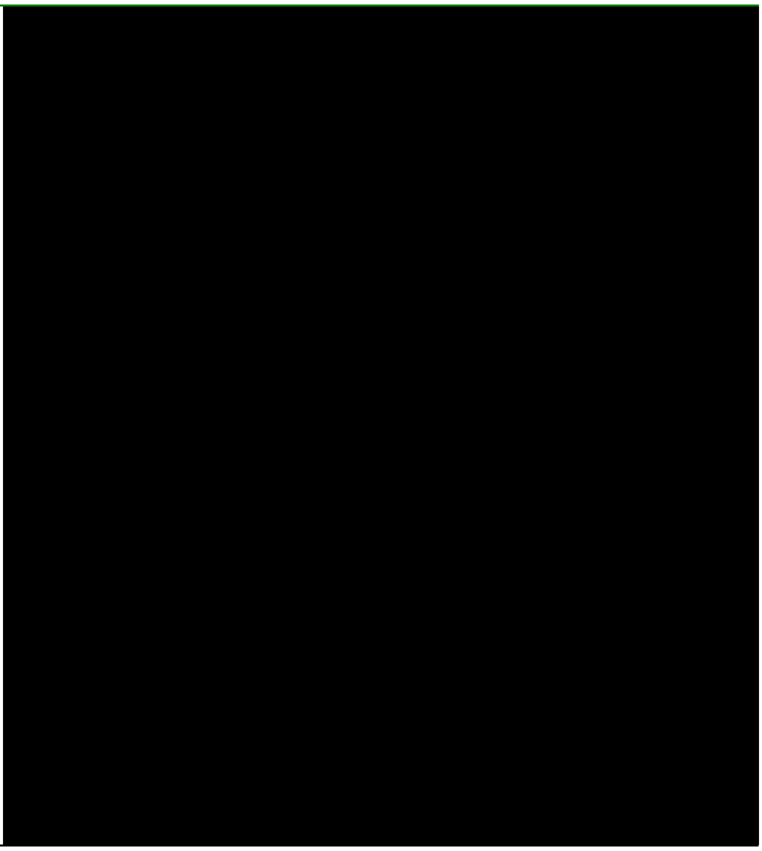
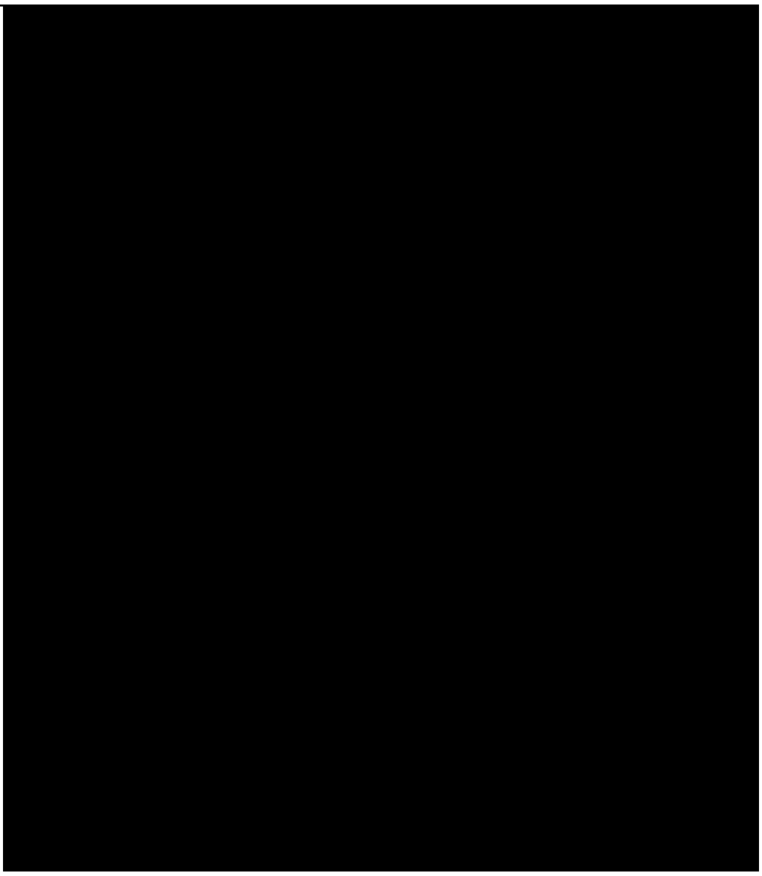


Reserve Design

A project undertaken as part of the NSW Comprehensive Regional Assessments

August, 1998



RESERVE DESIGN

LAND ASSESSMENT UNIT
NATIONAL PARKS AND WILDLIFE SERVICE

A project undertaken for
the Joint Commonwealth NSW Regional Forest Agreement Steering Committee
as part of the
NSW Comprehensive Regional Assessments
project number NA 43/EH

August 1998

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The project has been overseen and the methodology has been developed through the Environment and Heritage Technical Committee which includes representatives from the New South Wales and Commonwealth Governments and stakeholder groups.

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CONTENTS

PROJECT SUMMARY

This working paper describes a project undertaken as part of the comprehensive regional assessments of forests in New South Wales. The comprehensive regional assessments (CRAs) provide the scientific basis on which the State and Commonwealth Governments will sign regional forest agreements (RFAs) for major forest areas of New South Wales. These agreements will determine the future of these forests, providing a balance between conservation and ecologically sustainable use of forest resources.

