
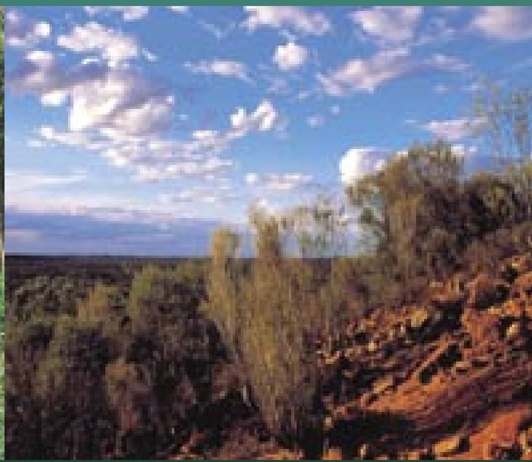


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Risk Assessment and the concept of Ecosystem Condition in Park Management

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Parks Victoria Technical Paper Series No. 13

Risk Assessment and the Concept of Ecosystem Condition in Park Management

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June 2004

Executive Summary

Parks Victoria is responsible for the management of parks and reserves that are the core areas for biodiversity conservation across the state of Victoria. Identification and monitoring of valued attributes within parks and potential threats to those attributes are essential parts of the management process. Where resources are limited, prioritisation of the attributes and threats will allow those resources to be utilised where they can be most effective in achieving policy goals.

The Ecosystem Condition Assessment project aims to develop and test methods for a more effective identification and prioritisation of factors affecting ecosystem condition in Victorian parks and reserves. It aims to refine the approach to ecological risk assessment applied in the Environmental Action Plans of Parks Victoria, and link the monitoring protocols currently under development with risk assessment in a way that explicitly embraces multiple valued attributes and threatening processes. The methods have the potential to enhance the ability of Parks Victoria to report on attributes of parks that are relevant to management goals.

An approach to risk assessment broadly following that outlined in the Australian Standard for Risk Management and incorporating concepts and methods drawn from disciplines including psychology and engineering was trialled at two workshops held in regional Victoria. Key concepts included:

- undertaking group assessments to incorporate a diversity of thoughts on an ecological issue, and avoid the personal biases of any one individual,
- defining hazards clearly and in relation to specific consequences to reduce disagreement that may arise from differing interpretations of the same hazard, and
- explicitly incorporating the degree of uncertainty about the risk associated with particular hazards in any priority listing, to indicate that a range of opinion exists and also that there may be a need for additional information.

Visual tools such as influence diagrams and fault trees are valuable to:

- clarify thinking for those involved in their creation,
- explain the logic behind management decisions to interested parties,
- provide a record of the logic behind management decisions, which may be useful at times of review, or when new staff are engaged, and
- demonstrate to external stakeholders, the level of understanding and expertise of the staff responsible for the risk assessment.

The ecological risk assessment framework outlined in this report could be used to provide a formal basis for the selection of monitoring variables. By simultaneously considering multiple values and threats across a park in a risk interaction matrix, the assessment could be considered to be moving towards an ecosystem-based approach. Basing a monitoring strategy on such matrices would be inherently adaptive in nature because the selection of monitoring variables would be tailored to suit the circumstances in a given park, rather than relying on a generic prescription. Furthermore, a change in the risk status of an attribute may result in a corresponding change in the level of monitoring effort flagged for that attribute. This feature, combined with the focussing of monitoring effort on the attributes at greatest risk or on the threats that pose the greatest risk, makes the approach an efficient and cost-effective way to design a suite of monitoring programs.

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1 Introduction

Parks Victoria is responsible for the management of parks and reserves across the state of Victoria. These parks and reserves are the core areas for biodiversity conservation across the state (Parks Victoria 2000a). Identification and monitoring of valued attributes within parks or potential threats to those attributes are essential parts of the management process. Where resources are limited, prioritisation of the attributes and threats will allow those resources to be utilised where they can be most effective in achieving policy goals.

In the last decade or two, there has been a general trend towards broad-based ecosystem management rather than the isolated management of single species or other valued attributes (Grumbine 1994). However, because our knowledge of communities and ecosystems is incomplete, it is desirable to apply risk-based methods in management so that the uncertainties that stem from incomplete knowledge will be incorporated.

The Ecosystem Condition Assessment project aims to develop and test methods for a more effective identification and prioritisation of factors affecting ecosystem condition in Victorian parks and reserves. It aims to refine the approach to risk assessment applied in the Environmental Action Plans of Parks Victoria, and link the monitoring protocols currently under development with risk assessment in a way that explicitly embraces multiple valued attributes and threatening processes. The development of methods will be guided by the management objectives of individual parks. The project should result in methods that enhance the ability of Parks Victoria to report on park attributes that are relevant to management goals.

1.1 OBJECTIVES

The following objectives were developed over the period of the project, following several meetings between Parks Victoria and the University of Melbourne, and were adapted as the needs of Parks Victoria evolved:

- Providing an understanding of the various components of ecosystem condition, including a review of the current state of knowledge, and in particular,
- reviewing the literature on concepts of ecosystem services and critically evaluate their utility in supporting sustainable natural resource management,
- reviewing the literature on relationships between ecosystem services and risk-based natural resource management, and

- identifying the approach to ecosystem condition taken by some key agencies, including the New Zealand Department of Conservation and NSW National Parks and Wildlife Service.
- Developing an approach to ecological risk assessment that is effective and transparent, and links broad-based management goals for park ecosystems with the finer level of detail required for specific monitoring protocols.
- Trialing the approach at selected sites to assess utility.
- Evaluating the approach and options for implementation.

2 Ecosystem Services and Ecosystem Condition

2.1 ECOSYSTEM SERVICES

The concept of ecosystems providing benefits to humanity has a long history, dating back at least to Plato (Daily 1997) and appearing intermittently in the scientific literature (*e.g.,* Marsh 1864; Leopold 1949). A list of ìenvironmental servicesî possibly under threat was published in 1970 (SCEP 1970), and is believed to represent the first compilation of ecosystem services (Mooney & Ehrlich 1997). The term ìecosystem servicesî was coined by Ehrlich and Ehrlich in 1981 to refer to the ìarray of absolutely essential, free public servicesî through which ìnatural ecosystems support human lifeî. This is echoed in the definition of Daily (1997): ìthe conditions and processes through which natural ecosystems, and the species which make them up, sustain and fulfill human lifeî. Other authors have explicitly widened the definition to cover more than basic life-support services, for example ìany functional attribute of natural systems that is easily perceived K as beneficial to human societyî (Cairns & Pratt 1995).

Examples of ecosystem services include processes such as purification of the atmosphere or pollination of crops, the provision of goods such as timber or fish, or of less tangible benefits such as aesthetic enjoyment or religious inspiration. Some authors distinguish between goods and services (*e.g.,* Norberg 1999), while others will further distinguish between goods and services and processes (*e.g.,* Christensen *et al*. 1996). Some of these distinctions appear to be somewhat pedantic, given that a service could be defined as the provision of goods. A list of services in the widest sense of the term is presented in Table 1, but has been categorised as processes, goods and intangibles.

Norberg (1999) categorised ecosystem services in a different way, using ecological criteria. The first category is those services that are associated with a particular taxon and could be considered to be internal to an ecosystem, for example, the production of goods such as fish or timber, or the pollination of crops by insects. The second category is for those services that regulate exogenous physical or chemical inputs, such as the regulation of river flows during storm periods by vegetation. His third category is for services related to the organisation of biotic entities. Examples include the supply of flowers with attractive patterns for markets, or the spatial distribution of species within an ecosystem that may be considered fundamental to its ability to function. An alternative classification is that of Daily (2000) which uses the following categories: production of goods, regeneration processes, stabilizing processes, life-fulfilling functions and preservation of options. Her last category covers ìthe maintenance of the ecological components and systems needed for future supply of these goods and others awaiting discoveryî.

Table 1. Ecosystem services.

There may be some overlap in descriptions of services, depending on the phrasing used by the authors.

Type of Service	Item	Source	Relevance to Parks Victoria
Processes	Purification of air	Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Daily 1997	Minor contribution to large-scale process
	Maintenance of the atmosphere	SCEP 1970 Christensen *et al*. 1996 Costanza *et al*. 1997 ANZECC & BDAC 2001	Minor contribution to global process
	Protection from ultraviolet radiation	Daily 1997	Minor contribution to large-scale process
	Regulation or stabilisation of climate	SCEP 1970 Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Costanza *et al*. 1997 Daily 1997 (partial)	Minor contribution to large-scale process
	Moderation of temperature extremes and the force of wind and waves	Daily 1997	Possible local contributions
	Purification of water	Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Daily 1997 ANZECC & BDAC 2001	Possible local contributions to process Parks located in catchments may make an important contribution
	Mitigation of floods and droughts	SCEP 1970 (floods) Costanza *et al*. 1997 Daily 1997 ANZECC & BDAC 2001 (floods)	Possible local contributions to process
	Maintenance of hydrological cycles	Christensen *et al*. 1996 Costanza *et al*. 1997	Minor contribution to large-scale process
	Supply of energy by green plants	SCEP 1970	Minor contribution to large-scale process

Table 1 (continued).

Type of Service	Item	Source	Relevance to Parks Victoria
Processes (cont.)	Detoxification and decom-position of wastes	SCEP 1970 Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Costanza *et al*. 1997 Daily 1997 ANZECC & BDAC 2001	Local contributions to process
	Nutrient cycling	SCEP 1970 Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Costanza *et al*. 1997	Local contributions to process
	Generation and renewal of soil and soil fertility	SCEP 1970 (soil for-mation) Ehrlich & Ehrlich 1981 Christensen *et al*. 1996 Costanza *et al*. 1997 Daily 1997 ANZECC & BDAC 2001	Local contribution to process
	Dispersal of seeds and translocation of nutrients	Daily 1997	Local contribution
	Control of the vast majority of agricultural pests	SCEP 1970 Ehrlich & Ehrlich 1981 Daily 1997 ANZECC & BDAC 2001	Local but minor con-tribution
	Trophic regulation of pop-ulations	Costanza *et al*. 1997	Local contribution
	Provision of habitat	Costanza *et al*. 1997 ANZECC & BDAC 2001	Major focus of PV activity
	Maintenance of biodiversity from which humanity has derived key elements of its agricultural, medicinal and industrial enterprise	Daily 1997 ANZECC & BDAC 2001	Major focus of PV activity
	Maintenance of a genetic library	Ehrlich & Ehrlich 1981 Costanza *et al*. 1997	General contribution

Table 1 (continued).

Type of Service	Item	Source	Relevance to Parks Victoria
Goods	Provision of food items: fish, game, crops, nuts, fruits	SCEP 1970 (fisheries) Ehrlich & Ehrlich 1981 Costanza *et al.* 1997 ANZECC & BDAC 2001	Minor contributions
	Provision of raw materials: timber, fuels, fodder Biomedical products	Costanza *et al.* 1997 ANZECC & BDAC 2001	Minor contributions
Intangibles	Provision of aesthetic beauty and intellectual stimulation	Christensen *et al*. 1996 Daily 1997	Major focus of PV activity
	Support of diverse human cultures	Daily 1997 ANZECC & BDAC 2001	Possible local contri-butions
	Availability of recreational activities and eco-tourism	Costanza *et al.* 1997 ANZECC & BDAC 2001	Major focus of PV activity

Several of the services listed in Table 1 are particularly relevant to Parks Victoria in its role as a manager of parks and reserves. The maintenance of biodiversity (see Section 2.4) may be considered as a core business of Parks Victoria (S. Troy, PV, pers. comm.), while the provision of aesthetically pleasing areas for recreation and tourism is also a major focus of park operations. The provision of more specific services may be important in some individual parks, for example, the supply of fresh water to surrounding regions from the Grampians National Park (Parks Victoria 2000b). Parks also contribute in a general way to global environmental services such as the purification of air and the stabilisation of climate.

An Ecosystem Services Framework was devised by Daily (1999, 2000) as an aid to systematically characterizing and managing ecosystem services. The four elements of her framework are identification, characterisation, establishing safeguards and monitoring. Identification should involve the systematic cataloguing of both the sources of the services and the consumers of those services, while characterisation should determine the ecological, economic and other attributes of those services. This knowledge would enable identification of a desirable mix of services and creation of the institutional settings for safeguarding those services. Monitoring of ecosystem services would be needed to identify changes in the supply or quality of those services and thus evaluate the success of the safeguards. It is notable that Daily consistently uses the term ìsafeguardsî, but the context is frequently

suggestive of ìmanagementî, for example, with regard to timber production or securing the desired range of options. Presumably ìsafeguardsî could encompass both management and regulation, while ìmanagementî has been known to refer to cases of short-term exploitation with little or no control for long-term sustainable benefits (Christensen *et al.* 1996).

Daily (2000) and Balvanera *et al.* (2001) observed that catalogues and maps of ecosystem services would be valuable tools in planning and management, but noted that there was little or no such systematic recording of services. A framework for applying the concept of ecosystem services to natural resources management was outlined by Cork *et al*. (2001), and is currently being applied to seven case studies in Australia (Cork *et al.* 2001). One case study is the Goulburn Broken Catchment in south-eastern Australia, and the first stage, an inventory of ecosystem services (Binning *et al.* 2001), was recently completed.

While not all ecosystem services are directly relevant to Parks Victoria, the concept is tied to several others that do have considerable relevance to the management of parks and reserves.

2.2 ECOSYSTEM CONDITION

Ecosystem condition is a somewhat loosely-applied term, with few formal definitions. In relation to water quality, it has been defined as the ìcurrent or desired status of health of an ecosystem, as affected by human disturbanceî, with three states or categories recognised: high conservation/ecological value systems, slightly to moderately disturbed systems, and highly disturbed systems (ANZECC & ARMCANZ 2000). In relation to vegetation, it has been acknowledged that ìcondition is a very hard quality to measure and monitor, and more work is needed on how it would best be doneî (ANZECC 2000).

The term condition may be used with reference to a benchmark such as ìpristineî or, in Australia, ìpre-European settlementî, either of which may be difficult to determine in its own right. Measurement of vegetation condition against benchmarks is the approach used in a rapid assessment technique developed for Parks Victoria (Leversha *et al*. 2001) and in the Habitat Hectares approach (Parkes *et al*. 2003; McCarthy *et al*. 2004; Parkes *et al*. 2004).

Condition may also be considered as one component of the Pressure-State-Response scheme for environmental indicators (OECD 1993, cited in Saunders *et al.* 1998) where it equates to state (DEST 1994).

With regard to ecology and ecosystems, the term condition has been used when describing both health (*e.g.*, Cairns & Pratt 1995; Fairweather 1999) and integrity (*e.g.*, Karr 1996). The concept of ecosystem health (Schaeffer *et al.* 1988; Rapport 1989) can be traced back to the late 1700s (Rapport *et al.* 1999), and encompasses the extent to which the ecosystem has

been degraded, its level of organisation and its resilience to stress (Rapport *et al.* 1998). Ecosystem/ecological integrity (Karr & Dudley 1981) combines both biotic components and ecological processes to consider the capacity of a system to support and maintain the full range of genes, species and assemblages expected in a natural habitat (Karr 1996). It might be distinguished from ecosystem health as referring specifically to a condition unchanged from some original state (Karr 1996). It should be noted that there is considerable debate about the validity and/or usefulness of these concepts, their definitions, and the extent to which they do or do not overlap (Rapport 1998).

2.3 ECOSYSTEM MANAGEMENT

A desire to retain the services that an ecosystem may provide should logically engender a concern for the welfare of that system, because a damaged ecosystem may have a limited ability to provide those services. This anthropocentric concern with ecosystem health, condition or integrity is the basis for the paradigm of ecosystem management (Lackey 1998). However, there are various definitions of ecosystem management (Christensen *et al*. 1996; Lackey 1998). Some specifically encompass ecological health or ecological integrity, while others make no mention of such concepts. For example, whether or not ìthe application of ecological and social information, options and constraints to achieve desired social benefits within a defined geographic area and over a specified periodî (Lackey 1998) encompasses ecological health will depend entirely on the interpretation of the reader. In contrast, ìto restore and maintain the health, sustainability, and biological diversity of ecosystems while supporting sustainable economies and communitiesî (US EPA 1994, cited in Lackey 1998) explicitly includes ecological health. Grumbine (1994) based his working definition of ecosystem management on a survey of peer-reviewed literature and specifically included the protection of ecosystem integrity as a general goal. However, critics of ecosystem management would argue that it is basically aimed at reducing the extractive use of natural resources and preserving natural ecosystems (Christensen *et al*. 1996), and that it is a negative and restrictive approach.

Several authors have identified key issues for ecosystem management. The seven pillars of Lackey (1998) are designed to bound and define the concept. They address the values of concern, adequate definition of spatial boundaries, the condition needed to achieve desired social benefits, the stability of the system, whether or not biodiversity is a desired benefit, sustainability of the system over a given time frame, and the extent to which scientific input should influence decision making. Brussard *et al*. (1998) list seven critical steps in the process of ecosystem management:

- Define and delineate the system to be managed.

- Define strategic goals.
- Understand the system.
- Consider socioeconomic data.
- Link the ecological and socioeconomic data in a model which defines management actions to achieve the specified goals.
- Implement the actions.
- Monitor the results of those actions.

Christensen *et al*. (1996) identified eight components of the management of an ecosystem which they considered essential for it to be considered as true ecosystem management, including a sound ecological understanding, the recognition of sustainability as a fundamental value, the explicit setting of management goals, and adaptability and accountability in response to the outcomes of rigorous and relevant monitoring programs. They view science as a model for ecosystem management, with monitoring programs fulfilling the role of research to test the hypothesis that the current management actions will achieve the desired goals for the ecosystem (Peterson 1993). Further, they recognise that monitoring may be logistically difficult at the ecosystem scale, and be seen as an additional and unacceptable cost in the short-term, but point to its value in assessing the effectiveness of particular management actions.

A distinction has been drawn between ecosystem management and ecosystem-based management by Slocombe (1998), with the former being ecologically-based and referring to smaller spatial scales, while the latter refers to larger spatial scales and is multidisciplinary. However, reference to Lackey (1998) and Brussard *et al*. (1998) suggests that the distinction made by Slocombe is not shared by all authors, as the lists of the former authors in relation to ecosystem management appear to fit Slocombeís description of ecosystem-based management.

