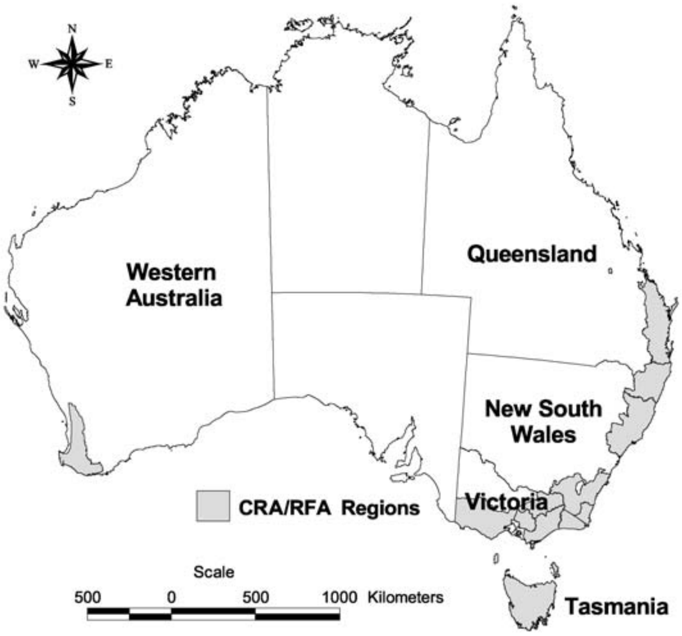

Figure 1. States and regions covered by Comprehensive Regional Assessments (CRAs) (the South East Queensland CRA did not proceed to a Regional Forest Agreement)

Introduction

Australia's Regional Forest Agreement (RFA) program, established under national forest policy (Commonwealth of Australia 1992), was a joint national and State government program designed to resolve conflicts over the use and management of key public native forests. Covering 45 million ha in twelve regions in five States (Fig. 1), the program considered about 6% of Australia's land area and 16% of its total forests, including a substantial portion of its timber production forests (Montreal Process Implementation Group 1997).

When the program started in 1995, about 17.6 million ha of publicly owned native forests were in formal conservation reserves; with an additional 13.4 million ha being managed for multiple uses, including timber production (National Forest Inventory 1998). At completion in 2001, the area of conservation reserves had been increased to 20.4 million ha and the area of multiple use forests reduced to 11.9 million ha. These outcomes have serious implications for forest industries because increasing the area of conservation reserves necessarily reduces the area of land available for competing uses, including timber production.

The RFA program had three major aims:

- to develop a national, first class, scientifically based system of 'comprehensive, adequate and representative' (CAR) forest conservation reserves to maintain regional environmental, heritage and social values;
- to lay the foundations for ecologically sustainable management of multiple use forests; and
- to secure access to timber resources for sustainable, internationally competitive timber industries over the ensuing 20 y and beyond, subject to review.

In order to achieve these aims, the program was mandated to employ the best available science and wide-ranging consultation with stakeholders (Davey *et al.* 2002). Each RFA commenced with a scoping study with stakeholders in each region to define terms of reference, followed by a Comprehensive Regional Assessment (CRA) prepared according to the terms of reference. Each CRA covered collection and analysis of environmental, economic and social data on the region's forests and communities, including data relevant to international conventions for protecting biodiversity and endangered species. This required, among other things, agreed criteria — the JANIS (Joint Australian New Zealand Interdepartmental Subcommittee) criteria — for establishing a national system of comprehensive, adequate and representative forest conservation reserves (Commonwealth of Australia 1997).

Under the JANIS criteria, *comprehensiveness* includes the full range of forest communities recognised by an agreed national scientific classification at appropriate hierarchical levels; *adequacy* refers to the maintenance of ecological viability and integrity of populations, species and communities; and *representativeness* refers to the degree to which sample areas of forest selected for inclusion in reserves reasonably reflect the biological diversity of the communities within each region.

During the RFA process, a comprehensive report of findings for each region — the CRA report — supplemented by more detailed technical reports on particular aspects, was published to facilitate debate and stakeholder submissions. These reports provided explicit or implicit information on a wide range of forest goods and services, summarised in Table 1, which subsequently had to be evaluated in the integration and decision-making stages. There were also public meetings and other consultations to enhance communication and understanding on issues and options for resolving them. These submissions were evaluated as a basis for a second report on options and/or directions, which was also presented to stakeholders to obtain their input for drafting each RFA. Implementation of each signed RFA will be reviewed after 5 y, followed by review of each agreement after 20 y.