Project objective/s

This project deals with issues relating to the spatial design or configuration of reserves. It does not address selection issues relating to which entities (or how much of each entity) should be included in reserves, nor issues relating to the type of protection (e.g. formal versus informal reservation) to be afforded to different parts of the reserve system. The paper attempts to discuss spatial design criteria against a background of the scientific literature and the resultant debates. All relevant JANIS criteria are dealt with under the broad design principles of shape, size, connectivity and replication.
The specific aims of this discussion paper are to:

1. Highlight JANIS criteria relating to reserve design (or spatial configuration) principles,
2. Provide a literature review based on core reserve design principles; size, shape, connectivity and replication.
3. Highlight existing spatial configuration tools or mechanisms being employed in the CRAs.
4. Provide, where needed, recommendations on how reserve design principles should be further addressed in the CRA process.

Methods

JANIS specifies spatial configuration criteria for entities as well as reserve design in general. There are many reserve design issues raised in these sections of JANIS that need to be addressed in the scope of this paper. These issues were addressed under the broad design sections mentioned above.

Key results and products

Key recommendations for reserve design investigate issues of size, shape and connectivity. In particular, these issues address: boundaries with ecological integrity and boundary-area ratios; spread and location of reserves across environmental gradients and away from threatening processes; satisfying criteria for reserves; and, corridors and linkages between reserves.

1. INTRODUCTION

1.1. CONTEXT AND AIMS

This document has been prepared by the NPWS for the purpose of the NSW eastern forests Comprehensive Regional Assessments (CRAs). The document is set within the CRA context, which include:

- adoption of reserve criteria as outlined by The Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee (JANIS) report,
- agreements on the application of the above (for example, the type and number of criteria and entities to be considered),
- agreement on the areal reservation targets and weights assigned to individual entities
- the context of the landscape under consideration being forest ecosystems in eastern NSW.

This paper deals only with issues relating to the spatial design or configuration of reserves. It does not address selection issues relating to which entities (or how much of each entity) should be included in reserves, nor issues relating to the type of protection (e.g. formal versus informal reservation) to be afforded to different parts of the reserve system. These issues are being addressed elsewhere in the CRA process. The paper attempts to discuss spatial design criteria against a background of the scientific literature and the resultant debates. Although relevant to the establishment of a CAR reserve system, the reserve design criteria outlined in JANIS for implementation in the CRA planning process, are at times overlapping. As such, all relevant JANIS criteria will be dealt with under the broad design principles of shape, size, connectivity and replication. Hence, the specific aims of this discussion paper are to:

1. Highlight JANIS criteria relating to reserve design (or spatial configuration) principles,
2. Provide a literature review based on core reserve design principles; size, shape, connectivity and replication.
3. Highlight existing spatial configuration tools or mechanisms being employed in the CRAs.
4. Provide, where needed, recommendations on how reserve design principles should be further addressed in the CRA process.

1.2. JANIS CRITERIA RELATING TO SPATIAL DESIGN AND CONFIGURATION OF RESERVES

This section identifies those elements of JANIS that specifically relate to spatial design and configuration of reserves. JANIS specifies spatial configuration criteria for entities as well as reserve design in general. There are many reserve design issues raised in these sections of JANIS that need to be addressed in the scope of this paper. No one issue stands alone—they are all intertwined, influence each other and are at times conflicting. As such, these issues will be addressed under the broad design sections mentioned above.

1.2.1. JANIS sections relating to entities

SECTION 3.2

Adequacy relates to the maintenance of ecological viability and integrity of populations, species and communities (NFPS, 1992).

SECTION 6.1 - Discussion, 6.1.1

The Convention on Biological Diversity and the National Strategy for the Conservation of Australia's Biological Diversity consider biodiversity at three levels: genetic, species and ecosystem. While there is considerable information on the spatial patterning of biodiversity at the ecosystem and species levels, the information on genetic variation is limited. Although, it is possible and desirable to use this limited genetic information in planning a reserve network, the biodiversity criteria outlined (see Section 6.1.2) relate primarily to biodiversity at the forest ecosystem and species levels.

SECTION 6.1 - Biodiversity criteria, 6.1.2, point (4)

Reserved areas should be replicated across the geographic range of the forest ecosystem to decrease the likelihood that chance events such as wildfire or disease will cause the forest ecosystem to decline.

SECTION 6.1 - Biodiversity criteria, 6.1.2, point (6)

Reserves should be large enough to sustain the viability, quality and integrity of populations.

SECTION 6.1 - Biodiversity criteria, 6.1.2, point (7)

To ensure representativeness, the reserve system should, as far as possible, sample the full range of biological variation within each forest ecosystem, by sampling the range of environmental variation typical of its geographic range and sampling its range of successional stages.

SECTION 6.2 - Old-growth forest criteria, 6.2.2, point (2)

- the representation of old-growth forest across the geographic range of the forest ecosystem;

- appropriate reserve design;

- protection of the largest and least fragmented areas of old growth.

1.2.2. JANIS section relating to general reserve design and configuration

SECTION 7 - Reserve design and management

- boundaries should be set in a landscape context with strong ecological integrity, such as catchments;

- large reserved areas are preferable to small reserved areas, though a range of reserve sizes may be appropriate to adequately sample conservation values;

- boundary-area ratios should be minimised and linear reserves should be avoided where possible except for riverine systems and corridors identified as having significant value for nature conservation;

- reserves should be developed across the major environmental gradients if feasible, but only if these gradients incorporate key conservation attributes which should be incorporated in the CAR system;

- each reserve should contribute to satisfying as many reserve criteria as possible;

- reserve design should aim to minimise the impact of threatening processes, particularly from adjoining areas;

- reserves should be linked through a variety of mechanisms, wherever practicable, across the landscape.