The original concept of an ecosystem referred to the complex of organisms inhabiting a region and the inorganic components of their physical surrounds (Tansley 1935). A major practical difficulty with this concept in a management context is that the boundaries of such an entity may be difficult to define (Suter & Bartell 1993), a concern echoed in the key issues raised by both Lackey (1998) and Brussard *et al*. (1998). However, with regard to risk assessment, Suter and Bartell (1993) noted that the terms ìcommunityî and ìecosystemî have become almost interchangeable. Such usage suggests that, in a practical sense, the management of any multi-species and relatively large-scale area may be effectively regarded as ecosystem management.

It is desirable to set management goals in terms of the desired state of the ecosystem rather than the management actions undertaken (Christensen *et al*. 1989, 1996). Only by doing so can the effectiveness of those actions in reaching the desired goals be assessed. A frequent goal of management is the preservation of habitat in its ìnaturalî condition or its restoration to a known earlier condition, but both of these options may present substantial difficulties in identifying the desired condition (Christensen *et al*. 1996). In the context of fisheries, de Young *et al*. (1999) suggested that management goals must include secondary objectives of social and economic well-being of humans associated with a fishery, as well as the primary goal of the maintenance of ecological integrity for the sustainability of the fishery itself.

Management Strategy Evaluation, or MSE, (Hilborn & Walters 1992; Smith 1994) is a relatively recent approach to the management of natural resources harvested commercially. The aim is to support an informed choice between alternative management strategies, each designed to achieve a different broad objective. Often there is no clear ìbestî strategy, but each has known advantages and disadvantages that must be balanced in the decision-making process. Simulation modelling is used to examine the performance of each strategy in turn, with respect to its objective, while also incorporating both natural variability in populations and uncertainties in parameter estimates. MSE has been applied to marine fisheries for finfish (*e.g.*, Punt *et al*. 2001) and marine mammals (*e.g.*, Wade 1998, cited in Butterworth & Punt 1999), and has been identified as potentially more beneficial in fisheries management than some techniques previously used (Butterworth & Punt 1999). However, it is not without potential difficulties, in particular, the initial selection and possible weighting of the alternative hypotheses, and the possibility of operating models being quite complex (Sainsbury *et al.* 2000).

2.4 BIODIVERSITY

The maintenance of biodiversity is a key ecosystem service (Table 1), and one of the most relevant to the operations of Parks Victoria.

While the term biodiversity has been simplistically equated with species richness (Redford & Sanderson 1992), it more correctly refers to the variety of all life forms, the plants, animals and microorganisms, the genes they contain and the ecosystems of which they form part (Saunders *et al.* 1998). As such it encompasses three fundamental levels of organisation: the ecosystem, the species and the gene (Norse *et al*. 1986, cited in Noss 1990). This can be alternatively expressed as the ecological, the taxonomic and the genetic hierarchies (Angermeier & Karr 1994). Ecological processes are included in the definition of biodiversity by Noss (1990), because, although they may include abiotic components, they can also be considered critical to the maintenance of biodiversity. They are, however, specifically excluded by Angermeier & Karr (1994), who differentiate biodiversity and biological integrity.

They regard the former as consisting only of biotic elements and the latter as being a combination of those elements with processes. For example, an area could have high biodiversity, indicated by high species richness, but still have reduced biological integrity if many of the species present were exotic rather than native to the area (Angermeier & Karr 1994). Non-native species may be less efficient at carrying out some functions of an ecosystem than species native to the system (Ehrlich & Mooney 1983).

The preservation of ecosystem services is often used as a justification for the conservation of biodiversity (Myers 1996; Balvanera *et al*. 2001), but conclusive links between the two have not been made (Myers 1996; Tilman 1997; Balvanera *et al*. 2001). Both Myers (1996) and Tilman (1997) have explored possible links in some detail.

In the view of Myers (1996), biodiversity provides a medium for the flows of energy and materials that give ecosystems their functional properties, and supports and fosters the resilience of ecosystems. Any reduction in biodiversity could lead, via these pathways, to reduced integrity of ecosystem processes that provide the services desired by mankind (Myers 1996). Myers (1996) sees resilience as being closely associated with the provision of many services, such as climate regulation, crop pollination and pest control, but concedes that there is uncertainty and controversy regarding the general relationship between biodiversity and ecosystem services. For example, where there is redundancy in species composition, that is, where there are several species capable of fulfilling a given functional role (Walker 1992), some loss of biodiversity can occur without affecting the functioning of an ecosystem (Lawton & Brown 1994; Clarke & Warwick 1998a). A question of considerable management interest that arises from the concept of ecological redundancy is: how many taxa can be lost without affecting ecosystem function? Unfortunately there is no simple answer to that question (Woodward 1994), and Walker (1992, 1995) expressed concern that the concept of redundancy may be used to imply that loss of taxa is acceptable.

Tilman (1997) discussed evidence in the scientific literature for links between biodiversity and the productivity, stability and sustainability of ecosystems. He cited examples of crop productivity being higher where two or more crop species are grown together, as reviewed in Trenbath (1974) and Swift and Anderson (1994), as well as the multi-species experiment of Naeem *et al*. (1995) where productivity was a significantly increasing function of species richness. Following a review of this evidence, he suggested that the effect of biodiversity on productivity was a positive but indirect effect as a result of a greater range of species traits exhibited by a richer assemblage. As a result of his own studies of drought conditions in grasslands (Tilman 1996) and other studies of diversity and stability, Tilman (1997) saw biodiversity as enhancing ecosystem stability, although simultaneously reducing the resistence of individual species abundances to perturbation. With regard to ecosystem

sustainability, he was unable to find any long-term field tests of dependence on biodiversity, but suggests that evidence for productivity and nutrient retention support the case for dependence.

In the view of Christensen *et al*. (1996), biodiversity may be considered an integral component of ecosystem management in the sense in which they use the latter term, because they believe the overall sustainability of an ecosystem to be dependent on its biodiversity via enhanced stability and resistence to disturbance.

2.5 THE MEASUREMENT OF BIODIVERSITY

Because biodiversity is not a single parameter that can be measured directly, surrogates and/or multiple measures may be employed. If multiple measures are used, they may be considered separately, combined in some form of univariate index, or analysed using multivariate methods.

2.5.1 Indicators

Indicator variables are often used as surrogates for biodiversity (Noss 1990). Desirable characteristics of indicators as listed by Noss (1990) are:

- sufficient sensitivity to give early warning of change,
- broad geographic applicability,
- applicability across a wide range of stress,
- ease of use,
- cost-effectiveness,
- ability to differentiate between natural and man-made changes, and
- relevance to ecologically significant phenomena.

The list of criteria for biodiversity indicators for national State of the Environment reporting in Australia (Saunders *et al*. 1998) covers similar characteristics, but in addition, includes several relating to policy requirements and community involvement.

Franklin (1988) identified composition, structure and function as three fundamental attributes of ecosystems that determine the biodiversity of an area. These have been adopted by Noss (1990) in his hierarchical approach to monitoring biodiversity. He crossed these attributes with four hierarchical levels of organisation (regional/landscape, community/ecosystem, population/species and genetic) to produce a matrix of twelve categories for which indicators should be identified and monitored. He also gave examples of suitable indicator variables for

each category (Table 2). For example, at the ecosystem level, species richness could be used as a measure of composition, canopy openness as an indicator of structure, and predation rate as a measure of function. The Broad Vegetation Types and Ecological Vegetation Communities currently used by Parks Victoria (Parks Victoria 2000a & b) are compositional attributes at the regional/landscape and community/ecosystem levels of organisation respectively. Fragmentation of habitats both at the regional/landscape level across the state and at the community/ecosystem level within individual parks or groups of parks is also a concern for Parks Victoria (Parks Victoria 2000a).

Table 2. Example indicators in a hierarchical approach to monitoring biodiversity.

Level of Organisation	Attributes of Biodiversity		
	Composition	**Structure**	**Function**
Regional/landscape	proportions of hab-itat types	habitat fragmenta-tion	patch persistence
Community/ecosystem	species richness	canopy openness	predation rate
Population/species	abundance or cover	population struc-ture	fertility rate
Genetic	allelic diversity	generation overlap	rate of genetic drift

Source: Noss (1990).

At the population level, Noss (1991) identified five special categories of species which he believed may warrant special efforts with regard to conservation. Indicator species are those which demonstrate effects that would also occur for other species in the same habitat. Keystone species are those whose presence has a disproportionately large influence on the structure of the community of which they are part (Paine 1969; Power *et al*. 1996). Umbrella species are those occupying a large area, and which, if adequately protected, would also provide protection for other species in the area (Noss 1991). Flagship species are the charismatic species which attract public attention and sympathy in conservation debates (Noss 1991), while vulnerable species are rare or otherwise prone to extinction for a variety of reasons (Noss 1991).

Saunders *et al*. (1998) also identified a list of possible indicator variables for biodiversity, but in contrast to Noss, used categories of pressure, condition and response (OECD 1993, cited in Saunders *et al*. 1998) to group their indicators in a manner designed to reflect the relationship between the indicator and human activities. For example, change in land use could be used as an indicator of pressure, percentage of endemic species as an indicator of condition or state, and proportion of area protected as an indicator of response. Their indicators of condition for biodiversity are listed in Table 3.

Table 3. Indicators of condition for biodiversity.

Indicator (Saunders *et al.* 1998)	Potential value in ECA project
Number of subspecific taxa (as a first approximation of genetic diversity)	Too detailed a measure for routine use. Noted as being more useful for widely distributed species, so perhaps less so for within-park studies
Population size, numbers and physical isolation	Both useful and practical for some species
Environment amplitude of populations (*i.e.*, the extent to which a species maintains occupancy of the full range of habitats in which it naturally occurs)	ìDistribution approachî would be practical, but is perhaps better suited to study areas greater than an individual park
Genetic diversity at marker loci	Too technical a measure for routine use
Number of species	May suit some groups of vertebrates and vascular plants, but could require a great deal of sampling and/or taxonomic expertise for many groups of invertebrates, microorganisms and non-vascular plants
Estimated number of species	Uncertainty in estimates for some lesser known groups may be considerable May not be a responsive or useful variable for monitoring
Number of species formally described	May be more indicative of the availability and level of interest of taxonomists than of species richness
Percentage of number of species described	Indicative of the availability of taxonomists and level of interest in particular groups May be inaccurate if total number is poorly estimated
Number of subspecies as a percentage of species	Too detailed a measure for routine use Percentage will be inaccurate if total number is poorly estimated
Number of endemic species	Of interest, but very dependent on knowledge of species distributions May not be a very responsive variable for monitoring, but decreases would be cause for considerable concern
Conservation status of species	Currently used by PV
Direct economic importance of species	Limited relevance for a parks management authority, except for the usually unspecified value of ecosystem services
Percentage of species changing in distribution	Change in distribution might be useful and practical measure for some species, but too difficult to determine for many others Percentage will be inaccurate if total number is poorly estimated

Table 3 (continued).

Indicator (Saunders *et al.* 1998)	Potential value in ECA project
Number, distribution and abundance of migratory species	May be relevant for some parks (*e.g.*, RAMSAR sites)
Demographic characteristics of target taxa	Valuable for threatened species or those that threaten species of concern Data collection may be resource-intensive
Ecosystem diversity	Currently used by PV, particularly in relation to vegetation types
Number and extent of ecological communities of high conservation potential	Currently of interest to PV

2.5.2 The use of indices

The importance of using a multi-faceted approach rather than relying on single measures has been emphasized in relation to the monitoring of biodiversity (*e.g.*, Noss 1990), and also for the assessment of biological integrity (*e.g.*, Karr 1991) and for risk assessment (*e.g.*, Wenger *et al*. 2000). One approach to addressing this issue is to use a number of different measures, but for convenience of later arithmetic manipulation, to combine them in a single easily-manageable index. One example is the Index of Biological Integrity. The IBI is a modelling approach that was originally developed for assessment of the integrity of freshwater fish communities (Karr 1991). It incorporated 12 indicators covering abundance and condition, species richness and composition, and trophic composition of the community. These were individually ranked on a five point scale by comparison with a reference site, then simply added together to form a single numeric index. The IBI has been adapted for other assemblages such as riverine benthos (Kerans & Karr 1994) and estuarine benthos (Weisberg *et al*. 1997). Other indices constructed from multiple indicators include the following:

- Index of Plant Community Integrity (DeKeyser *et al*. 2003), which uses principal components analysis and cluster analysis on measures, including species richness and percentage of introduced species, to generate five classes of wetland vegetation quality for the study of mitigation or restoration projects,
- Floristic Quality Assessment Index (Lopez & Fennessy 2002), which assesses wetland condition on the basis of expert knowledge of the likelihood of species being encountered at disturbed sites within a study area,
- Ecosystem Health Index (*e.g.*, Counihan *et al*. 2002) which is based on physico-chemical and biological indicators, and is used as a reporting tool on a regional scale for waterways in south-east Queensland (see Section 3.2.1),

- Index of Stream Condition (Ladson *et al*. 1999), which is based on five subindices, each of which is composed of multiple indicators, and involves scoring relative to a presumed state of ìnaturalnessî,
- Riparian, Channel and Environmental Inventory (Petersen 1992), which was designed primarily for assessments in agricultural landscapes, and involves scoring of 16 characteristics of small stream channels.

The IBI has also been used in a risk assessment framework to identify stressors of freshwater fish and invertebrates, and appropriate management actions to protect them (Cormier *et al*. 2000; Diamond & Serveiss 2001)

It should be noted that the use of indices can result in loss of information and over-generalisation. Rakocinski *et al*. (1997) noted that the benthic index used by Engle *et al*. (1994) was less able to discern differences in macrobenthic responses to contamination gradients than was a canonical correspondence analysis model. Suter (1993a) disputed the benefits of using indices such as the IBI, which combine heterogeneous variables. He detailed problems including difficulty in determining why an index was high or low, lack of obvious meaning of index values, and arithmetic problems relating to the magnitudes of the component variables and to the functions used to combine them. He proposed that more useful indices of assessment endpoints that he considered to be more tangible than ecosystem health (or integrity) could be constructed from homogeneous sets of parameters, for example, an index of eye irritation composed of concentrations of air pollutants.

There are also approaches which combine parameters from different components of a system under study, but without the reduction to a single index. The Sediment Quality Triad (Long & Chapman 1985; Chapman *et al.* 1996) is one such approach, used for the assessment of benthic communities in contaminated areas. It incorporates parameters relating to sediment quality, the resident community, and toxicity testing, and results can be presented in a qualitative *a priori* decision matrix (Chapman *et al*. 1996). Chapman *et al*. (1997) pointed out that the use of multiple parameters for one or more parts of the triad is acceptable, but explicitly recommended against the use of a single holistic index. De la Mare and Constable (2000) used standard multivariate statistical methods to combine multiple parameters relating to a krill fishery into a more manageable set of three indices: one for the krill, one for their predators, and a third for environmental variables.

A recent application of an index to identify changes in biodiversity in degraded habitat combines multivariate statistical methods with the use of a control chart style of presentation for management purposes. The average taxonomic distinctness of Warwick and Clarke (1995) is a generalisation of Simpsonís diversity index (Simpson 1949) and is similarly

independent of sample size (Clarke & Warwick 1998b). When combined with a measure of variation in taxonomic distinctness, a funnel plot similar to a control chart is produced which shows bounds within which the average distinctness might be expected to fall with a given degree of confidence (Warwick & Clarke 1998). Points representing degraded habitats may be expected to fall outside these bounds, and would thus be flagged for consideration by managers for possible remedial action.

Multivariate data for aquatic fauna can be used to assess the health of Australian rivers with the rapid bioassessment technique AUSRIVAS (Davies 2000, Simpson & Norris 2000). The presence or absence of multiple taxa recorded during rapid, standardized sampling at sites of interest is compared with that predicted from a model based on species composition at known reference sites. A ratio of the observed number of taxa to the expected number is calculated and the O/E ratios provide a measure of river health relative to reference conditions. Leversha *et al*. (2001) have developed a rapid assessment method for terrestrial vegetation condition (see Section 2.2).

3 Approaches to ecosystem condition/management by other agencies

3.1 NEW SOUTH WALES

3.1.1 National Parks and Wildlife Service

In NSW, the National Parks and Wildlife Service has a lead role in the development of ecologically sustainable and integrated landscape management, including responsibility for the conservation of native plants and animals, and for the range of natural environments that exist in the state (NSW NPWS 2003a). The conservation of biodiversity is a major focus, both within the parks system and external to it. NPWS takes a lead role for at least one action within 14 objectives from the total of 29 listed under the NSW Biodiversity Strategy (NSW NPWS 1999).

This interest in biodiversity reflects similar concerns to those of Parks Victoria although the focus of activity is somewhat different. Risk management following the assessment protocols of AS 4360 (SA/SNZ 1999) appears largely restricted to cultural heritage issues and occupational health and safety (*e.g.*, NSW NPWS 2003a & b), although individual NPWS staff are known to have interests in ecological risk assessment. In particular, they have developed a number of explicit, spatially structured population models for several species of threatened plants to evaluate risks and the potential benefits of alternative management options (*e.g.*, Regan *et al*. 2003). They rely on the IUCN protocols and related techniques to assess conservation status and set priorities for individual species and use the records of these species to rank priorities for area management.

3.1.2 Department of Infrastructure Planning and Natural Resources

The Department of Infrastructure, Planning and Natural Resources (incorporating the former Dept of Land and Water Conservation) has interests in ecosystem condition and ecosystem services.

The Centre for Natural Resources within DIPNR has an explicit role in the development of tools for the assessment and monitoring of ecosystem condition in wetlands (NSW DIPNR 2004).

Smith *et al*. (2000) from DLWC highlighted the role of native vegetation in the provision of many ecosystem services including the maintenance of biodiversity, stabilisation of climate on a local scale, recycling of nutrients and the purification of water. Among their recommendations for future research in rural landscapes was the monitoring of changes in native vegetation condition. They also suggested the assessment of environmental risks associated with future research projects.