Table 1. Wood and non-wood market and non-market goods and services that affect forest-use decisions. These are assigned explicit or implicit values (valuation) to compare different reserve design scenarios (evaluation) when trade-offs are made to accommodate competing demands.

Wood market goods	Non-wood market goods and services	Non-wood non-market goods and services
Sawlogs	Honey	Biodiversity
Peeler logs	Cut flowers	Old growth
Roundwood products	Seeds	National Estate
	Commercial hunting	Wildlife
Pulpwood	Grazing	Flora
	Water	Endangered species
	Tourism	Landscape
	Recreation	Gene pools
		Spiritual values

Various tools and procedures, called 'integration systems', were developed to synthesise CRA outcomes and assist decision-making during scenario development and evaluation. Integration in this context involved generating alternative scenarios and evaluating trade-offs to design a comprehensive, adequate and representative system of forest conservation reserves and satisfy industry's requirements for timber, and other community expectations.

The purpose of this paper is to:

- explain key planning concepts;
- outline a model of the planning processes for multiple resources used to develop Regional Forest Agreements;
- illustrate tools and procedures, called 'integration systems', that were used to integrate data, generate alternative scenarios, and evaluate trade-offs between conservation and timber interests; and
- discuss improvements for future regional multiple resources planning.

Planning concepts

Land-use planning is a process that society uses to help organise its affairs. The process involves considering alternative futures (e.g. different land uses), selecting preferred options, and then endeavouring to implement them (Spencer 1984). Because social values influence choices, such planning is both political and technical.

Strategic planning covers aspects that have potential to cause greater changes than others, including greater demands on resources, either directly by affecting major actions, or indirectly by triggering significant chain reactions among related activities. Therefore inter-relatedness is a characteristic that, sometimes more than magnitude, makes decisions strategic (Friend 1976). Strategic planning is also generally long-term, robust and relatively corporate in its outlook (Solesbury 1974). Strategic decisions are reached after considering major alternatives, which usually are specified only at a low level of detail to make an overview possible. These larger or greater strategic decisions are distinguished from more detailed and limited tactical decisions.

Tactical planning (decisions) requires more detailed specification of alternatives that, in a rational planning process, should be taken only within an agreed strategic framework. However, there is no absolute distinction between strategic and tactical planning; high level decisions are strategic in relation to low level decisions, and decisions that appear strategic in one circumstance may appear tactical in another (Ackoff 1970).

Rational planning requires the generation and evaluation of alternatives to achieve its objectives (Banfield 1959). Evaluation involves analysing a number of options to compare their advantages and disadvantages, and recording findings in a logical, transparent framework (Davis and Johnson 1987). Valuation covers one stage of this process — quantifying significant elements in each option so that their relative importance can be assessed (Litchfield *et al.* 1975; Sinden and

Worrell 1979). Evaluation is therefore a process for comparing alternatives which uses quantitative and other bases to help stakeholders reach decisions.

RFA planning model

Steps for preparing RFAs followed a rational planning approach as described by Faludi (1987) and outlined in Figure 2. The figure is based on a continuous, cyclic planning process depicted by Bather *et al*. (1976) as modified by Bugg *et al.* (2002). It illustrates iterative, strategic processes that progressively incorporate refined data and methods to generate and evaluate new scenarios. The model therefore provides opportunities for refining processes and outcomes as new data, methods and understanding evolve. The main elements of the model are: new strategies, reserve design and resource impact assessment, social and economic modelling, input from stakeholders, agreed design, monitoring and review.

New strategies

Several inter-connected adaptive processes are driven and constrained by strategic policies, shown as new strategies along the top of Figure 2. Strategies change over time and provide a policy framework for establishing aims and objectives. The National Forest Policy Statement (Commonwealth of Australia 1992) provided an overarching strategic framework, whereas JANIS conservation objectives (see later) provided explicit criteria to guide the design of conservation reserve systems and assess the merits of different designs. Other strategies covered levels of sustainable yield, employment, industry development, use of private forests, and plantation development.

Reserve design and resource impact assessment

The generation and evaluation of alternative reserve designs, a major focus of the RFA program, generated flow-on effects to the rest of the program. All RFA reserve designs considered non-wood values from the perspective of JANIS targets (described later), plus wood and other commercial products (Table 1) from the perspectives of viable industries, dependent communities and requirements for ecologically sustainable forest management (ESFM). Various tools were used to assist these processes. All were designed to help develop scenarios and evaluate their pros and cons.