1.2.3. Reserve design and selection principles

Reserve design principles are those size, shape and configuration decisions which are made in order to finalise the placement of the boundaries of a conservation mechanism (in this case a reserve or reserve network). The decisions are primarily made to enhance the adequacy of the reserve or reserve network for protecting the target entity or feature. However, practitioners also apply these principles to:

- ensure appropriate protection of cultural heritage (both indigenous and non-indigenous)
- to incorporate other features such as scenic or recreational features
- the use of a cadastral feature for ease of legal definition and management of a reserve, and
- to incorporate access to allow for management of an area

There are two distinct aspects to conservation evaluation, reserve design and reserve selection. Before reserves can be designed to ensure their adequacy, those areas that are the most important to preserve must be identified and selected for conservation. Reserve selection usually involves systematic ranking and scoring procedures to effectively choose sites that contain the targeted features for incorporation into nature reserves, thus increasing the potential of the reserve system to efficiently conserve biodiversity (Pressey, 1990). Historically, much emphasis has been placed on reserve design principles (Slatyer, 1975; Noss, 1983; Soule and Simberloff, 1986; Noss, 1987; Scott *et al.*, 1989; Simberloff, 1994). These are based on ecological theories that seek to gain a better understanding of ecosystem structure, how species are distributed across the landscape in space and time, and how to apply these concepts to formulate conservation policy and to design adequate nature reserves. The many recommendations for the best size, shape, and connectivity across the region with respect to position in a patchwork of often urban, rural and natural land have been adopted by applied ecologists and reserve design planners. Mechanisms and guidelines for the application (i.e. ‘operationalising’ the JANIS criteria) are needed for the CRA process.

1.3. SPATIAL CONFIGURATION FUNCTIONALITY WITHIN C-PLAN

The C-Plan software package being used to select reserves in NSW CRAs has recently been extended to incorporate automated derivation of indices relating to two attributes of reserve configuration:

- patch size and connectivity; and
- geographical and environmental spread.

Each of these attributes can be measured in relation to any specified entity (e.g. species, forest ecosystem) or set of entities. The attributes can be considered at two different points within C-Plan. When reporting on progressive achievement of areal targets the software can now also report on progressive achievement of spatial configuration goals for reservation of specified entities. For patch size/connectivity this is reported in terms of an index reflecting the size and connectivity of reserved patches of a given entity. For geographical/environmental spread this is reported in terms of an index measuring the extent to which reserved areas of an entity are spread across the geographical and environmental range of the entity.

C-Plan can also consider spatial configuration when estimating the potential contribution that currently unreserved planning units would make to the reserve system. ‘Irreplaceability’ indices can now be automatically adjusted (weighted) to reflect not only the contribution that a planning unit would make to achieving areal targets but also the contribution to achieving spatial configuration goals in terms of patch size/connectivity and geographical/environmental spread.

All of the new functionality is designed to run in ‘real time’ during selection of reserves. In other words, the indices can be calculated fast enough (in seconds rather than minutes or hours) to facilitate iterative recalculation whenever a change is made to the configuration of the reserve system.

The new C-Plan functionality is being documented in detail in a separate CRA report. The functionality is referred to in the following sections of this paper wherever it is deemed relevant to the design criteria discussed.

2. RESERVE DESIGN PRINCIPLES

2.1. INTRODUCTION

The following section is an overview of the current scientific literature on core reserve design principles, the means by which the CRAs can address these issues, and the mechanisms and tools available for use in the process. The principles dealt with in this section are both entity specific and for general reserve design.

2.2. SIZE

2.2.1. JANIS criteria relating to size

SECTION 3.2. Adequacy

Adequacy relates to the maintenance of ecological viability and integrity of populations, species and communities (NFPS, 1992).

SECTION 6.1. Biodiversity criteria

- reserves should be large enough to sustain the viability, quality and integrity of populations.

SECTION 6.2. Old-growth forest criteria

- protection of the largest and least fragmented areas of old growth.

SECTION 7. Reserve design and management

- large reserved areas are preferable to small reserved areas, though a range of reserve sizes may be appropriate to adequately sample conservation values;

2.2.2. Size issues

To understand the effects of habitat fragmentation and loss, conservationists and reserve planners turned to theoretical ecologists and biogeographers. Conclusions drawn from MacArthur and Wilson's (1967) model of island biogeography and the species-area curve are, all else being equal, larger areas will hold more species than small fragmented areas that contain the same habitats. The application of these theories to the design of nature reserves were some of the first attempts to apply ecological theories to practical problems of ecosystem management and conservation. They were embraced widely by ecologists and land managers who welcomed the simplistic and seemingly logical model as a reserve design doctrine in times of accelerating environmental problems (Dyer and Holland, 1991). Other studies on optimal reserve size concluded that larger reserves will contain a greater variety of environmental heterogeneity (which has been positively linked with species diversity) (Burnett, *et al*., 1998), will buffer against the detrimental effects of catastrophic events (Benson, 1993), and will decrease genetic deterioration and the likelihood of demographic imbalance (for example, a population containing a large proportion of males) (Soule and Simberloff, 1986).