3.2 QUEENSLAND ñ MORETON BAY WATERWAYS AND CATCHMENTS PARTNERSHIP

Ecosystem health forms the basis of a monitoring program for coastal waterways in south-east Queensland established by the Moreton Bay Waterways and Catchments Partnership (MBWCP 2002). Data is collected regularly for both physico-chemical and biological variables that are seen as key indicators of health, and spatial prediction analysis applied to annual median values to generate estimated median values across each geographic reporting zone (Counihan *et al*. 2002). The proportions of a reporting zone that comply with the relevant environmental objective are recorded for each indicator, and an environmental health index constructed as the average of these compliance ratios across all indicators. In conjunction with expert opinion for variables not amenable to the spatial analysis, the index provides a monitoring tool for actions under the South East Queensland Regional Water Quality Management Strategy.

3.3 AUSTRALIA ñ DEPARTMENT OF ENVIRONMENT AND HERITAGE

The National Parks and Protected Area Management Committee has been established "to provide an inter-Governmental mechanism for identification and resolution of park and protected area management issues at a National level across Australia and New Zealand" (DEH 2004). A series of ìBest Practiceî reports is available to share information among the various agencies involved in the committee and other interested parties.

One such report is a review of current approaches to performance measurement in protected area management (Qld PWS 2002) which provides basic information on projects using indicators for ecological habitats and general ecosystem monitoring undertaken by agencies both in Australia and overseas. The concepts of ecosystem condition, health or integrity and the maintenance of biodiversity figure in several of these projects (Table 4).

Table 4. Selected projects with a focus on the measurement of indicators for ecological habitat or ecosystem monitoring.

Project Objective	Project Name	Responsible Organisation
To examine entire parks system in regard to changing *species richness and composition* in Canadian National Parks	Changing species rich-ness and composition in Canadian National Parks (see Section 3.5)	Parks Canada Agency
To manage K prairie sites K to main-tain the *ecological health* of the sites and the overall *ecological integrity* of the park's landscape	Spruce Woods Provincial Park Prairie Management Plan	Parks and Natural Areas Branch, Manitoba Conser-vation, Canada
To identify the present status of seagrass *habitats* and determine if there has been a decline in their *distribution* or *quality*, as a response to increased changes in the catchment over the last 5 years	Seagrass Habitat, Issues & Management ñ Great Sandy Region	Qld Parks and Wildlife Service Qld Dept of Primary Industries Environment Australia
To evaluate the effects of current timber harvesting practices in Jarrah forest on *biodiversity*	Kingston project	Dept of Conservation & Land Management, CALM Science Division, WA
To assess performance of public agencies in the protective management of the estuary and its watershed, and to inform the public about changes in the *ecological condition* of the estuary	Pauatahanui Inlet Cockle Monitoring	New Zealand Dept of Conservation
To monitor the outcomes of wild animal control operations	Forest condition monitor-ing	New Zealand Dept of Conservation, Waikato Conservancy
To restore *ecosystem processes* so that fauna once present on the Auckland mainland can be returned to the area and can survive long term (20 years plus)	Wenderholm mainland island	Auckland Regional Coun-cil, NZ
To determine whether possum control programmes are benefitting the entire forest long term	Waitakere Ranges *forest health* monitoring	Auckland Regional Coun-cil, NZ
To assess the effectiveness of major investments by councils and industry in environmental protection (*e.g.*, improved sewage treatment and stormwater management) in protecting and restoring the *ecosystem health* of SEQ waterways	Ecosystem Health Monitoring Program (see Section 3.2.1)	Qld Environment Pro-tection Agency Marine Botany Group, Uni of Qld CSIRO Marine Research CSIRO Mathematics & Information Sciences Qld Health Scientific Services

Source: Qld PWS (2002).

3.4 NEW ZEALAND ñ DEPARTMENT OF CONSERVATION

The Department of Conservation is the central government body in New Zealand charged with conserving the natural heritage and managing national parks, reserves and conservation areas. It is also one of the four key agencies responsible for implementing the New Zealand Biodiversity Strategy.

Late in 2002, DOC contracted the development of a framework for monitoring biodiversity and reporting its condition to Landcare Research (an independent Crown Research Institute). The broad objectives of the program are to (E. Wright, DOC, pers. comm.):

- detect changes in biodiversity that exceed the range of natural variation across a range of spatial and temporal scales,
- provide an early warning of potential irreversible changes,
- provide reports on changes in pressure and the status of biodiversity condition, and
- enable DOC to meet NZ national and international commitments for monitoring biodiversity.

The scoping document for the project outlined the general requirements and constraints for the framework, and recognised that the choice of variables to monitor was a complex question.

3.5 CANADA ñ PARKS CANADA

The maintenance of ecological integrity was introduced as the prime mandate for Canadian national parks in 1988, and with it came an approach to park management with strong links to Grumbineís (1994) dominant themes of ecosystem management (Zorn *et al*. 2001).

Parks Canada recognises three major components of ecosystems for management purposes: biodiversity, ecosystem functions and stressors, the main concerns within each currently being threatened species, fire and roads respectively (Parks Canada 2003). These three components form the basis of a monitoring framework for ecological integrity (Table 5) which it is hoped will make monitoring more scientifically sound and more aligned with the management goal of maintaining or restoring ecological integrity. It is the aim of Parks Canada for every park to have developed an initial suite of indicators within this framework by March 2004, with developing and testing of the indicators to continue until March 2008 when monitoring of the final suites of indicators should be implemented. However, when discussing national parks in Ontario, Zorn *et al.* (2001) noted that there are practical constraints on the number of indicators that can be routinely monitored.

In 2003, the Canadian Wildlife Service introduced the notion of Critical Habitat under new legislation design to ensure the long-term viability of species. Defining Critical Habitat depends on characterizing the habitat requirements of the species based on life-history and the habitat features, and on determining and locating the amount and configuration of habitat required for the survival or recovery of the species. Almost certainly, this creates a motivation for single-species conservation with a reliance on spatially-explicit habitat and population models.

While the concepts of ecological integrity and ecosystem management are clear in the approach of Parks Canada, risk assessment does not appear to play a role in its choice of indicators.

Table 5. Ecological integrity reporting framework.

Biodiversity	Ecosystem Functions	Stressors
Species richness: Changes in species richness Number and extent of exotics	Succession/retrogression: Disturbance, frequency and size (fire, insects, flooding) Vegetation age class distri-butions	Human land-use patterns: Land use maps, road densities, population den-sities
Population dynamics: Mortality/natality rates of indi-cator species Immigration/emigration of indi-cator species Population viability of indicator species	Productivity: Landscape or by site	Habitat fragmentation: Patch size, inter-patch dis-tance, distance from interior
Trophic structure: Size class distribution of all taxa Predation levels	Decomposition: By site	Pollutants: Sewage, petrochemical, *etc*. Long-range transportation of toxins
	Nutrient retention: Calcium and nitrogen by site	Climate: Weather data Frequency of extreme events
		Other: Park specific issues (*e.g.*, disease in local animal populations)

Source: Parks Canada (2003).

4 Risk Assessment in Ecosystem Management

4.1 WHY IS RISK ASSESSMENT IMPORTANT IN ECOSYSTEM MANAGEMENT?

Our knowledge of ecosystems is far from complete (Christensen *et al*. 1996), and this lack of knowledge is likely to lead to uncertainties in predicting the outcomes of management actions. However, these uncertainties are often not acknowledged or incorporated in ecosystem management (Shrader-Frechette 1998). The basis of risk assessment is the quantification of uncertainty of an undesirable event occurring (Suter 1993b), thus a risk-based approach to ecosystem management will incorporate acknowledgement and quantification of the uncertainties in management outcomes.

Risk assessment procedures are now being more widely applied in ecosystem management. For example, in the management of Green Bay (Harris *et al*. 1994) and the St. Croix National Scenic Riverway (Wenger *et al*. 2000) in the USA, subjective risk assessment and fuzzy set theory were used to rank stressors identified during workshops of experts concerning these bodies of water. Reclamation of wetlands and shorelines, and the introduction of exotic species were identified as the most important problems for Green Bay, and riverway development as the main issue for the St. Croix riverway. Graph theory then identified relationships among the individual stressors, highlighting that effects of riverway development along the St. Croix could be exacerbated by interactions with other stressors, and it was hoped that this information will be used to develop appropriate management plans (Wenger *et al*. 1999). There have also been calls for the application of risk assessment and management in fisheries management, a branch of natural resources management that has been notable for some spectacular failures (Hilborn *et al*. 2001).

4.2 ECOLOGICAL RISK ASSESSMENT

Ecological risk assessment is the process of estimating likelihoods and magnitudes of the effects of human actions or natural events on plants, animals and ecosystems of ecological value (SA/SNZ 2000), that is, the study of risks to the natural environment (Barnthouse & Suter 1986, cited in Suter 1993b). It provides a basis for comparing and ranking risks, so that risk managers can focus attention on the most severe risks first. Risk assessment is generally couched in terms of adverse or undesired effects (*e.g.*, Suter 1993b), and stressors or sources of risk in ecological risk assessment are physical, chemical or biological entities that induce an adverse response (SA/SNZ 2000). However, risk may also be regarded in a more neutral light, simply as the chance of an event occurring that will have an impact upon an objective of interest (SA/SNZ 2000). The ERA process should be iterative, allowing new

information to be incorporated into the risk assessment as it becomes available. It is thus a branch of risk assessment particularly relevant to ecosystem management.

Lackey (1994) lists five approaches to ecological risk assessment currently utilized in ecosystem management, including the traditional animal-toxicity paradigm (*e.g.*, Suter 1993b), environmental impact assessment, and a modelling approach which covers a variety of different quantitative methods. He contrasts these with the human health paradigm (*e.g.*, Rapport 1989, Cairns *et al*. 1993), noting that health and sickness are more readily distinguished for humans than for ecosystems. Shrader-Frechette (1998) claims that ecological risk assessment is dominated by the animal-toxicity paradigm and the health paradigm. The former has a large body of accumulated data on the responses of individual species to chemical stressors, but makes the frequently unwarranted assumption that test conditions and test species are representative of whole ecosystems, while the latter aims for a more holistic approach but suffers from a lack of direct means to quantify ecosystem health (Shrader-Frechette 1998). However, if suitable measures and timescales could be identified, the problem of quantification within the ecological health paradigm could be addressed by modelling approaches such as logistic regression. Shrader-Frechetteís view of the dominant paradigms also overlooks the importance of population viability analysis (Morris *et al.* 1999) and related approaches which are central to conservation biology (Burgman & Lindenmayer 1998).

4.3 ASSESSMENT ENDPOINTS

To be successful, an ecological risk assessment must have clearly defined endpoints (Suter & Barnthouse 1993) that should be relevant to management goals, in this case, relevant to the conservation objectives of Parks Victoria.

An *assessment endpoint* is a formal expression of the environmental attributes or values to be protected (Suter 1989, cited in Suter & Barnthouse 1993). The term generally refers to characteristics of populations or ecosystems over a large scale (Suter & Barnthouse 1993), and as such, may be linked to broad concepts such as ecosystem condition or to the provision of particular ecosystem services. For example, the long-term conservation objective of maintaining existing populations of threatened species in the Grampians National Park (Parks Victoria 2000b) is clearly related to the ecosystem service of the maintenance of biodiversity. One appropriate assessment endpoint for this objective would be ìno decline in the distribution/abundance/structure of populations of (those) threatened speciesî.

However, because assessment endpoints are not always easily quantified, it is also important to define more readily quantifiable *measurement endpoints* for operational purposes (Suter & Barnthouse 1993). The annual percentage change in the population of a

particular threatened species, or the percentage of an EVC defined as old-growth would be suitable as measurement endpoints for the above objective. These values may be seen as indicators of the broader assessment endpoints. Should the population or extent of old-growth vegetation change to a degree that is considered beyond the normal range of variation, the assessment endpoint would be deemed not to have been met.

4.4 HAZARD IDENTIFICATION

Individual attributes or values of the environment may be threatened by one or more hazards, a hazard being any source of potential harm, or any situation with potential to cause adverse effects (SA/SNZ 2000). Hazards may be physical, chemical or biological entities (ìstressorsî; US EPA 1998) or threatening processes such as the clearing of land or the discharge of waste. Hazard identification is a formal process involving the development of conceptual models linking ecological processes and management practices to ecosystem condition. The models are developed in collaboration with stakeholders, managers and relevant scientists.

Any risk assessment is reliant on initial identification of all hazards relevant to the situation because failure to identify a particular hazard would result in its exclusion from further consideration. Thus it is essential that all potential sources of harm be identified, if only to be later flagged as of low risk (SA/SNZ 1999).

All steps in a risk assessment, including hazard identification and assessment, depend on a decent conceptual model. Models are abstractions, representing how we think the world works. A diagram is the simplest form of a conceptual model. The diagram communicates many issues: the spatial scale of the problem, the level of detail, conceptual compartments and discontinuities.

Influence diagrams represent models in a slightly different form. They are a visual representation of the functional components and dependencies of a system. Shapes (ellipses, rectangles) represent variables, data and parameters. Arrows link the elements, specifying causal relations and dependencies.

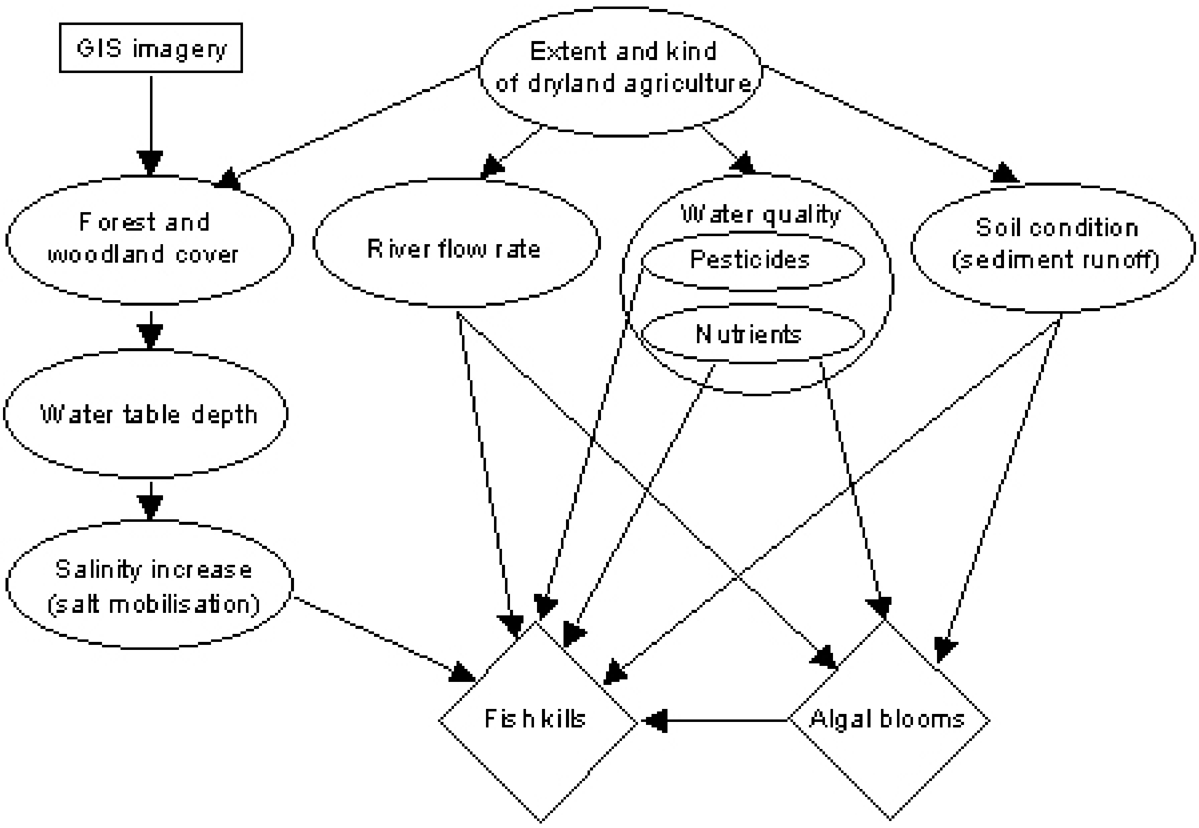

Figure 1. Influence diagram showing conceptual relationships among system components in a freshwater catchment.

Source: Hart *et al.* (2003).

In Figure 1, the hazards include salinity increases, changes in river flow, and deterioration in water quality and soil condition. Each contributes to at least one of the consequences that management is trying to avoid (the two diamonds). Data are available to monitor vegetation cover (shown by the square). Major direct influences among system components are represented by arrows. Note, for example, that there are no compartments within the river. This captures an assumption that the chemical and biological composition within the river is more or less uniform.

The figure assists in identifying causal relationships. It defines processes and pathways by which materials and energy flow through the system. For example, several process and events may contribute to the unwanted outcomes (fish kills and algal blooms).

The analyst works with experts, stakeholders and background information. The conceptual model may be developed iteratively until all participants in the risk assessment are happy that it adequately captures the way the system works in a way that makes sense for the

problem at hand. The model may then help to identify hazards or become a template for developing a mathematical model.

4.5 AIDS TO HAZARD IDENTIFICATION

Even with good conceptual models, it is very easy to overlook something. A single hazard can lead to multiple adverse effects. Several hazards can have the same effect.

It often worthwhile to separate proposals and management options into phases. Things like building and road developments, for instance, involve:

- exploration or site evaluation,
- benefit-cost (investment) analysis and facility design,
- construction,
- commissioning,
- operations, and
- decommissioning.

The process may be iterative, including performance monitoring and redesign. The hazards (human health, economic, social and ecological) associated with each phase are best treated separately.

A good hazard identification and assessment phase makes use of as many tools as possible, in an attempt to form as complete a list as possible.

In risk management systems, hazard identification continues throughout the life of a product or project. Hazards encountered by users, for instance, may not have been anticipated by developers or project managers. New hazards should be added to the register as they arise. Corrective management actions should then seek to reduce risks.