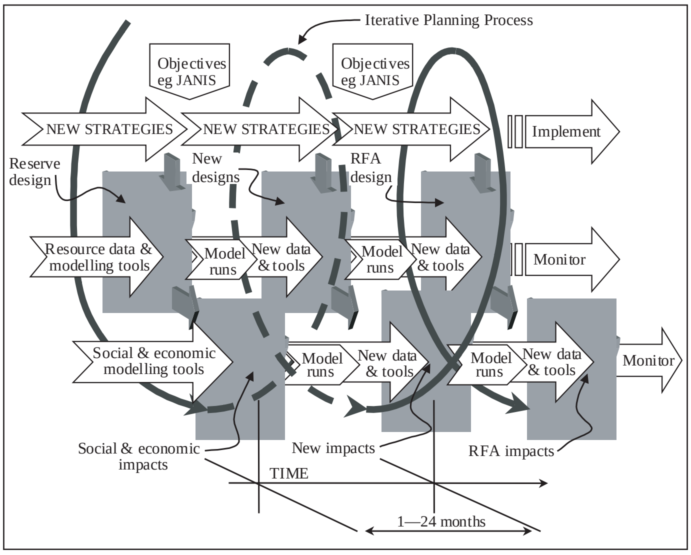

Figure 2. Model of RFA planning processes based on continuous, cyclic planning process depicted by Bather *et al.* (1976) as modified by Bugg *et al.* (2002), illustrating iterative, strategic processes that progressively incorporate refined data and methodologies to generate and evaluate new scenarios

The design of each regional conservation reserve system and complementary multiple-use forest system required substantial data, analyses, consultation and conflict resolution. The process started by gaining a good understanding of the conservation and economic resources of each region's forests, its industries' future wood requirements, and the region's social and economic capital and needs. Figure 2 identifies the first stage of this iterative process as 'resource data and modelling tools', which leads into 'model runs', followed by 'new data and tools', etc. Having generated a reserve design, the next step was to assess its impact on sustainable timber supply from the remaining multiple-use forests.

The model therefore illustrates that strategic planning is a dynamic, continuous process in which new policy positions are generated from a background that is 'one of continuous erosion or decay of existing policy positions as they gradually lose their relevance in a volatile social, economic and political environment' (Friend 1976).

Social and economic modelling

Output from each resource impact assessment was input for 'social and economic modelling', another iterative component of the overall process. These assessments focused on the effects of potential changes in the resource base over time on industry and employment. Successive iterations accounted for new reserve designs and consequent effects on resource availability and use, plus fortuitous or commissioned new data and tools.

Input from stakeholders

Figure 2 does not explicitly identify inputs from stakeholders, but they were significant in data collection, reserve design, evaluation and RFA negotiations. Major opportunities and methods for public participation are shown in Table 2. Their effectiveness varied according to circumstances, including stakeholders' awareness and motivation — e.g. whereas some stakeholders knew what they wanted and how to influence outcomes, others didn't even have clear objectives. Therefore methods were required to inform stakeholders as well as solicit information from them. An overarching aim was to employ methods to disseminate and receive information that engendered community trust and confidence in the processes and outcomes.

Agreed design

The final result ('RFA design') was an acceptable package of conservation reserves and multiple-use forests that met agreed objectives for conservation, wood supply, and associated social and economic impacts.

Table 2. Stakeholder roles in RFA processes and their relationship to principal activities in a generic linear planning model

Steps in generic linear planning model	RFA planning equivalents	Stakeholder roles in RFA program
Define problem	Forest conflicts	Expressions of concerns
Decide to act	National forest policy statement	Political pressure
Define goals and objectives	CAR reserve criteria, ESFM, competitive industries	Advice on technical and societal goals and objectives
Collect data, analyse and forecast	CRAs	Provision of information on technical and value issues
Generate alternative plans	Integration, Options report and/or Directions reports	Consultations and interactive analysis
Evaluate and select best plan(s) (decision-making)	Decision support tools, stakeholder inputs, impact assessments, signed RFAs	Inputs and pressures relating to values, judgements, and technical and political issues
Implement plan	ESFM, strategic management plans, tactical operational plans, active management	Representation on planning and management committees
Monitor and review	Inventory, analysis and review	Surveillance, independent monitoring and political pressure

Monitoring and review

Monitoring and review are required to determine whether RFA requirements are being implemented as planned, and determining their effects on the forests, industries and communities, as well as appropriate responses for improvements.