In discussing the ambiguity of the species/area curve in relation to reserve design principles, Simberloff and Abele (1976) stated that the notion that reserves should always consist of the largest possible area was based on a ‘limited and insufficient theory’, thereby starting the prolonged and sometimes bitter single large or several small (SLOSS) reserve debate. The belief that extinctions from fragmented areas were inevitable, because newly fragmented areas will hold more species and diversity than equilibrium allows (Diamond, 1975), is a generalisation that has influenced reserve design in the past to focus only on those areas that are considered to be large and continuous. As a result, small fragments may be overlooked when assessing areas for reserve acquisition. Some authors found that reservation of small fragments had positive effects on conservation of the biota. Simberloff and Abele (1982) found that small fragments of habitat (in combination) may actually contain more species than a contiguous area of a comparable size. Quinn and Hastings (1987), found that some degree of fragmentation extended the persistence time of threatened species, as long as the fragments were not too small. They devised simple models to estimate the number of patches of a habitat needed to ensure the viability of populations by taking the square root of the carrying capacity of the target species. They did, however, caution against using their models to form reserve design generalisations because of their lack of predictive power. Nevertheless, their models were accused of taking the SLOSS debate to ‘a more extreme dichotomy, SLOPP (Single Large or Plentifully Patchy’) (Gilpin 1988). The general conclusion of the size debate was that both size and replication are important design criteria (Soule and Simberloff, 1986).

The presence of fragments within mainly agricultural land will greatly increase the diversity of that landscape which will increase the likelihood that at least some of the indigenous biota and their genetic diversity will survive (Ritters *et al.*, 1997). This does not mean that all land in agricultural areas should be as fragmented as possible, but rather that, in some cases, this will be the only way to achieve a representative reserve system. Some fragments are considered to be of high conservation value because they are the only remnant forest types in areas with a long history of intensive land usage (Margules *et al.*, 1982).

Fragmentation of habitat may be human induced or natural (Hansson, 1992). Accepting that habitats are those areas that are delineated by ecological criteria (Knight and Morris, 1996), are structurally and floristically distinct, and may be present in a landscape as distinct patches, a continuous tract of forest, therefore, may contain naturally patchy areas of habitat. If the conservation target is continuous habitat, the preservation of large areas of forests may not necessarily achieve this. Hence, although it is generally agreed that larger reserves may be more adequate in ensuring the viability of the populations supported by that reserve, even large reserves are not ‘immune to extinctions’ (Soule and Simberloff, 1986).

When habitat has been fragmented by human alteration of the landscape, measures must be taken to assess the viability of the remaining habitat patch. Metapopulation dynamics is an ecological theory that has been used to predict the effects of habitat fragmentations (Hanski, 1989). It differs from the theory of island biogeography in that it is concerned with several populations of the one species, as opposed to numbers of several species(Hanski 1989). Patch dynamics are usually based on metapopulation theory and the species-area curve (MacArthur and Wilson, 1967), and are used to assess the adequacy of a patch in maintaining a viable population. Soule and Simberloff (1986), believe that population viability analyses will enable planners to assess the optimal size of a reserve, and should therefore be an intrinsic aspect of reserve design. Some fragments (patches of habitat or ecosystem) will simply be too small or isolated to contain viable populations of the target organism. This is important to assess prior to negotiation.

Politics aside, scientific research has formed the basis of conservation decisions in order to come up with a practical approach in establishing the optimal reserve system. However, conclusions are often drawn from poorly designed experiments in inappropriate contexts (Murphy, 1989). Most of the research done has been to compare species lists from reserves of vastly different sizes (McNeill and Fairweather, 1993). Comparisons of this type can provide only weak inferences because they are confounded by factors such as habitat diversity, the shape of the reserves and often incomparable sampling methods.

Many theories have been generalised to cope with the issues of scale, thereby creating weak and untestable models (With, 1997a). Most studies focus on one type of entity for conservation, be it species, vegetation types or landscapes (Pressey, Possingham, *et al.*, 1997). This becomes problematic when the results from that study are generalised to encompass other entities at different scales (With, 1997a, Lombard, 1993) because the scale at which habitat is evaluated affects the apparent landscape variability and configuration of habitats as perceived by different organisms (Knight and Morris, 1996, Ritters *et al.*, 1997). For example, many theories are formed from studies based on species as the ecological unit and are then applied to broader scales (eg populations, communities or ecosystems) in order to understand ecological processes. Such theories, however, may be inadequate in the assessment of whether a patch, fragment or reserve will retain its biota. In other words, we cannot ignore the ecological needs of a species in creating reserves to conserve it (Lambeck 1997). Without knowledge of such issues as dispersal and foraging behaviour, predation pressures and intra- and interspecific competition for resources, the adequacy of reserves can not be properly addressed.

2.2.3. Size in the CRA process

The patch size/connectivity indices incorporated into C-Plan provide an efficient, automated mechanism for addressing issues of reserve size in the CRA process, particularly in relation to space demanding fauna species for which patch size/connectivity goals have been assigned. The reserve size requirements of space demanding species (for example owls and Greater Gliders) can serve as a surrogate for species in general. The patch size/connectivity index employed by C-Plan for these species will guide selection toward the largest and least fragmented ares of core habitat, where possible. The optimal reserve size for priority species is determined by the response to Disturbance and Conservation Requirements Projects prior to negotiation.