4.5.1 Checklists and unstructured brainstorming

Checklists and unstructured brainstorming are among the most common methods for assembling a list of hazards. Checklists are simple to construct and easy to use. They provide a record of the experience of people who have worked with the system. Brainstorming has the advantages of bringing new perspectives and of identifying causal relationships between system components and hazards. Checklists and brainstorming usually identify most of the hazards that lie within the operating experience of the people involved. Their disadvantages are that they do not encourage the participants to extend their thinking to new possibilities. They may lead to the false impression that all potential hazards

have been considered, particularly when existing lists are long and cumbersome (Hayes 2002a). They tend to overlook hazards when new technologies are introduced or new stresses are imposed on a system.

Lists and unstructured brainstorming are particularly susceptible to linguistic ambiguities and vague definitions. Words and phrases used to describe hazards may be misinterpreted by participants and by people who later use these lists to rank or quantify risks. They can be used most effectively in tandem with conceptual models and some of the other strategies outlined below. Because they represent a repository of collective experience and wisdom, they can be used after application of a more inductive strategy as an additional check on completeness.

4.5.2 Structured brainstorming

The Delphi and related techniques may be used for a variety of purposes including elicitation of parameters, they are often useful in putting together a relatively complete list of hazards, and scoping alternative conceptual models. When used for conceptual modeling and hazard identification, some of the steps may include:

- problem formulation and development of questionnaires,
- selection of experts,
- provision of background information, definitions and context to experts,
- elicitation of conceptual models and lists of hazards (often performed by participants independently),
- aggregation of results,
- review of results by experts and revision of answers, and
- aggregation of results, or iteration of feedback until consensus is achieved.

The drawbacks are that these methods can sometimes encourage uniformity. Some approaches do not give participants much opportunity to learn from one another.

4.5.3 The hazard matrix

Hazards may be characterized as a matrix of interactions between actions (environmental aspects; activities that may interact with elements of the environment), and components of the environment that may be affected by the actions (Figure 2).

Hazard matrices are particularly helpful in identifying hazards that have multiple effects, and in identifying hazards associated with different operational components of a project. Construction depends usually on checklists and brainstorming.

The links between aspects and environmental components represented by the crosses are a kind of conceptual model of environmental interactions, although the exact nature of the relationships is not specified. The matrix improves the probability that no interactions are overlooked, generating a more comprehensive list of hazards than brainstorming alone.

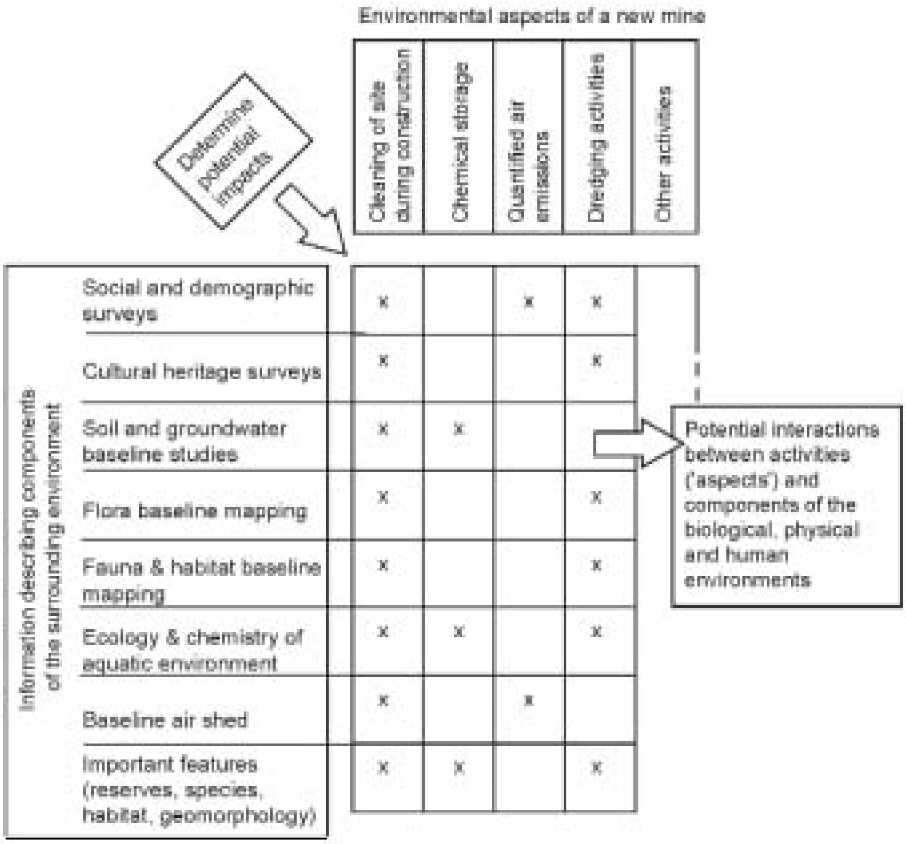

Figure 2. Part of a hazard matrix for an environmental impact assessment of a new mine. Source: Zaunbrecher (1999).

4.5.4 Hazard and Operability analysis

Hazard and operability analysis (HAZOP) is a kind of structured, expert brainstorming session. It uses conceptual models and influence diagrams together with guide words such as ìmore ofî, ìless ofî, and ìreverse flowî to prompt the thinking of a small team of experts. The experts, guided by a facilitator, apply ìwhat ifî type questions to each component of a system in a systematic manner (Kumamoto & Henley 1996; Lihou 2002).

HAZOP has been used to assess technical risks for several decades (CIA 1977). The words are designed to encourage a group of experts to interrogate a system and apply their expertise beyond their own experience (Hayes 2002a). The process operates as follows:

- A group of experts is assembled.

- A list of key words is compiled that describes the system, its components and operational characteristics.
- If the list is large (usually they are), the words are split into manageable sections associated with different subsections of the system.
- The list is distributed to the experts. They discuss potential problems in the system.
- A facilitator (or a computer program) prompts the use of keywords and guide-words to stimulate thinking.
- Potential problems are recorded as they are discussed.
- The group aims to reach consensus on hazards associated with each part of the system, and to specify what needs to be done. These deliberations are summarized in an Action Sheet that summarises cause, consequence, safeguards, and actions for each hazard.
- Action sheets including deadlines for implementation are distributed to relevant operational personnel.
- Personnel are required to submit Response Files that document implementation, feedback, and any recommended additional actions. These are available for review and audit.

The process generates a repository of information, containing actions, responses, dates and details of implementation, references to external information, and so on. The facilitated expert meeting provides an opportunity to address scenarios outside the normal operating conditions of the system. It depends on a conceptual model of the system. It is open-ended, more likely to identify all potential hazard scenarios than checklists or unstructured brainstorming, as are HHM (hierarchical holographic modelling) and FMEA (below; Hayes 2002a).

4.5.5 Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) is a deductive process that results in recommendations that reduce risk (Haviland 2002; FMEA Info Center 2002). Failure Modes are categories of failure, describing the way in which a product or process could fail to perform its desired function, defined in terms of the needs, wants, and expectations of people (ìshareholdersî, ìcustomersî or ìstakeholdersî). An FMEA is defined as ìa systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with themî (FMEA Info Center 2002; Figure 3).

FMEA shares this primary objective with HAZOP procedures but does not rely on structured brainstorming. Instead, it examines the behavior and interaction of individual components (ìelementsî) of a system to enable the consequences of undesired events to be assessed. It provides detailed examination of causal relationships between elements in a system, in addition to generating a list of hazards.

The process involves calculating a ìRisk Priority Numberî (*RPN*) for each hazard. The number is the product of three quantities, *Severity*, *Occurrence* and *Detection*. In the following, a ìcauseî is the means by which a particular element of the design or process fails:

- Severity is an assessment of the seriousness of the effect of the failure.
- Occurrence is an assessment of the likelihood that a particular cause will lead to a failure mode during a specified time frame.
- Detection is an assessment of the likelihood that the current controls (design and process) will detect the cause of the failure mode or the failure mode itself, thus preventing it from occurring.

The *RPN* is used to set priorities for action on hazards and to identify elements that require additional planning. Critical thresholds may be set above which action is mandatory. Actions are usually attempts to lower *Severity*, *Occurrence*, or *Detection* ratings. Adding validation or verification controls can increase the chances a problem will be detected (thereby reducing *Detection* scores). Design or process improvements may result in lower *Severity* and *Occurrence* ratings.

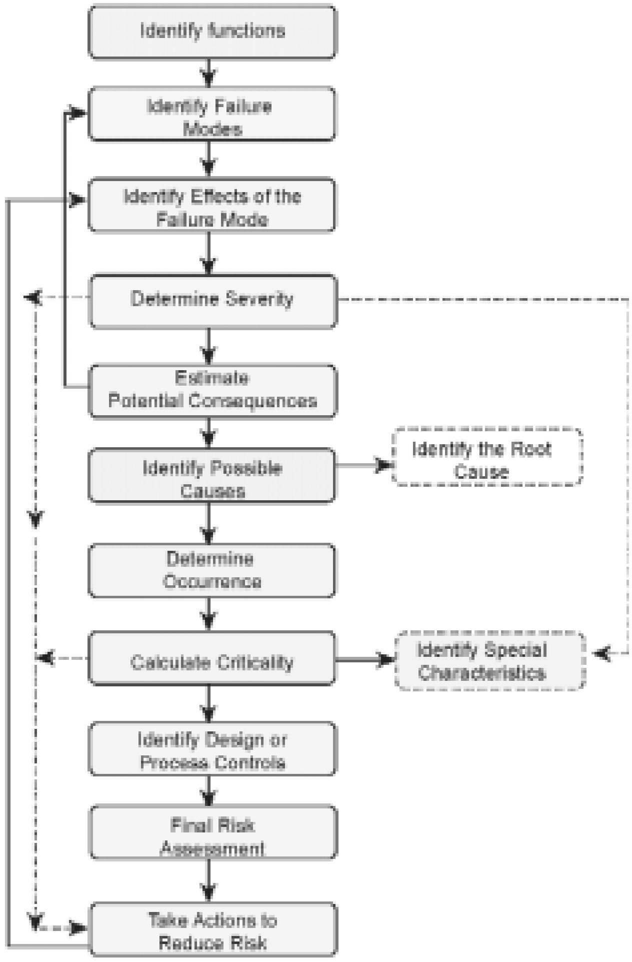

Figure 3. The elements of FMEA in a typical quality system.

Source: Haviland (2002).

FMEA ìelementsî are the individual components of a conceptual model. Typically, they are identified and analyzed in the FMEA process. They appear as column headings in the forms resulting from the process. Commonly, the forms list *Functions*, *Failure Modes*, *Causes*, *Effects*, *Controls* and *Actions*. *Failure Modes* are defined by the perspectives of the people involved in the risk assessment, or by those who bear the consequences of failures (Haviland 2002). This recognises the inherently subjective nature of hazard definition and, in a setting dealing with environmental risk, would translate to specifying the reasons why particular outcomes are considered to be hazards from the perspectives of different stakeholders.

The method accommodates the fact that a single cause may have multiple effects, and that a combination of causes may lead to a single effect. Causes can themselves have causes (fish kills may be caused by elevated salinity, in turn caused by vegetation clearance). Similarly,

effects can have downstream effects. Causes do not automatically result in a *Failure Mode*. To reflect this uncertainty, the term ìpotentialî is often used to describe causes.

4.5.6 Fault trees

A fault tree is a diagram that links all the processes and events that could lead to a particular outcome or failure (Figure 4). Fault trees complement *Failure Modes* and *Effects Analysis*, and are best developed in engineering where they are used to formalise conceptual models. They use structured brainstorming to define each component of a system, and consider the causal links and consequences of failure of each component.

Fault trees are constructed around AND/OR gates, using standard symbols (Kumamoto & Henley 1996). AND gates indicate that all contributing or input events must occur for the output event to take place, while an OR gate indicates that only one of the input events is required. Fault trees are used most often to identify hazards and help design mitigation strategies (Hayes 2002b). The tree allows a risk manager to see readily if there are any system components that provide efficient monitoring and remediation strategies. Branches that depend on AND conditions, for example, are valuable because management needs to focus on only one component of the set linked by the AND statement.

They are a versatile tool for mapping causal links between system components, but can become large and cumbersome even for modest problems. Care is required to handle what is called ìfailure modesî, events outside the modelled system that affect different components simultaneously. Similarly, fault trees may not adequately model dependencies between system elements.

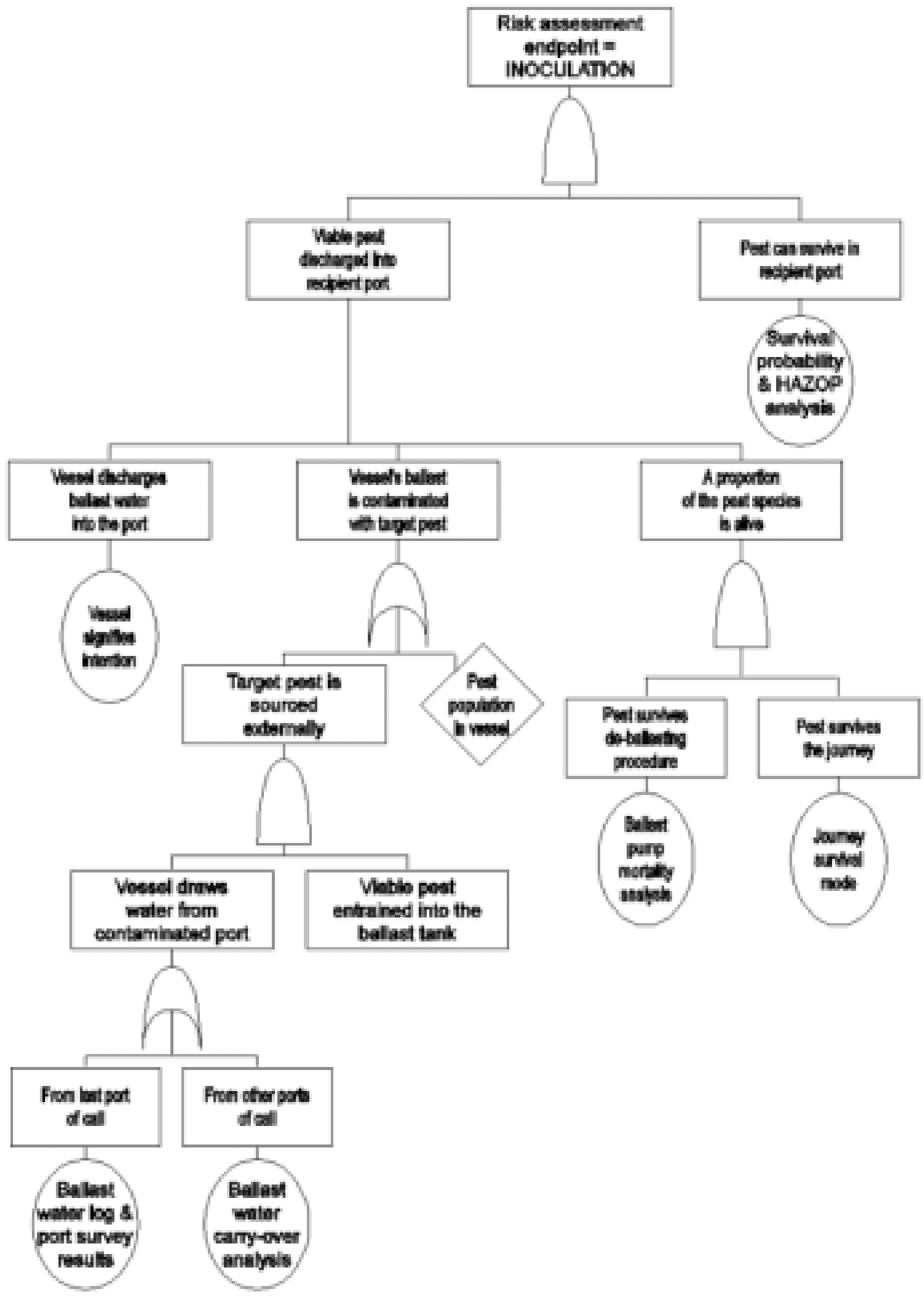

Figure 4. Part of a fault tree for marine pest introductions in ballast water.

Source: Hayes (2002b).

4.5.7 Scenario analysis

Scenarios are shared, agreed mental models. They are internally consistent descriptions of possible futures created in structured brainstorming exercises (van der Heijden (1996) describes the methods in detail). A scenario is a hypothetical sequence of events that focuses thinking on chains of causal relationships and their interaction with the decisions a person or a corporation might make.

Scenarios are constructed and communicated with a story line in which events unfold through time through a series of imagined causes and effects. The idea is to engage a group in value-free exploration of options. It distinguishes between the organisation itself, over which the strategist has control, the transitional environment made up of people and things the strategist can influence, and the contextual environment over which the strategist has no influence.

Scenario planning, as envisaged by Kahn and Wiener (1967), does not rely on probabilistic forecasts although quantitative projections may support the creation of scenarios. Rather, it relies on qualitative causal thinking to generate decisions that are robust to as wide a range of plausible, alternative futures as possible. Thus, decision champions needs to pay attention to a set of equally plausible, ongoing scenarios (van der Heijden 1996).

Scenario planning depends on the cooperation of participants. It requires that they are forthcoming about outcomes, dependencies, and uncertainties. Open dialogue may be more easily achieved in settings where participants share common objectives than in environments in which resource allocation is being debated and stakeholders stand to gain by the outcome at the expense of others.

Operating models are constructed for underlying processes. The models are used to evaluate different control rules and other heuristics that may be used on a routine basis by managers. Only those rules that work effectively over the full suite of scenarios are retained.

4.5.8 Multi-criteria decision-making

Multi-criteria decision making (MCDM) is a set of methods for eliciting and ordering preferences from people affected by a decision. The objective is to arrive at a decision that reflects social values.

MCDM works by defining all criteria against which an action may be evaluated, and identifying a preference scale or some other means of measurement of performance. A ìcoherentî set of criteria has the following properties (Roy 1999):

- Stakeholders are indifferent to alternative actions if they rank them the same against all criteria (implying the set is exhaustive).
- An action will be preferred to others if it is substantially better then all others on one criterion and equal on all others (implying the set is cohesive).
- The set is understood and accepted by all stakeholders.
- The conditions above may be violated if any criterion is omitted (implying the set contains no redundant elements).