Design of conservation reserves and multiple use forest systems

CRAs were undertaken to provide information for decisions about future forest use and management to be encapsulated in RFAs. Accordingly, information from CRAs was used to identify those forest areas that should be placed in conservation reserves and those areas that should be assigned to multiple uses, including timber production. Final designs for conservation reserves and multiple-use forests were usually reached after a series of iterations.

Therefore the reserve design process first split the public forest estate into two:

- conservation reserves; and
- multiple-use production forest.

Alternative reserve designs incorporated various technical and political evaluations. The process aimed to protect conservation values through including areas in dedicated reserves, setting aside special reserves in production forests (e.g. streamside reserves), and implementing ESFM in multiple-use forests (Chikumbo *et al*. 2001). Indicators, in many cases yet to be defined, will be monitored over time to evaluate the delivery of ESFM.

Superficially, the reserve design process emulated map overlay techniques of pre-GIS days (McHarg 1971). Planning units could be any shape and size, but it was better if they had identifiable ecological boundaries that coincided with the boundaries of management units. Design tools preferably facilitated interactive learning and decision-making by incorporating users' expert knowledge and political persuasion, including priorities for inclusions, such as wildlife corridors, and constraints such as high timber values. Whilst computerised tools were available to facilitate the reserve design process using linear programming and other techniques, they met with mixed success. Additionally, all methods had limited capacity to address uncertainty (levels of confidence).

Although a comprehensive planning approach to the identification of conservation reserves could be expected to include land under all ownerships, management and use (Spencer 1984), restrictions in the RFA program meant that conservation reserves could generally be created only in public native forests. They included dedicated formal conservation reserves, 'informal reserves' in multiple-use forests managed under conservation prescriptions (e.g. riparian buffers, steep terrain), and broad areas of multiple-use forests to be managed under ecologically sustainable principles. Dedicated reserves represented the highest level of protection, but multiple-use forests also contributed significantly to the achievement of conservation objectives, in addition to addressing wood supply objectives.

Where it was not practical or possible to meet all CAR objectives on public land, long-term strategies for protecting private lands were considered, including negotiated purchases of priority areas and incentives for landowners to manage their land exclusively for conservation purposes. Measures to protect private forests, however, were implemented only in exceptional circumstances because of limited Commonwealth and State powers and political sensitivities relating to controls over private land.

Criteria for forest conservation reserves

The JANIS guidelines (Commonwealth of Australia 1997) provided targets based on the pre-European (i.e. pre-1750) and current extents of various forest categories, regional targets for conservation reserves under these guidelines being:

- 15% of the area of pre-European (pre-1750) distributions of each forest ecosystem;
- at least 60% of remaining areas of vulnerable forest ecosystems;
- 100% of all remaining occurrences of rare and endangered forest ecosystems;
- 60% of old-growth forest identified at the time of assessment; and
- 100% of rare or depleted old-growth forest.

JANIS also specified design principles for defining the boundaries of conservation reserves, the main objectives being:

- to set boundaries in a landscape context, with ecological integrity;
- to establish large reserves in preference to small reserves;
- to minimise boundary-to-area ratios, except for riverine and corridor systems; and
- to locate reserves across environmental gradients.

Criteria for sustainable timber supply

As RFAs aimed to secure a sustainable, economic forest resource for timber industries over each 20-y agreement, it was necessary to determine sustainable timber yields and methods to implement them through ESFM (Chikumbo *et al*. 2001). Different systems for regulating timber yield were used in different regions, reflecting regional differences in resource characteristics, data and organisational methods. For example, Spectrum (described later) was used in Victoria and New South Wales (NSW) as a linear programming engine forming part of a suite of software, including GIS, to determine acceptable future yields under various constraints.

Integration: land assessment, and scenario generation and evaluation

Integration, in the context of RFAs, involved compiling different data layers and collectively analysing them to assist decision-making. With spatial data the approach was superficially similar to conventional map overlay techniques (McHarg 1971), but analytically more powerful due to the use of GIS. The approach generally involved compiling spatially referenced databases containing the information to be used in decision-making. The integrated information was then used to develop and evaluate various land-use allocation scenarios.

Whilst alternative designs for conservation reserves, called scenarios, aimed to meet JANIS conservation targets, they also had to be assessed to determine whether they had acceptable economic and social effects. Timber production options for multiple-use forests were evaluated to assess their effects on wood availability and forest condition, and their economic and social consequences. Techniques included cost-benefit analysis, modelling, simulation and optimisation. Preferred options provided a basis for negotiating formal agreements on forest use and strategic directions for management over the ensuing 20 y and beyond.