JANIS acknowledges that larger areas are, in general, preferable to smaller ones. It is therefore recommended that, where possible, large areas are chosen over smaller areas. However, there is also the issue of fragmentation, that is, some ecosystems may be so fragmented as to only allow the JANIS targets to be met by the reservation of small, isolated areas. The assessment of fragments for inclusion into the reserve system could be a highly complex and convoluted process and may best be done as a follow-up to the main CRA negotiations (particularly where fragments occur on private land). If the fragment represented an endangered and vulnerable ecosystem, it would then become a priority (JANIS 6.1.2 (1)). Generalisations have emerged from studies of fragmentation; the smaller the fragment the more pronounced the edge and the greater the edge effects. A greater degree of management is therefore needed counter the effects of edge-related degradation.

2.3. SHAPE AND CONTEXT

2.3.1. JANIS criteria relating to shape

SECTION 7. Reserve design and management

- boundaries should be set in a landscape context with strong ecological integrity, such as catchments;

- boundary-area ratios should be minimised and linear reserves should be avoided where possible except for riverine systems and corridors identified as having significant value for nature conservation

- reserve design should aim to minimise the impact of threatening processes, particularly from adjoining areas;

2.3.2 Reserve shape and edge effects

An important design principle to ensure reserve adequacy is shape. Fragmentation will affect the boundary area ratio, which will, in turn, affect species diversity and dispersal ability, and edge effects (Lord and Norton, 1990). Fragmented areas, however, may contain more high quality habitat than that contained in a non-fragmented landscape, or may simply be the last example of an extant habitat or ecosystem, and therefore may be valuable additions to a reserve system. This has influenced studies dedicated to testing which shape will best alleviate the problems of fragmentation. Diamond (1975) believed that elongated reserves would not only inhibit conspecific interaction, but negatively affect dispersal rates and thereby decrease the chance of species' survival, and that reserves should be as circular as possible to minimise edge related degradation. Kunin (1997), however, concluded that the effect of reserve shape is scale and size dependant, and for large reserves in general, an elongated shape was more likely to sample greater habitat heterogeneity and therefore harbour more species than square or round reserves.

Blouin and Connor (1985) looked at the correlation between the shape of islands and species diversity and concluded that shape alone is not an important criterion in the design of nature reserves, but, nevertheless, design should aim to lessen the impact of edge related degradation. Understanding the degradation caused by the effects from reserve edges is particularly important when assessing the long-term viability of the reserve. Edges were once thought to be beneficial to wildlife as species diversity increases near habitat edges (Yahner, 1998). There now seems to be a consensus that edge effects are deleterious and need to be addressed in reserve design principles (Turner and Corlett, 1996). Important aspects of edges are length and width (Yahner, 1998), and knowledge of the surrounding matrix and the effects it will have on the biota. Generalisations of edge effects and ways to buffer against these include:

- that introduced species will inhabit edges and although may increase the overall biodiversity will have negative effects on ecological function (Smallwood, 1993);
- the lower the solar radiation the weaker the edge effects, i.e. in Australia, south facing edges would not suffer as many effects as north facing edge; (Murcia, 1995)
- roads as edges are a barrier to some species, and an entry point into ecosystems for exotic species (Margules and Stein, 1989);
- more complex ecosystems (eg. rainforest) are less likely to be affected by fragmentation than less complex ecosystems (e.g. temperate forests) (Lord and Norton, 1990)
- most studies have found edge effects to disappear 50 m into the forest (Murcia, 1995).

Recognition of edge threatening processes alone, however, is not enough to curtail their effects. A thorough understanding of the impacts these threats will have on ecological processes and biodiversity is essential in order to design an adequate reserve system. Agriculture, mining, grazing and urban development will all affect the system in different ways. Smallwood (1993) found that agriculture as the surrounding matrix had the worst effect on the numbers of exotics entering a system, and on the general health of a system. Similarly, Bayne and Hobson (1997) found that fragments surrounded by agriculture have more deleterious effects on nesting birds. This contrasts sharply with Janzen (1983) who suggested that it might make more ecological sense to surround small fragments of relatively pure habitat with a low-invasive monoculture, such as wheat or sugar cane, or grazed pastures than to have similar habitats of different successional stages that will significantly affect the ecological balance of the remnant.

These conflicting studies highlight the need for a clear working definition of what an edge actually is, rather than relying on the intuitive notion of an edge - where one ecosystem stops and another one starts (Murcia, 1995). Studies have been done on many different species, at many different scales in a large array of forest types of different sizes with different edge characteristics and surrounded by a variety of matrices. Whilst there is a general agreement on what edge effects actually are, research results are often over simplistic and cannot be generalised into 'edge principles' that can be applied with confidence on a broad scale by land managers (Murcia, 1995).

Murcia (1995) proposes that one way to get around the scale issue in formulating generalisations for managers, is the use of abiotic edge effects, since abiotic factors are scale independent. Abiotic factors are the changes in the environmental conditions that result from proximity to a structurally dissimilar matrix. Factors to take into consideration are age of the edge, physiognomy, orientation, matrix type and management history of matrix habitat fragmentation.

2.3.3. Shape and context in the CRA process

There are several aspects of shape that need to be dealt with in the CRA process. In summary, the JANIS criteria are; reserve boundaries should have strong ecological integrity, boundary-area ratios should be minimised, and reserve design should aim to minimise the impact of threatening processes, particularly from adjoining areas. One of the ways to satisfy most of the above criteria would be to ensure congruency of the management boundaries with biotic boundaries. Biotic boundaries are the hypothetical boundaries necessary to maintain existing ecological processes and a given assemblage of species within a region (Newmark, 1985).