If the endpoints are constructed to be meaningful to stakeholders, they may be evaluated in terms of costs and benefits using multi-attribute utility functions (Borsuk *et al.* 2001).

Saaty (1992) described a process that may be used to structure and map the opinions of experts, generating a cohesive picture of areas of agreement and disagreement. Many factors influence stakeholder choices. An analytical hierarchy (a decision tree) may be used to order thinking about these factors, and to provide a means for quantifying the priorities. The approach documents the diversity of opinions in a group in a form that allows opinions to be examined and revised subsequently.

The process involves the following steps:

- Establish criteria that may effect a decision.
- Classify factors under broad headings (social, political, economic, landscape, ecological).
- Classify criteria within these broad headings, into related topics.
- Establish the endpoints of the decision tree as the criteria.
- Have each person in the group assigns weights (preferences) at each branch of the tree that reflect their importance in determining outcomes.
- Multiply scores for each criterion at each branch point together to generate a score for each criterion.
- Present scores anonymously to the group and discuss differences of opinion.
- Have participants revise their scores and generate new ranks for each criterion.

The value tree represents a model of values that affect the decision over management priorities (Belton 1999). The weights given to different criteria define acceptable tradeoffs. A preference may be expressed as a value of a continuous scale, or as judgments for all pair-wise comparisons between actions (*n*(ñ1)/2 comparisons for 2 actions) and against each criterion.

Fernandes *et al*. (1999) used MCDM to explore acceptable alternatives to the management of a marine park (Figure 5). They stratified stakeholders by their interest in the issue (hotels, government regulators, NGOs and so on). They assessed the relative importance of each pair of objectives at each level in the hierarchy. Comparisons were limited to groups of subcriteria within a criterion.

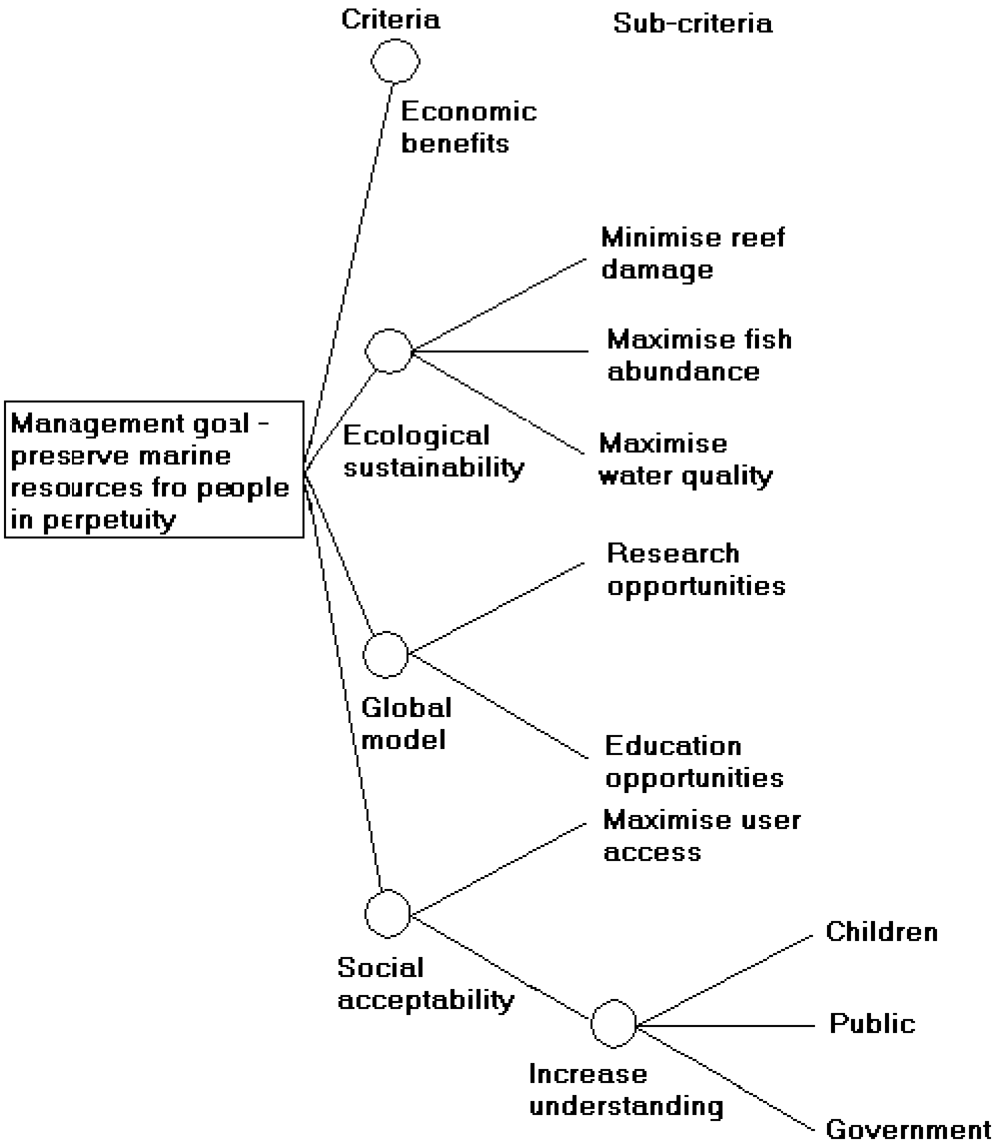

Figure 5. A MCDM value tree (a criteria hierarchy) for a decision about coral reef management on Saba, a small Caribbean island, involving economic, ecological and social trade-offs.

It provides for an assessment of decision alternatives against criteria. The ìglobal modelî criterion reflected the desire by stakeholders to have a reef management system that serves as an international standard. Economic benefits included many subcriteria such as tourism revenue from recreational divers, hotels and restaurants, development opportunities, fishing revenue and so on.

Source: Fernandes *et al.* (1999).

The assessment was determined by asking participants how important each component was for achieving the parent objective immediately above them in the hierarchy. Comparisons were made on a nine-point scale ranging from ìequally importantî to ìextremely more importantî. At the highest level in the hierarchy, the relative importance of each criterion was assessed independently by a single representative from each stakeholder group. These values were used to generate weights for each criterion.

Surveys of stakeholders were also used to frame five different reef management options. Experts evaluated the extent to which each of the high level objectives would be achieved under each management option. The weight of each management option depended on the weights assigned to each objective.

The analysis resulted in consensus among all stakeholders about the need for a managed park. It rejected options for elimination of the park and its no-fishing zones.

4.6 QUALITATIVE AND SEMI-QUANTITATIVE RISK ASSESSMENTS

The Australian Standard for Risk Management, AS/NZS 4360 (SA/SNZ 1999) is the most common approach to ecological risk assessment applied in Australia. For example, it is used by construction firms to assess site development risks, by resource and mining companies to evaluate potential ecological impacts of new proposals, and by fisheries managers to judge the sustainability of industry activities and harvest levels.

The risk management process involves seven steps (Figure 6), the first four of which are directly relevant to the risk assessment approach under development for Parks Victoria:

- Establish the context.
- Identify the risks (hazards).
- Analyse risks.
- Evaluate risks.

Assessments may be quantitative, or in the absence of relevant data, they may be qualitative and subjective. Qualitative assessments may be made semi-quantitative by the application of numeric values to the qualitative categories. This allows a more detailed prioritisation of hazards, but it should be noted that the values do no more than indicate relative priorities (SA/SNZ 1999). In both qualitative and semi-quantitative risk assessments, outcomes depend on subjective judgements of the likelihood that an event will occur and the severity of its consequences. Such assessments are therefore affected by the generally poor ability of people to judge probabilistic events (Fischhoff 1995), by their personal experience and beliefs (Pidgeon *et al*. 1992), by cultural differences in the perception of risk (Rohrmann

1994), and by cognitive biases such as framing effects (Kahneman & Tversky 1984), judgement bias (Fischhoff *et al*. 1977) and anchoring (Tversky & Kahneman 1974). Although the Australian Standard recognises the potential for group assessments to accom-modate the effects of individual subjectivity, in most applications the assignment of likelihood and consequence to each hazard is done once, by a single person.

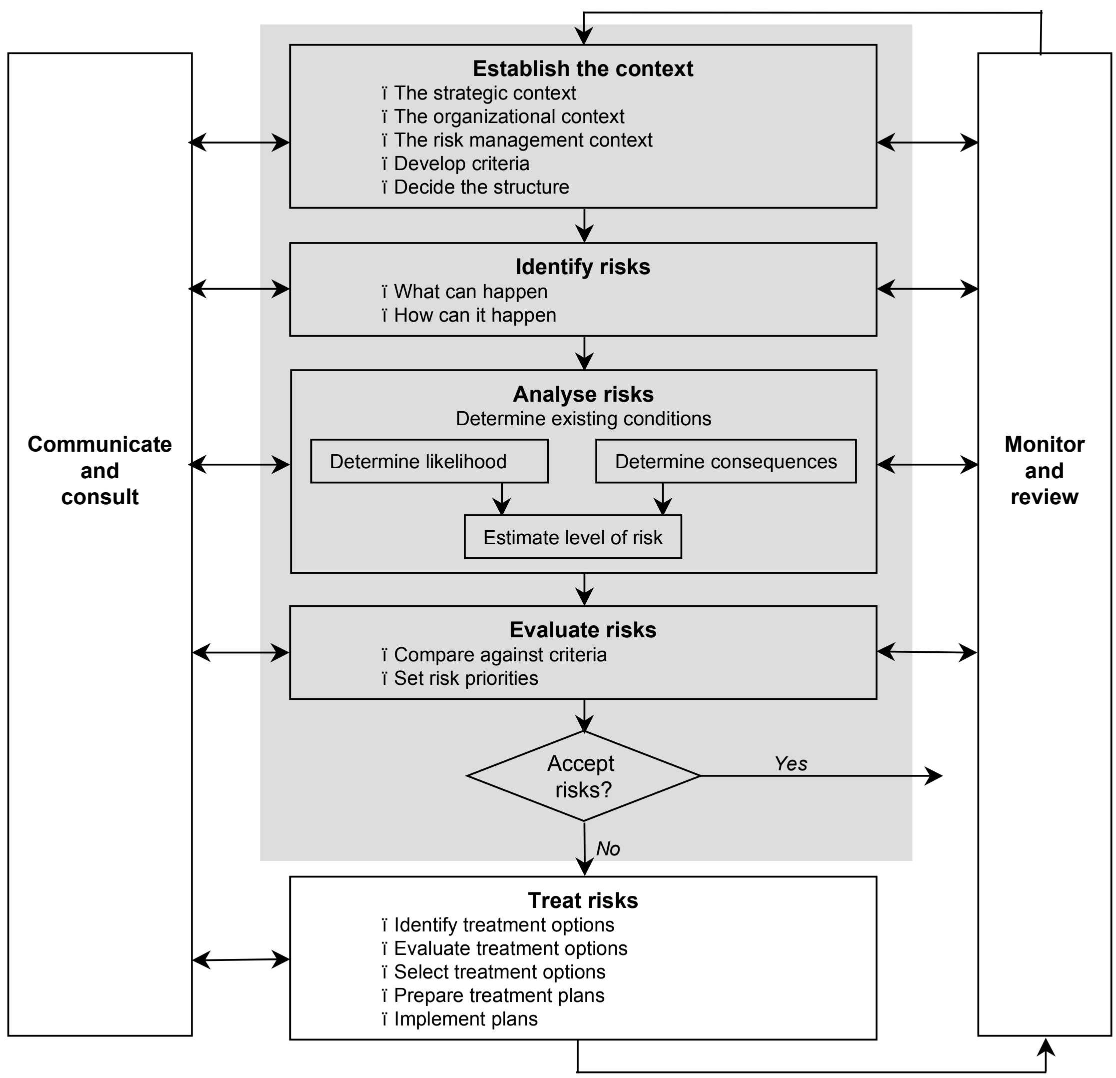

Figure 6. The risk management process of AS/NZS 4360.

Shaded areas indicate activities relevant to risk assessment within the Ecosystem Condition Assessment project.

Source: SA/SZN (1999).

Risk may be considered as a function of the *likelihood* of an event occurring together with its associated consequences, and the magnitude of those *consequences* (SA/SNZ 1999). The framework of an assessment often is presented in the form of a two-way table of likelihoods and consequences, with the resultant risks in the body of the table. Table 6 shows five-point scales for both likelihood and consequence, but scales may be defined to suit a particular application. A third dimension may also be included to incorporate the time frame being considered. Such two-way or three-way tables may range from purely qualitative to strictly quantitative, depending on the available information.

The use of qualitative methods of the form described in the Australian Standard is not yet widespread in natural resource and ecosystem management, but the approach has been recently applied to the Western Rock Lobster fishery in Western Australia (IRC 2002) and to the effects of shellfish farming activities on the marine environment in Tasmania (Crawford 2003).

Table 6. Semi-quantitative risk matrix.

		Consequence				
		Insignificant (1)	**Minor (2)**	**Moderate (3)**	**Major (4)**	**Catastrophic (5)**
Likelihood	**Almost certain (5)**	5	10	15	20	25
	Likely (4)	4	8	12	16	20
	Moderately likely (3)	3	6	9	12	15
	Unlikely (2)	2	4	6	8	10
	Rare (1)	1	2	3	4	5

Risk ratings, as the product of likelihood and consequence, are shown in the body of the table.

Source: SA/SNZ (1999).

5 Trialling an approach to risk assessment for Victorian parks and reserves

5.1 INTRODUCTION

An approach to risk assessment incorporating some of the concepts outlined in Chapter 4 was trialled at two workshops held at Parks Victoria offices in regional Victoria.

The first workshop was held at Halls Gap on 11th August 2003. It was attended by eight PV staff, six of whom were based in the Grampians National Park, one in the Mallee parks and one from the National Parks Division in Melbourne.

Activities included:

- management strategy evaluation,
- hazard identification,
- risk analysis, broadly following AS/NZS 4360, and
- the use of influence diagrams.

The second workshop was held at Mildura on 13th November 2003, and attended by ten PV staff, two of whom had also participated in the Grampians workshop. Nine attendees were based in the Mallee parks, and one was from Melbourne. Prior to the workshop, the facilitators visited Murray-Sunset and Hattah-Kulkyne National Parks in north-western Victoria. The purpose of the trip was to identify a preliminary list of hazards, to identify values that could be used in constructing a hazard matrix (see below), and to draft a few initial influence diagrams. Activities included:

- an initial briefing on the Australian Standard for Risk Management (AS/NZS 1999), the concepts of uncertainty in decision-making (Regan *et al.* 2002) and cognitive biases (Plous 1993) and an introduction to some tools to aid in hazard identification,
- unstructured brainstorming,
- use of a hazard matrix to consider all possible links between selected natural values and potential threats,
- risk analysis, broadly following AS/NZS 4360, and
- the use of fault trees to explore possible events leading to two failures of concern.

5.2 GRAMPIANS WORKSHOP

On the evening prior to the workshop, the objectives of the meeting and the methods to be applied were discussed informally by the facilitator and some of the participants. Previously, all participants had been provided with written background information on qualitative risk assessment, hazard identification and some of the methods used to assist in the identification stage.

5.2.1 Management Strategy Evaluation

The identification of alternative scenarios for the future is the first stage of an approach to natural resources management known as Management Strategy Evaluation (MSE; Smith 1994). The aim of the first session was to build scenarios based on the experience and views of park personnel. The elicitation was undertaken by the facilitator prompting participants to identify possible desirable states for the park in 20 years time. The process aimed to identify context and raise the profile of alternative paths to solve problems, upon which more explicit management models were developed in the afternoon session.

Scenario 1

The level of resourcing for management remains unchanged from the present.

Participants were each given the opportunity to describe characteristics of the park that, in their view, would indicate successful long-term management. They identified the following characteristics:

- Ecological characteristics such as:
  - a range of age classes of vegetation since the last fire, resulting in a diversity of habitats,
  - a low risk of catastrophic fire,
  - reduced populations of introduced species such as foxes, red deer and feral bees,
  - increased populations of threatened species such as the brush-tailed rock wallaby and the heath mouse,
  - increased security for threatened species, and
  - ìadequateî stream flows and ëgoodí water quality.
- Visitor management, including:
  - high visitor satisfaction,

  - more deliberate strategies for visitor management, reducing visitor pressure in the central areas of the park, and
  - unnecessary tracks and roads closed and revegetated.
- Education programs such as the improved use of the park by schools.
- Partnerships, including:
  - good relationships with neighbours,
  - collaborative efforts with neighbours to extend the ìhealthî of the park beyond its boundaries,
  - high level of community support, and
  - co-management of the park with the indigenous community.
- Knowledge base, including:
  - increased knowledge of what is within the park, *e.g.*, species distribution maps,
  - improved understanding of ecological processes,
  - high standard of scientific studies, and
  - increased capacity to detect problems and potential problems.
- Institutional setting, including:
  - less political influence on decision-making for park management, and
  - development and maintenance of highly-skilled and well-informed park staff.

While there tended to be general agreement over desirable characteristics, participants varied in the importance they would ascribe to characteristics. For example, the level of visitor satisfaction was considered to be more important than ecological issues by one participant, but less so by another. Given broad agreement over desirable goals for the park, the group discussed the need for appropriate measures to satisfy audit requirements and internal feedback standards.

Scenario 2

There will be a 90% reduction in funding from present levels, beginning next year.

Participants were asked to outline ways in which desirable management goals may be achieved. For instance, participants were asked whether they would dispense with some goals and concentrate on a subset, and if so, which goals would be forgone. If no goals were

dispensable, participants were asked to describe how they would achieve the full set of goals with a constrained budget.

Some participants favoured the elimination of some management goals. Others favoured retention of all goals, with alternative strategies in place to achieve them. Some of these strategies included:

- improved co-operation between PV and other stakeholders, and
- the development of alternative funding sources such as community support and direct investment by people with a financial interest in the park or the region.