Vector 'continuous line' data were used when precise representation of boundaries and generation of area summaries were required, but they required high computing capacity. Because of their lower computing requirement, grid (raster) systems were particularly useful and efficient for rapid analysis and visualisation of geo-referenced data, such as modelling with remotely sensed data. Relational databases, in conjunction with GIS, were used in most regions because of their advantages for manipulating and managing large amounts of data.

Another aim was to employ user-friendly interfaces, such as pull-down menus and simplified data sets, to enable scientists, policy staff and key stakeholders to interact in the development and evaluation of scenarios. Although available technology allowed for electronic visualisation and transfer of geographic data, hard-copy GIS-generated maps were widely used in decision-making and communication.

Whilst these approaches had previously been employed in Australia for a variety of forest planning purposes, the RFA program was distinguished by high levels of complexity due to its wide-ranging multiple objectives, requiring many layers of data for decision making, plus transparent repeatable processes that involved multiple stakeholders.

Integration software

Various types of integration software and methods were used in the RFA assessment and planning processes. Two tools used in NSW — C Plan and Spectrum — are briefly described to illustrate general concepts. There would have been advantages in using a common tool set for all RFAs, but that was not possible due to differences in regional characteristics, data availability, technical capacity, politics and stakeholder involvement. However, because the methods used to evaluate trade-offs aimed to achieve outcomes acceptable to all parties, they all had to be robust, transparent and repeatable, which in turn required comprehensive high quality data, rigorous assessments, and input from stakeholders at appropriate stages.

Timber harvest scheduling using Spectrum

A wide variety of tools and methods was used for timber scheduling because of regional differences and the multiplicity of approaches used by the different States. In NSW a scheduling tool known as Spectrum (USDA 1996) was used to determine long-term sustainable timber yields. Spectrum uses linear programming to find an 'optimum' solution space under various regional and local constraints. This is achieved through a process that seeks to maximise or minimise a linear expression subject to linear constraints. Due to practical constraints, it determines only a maximum or minimum within a feasible area (the 'solution space'). Algorithms for this purpose, including linear programming, can be used in conjunction with other techniques throughout the assessment and decision-making process (Frakes and Bugg 2001), including model calibration and evaluating tradeoffs for multiple objectives.

Spectrum was developed from FORPLAN, a software package designed in the United States Forest Service to schedule the management options of forested land over time within various constraints, including constraints to account for non-wood values. In other words, Spectrum provides a capability to model management scenarios across landscapes over time, within various constraints, at strategic or tactical levels (Sleavin and Camenson 1994).

Spectrum is a 'user-friendly' DOS program that has pull-down menus and pick lists supported by a mouse. It consists of a data entry system**,** model manager, matrix generator and report writer (Spectrum Manual 1997). It accepts tabular information about the size, silviculture and management prescriptions for each management unit, revenues and costs associated with each prescription, and constraints on the management units. The matrix generator interprets the model data and creates rows and columns for the linear programming software, as it attempts to maximise an objective function, such as revenue or wood production, subject to given constraints, including non-wood constraints (Chikumbo *et al.* 1999; Turner *et al.* 2000).

Spectrum has an add-on GIS sub-system, called Spectravision, which is an ArcView (ESRI 1996) extension designed to display Spectrum LP solutions. By interacting with Spectravision, the user can visually study solutions to a complex spatial optimisation problem. Hence the Spectrum/Spectravision package represents an interactive, exploratory LP system with a capacity to visualise an LP solution in several dimensions by giving time-series pictorial representations of a solution**.**

As previously explained, the process of determining a regulated 'sustainable yield' involved classifying components of the public forest estate as either 'conservation reserve' or 'multiple use' then determining trade-offs between arbitrary ecosystem reservation targets and potential timber production for defined patches of particular forest ecosystems. Calculating sensible future timber yields was usually complicated by a requirement for relatively regular, continuous flows of timber over timeframes (~15–20 y) typical of capital investments, constrained by various economic, technical and environmental harvesting protocols. As the period over which a yield is to be regulated depends on many factors, it varies from decades (e.g. south-eastern Queensland where harvesting in public native forests is being phased out) to hundreds of years (e.g. at Eden, NSW, where the aim is to support sustainable industries over the long term).

Figure 3 illustrates yields determined under various constraints for a large forest estate, viz:

(a) unconstrained 'natural'yield of timber from a forest estate resulting from on-schedule harvesting. Clearly the large fluctuations in annual yields in this example would be unsatisfactory for industry, which usually requires a fairly regular flow of product. In practice, such yields would be regulated to provide a more uniform supply, possibly at the level of long-term sustainable yield for the particular forest and management regime.