In the context of the CRAs, alignment with already protected areas, or reserves that incorporate natural catchments to promote ecological integrity would be the most practical way of satisfying these criteria. This may be best achieved by displaying a shaded DEM or Landsat image as a background to planning units in C-Plan during negotiations.

The patch-size/connectivity index in C-Plan will to some extent guide selection of areas so as to minimise boundary-area ratio. In addition, it would be desirable, at critical points during negotiations, to calculate the boundary-area ratio of the current reserve system using standard GIS functionality. While this calculation would be time consuming, it would provide an overall measure at the landscape scale and would allow for comparisons of reserve configuration options.

In order to make decisions on boundary shape, it is also important to assess the threats to the reserve. Knowledge of how the surrounding land use may affect the reserve will be necessary prior to the negotiation process. For those target species that will utilise successional forest growth, it may be beneficial for reserves to be surrounded by State Forests, as opposed to areas with more intensive land use such as agriculture (Welsh and Healy, 1993: Thompson *et al*, 1992). If there is no choice, and the nominated area lies adjacent to areas with intensive land use, a thorough knowledge of the industry and the nature of the surrounding matrix will be necessary in order to understand the long-term threats to the reserve (for example, from fire, disease, weed and pest invasion, etc.) and to decide the appropriate steps for management.

2.4. CONNECTIVITY AND CORRIDORS

2.4.1. JANIS criteria relating to connectivity

SECTION 7. Reserve design and management

- boundary-area ratios should be minimised and linear reserves should be avoided where possible except for riverine systems and corridors identified as having significant value for nature conservation;

- reserves should be linked through a variety of mechanisms, wherever practicable, across the landscape.

2.4.2 Connectivity issues

A connected landscape or a series of stepping stone reserves are seen as a solution to the deleterious effects of habitat fragmentation and the resultant edge effects, isolation of populations under threat from inbreeding (failure of metapopulation dynamics), and local extinction from small reserves (Beier and Loe, 1992). Connectivity may be facilitated via corridors, chosen during the reserve selection process or developed post-reservation. Pre-reservation corridor selection only will be dealt with in the scope of this paper.

Three main types of corridors exist, dispersal corridors (continuous tract of habitat), landscape linkages (a series of stepping stone reserves) (Schultz, 1998), and linear habitats (for example, fence rows in agricultural landscapes and stream-side buffers) (Beier and Loe, 1992). Small remnants may prove useful as habitat linkages, but their effectiveness will depend on the dispersal of the organisms and the nature of both the land in and between the reserves (Lubow 1996). Stepping stones may range in size from small isolated reserves (Schultz, 1998) to remnant trees in a clearcut forest (Desrochers and Hannon, 1997). The configuration of these stepping-stone reserves is entirely species specific. Butterflies, for example, may need either a series of stepping-stone reserves (Fahrig and Paloheimo, 1988), or extended streamline habitat (Schultz, 1998). Therefore important information needed to assess corridor configuration is whether the target organism disperses in a random or non-random fashion (Fahrig and Paloheimo, 1988), is a specialist or generalist (Henein *et al.*, 1998), or if the organism relies on connectivity of transient or successional habitats (Tiebout III and Anderson 1997). Transient habitats can be caused by natural disturbance, i.e. fire, flooding, herbivory, or may be human induced, i.e. logging and livestock grazing.

For continuous tracts of habitat, or dispersal corridors, the length, width and structure depends, again, on the dispersal behaviour and demographics of the organism in question. It is generally agreed that the most important of these criteria is structure (Beier and Loe, 1992, Andreassen *et al.*, 1996). Because the land in question will never be discrete, the biophysical characteristics of the adjoining areas must be taken into consideration (Turner *et al*., 1995). Desrochers and Hannon (1997) found that the majority of birds that they studied were twice as likely to travel through forested areas than cleared patches, even if the forested areas were three times as long. Tutin *et al.* (1997) found that large mammals (>2kg) were willing to travel several hundred metres across open grassland to visit forest fragments. Therefore, knowledge of how species will interact with landscapes of different structural attributes will determine if dispersal and migration will be possible through the surrounding matrix. For some species, corridors may not be necessary if the surrounding matrix is amenable to vagility, in which case, small, isolated fragments may indeed be a valuable addition to the reserve system (Turner, 1996). For others, this small totally isolated fragment would not be viable. It is also important to consider the characteristics of the areas to be linked (Beier and Loe, 1992, Lindenmayer, 1998). A corridor between two small, debilitated fragments will not necessarily increase the viability of those fragments.

One possible way to overcome potential problems from edges and isolation is to include riverine landscapes in reserve systems. Riverine landscapes are described as those that encompass rivers, streams, floodplains, wetlands, groundwater and the biota that inhabit these ecosystems (Ward 1998). Bentley and Catterall (1997) found that riparian habitats contained higher species richness and abundances of birds than did dryland areas. They proposed that birds that utilised riparian habitats also used riparian corridors. The preservation of riparian systems will, however, only protect those organisms that utilise these ecosystems. Nevertheless, the preservation of these landscapes would not only preserve the biodiversity of these systems (Zwick, 1992), but help provide a continuous reserve system.

Connectivity of habitat and ecosystems may be one way to ease the deleterious effects of fragmentation (Beier and Loe, 1992), but it has been argued that implementation of the best possible continuous reserve scenario based on sound scientific evaluation may be deleterious to the long-term survival of biodiversity. The spread of fire, disease and pest species through a connected reserve system are potential threats and may need to be taken into consideration when planning (Simberloff and Cox, 1987). There is, however no documented cases of ecological catastrophes caused by the presence of corridors (Beier and Loe, 1992).