There was no clear consensus on which ecological goals could be compromised (if any) under much more stringent budget conditions. For instance, participants agreed reductions would have to be made in the acquisition of knowledge, but it would be desirable to keep the knowledge base activities progressing, albeit more slowly and perhaps using new partnerships with research organisations and local community input.

Scenario 3

Funding will be reduced by 90% from present levels, and the climate becomes 6°C hotter, thus increasing the risk of fire threefold.

Participants discussed which ecological goals could be sacrificed. They suggested:

- the re-introduction of rock wallabies, and
- the management of red deer.

In general, the group agreed goals should be revised where it is unlikely that management would be effective. For instance, it was pointed out that more fires may in fact wipe out the red deer population in the park, but that foxes would probably still be a concern. It was agreed that educational programs should probably be retained.

Scenario 4

In addition to the changes outlined in Scenario 3, there will be increased pressure to lift visitor numbers by introducing more charismatic fauna, specifically, koalas.

The group concluded that other ecological and management objectives would not be compromised by such an initiative. One participant would resist pressure to introduce more koalas.

Scenario 5

Funding will be reduced to 90% of present levels, but without the added stress of climate change. A change of government results in the park being run by a board of management consisting of farmers and graziers.

The group speculated about the development of new social and ecological hazards. For instance, such a change may precipitate:

- grazing introduced to the park, and
- rock wallabies reintroduced to test the nature of grazing impacts.

Substantial changes in the ecological context of park management would create an imperative for additional monitoring. However, it would be unlikely that other park management objectives would be dispensed with.

Scenario 6

Funding will be reduced to 90% of present levels, but without the added stress of climate change. A change of government results in the park being run by a board of management consisting of farmers and graziers. The new board of management wishes to reduce monitoring and to eliminate foxes that prey on lambs.

The group discussed the role of park managers in this scenario. They concluded that they would still be responsible for managing threatened species and introduced species. The group speculated on the need to couch proposals for monitoring in terms that would make the value of monitoring apparent to a new board. The group agreed water management is a complex issue and may demand more time and resources in the new system in which grazing is supported within the park.

Scenario 7

The level of resourcing for management remains unchanged from the present. However, there are many new introduced species in the park, and it is not clear which of them will be the most damaging.

The group discussed what should be done. Their recommendations were to:

- consider the broader landscape management picture,
- address fire and water management issues,
- encourage community support for the park, *e.g.*, fencing and planting by park neighbours,
- try a major eradication effort for new introductions,
- tolerate those introduced species that do not have major effects on native species, and

- recognise that ecosystems do change.

Conclusions from the MSE session

Under the full range of scenarios explored by the group, the management of social context, introduced species, threatened species, fire and water remained priority activities for park management. These management objectives are not independent of one another. Changes in the factors that influence fire probability have consequences for water quality, threatened species and new invasive species. Changes in the flux of invasive species may have implications for the way in which the park managers interact with the local community, and may in turn be influenced by changes in fire management practices. Most participants were uncomfortable with relinquishing any of the park objectives identified at the outset, even under drastically different social and ecological conditions. Objectives were relinquished only when circumstances prevented managers making a difference to the outcomes.

5.2.2 Hazard identification

Two dominant themes from the MSE session were selected for evaluation: fire and water management. The ecological objectives (assessment endpoints) of park management were re-defined as follows:

- For fire, the objectives included maintaining a range of ecological conditions in the park, with areas of different ages since the last fire, largely focussing on the maintenance of biodiversity and the provision of habitat (Table 7), but also including issues of economics and human health and safety.

- For water supply, the objectives included maintaining ecological flows and habitat in the park, and maintain water quality and volume for stakeholders, encompassing the ecosystem services of purification (and supply) of water and provision of habitat.

- To aid in the identification of hazards for each objective, possible interactions between the hazards and park activities were identified in a hazard matrix (Tables 7 & 8). To minimize differences in interpretation of the hazards among assessors, each hazard was defined in terms of specific consequences.

Table 7. Matrix of hazards to the maintenance of a range of different ecological conditions with regard to age since the last fire versus selected park activities, Grampians workshop.

Hazard	Consequence	Activities							
		Road maintenance	Visitors	Weed/pest control	Change in assets	Research (heritage)	Fuel reduction	Liaison	Water - commercial uses
Burn unit size	wrong distribution of age classes	x			x	x	x	x	x
Flammability of EVC	vegetation will not burn as desired				x		x	x	x
Early suppression of fire	uniformity of compo-sition	x	x						
Total suppression of fire	disease and weed intro-duction	x	x						
Climate change	extreme fires								
Climate change	no fires								
Protection of property	increased fire frequency	x	x						
Personal liability/risk	decreased fire frequency	x	x						
Protection of one threatened species	sub-optimal management for other species	x							
DSE approval	sub-optimal management								
Target class structure	sub-optimal management		x						
Unplanned ignition	sub-optimal management	x	x						

ìxî denotes possible interaction between hazard and activity. Shaded cells in body of table denote interaction not assessed.

Table 8. Matrix of hazards to the maintenance of water supply versus selected park activities, Grampians workshop.

Hazard	Consequence	Activities					
		Visitors	Fire control	Weed control	Pest control	Road maintenance	Water harvesting
Fire	declining volume and quality of water	x	x			x	
Legislation for ecological flows	lack of control sub-optimal management						x
Water harvesting	loss of populations/habitat	x	x	x		x	
Maintenance of water supply infrastructure	loss of populations/habitat	x	x	x	x	x	x
General park infrastructure	reduced water quality (effluent, sedimentation)	x	x	x		x	x
Pest animals	reduced water quality						
Climate change	reduced water yield		x	x	x		x
Bureaucratic disagreements	sub-optimal management		x	x	x	x	x
Effluent and waste	reduced water quality	x	x	x	x	x	x
Visitor activities, *e.g.,* on-site camping, 4-wheel driving	reduced water quality reduced habitat quality	x	x	x		x	x
Poor knowledge of water quality targets	sub-optimal management		x	x	x	x	x

ìxî denotes possible interaction between hazard and activity.

5.2.3 Semi-quantitative risk assessment

Once a list of hazards was agreed for each ecological objective (first two columns of Tables 7 & 8), each assessor independently and subjectively assigned scores on a scale of one to five reflecting:

- the likelihood of the hazard occurring (ranging from almost certain to highly unlikely), and
- the magnitude (severity) of its consequences (ranging from catastrophic to slight) where a score of one indicated a rare event or an insignificant consequence, while a score of five indicated an almost certain event or catastrophic consequences.

A risk rating was calculated from the product of the likelihood and consequence, with possible scores ranging from 1 to 25. From these risk ratings, the hazards were ranked for

each assessor, from highest priority to lowest. During the workshop these calculations were undertaken using the specialized computer program ìSubjective Risk Assessmentî (Campbell, H. and Burgman, M. 1999. Interactive software for PC and MacIntosh environments. University of Melbourne). Some calculations were also performed after the workshop using a general statistics package, Systat (Ver. 10 for Windows. SPSS Inc., Chicago, IL).

When a risk assessment is carried out by a group rather than a single individual, some disagreement among assessors is to be expected as perception of risk is very much an individual matter. It is possible to compare the risk rankings of pairs of assessors using Spearmanís rank correlation. A value of 1 indicates perfect agreement. A value of 0 indicates that the two people neither agree nor disagree; their relative assessments are essentially random with respect to one another. A value of -1 indicates two people have completely opposite positions.

For the fire objective, correlations ranged from -0.53 to +0.53, with a median value of +0.18. With a view to the possible resolution of some types of disagreement, the correlations were examined and individual hazards were discussed. This resolved some differences in understanding about time scales and the interpretation of likelihoods, and also resulted in somewhat clearer terms and definitions. Following the discussion, the assignment of likelihoods and consequences to each hazard by individual assessors was repeated, leading to a second set of risk ratings for each hazard. Hazards were again ranked, and a second round of correlations was calculated. Figure 7 shows the correlations between pairs of assessors that resulted from both the first round and second rounds of assessment. In the second round, both the minimum and maximum values increased, to -0.33 and +0.55 respectively, indicating that some linguistic uncertainties had been resolved. However, the median correlation fell slightly in the second round, from +0.18 down to +0.11, as some pairs of assessors found themselves in even greater disagreement after the second round. There were nearly as many decreases in correlation coefficient as increases (Figure 7).

Given that at least some of the original linguistic uncertainties had been addressed, it is likely that remaining disagreements were a result of genuine differences of opinion. For instance, one participant felt that any hazard that detracted from the objective of maintaining different vegetation age classes should be given a maximum value of 5. Other participants were willing to accept lower scores.

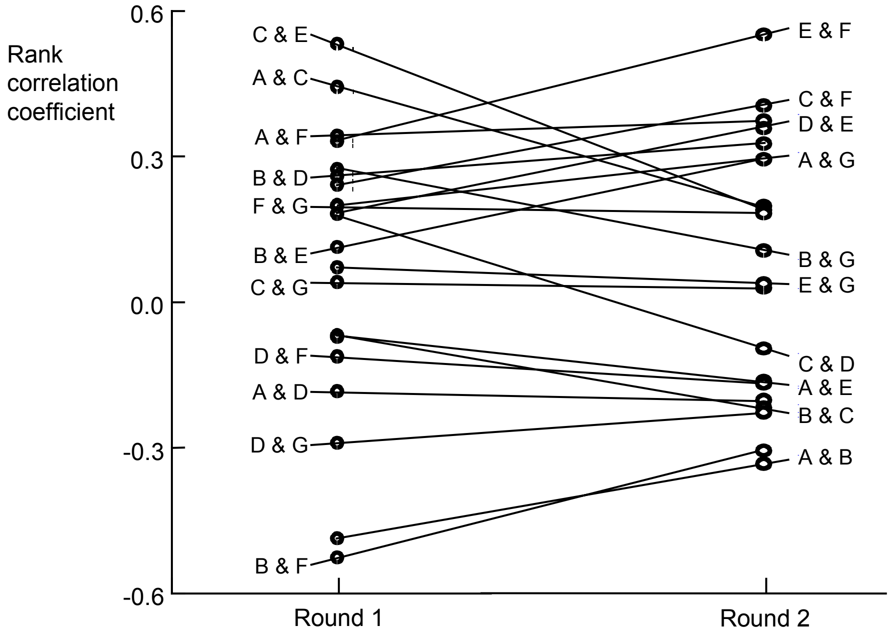

Figure 7. Spearman's rank correlation of risk rankings between assessors for the objective of maintaining a range of ecological conditions in terms of time since last fire, Grampians workshop.

For the water supply objective, only six of the original eight assessors were present, and it was explicitly agreed that the time frame for consideration should be 5 years. With regard to the rank order of the hazards, there was less disagreement overall among assessors for the water supply assessment. Correlation coefficients ranged from -0.02 (*i.e.*, no particular pattern) to +0.84, with a median value of +0.40. Time constraints precluded the group discussing their differences and re-evaluating their assessments.

There are no ìcorrectî scores for likelihood and consequence in this style of assessment. The range of values reflects different opinions about fact, and different weights that reflect each personís personal values and perceptions. It is important that differences such as those found here be recognised in the evaluation of hazards. Figure 8 shows the hazards for the fire objective ranked from highest to lowest by their mean risk rating, averaged across all assessors. It also show the level of uncertainty associated with each mean, as a horizontal bar indicating the range of ratings spanned by the group of assessors. For example, in the second round of the fire assessment, participants were largely in agreement that changing climate resulting in no unplanned fires presented a low risk to objectives, their level of agreement being indicated by the narrow range of risk ratings [3, 6]. In contrast, target class structure scored risk ratings ranging from 3 to 25 (from a possible range of 1 to 25), indicating substantial disagreement among the assessors. It is very likely that further

discussion about the ideas behind the different opinions would reconcile some of these differences, resulting in greater (although not perfect) agreement.

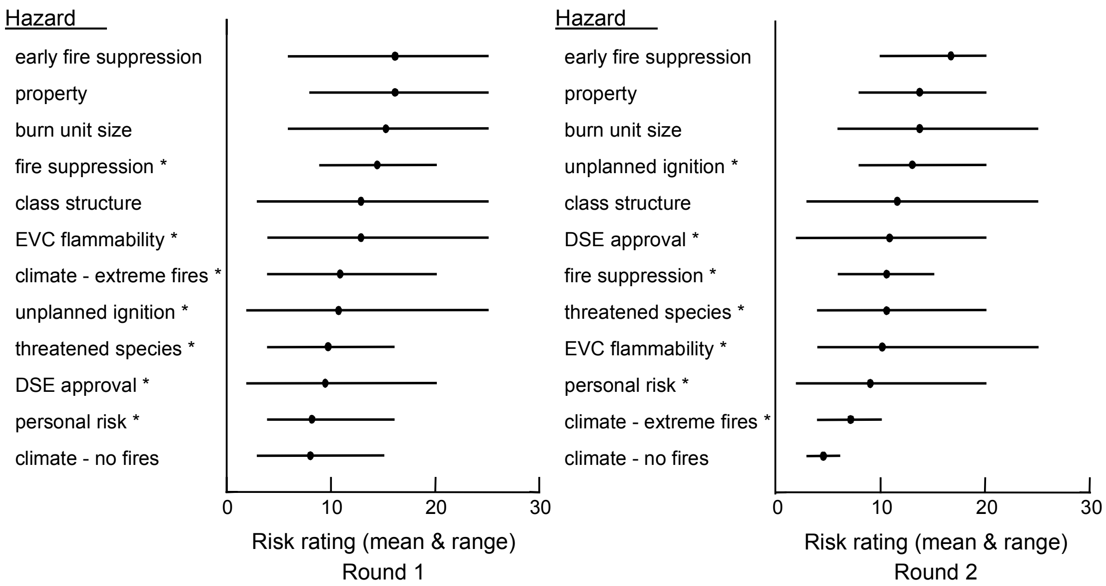

Figure 8. Risk rating of hazards to the maintenance of a range of ecological conditions in terms of time since last fire, Grampians workshop.

An asterisk indicates a hazard whose rank order changed between rounds.

In both rounds of the fire assessment, early fire suppression, protection of property, and burn unit size were seen as the top three hazards to the maintenance of a range of vegetation age classes (Figure 8). In the second round, uncertainty about the first two hazards was reduced relative to that in the first round, presumably as a result of the discussion. However, for the third hazard, burn unit size, the level of uncertainty was the same for the two rounds.

For the water supply objective, ranking of the hazards by mean risk rating is shown in Figure 9, with uncertainty again indicated by the range of ratings associated with each mean. The top priority hazard was the harvesting of water, followed by poor knowledge of water quality targets and then bureaucratic disagreements. The range of risk ratings for hazards ranked second to sixth indicates considerable uncertainty among assessors for these hazards. The results of this step were the precursor to the development of more explicit conceptual models.

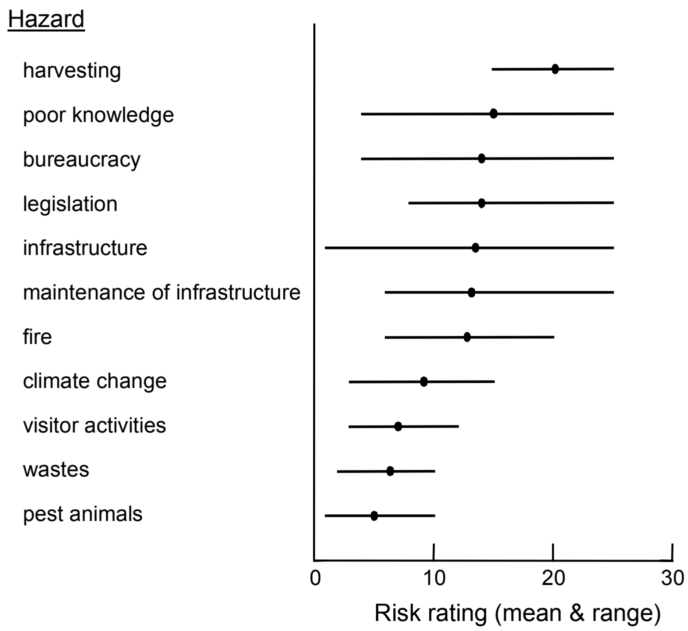

Figure 9. Risk rating of hazards to the maintenance of ecological water flows, Grampians workshop.

5.2.4 Influence diagrams

An influence diagram is a graphical model used to represent the structure of a decision problem and the relationships among its components (Shachter 2003). It should facilitate understanding of the knowledge, uncertainties, objectives and decisions involved, and assist in communication of the issues to other parties (Morgan & Henrion 1990).

A simple form of influence diagram was used to facilitate understanding of the factors affecting water yield from the park, with particular reference to three concerns related to reduced yield:

- the possible decline in the abundance and distribution of threatened species,
- the possible decline in the quality of riparian and in-stream habitats, and
- the possible decline in the quality of potable water.

It was recognised at the outset that the factors either affecting water yield or affected by it might vary depending on the exact location within the park that the assessment referred to. Figure 10 shows an influence diagram for a location within the park, upstream of the point at which water is harvested.

During the workshop, the focus was on relationships of various factors to water yield, and possible relationships among factors were not specifically addressed. However, some of these additional relationships have been included in the influence diagram (Figure 10). This illustrates the value of building the diagrams. They elicit thinking about relationships among ecosystem components that are easy to ignore or overlook when people focus on individual hazards in isolation. Often they lead to a revision of the list of hazards, and to a reassessment of the likelihoods and consequences of hazards. They summarise thinking about how an ecosystem functions.