(b) non-declining yield with threshhold increases over time. Potential yields are constrained by preventing a decline in harvest yields over time but accepting or planning threshhold increases. This can be achieved by delaying some on-schedule harvests and bringing others forward in time to achieve a desirable yield profile and/or increasing yields over time through improved management. This strategy can provide significant benefits for industry and may or may not enhance ecological values.

(c) non-declining yield, smoothed as for (b) but with an additional constraint on how much the yield can increase at different times — in this example increases up to 2.5% of the yield of the previous year are allowed. This strategy differs from (b) in that increases in yields over time are smoothed, thus enabling dependent industries to adjust through incremental change.

(d) forced maximum yield followed by a threshhold reduction and then non-declining yield. This scenario forces maximum production in the first few years to provide industry with certainty in the short term, enabling it to 'buy' time to make informed investment decisions about how to cope with a future substantial reduction in the wood resource.

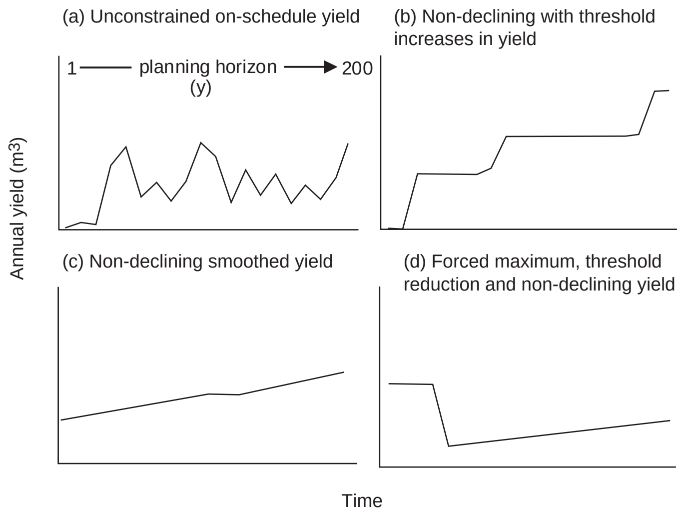

Figure 3. Spectrum output for sawlog yields over 200 y to meet different objectives for a large forest estate

Development and evaluation of conservation scenarios using C Plan

Integration in the RFA program covered synthesis of environmental, heritage, resource, economic and social assessments for decision-making, and many integration systems were used to facilitate stakeholder interactions for developing and evaluating scenarios. This interaction facilitated the capture of stakeholders' knowledge on resources, issues and the policy environment, and enabled them to become more familiar with the data and issues affecting possible outcomes.

Although scenarios were developed to achieve defined objectives, many were discarded as unacceptable after evaluation (Bugg *et al.* 1999). It was important, however, to record details on the development and outcomes of all scenarios to avoid repetition and to reach conclusions in an efficient way. Principles of reserve design were incorporated in the scenario development phase, and, where necessary, boundaries were modified to account for management and legislative constraints.