2.4.3. Connectivity in the CRA process

Measurements of the connectivity of a landscape may be automated into C-Plan. There is a need to build an underlying data structure that can store the geographical distance between sites. In the context of forest ecosystems, this measure must also have some measure of similarity of habitat, in order for C-Plan to identify where the compartments sit in both geographical and biological space. The effective identification of compartments that lie close to existing reserves may conflict with the need for the geographic range of the features, which may only survive in small remnant patches that are highly fragmented and surrounded by an inhospitable matrix.

When the target entity is species, a sound knowledge of the matrix is needed to determine if that matrix is conducive to dispersal and migration. If so, then a corridor may not be necessary. It must be noted, however, that connectivity decisions made for one species may not lend themselves well to biodiversity in general. Therefore, decisions on corridors will be for those species that are at most risk from fragmentation. This does not mean that connectivity will only be looked at for target species—reserves need to, where possible, be connected.

The patch size/connectivity index in C-Plan will help in planning connectivity for species most at risk from fragmentation.

2.5. REPLICATION

2.5.1. JANIS criteria relating to replication

SECTION 2. The forest conservation framework

To maintain the genetic diversity of native forest species

SECTION 6.1. Biodiversity criteria

Reserved areas should be replicated across the geographic range of the forest ecosystem to decrease the likelihood that chance events such as wildfire or disease will cause the forest ecosystem to decline.

To ensure representativeness, the reserve system should, as far as possible, sample the full range of biological variation within each forest ecosystem, by sampling the range of environmental variation typical of its geographic range and sampling its range of successional stages.

SECTION 6.2. Old-growth forest criteria

-the representation of old growth forest across the geographic range of the forest ecosystem;

SECTION 7. Reserve design and Management

--reserves should be developed across the major environmental gradients if feasible, but only if these gradients incorporate key conservation attributes which should be incorporated in the CAR system;

2.5.2. Replication issues

Replication of a feature/entity across its geographic and environmental range is perhaps the most important reserve design criteria. The many threats posed to biodiversity from the fragmentation and loss of habitat, and the conflicts of the reserve design criteria can be alleviated, to some degree, by replication of that feature or entity. This can apply to all scales of conservation, but is particularly important in the conservation of threatened species (Noss *et al.*, 1997). Species that are widely protected across their range are less likely to suffer extinction brought on by the effects from habitat loss and fragmentation. Replicated habitat types would also guard against possible future problems, for example, extinctions due to species turnover (Margules *et al.*, 1988) and stochastic events (Benson, 1993), and is a particularly important measure to combat the proposed problems from climate change (Peters and Darling).

Section 6.1.7. of JANIS specifically states the importance of sampling across the geographic and environmental gradients within forest ecosystems to pick up internal biological variation. This will allow for the reservation of genetic variation and successional stages of the target entities. Genetic variation, although not explicitly contained within JANIS as a reserve design or selection criterion, is essential for the viability of a population. Genetic variation will not only occur in distinct regions, but may occur in separate sites within the same region (Soule and Simberloff, 1986). The usefulness of these sites to an adequate reserve system will depend on their size, how far apart they are and whether the species contained within the distinct sites can disperse over the matrix separating the two sites and intermix. If genetic diversity and geographic replication is to be maintained, multiple representations of species, habitats, or ecosystems, and highly altered and fragmented land may need to be added to the reserve system. These areas would require a fairly intensive management programme to ensue the viability and adequacy of that reserve.

2.5.3. Climate change

Traditional reserve design criteria in the past have not considered the effects of climate change (Peters and Darling, 1985). In the event of global warming, many species will be lost because they will have no reserves set aside for them that will cater for their ability to cope with the changes (for example, altitudinal migration). Even those that do have secure home ranges may suffer as a result of climate change. Climate change can influence predation rate, parasitism, competitive interactions and reproduction, and will, in some way, affect all species (Peters and Darling, 1985).

The design and selection of a reserve system should attempt to combat some of the potential effects from climate change, but again the scale at which the research should be addressed is contentious (Halpin, 1997). From a species perspective, organisms most likely to suffer are those that have peripheral populations, are geographically localised and genetically impoverished, and are specialists and poor dispersers. Also affected will be annuals, and montane, alpine, Arctic and coastal communities (Halpin, 1997). Alternatively, the habitat or ecosystem approach may be taken, in which case it is believed that reserves with large altitudinal heterogeneity will allow for the altitudinal shift many species may exhibit due to climate change. Those reserves that do not have geographical and altitudinal heterogeneity may force its inhabitants outside the reserve boundaries. Other recommendations for reserve design and selection to combat global climate change include replication of habitat and ecosystem type in the form of stepping stone nature reserves with connective corridor systems, protected buffer zones, and management planning at the regional ecosystem level (Halpin, 1997, Shafer, 1990).

Increased fire frequency and intensity is one proposed outcome from climate change. To combat this, there are two different approaches to reserve design. There are those that argue against the single large reserve and favour replication across the geographical range as a buffer against stochastic events that may wipe out an entire reserve and all that it contains. Alternatively, some believe large reserves with heterogeneous soil types, moisture gradients and topography would be an advantage in order for species to cope with the outcomes of climate change (Peters and Darling, 1985)

Halpin (1997) believes that the push for continuous reserves with greater environmental and climatic gradients, buffer zones and proper management plans now being proposed in response to global climate change, are without proper analysis of the benefits and costs of such a system. His alternative is to manage for and maintain healthy habitats and ecosystems to combat the effects of climate change, by limiting the stress placed on the reserve from the outside. Generally, recommendations from the literature are for multiple representations of relatively large reserves throughout the range of the target entity or feature to buffer against the effects of climate change and stochastic events (Noss *et al.*, 1997).