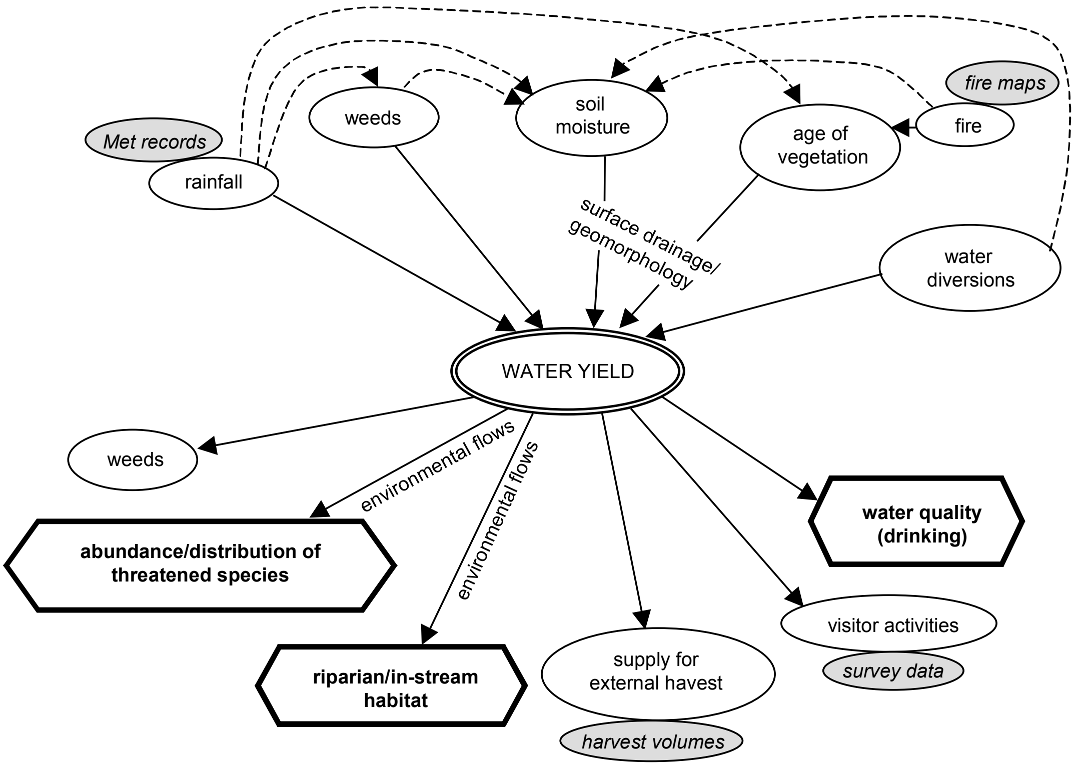

Figure 10. Influence diagram for water yield from the park, Grampians workshop.

Solid arrows indicate relationships identified during the workshop. Dashed arrows indicate those identified subsequently.

In this case, the construction of the influence diagram elicited the following comments from participants:

- People outside the Grampians area may well have a different view of priorities.
- Areas downstream of the water harvest point may be more important to Parks Victoria than the upstream area considered in the diagram, as they will be affected by the

harvesting process, with possible repercussions in terms of reduced environmental flows.

- The diagram might prove useful in considering the issues addressed in the hazard matrix, possibly in terms of the weighting applied to different hazards.

The group discussed the potential for logic trees to be used to inform policy-makers and funding organisations about recognising the value of park management. For instance, the trees make apparent the link between fire management, vegetation age class structure, and water yield. The elements cannot be managed in isolation. If used strategically and effectively, resources devoted to one element, such as the management of age structure, are a necessary part of the delivery of other management objectives, such as water yield.

5.2.5 Discussion of the Grampians workshop

The Grampians workshop trialled the application of several established tools for risk assessment and decision-making to ecological problems associated with the management of a national park. Management strategy evaluation (scenario building), subjective risk assessment, hazard matrices and influence diagrams were used collectively to identify and assess hazards.

Additional tools such as Hazop and FMEA were identified in the preliminary background reading, but were not employed during the workshop due to lack of time. However, they would be appropriate methods to apply to the problems addressed in the workshop.

In the subjective risk assessment process, the issue of the time frame over which hazards may eventuate was not addressed explicitly. However, this could be done by including a score for the immediacy of an event in the calculation of the risk rating, and would avoid the potential difficulty of assessors considering different time frames when assigning their subjective likelihood and consequence scores. The imminence of threats is a core part of FMEA, one of the reasons why this approach may have particular utility in park management.

The application of these methods in park management will need to consider how hazards are benchmarked, *i.e.*, tied to values that reflect the importance of a risk. Values resulting from the product of a likelihood and a consequence rating need to be tied to agreed standards, so that auditors and senior managers can be assured of appropriate responses and lines of responsibility for managing risks of different seriousness.

Development of more explicit models may begin with drafting influence diagrams and logic trees. They summarise available understanding about ecosystem processes succinctly. They may serve to assist park managers to meet management goals by communicating this understanding to other stakeholders and managers.

5.3 MALLEE PARKS WORKSHOP

This workshop focussed on the natural values in the Hattah-Kulkyne National Park and the maintenance of biodiversity, to give the deliberations a concrete context at a scale at which they would be applied in routine practice.

5.3.1 Hazard Identification

The unstructured brainstorming session focussed on perceived major hazards to the natural values of Hattah-Kulkyne National Park, and resulted in a hazard matrix of 10 natural values and 12 potential threats to those values (Table 9). In a full application, each hazard would need to be examined and ranked, leading to a comprehensive screening-level assessment in which hazards that pose minor, acceptable or trivial risks are excluded from further consideration. However, for this workshop, a subset of ten hazards addressing various aspects of ecosystem condition was selected for further consideration. A detailed definition for each hazard was agreed on for the next stage of the assessment:

- the presence of trespassing or reintroduced cattle for more than 6 months in any one year affecting four listed communities in the Pine/Buloke/Belah vegetation complex over the next 10 years
- predation by feral cats reducing lizard populations by 20% over the next 10 years
- suboptimal environmental flows causing dieback in more than 20% of riverine woodlands
- density of feral bee colonies greater than 75 per km^2 over the next 10 years, thus affecting the availability of tree hollows
- inappropriate fire regime resulting in young or old growth age classes of Mallee vegetation departing more than 50% from ideal
- rabbit or goat grazing resulting in less than 5% of tree and shrub stems having a basal diameter of less than 5 cm in the four listed communities in the Pine/Buloke/Belah vegetation complex
- predation by foxes resulting in negative growth of the population of Malleefowl *Leipoa ocellata*
- kangaroo grazing resulting in negative growth of populations of the Regent parrot *Polytelis anthopeplus*
- absolute biomass of aquatic weeds in wetland communities increasing by 20% or more
- fragmentation of the landscape resulting in the loss of at least one Mallee bird species

Table 9. Hazard matrix of environmental values in Hattah-Kulkyne National Park and potential threats to those values.

Environmental Values	Potential Threats											
	Trespass or re-introduction of cattle	Overgrazing by kangaroos	Grazing by rabbits and goats	Inappropriate environmental flows	Irrigation impacts on groundwater	Predation by feral cats	Predation by foxes	Feral bees	Presence of weeds	Fragmentation of landscape	Inappropriate fire regime	Drought severity/frequency
Riverine woodlands	X	X	X	X	X		x	X	X		X	X
Four listed communities in Pine/Buloke/Belah complex	X	X	X		X		x	X	X		X	X
Malleefowl	x	x	X			X	X			X	X	X
Regent parrot	X	X	X	X	X	X	X	X		X	X	X
Lizards	X	X	X			X	X			X	X	x
Mallee bird community	X	X	X	X	x	X	X	X	X	X	X	X
Wilderness values	X	X	X		X	X	X	X	X		X	X
Wetlands	X	x	x	X	X	X	X	X	X		X	X
Old growth/young Mallee mosaic	x	X	X		x			X	x		X	
Availability of hollow-bearing trees	X	X	X	X	X			X		X	X	X

A cross denotes a possible interaction between value and threat, with ìXî indicating a strong interaction and ìxî indicating a weak one. A highlighted cell denotes an interaction considered in the next stage of assessment.

5.3.2 Subjective rating and ranking of hazards

A semi-quantitative risk assessment was undertaken as described in Section 5.2.3.

The rank order of mean risk ratings of the hazards in the two rounds of assessment is illustrated in Figure 11. The risk to wetlands of inadequate or untimely environmental flows was seen as the most important of the ten hazards considered, while the indirect effects of kangaroo grazing on Regent parrot populations was believed the least important. The differing opinions among the workshop participants about the likelihoods and consequences they believed to be associated with each hazard resulted in a range of risk ratings for each hazard, representing the uncertainty about each mean rating. For example, uncertainty was greatest for the effects of grazing by rabbits and goats, with risk ratings ranging from 4 to 20 in each round. In contrast, kangaroo grazing was the hazard on which participants were in the greatest agreement, as evidenced by its relatively small range of risk ratings. Shifts in the rank order of the hazards between the two rounds of assessment occurred for six of the ten hazards, and indicate changes in the views of the participants between the rounds.

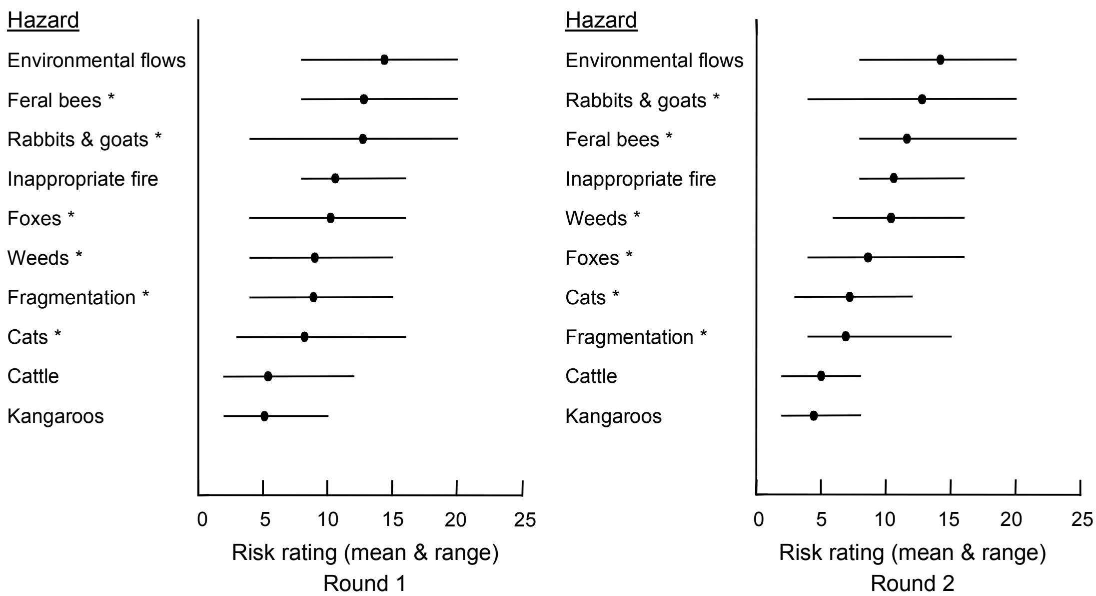

Figure 11. Risk rating of selected hazards to natural values in Hattah-Kulkyne National Park.

An asterisk indicates a hazard whose rank order changed between rounds.

The risk to wetlands of inadequate or untimely environmental flows was ranked first or equal first by 50% of participants in each round of assessment, and never ranked lower than fifth. The next hazard in terms of frequency of top ranking was the risk of rabbit and goat grazing

to communities in the Pine/Buloke/Belah vegetation complex, which was ranked first or equal first three times in each round of assessment.

Spearmanís rank correlation coefficients between pairs of workshop participants are shown in Figure 12. In the first round of assessments, correlations ranged from -0.08 to 0.93, with a median of 0.48. There were no strongly negative values, indicating no strong disagreement in the rank order of hazards among participants. In the second round of assessment, correlations improved for 33 of the 45 pairings of participants, and the median rose to 0.58, although the minimum correlation fell slightly to -0.11.

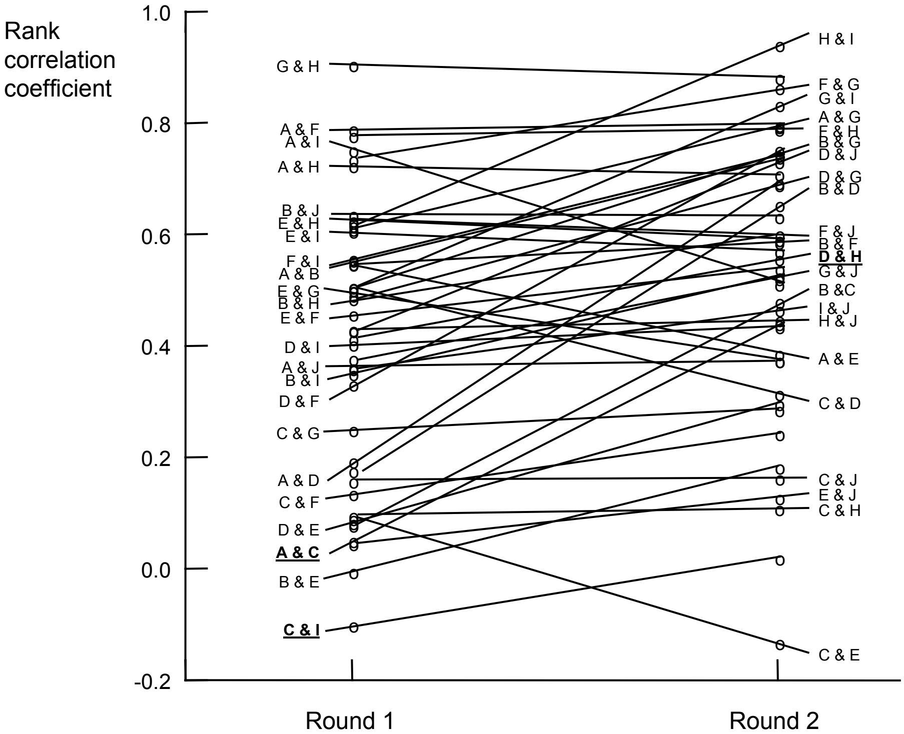

Figure 12. Spearman's rank correlation of risk rankings between pairs of Mildura workshop participants.

Initially, discussion between the rounds of assessment focussed on pairs of assessors with substantial disagreement in their rank order of hazards. Examples are given below:

Participants C and I

- The rank correlation was -0.08 in the first round.

- *I* rated aquatic weeds as his highest risk, with a rating of 15 (likelihood 3 x consequence 5), while *C* ranked this hazard as his lowest priority with a rating of 4 (likelihood 2 x consequence 2).
- *I*, having already observed some species floating downstream, believed that weeds constitute an important hazard for the next ten years. In contrast, *C* believed that there has been adequate opportunity for weeds to infest the wetlands, and observed that there has been no major infestation to date.
- By the end of the discussion on weeds, it also became apparent that each assessor was considering different weed species.
- The rank correlation in the second round increased slightly to 0.05.

Participants A and C

- The rank correlation was 0.08 in the first round.
- They differed in their priority hazards, with *C* ranking feral bees (risk rating = 20), foxes (16) and cats (16) as his top three hazards, while *A* considered rabbits and goats (risk rating = 15) to be the most serious hazard followed by environmental flows, feral bees, inappropriate fire, foxes, and weeds (each scoring 12).
- Cats: *A* and *C* agreed that the consequences of cat predation were high (4), but differed on the likelihood of cats causing an impact over the next ten years.
- Feral bees: They agreed on likelihood but disagreed on consequence, *C* believing there is a trend of increasing numbers that will cause a problem in future, while *A* considered that fauna such as parrots have demonstrated an ability to exist at the current ìhighishî numbers of bees.
- The rank correlation increased to 0.47 in second round.

Differences in hazard ratings were also considered for participants who were in more general agreement about the rank order of hazards.

Participants D and H

- The rank correlation was 0.44 in the first round.
- Both participants gave environmental flows a risk rating of 16. This was the highest rating given by *H*, and was followed by rabbits and goats (12) and inappropriate fire (9). However, the rating of 16 placed environmental flows equal second on *D*ís list of hazards, as feral bees scored higher (20) and cats rated equally (16).

- Feral bees: Based on generally observed impacts, *H* saw the consequences of feral bees as minor (2), contributing to an overall rating for this hazard of 8, while D was thinking specifically of effects on Major Mitchell parrots, and thus considered consequences as major (4).
- Both participants acknowledged that the rank assigned to a particular hazard may depend on an assessorís previous exposure to the different hazards.
- The rank correlation increased to 0.58 in the second round.

5.3.3 Fault Trees

Fault trees were constructed around two hazards from the list in Section 5.3.1.

A fault tree for the failure of Blackbox and River Red Gum regeneration is shown in Figure 13. The basic tree as devised by the workshop facilitator had 9 elements, but a further 11 elements were added during the course of the discussion among workshop participants.

In addition to identifying additional possible contributory factors in the failure of regeneration, the discussion also distinguished between types of factor. Some, such as rainfall, are clearly beyond the control of the management agency, and are in fact monitored by other organisations. Others factors, for example grazing pressure, may be subject to both management action and monitoring programs. It was also recognised that little was known about another group of factors, such as the frequency with which treefalls and deliberate interference with regulator gates may occur.

In the second fault tree, the consequence component of a hazard from Section 5.3 served as the ìtop eventî or ìfailureî. The tree was constructed for a decline in lizard populations of the park (Figure 14), with predation by feral cats being one of the possible contributing events initially introduced by the facilitator. As with the previous tree, discussion generated additional events that could contribute to the failure.