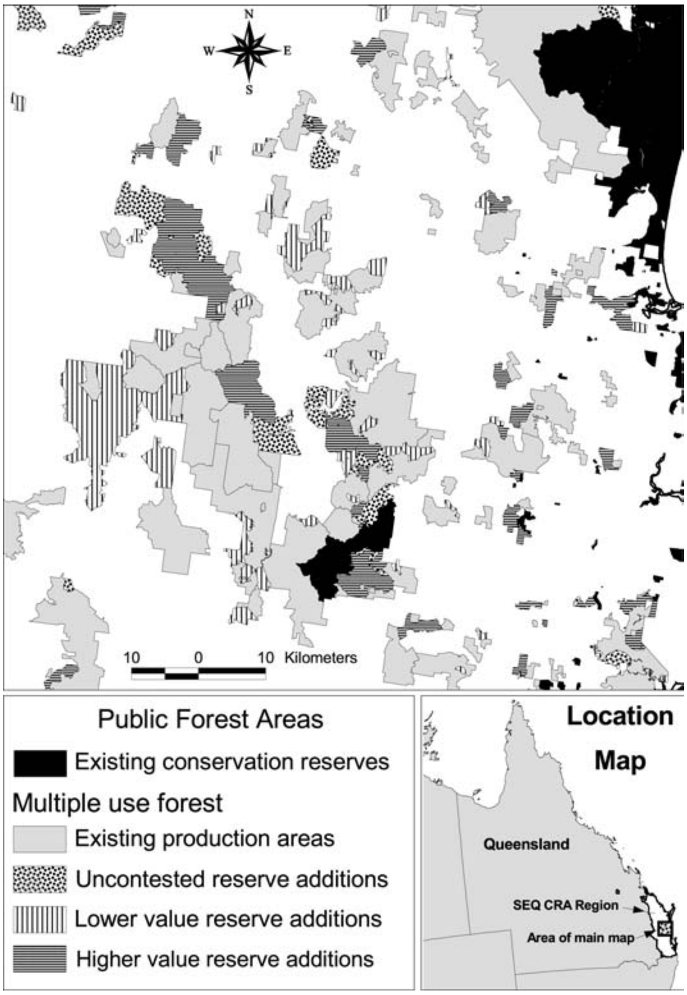

Figure 4. Integrated output for two alternative reserve design scenarios in South East Queensland that identifies areas of agreement on proposed land-uses and areas of possible conflict between timber production and conservation interests

New tools developed for integration covered design of conservation reserves, reporting on target achievements, resource impact assessment, and land-use allocation. Often some or all of these functions were combined in a single tool. Some systems were used interactively to develop understanding and explore solution spaces; others attempted to automate decision-making using optimisation and other solution algorithms with multiple data sets. Most approaches allowed generation of scenarios that were then evaluated and revised within the application or in subsequent stages of an iterative process. Figure 4 illustrates output from a scenario in south-eastern Queensland and identifies areas of agreement on proposed land uses and areas of possible conflict between timber production and conservation interests.

A range of systems was used to help design conservation reserves in the RFA integration process (Bugg *et al*. 2002). One system, C Plan, was used during negotiations in NSW and is discussed here because of its use as part of a more comprehensive decision-making process (Chikumbo *et al*. 1999). C Plan is a conservation planning software tool that incorporates the concept of 'site irreplaceability' (the importance of land areas for conserving biodiversity) in a GIS package (Pressey *et al*. 1994). Accordingly, management units with high conservation values, and hence a high irreplaceability index value, are excluded from timber harvesting or identified for only light harvesting.

In C Plan the spatial integrity of polygons is preserved in each analysis, making it convenient to export a C Plan output file of a reserve scenario to other tools for further analysis, such as the Spectrum tool used for scheduling timber harvests through time in production forests. Spectrum also accepts analysis units generated in a GIS.

The notion of irreplaceability as defined by Pressey *et al.* (1994) is a measure of the importance of incorporating an area into a conservation reserve and, conversely, the negative effect of its exclusion. A related concept of 'complementarity' is a measure of the enhancement achieved through addition(s) to an existing reserve system. Both notions are applied in the C Plan software to assess the value of conservation resources for achieving biodiversity targets.

Discussion

The CRA/RFA model was adopted to meet particular requirements of a scientific, technical and political process. Whilst it stimulated development of improved methods and tools, it was also deficient in several ways. This discussion considers the need for an improved model to be developed that could be applied in future forest planning and other natural resources management applications, such as greenhouse and salinity abatement issues. All these processes require a continuous improvement cycle guided by in-depth data analysis and modelling.

Although the CRA/RFA process attempted to achieve balanced outcomes, individual resource assessments were generally made in isolation and incorporated as static layers in decision-making. For truly balanced outcomes, analyses of dynamic information are needed, with interaction and feedback incorporated explicitly. For example, reservation of areas for conservation purposes will impact on timber harvesting and rural communities, so it would be an advantage to have a dynamic evaluation system that could be used to rapidly test different levels of reservation.

Natural resources data usually have a temporal dimension as well as a spatial one; for example, timber harvesting over space and time, and the spatial and temporal effects of climate variability on tree growth. Therefore systems need to be developed that are capable of simultaneously exploring the effects of spatial and temporal parameters on the solution space. Model simulation and optimisation approaches can contribute to this objective.

Decision processes should explicitly consider uncertainty to account for normal and episodic variability. For example, ecological boundaries are usually fuzzy, so any unit, however small, will never be completely homogeneous for all values. Therefore the distribution of parameter values is important, but because these can either be normally distributed or skewed, they contribute to the uncertainty of boundary definition, location, and classification (Burrough 1986). In spite of this knowledge, uncertainty was rarely considered explicitly in RFA assessments because of technical and data deficiencies (e.g. it is difficult to account for uncertainty in a linear programming expression).