2.5.4. Replication in the CRA process

Replication of forest types and species across their natural range is necessary in order to sample for environmental, geographical and genetic variation. It is also important as insurance against the negative effects from future fragmentation of habitat that may result from either human or natural causes. This conflicts strongly with the JANIS criteria relating to reserve size, connectivity and reserve selection efficiency, but the most important aspect of reserve design is ensuring that the chosen configuration will be adequate in maintaining the biota that it is meant to conserve. In addition, replication of biological variation is a JANIS criterion in its own right.

The environmental/geographic spread index within C-Plan can be used to guide selection of reserves to ensure sampling of forest ecosystems across their geographic range. It is also considered desirable that this index be used to guide selection of reserves for species to ensure the reservation of genetic variation throughout their range.

JANIS sections 6.1 and 7 both deal with the notion that reserves should adequately buffer against threatening processes, of which climate change is one. Different authors present multiple options to deal with the threats from climate change in the future. Amelioration of the reserve system to counter the effects from climate change will depend entirely on the context and scale of the problem. Section 3.2 explicitly states that replication of geographical, environmental and biotic domains will increase the adequacy of the reserves which will in turn, buffer against stochastic events (eg fire). Also, having relatively large reserves with greater environmental heterogeneity will greatly diminish the possibility of entire forest types succumbing to the threats of fire, disease or natural disasters.

3. CONCLUSIONS/ RECOMMENDATIONS

This document was written in the context of the CRA process in the eastern forests. It is therefore acknowledged that for other ecosystems, such as arid or semi-arid landscapes, this framework may require adaptation. It is also acknowledged that there is limited opportunity to influence management of areas outside of public land as part of the immediate negotiations.

Notwithstanding the above, this document has referred to the broader application of reserve design principles by practitioners outside of the CRA as a means of better illustrating the application of these concepts.

Size, shape and connectivity reserve design criteria outlined in JANIS, and Section 7 in particular, are conflicting, both within and between criteria, and are highly context specific. This has implications for the successful implementation of a hierarchical operational approach to reserve design. As such, the following recommendations for addressing reserve design in the CRA process are context specific, and will focus mainly on design requirements for species and forest ecosystems.

3.1. RECOMMENDED APPROACH TO ADDRESSING JANIS RESERVE DESIGN CRITERIA IN CRAS

This section summarises recommendations made in Section 2. These recommendations are presented in relation to each of the reserve design criteria listed in Section 7 of JANIS, with reference to other JANIS design criteria where necessary.

1. Boundaries should be set in a landscape context with strong ecological integrity, such as catchments;

During reserve negotiations satellite imagery and shaded DEMs should be loaded and displayed, where necessary, as a backdrop behind the planning unit layer within C-Plan. This will facilitate alignment, where possible, of reserve boundaries with catchments and other natural features.

2. Large reserved areas are preferable to small reserved areas, though a range of reserve sizes may be appropriate to adequately sample conservation values;

A range of reserve sizes will be required to achieve a balance between maximising the number of entities reserved (to target) and maximising long term viability of reserved ecosystems and species (particularly space demanding fauna). The size of individual reserves should be determined largely by the requirements of the specific conservation entities intended to be protected. The areal target will need to allow for changes due to natural disasters, climate change and ecological processes. The patch size/connectivity functionality within C-Plan provides an effective means of guiding decisions on reserve size, particularly in relation to the needs of space demanding fauna species for which configuration goals have been set (in accordance with JANIS Biodiversity Criterion 6).

3. Boundary-area ratios should be minimised and linear reserves should be avoided where possible except for riverine systems and corridors identified as having significant value for nature conservation;

The patch size/connectivity functionality within C-Plan can provide some guidance in ensuring minimisation of boundary-area ratios and appropriate location of corridors. This functionality, however, should be augmented by the application of standard GIS functions to calculate and monitor the boundary-area ratio of the reserve system at key points during negotiations.

4. Reserves should be developed across the major environmental gradients if feasible, but only if these gradients incorporate key conservation attributes which should be incorporated in the CAR system;

The geographical/environmental spread functionality within C-Plan should be employed to guide selection of reserves across the geographical and environmental range of forest ecosystems for which configuration goals have been set (in accordance with JANIS Biodiversity Criteria 4 and 7). It is also recommended that this functionality be employed, where required, in relation to species to ensure that reservation is spread appropriately across the geographical range of species likely to exhibit substantial genetic variation.

5. Each reserve should contribute to satisfying as many reserve criteria as possible;

This criterion is already addressed effectively through the use of irreplaceability and summed irreplaceability indices within C-Plan.

6. Reserve design should aim to minimise the impact of threatening processes, particularly from adjoining areas;

During reserve negotiations satellite imagery and land tenure should be loaded and displayed, where necessary, as a backdrop behind the planning unit layer within C-Plan. This will assist in locating reserves, where possible, away from major developments and areas of intensive land use.

7. Reserves should be linked through a variety of mechanisms, wherever practicable, across the landscape;

The patch size/connectivity functionality within C-Plan should be employed to guide selection of corridors to best serve the needs of specific entities for which connectivity goals have been set (particularly space demanding fauna and those most sensitive to fragmentation of habitat).

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