The process could be improved by considering uncertainty in decision-making, using the output of model simulations to determine confidence levels for achieving expected outcomes. This would allow choices to be made within a framework of acceptable risk. Although this approach has been used for determining sustainable timber yield for some time, its use in general dynamic decision support systems is more recent.

There could also be merit in applying the concepts of management of uncertainty, discussed in Friend and Hickling (1987) and based on research into processes of decision-making for urban planning in the United Kingdom. This approach — the strategic choice approach — uses the analysis of inter-connected decision areas to isolate possible solutions and the uncertainties associated with them. This analysis may show the need to make some decisions early and leave others to be further researched until the uncertainties have diminished, or until there are new pressures for decisions. Essentially the approach gives more explicit recognition to processes that decision-makers usually go through intuitively but with very little direct communication of underlying assumptions between participants.

Planning and decision-making for natural resources need to consider multiple objectives at strategic, tactical and operational planning levels. Decision support tools available include decision matrices and multiple objective optimisation techniques. For example, the relative importance and interaction of issues under consideration can be represented and evaluated within a decision matrix. Usually the information is presented at the planning unit level, but priorities and targets are set for individual themes (or decision criteria). Methods used in natural resources planning should also be spatially and temporally explicit.

RFA negotiations, among other things, were guided by assessment of the likely effects of particular reserve designs on forest sector employment. These would affect dependent communities and influence the level of compensation required for firms adversely affected. However, the ecological (reserve design), economic (timber yields, etc.) and social (employment, etc.) components were considered separately and in that order, because of the lack of established tools for integrating them.

For regulating timber yields, the Spectrum tool had significant merit, but also shortcomings. For example, it cannot incorporate spatial adjacency constraints imposed by targets for fragmentation, minimum area and aggregate area. However, as demonstrated by Chikumbo *et al*. (2000) and reviewed in Kurttila (2001), new tools are becoming available for these purposes.

The complexity of natural resource management problems generally means that the notion of optimum solutions is not realistic. Linear programming algorithms, however, can provide a means for exploring and evaluating possible solution spaces. Obtaining a linear programming solution requires concurrent consideration of all significant decision criteria, but many assessments and the ways that they were used in integration in the RFA program did not allow simultaneous consideration of all aspects of the problem. In reality this is a daunting, complex undertaking, although information systems and processing techniques now have improved capacity for assisting. There will always be limitations imposed by the complexity of numerous interacting variables, the frequently very large data sets, and the need to simplify systems and data to facilitate their use by non-specialist stakeholders.

An example of a spatially explicit optimisation is provided by the use of Spectrum with Spectravision to develop a harvesting plan over time, taking into account landscape configuration. This is an area where a new generation of tools is being developed (Frakes and Bugg 2001). The concept can be extended to include multiple objectives through techniques such as goal programming and dynamic programming.

In defining decision-making processes, the recording of decisions and the sharing of information deserve attention in order to achieve outcomes that are both repeatable and credible. An evaluation of the basis for decision-making is also required. There is a further need for continuous model development and testing to avoid ‘black box’ solutions that will not gain acceptance or assist greater understanding of the issues being addressed.

Conclusions

The RFA program has advanced the science of natural resources planning in Australia, and it has produced negotiated outcomes to meet agreed objectives, explicitly considering economic, social and environmental values. Tools used to develop and evaluate future scenarios and assist validation and decision-making incorporated advanced technologies, such as C Plan and Spectrum. In spite of the technical sophistication of these tools, however, the process still required expert knowledge and judgement in relation to data and the interpretation of outputs. Further work is required to account for additional values, to improve evaluation methods, and to refine the tools and methods for applying them in decision-making.

RFAs have a rational planning framework in which multiple objectives are considered, so as to achieve balanced outcomes. The supporting tools used in this context incorporated a number of different methods and planning units. Ideally the integration process, including the human element and tools used to assist the process, should encompass all aspects of a problem simultaneously and explore the range of possible solutions, accompanied by sensitivity analysis indicating the robustness of preferred outcomes. Whatever tools are used, the scale and quality of the analysis, and types and quality of data, should be consistent with the approach. Uncertainty and spatial relationships should be considered explicitly in the decision-making process, and these are areas where further development is required.

Natural resources planning is a complex undertaking in which issues should not be considered in isolation from each other. The CRA/RFA process provides a model for undertaking such complex, multi-objective projects that can be extended and adapted for other purposes, such as environmental management for greenhouse gas reduction, or targeted tree planting in degraded catchments to improve water quality and abate salinity.

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