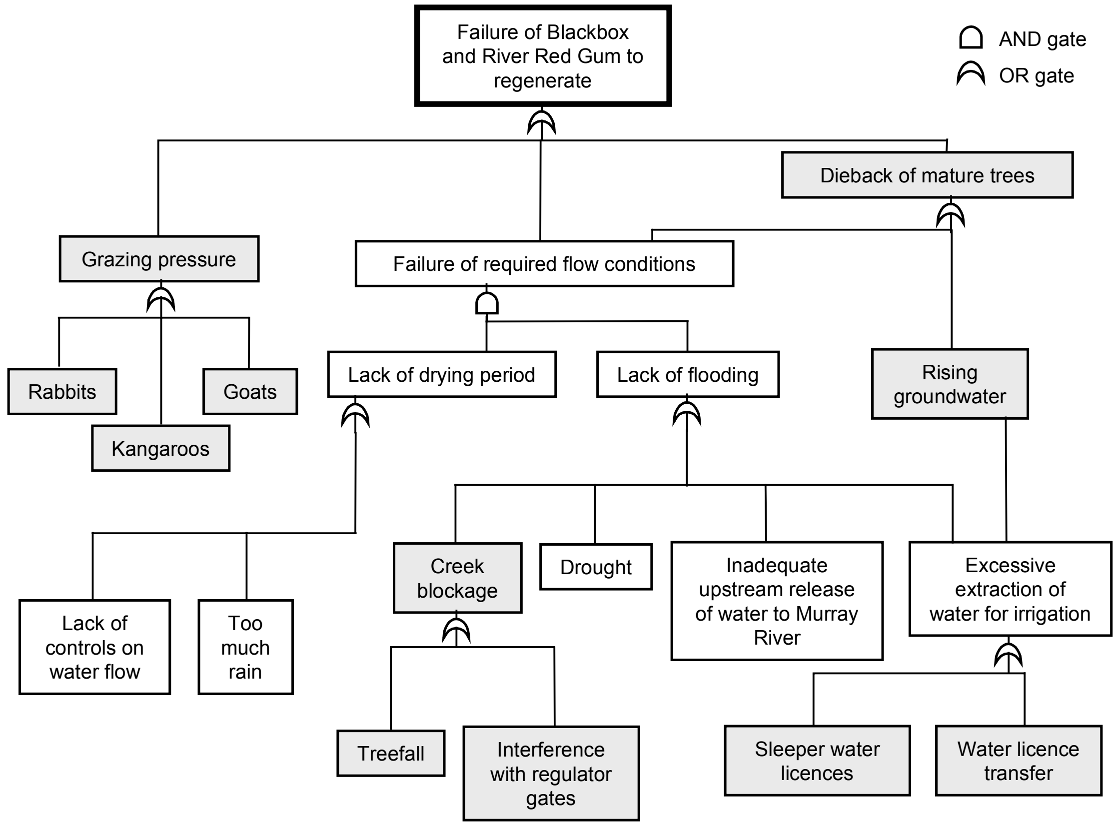

Figure 13. Fault tree for failure of Blackbox and River Red Gum stands to regenerate, Mallee parks workshop.

Unshaded boxes represent events initially included in the tree, shaded boxes those added during the discussion.

The tree illustrated that feral cats are not the only factor that could affect lizard populations, and identified several management actions that could indirectly affect lizards. For example, control measures resulting in reduced populations of foxes could reduce predation pressure on lizards and thus allow an increase in their numbers. It was also pointed out that if a program such as the adaptive experimental management program for fox control resulted in no effect on lizard populations, the fault tree would suggest alternative mechanisms that may be limiting the lizard numbers.

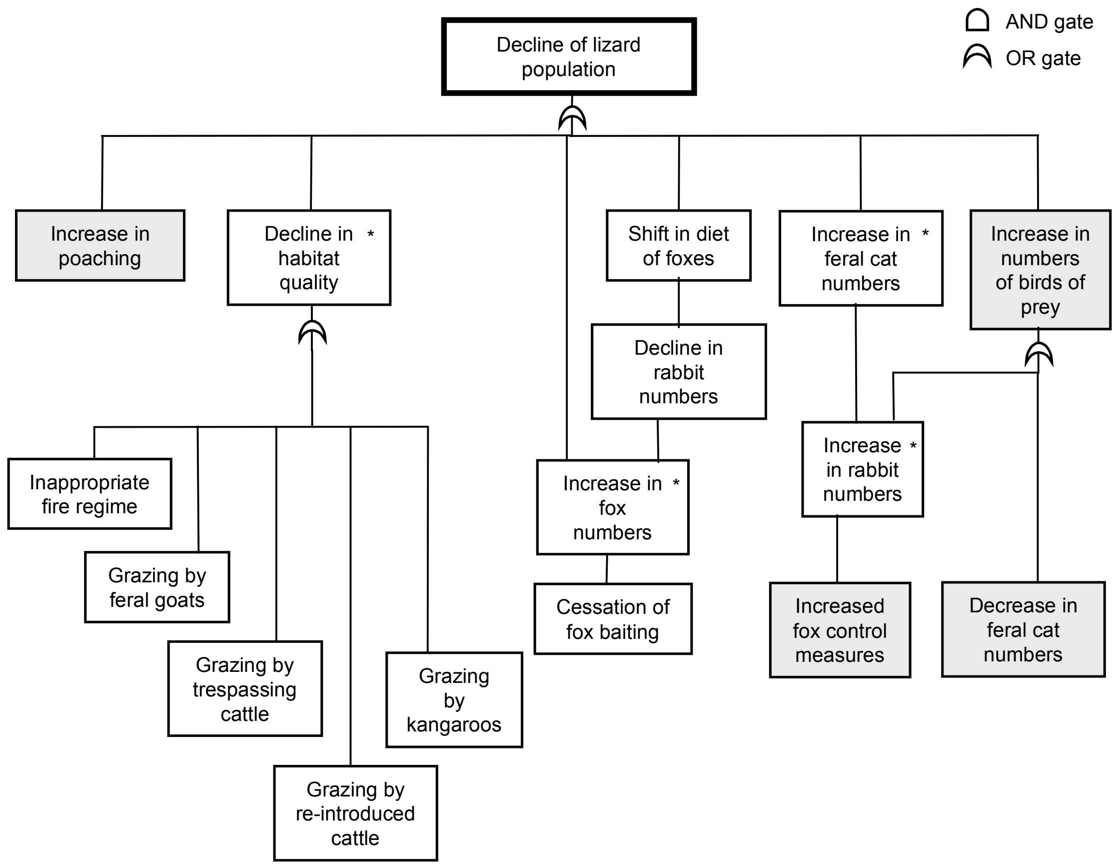

Figure 14. Fault tree for decline in lizard population, Mallee parks workshop.

Unshaded boxes represent events initially included in the tree, shaded boxes those added during the discussion. Asterisks indicate events where more data would be desirable.

5.3.4 Discussion of Mallee parks workshop

The workshop described here was concerned not simply with performing a qualitative risk assessment, but with expanding the approach outlined in the Australian Standard to specifically address some potential sources of uncertainty, and to acknowledge uncertainty in the results of the assessment.

Differences of opinion about the relative importance of hazards may come about because of differing interpretations of vague or ambiguous language, or as a result of cognitive biases. But there may also be genuine differences arising from different personal experiences and beliefs. It is as important to preserve these genuine differences and take them into account when making management decisions as it is to eliminate those differences that arise through misunderstanding and misinterpretation.

Consider two hazards rated as being of equal importance in terms of some measure of central tendency, one with a small range of variation about the central measure, and the

other with a large range. If a broad spectrum of assessors agreed that the hazard was of a particular level of importance, an appropriate management action might be implemented with some degree of confidence. If, however, there was substantial disagreement, the immediate need may be to obtain more information on the hazard and its possible consequences, or to invoke an adaptive management strategy that both informs and manages. It is for this reason that the final ranking of hazards presented in Figure 12 includes a measure of the associated uncertainty about each mean rank.

The participants in this workshop constituted a relatively homogeneous group of assessors in terms of their professional expertise, all being engaged in national park management. However, even within such a homogeneous group, there were differences of opinion, as demonstrated by the poor correlation for many pairs of participants in the first round of assessment (Figure 8). Burgman (2001) reported qualitatively similar median values for Spearmanís correlation in two similar trials, one using tertiary students and the other with environmental scientists from regulatory authorities or management agencies.

In the second round of assessment, the median correlation increased by 0.10, indicating a general increase in the level of agreement among participants. Similar increases were also reported by Burgman (2001) in his trials. This may be attributed to some reduction in ambiguity, vagueness or underspecification (Regan *et al.* 2002) in the definitions of the hazards. For example, when participant *C* considered the impact of feral bees, he was anticipating effects from increasing numbers of bees in the future, while *A* was considering the affects of bee numbers as they are at present. Once this difference in definition of the hazard was identified, their scores for this hazard moved closer together.

However, in spite of the increase in the median correlation coefficient in the second round, the level of disagreement actually increased for 27% of participant pairs, indicating that genuine differences of opinion not only remained after the reduction in linguistic uncertainty, but may even have strengthened. One cause of different prioritizing of the hazards appeared to be differing interpretations of the available ecological evidence, for example, those of participants *C* and *I* in relation to aquatic weeds. This highlights the importance of considering a range of opinions as to what might eventuate from the current status and trends of the system.

Including a wider range of participants, for example, adjoining landholders, tourism operators and members of ìFriendsî groups, would introduce a greater range of opinion and experience to the assessment, and would be likely to result in greater uncertainty in the prioritizing of hazards. However, such a process would be more inclusive. Assessment outcomes may thus be more acceptable to stakeholders than if they were excluded from the

process (Burgman, in press). The system also has the potential to explain the thinking behind management priorities recommended by Park managers.

Even with the level of disagreement that was evident among participants, it was generally accepted that the risk to wetlands of inadequate or untimely environmental flows was an important issue, ranked first more frequently than any other hazard, and never ranked lower than fifth by any participant. Thus, this hazard would clearly seem to be the priority hazard among those considered. While environmental flows may be largely beyond the control of the management agency, further exploration revealed some aspects of the problem in which it could play a contributory role.

Development of the fault trees was the means of eliciting additional information from workshop participants, resulting in the identification of a relatively large number of additional factors which may contribute to the ìtop eventî. The process of developing the tree also resulted in the identification of factors about which more information is required (Hayes 2002b), for example, the frequency of treefalls that lead to creek blockages in the fault tree dealing with regeneration. The fault trees themselves provide a record of the reasoning behind decisions to manage or monitor certain events, or to take no action in the case of others, and thus demonstrate the ecological expertise of park staff. They can also can be used to assist in communication with external stakeholders.

The workshop was undertaken as an experimental exercise, and occupied a single day. The shortage of time limited the ranking exercise to a subset of the possible hazards and permitted only a brief exploration of ecological relationships. In reality, considerably more time would be spent in the elicitation process, perhaps 3 hours a day, 3 times a week for two or three weeks. The minimum that could be hoped for in assessing the hazards for a single park would be one half-day for a hazard identification process, one half-day for hazard ranking and re-ranking, and one half day for some detailed development of influence diagrams and logic trees for some of the most serious hazards. The group of participants would be more diverse, and the list of hazards to be analysed would not be artificially truncated for convenience. Depending on the experience and expertise of the participants, background information on existing knowledge of the system may be provided. However, the same effort to overcome linguistic uncertainties and to retain genuine differences of opinion would be essential to produce a transparent and informed risk assessment to improve decision-making for ecosystem management.

5.4 RESPONSES TO THE WORKSHOPS FROM PARKS VICTORIA STAFF

Four individual responses were received from participants in the workshops. Their observations are summarized below:

- A short time at the beginning of the workshop presenting information on the methods to be used appeared to be more effective than simply providing written information prior to the workshop. (It is likely that Parks staff had little time for preliminary reading, given the time commitment in attending the workshops.)
- The preliminary reading was unnecessarily technical, and the workshop presentation also suffered from this failing at times.
- A one day workshop is very rushed, and does not allow sufficient time to fully assess major threats, *i.e.*, to generate a ìrealî outcome.
- The workshop offered an innovative and achievable approach to resolving issues when little data is available.

6 Risk Assessment in Parks Victoria

6.1 RECOMMENDATIONS FOR RISK ASSESSMENT

Undertake group assessments to incorporate a diversity of thoughts on an ecological issue, and avoid the personal biases of any one individual. The more broadly-based the group, the better the assessment will be.

To minimize unforseen outcomes in the future, include all possible valued attributes and potential threats to them in the initial stages of the risk assessment. If the hazard matrix becomes unwieldy, hazards might be grouped by conservation objective or assessment endpoint to produce a number of smaller matrices for a single park, provided some sensible prioritisation of hazards from different matrices can subsequently be applied.

Define hazards clearly and in relation to specific consequences to reduce disagreement on risk that may arise from differing interpretations of the same hazard. A one to one relationship between hazards and consequences for the purposes of the assigning of likelihoods and consequences may produce a long list of hazards for assessment, but should be worthwhile in terms of the reduction in unnecessary uncertainty.

For informed decision-making, the degree of uncertainty about the risk associated with particular hazards should be explicitly incorporated in any priority listing. The uncertainty is not simply a nuisance. It is valuable in that it indicates that a range of opinion exists and may also be indicative of a need for additional information.

Use tools such as influence diagrams and fault trees to:

- clarify thinking for those involved in their creation,
- explain the logic behind management decisions to interested parties,
- provide a record of the logic behind management decisions, which may be useful at times of review, or when new staff are engaged, and
- demonstrate to external stakeholders, the level of understanding and expertise of the staff responsible for the risk assessment.

Repeat the risk assessment on a regular basis (perhaps every two or three years), both to identify any new attributes or threats and to detect any change in the status of existing ones.

6.2 RISK ASSESSMENT AND THE DEVELOPMENT OF MONITORING PROTOCOLS BY PARKS VICTORIA

The ecological risk assessment framework outlined in this report could be used to provide a formal basis for the selection of monitoring variables. The prioritisation of hazards it produces would allow resources to be allocated to monitoring the most crucial attributes of a Park, and those at greatest risk of damage, as part of an overall risk management process (Figure 6).

The two workshops reported in Chapter 5 produced simple lists of hazards in order of the perceived risk attached to each, with an indication of the uncertainty about the risk rating of each hazard (Figures 8, 9 & 11). A list of this form could be used to identify which hazards may be considered as priorities for monitoring and/or risk reduction measures on ecological grounds. However, had the hazard identification stage not been simplified for the purposes of the trials, the lists would have been considerably longer and potentially more complex. For example, the hazard matrix for the Mallee trial initially identified 103 plausible interactions between valued attributes and potential threats from the total of 120 possibilities (Table 9). Furthermore, presenting the 103 hazards as a simple list would not directly address the situation of any one attribute facing multiple threats, or any given threat potentially impacting several valued attributes. However, presenting the risk ratings as a matrix rather than a simple list would allow these circumstances to be identified with relative ease. The ratings themselves could be presented in the matrix, or they could be categorised (*e.g.*, as in Table 10) to readily identify a set of high risk values or threats for consideration for monitoring.

Table 10. Categories of risk.

		Consequence				
		Insignificant (1)	**Minor (2)**	**Moderate (3)**	**Major (4)**	**Catastrophic (5)**
Likelihood	**Almost certain (5)**	5	10	15	20	25
	Likely (4)	4	8	12	16	20
	Moderately likely (3)	3	6	9	12	15
	Unlikely (2)	2	4	6	8	10
	Rare (1)	1	2	3	4	5

Risk ratings, as the product of likelihood and consequence, are shown in the body of the table. In this particular scheme, risk ratings have then been categorised as follows: 15ñ25 high (dark shading), 5ñ12 moderate (light shading), and 1ñ4 low (unshaded).

Source: SA/SNZ (1999).

Table 11. Generic risk matrix, with risk ratings categorised as High, Medium or Low.

		Potential Threat										**Level of Concern**
		T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	
Valued Attribute	**A1**	M		L-M	L-M	L-M	M	L-M		M	M-H	2
	A2	M-H	M	M-H	H	H	H	M-H	L-H		H	3
	A3	L-M		M	L-M	L-M	L-M	L		L	L-H	2
	A4		L-M	L-M						L-M	M-H	2
	A5	L-M	L-M	L	M	L-M	L	M	L	L	L-H	2
	A6	L	L	L-M	L		L-M	L	L	L	M	1
	A7		L-M	L-M	L	M	L		M	L		1
	A8			M	L-M	M	L-M	M	M	L	H	2
	A9					L-M	L			L-M	M	2
	A10	L-H	H	M-H	M-H	M	H		M-H	M	H	3
Level of Concern		2	2	2	2	2	2	2	2	1	3	

Note that uncertainty in the risk ratings has been carried forward into the categories.

A generic example of a risk matrix showing categories of high, medium and low for risk is given in Table 11. In addition, the risks posed to each attribute have been summarized in the final column, and the risks posed by each threat in the last row. By simultaneously considering multiple values and threats across a park, including attributes such as the biodiversity surrogates discussed in Section 2.5.1, the risk assessment could be considered to be moving towards an ecosystem-based approach. However, the validity of this claim depends on the initial hazard identification stage encompassing a wide range of values and threats. Essentially, any ecosystem management system will result in good conceptual models. The degree of resolution in these models will depend on the state of ecological knowledge, and the social and ecological imperatives to make predictions and manage particular attributes of the system, such as water, fire probabilities, and invasive and threatened species.

Given that resources for monitoring programs are virtually always limited, it is appropriate to consider applying different levels of monitoring effort in accordance with the perceived level of concern with overall risk. The three-tiered approach to monitoring proposed for rare plant species by Menges and Gordon (1996) could be adapted for the Parks Victoria framework. Their approach incorporated the following levels of monitoring effort:

- Level 3: intensive monitoring of populations for population viability analysis.
- Level 2: quantitative monitoring of population size or condition for trend analysis.
- Level 1: broad-scale survey of population or habitat distribution for mapping purposes.

Recognizing that PV staff in any single park are unlikely to be able to undertake more than two or three monitoring programs at a time (C. Miller, PV, pers. comm.), we propose that the Menges and Gordon approach be modified as follows for the PV monitoring framework:

- Level 3: entities are deemed to be at high risk. Those to be formally monitored should be selected from this level, with the final choices depending on factors such as ease and cost of measurement, and the ability to detect ecologically meaningful change. Appropriate measurement endpoints could then be defined for the selected attributes or threats, for example, percentage change in the distribution of habitat A2, or population numbers of predator T10 (Table 6.2).
- Level 2: entities are deemed to be at moderate risk. A watching brief may be appropriate.
- Level 1: environmental values or attributes are considered to be at low risk. No monitoring to be undertaken, but the risk to these attributes should be reassessed in subsequent rounds of the assessment process.

Basing a monitoring strategy on risk interaction matrices would be inherently adaptive in nature because the selection of monitoring variables would be tailored to suit the circumstances in a given park, rather than relying on a generic prescription. Furthermore, a change in the risk status of an attribute may result in a corresponding change in the level of monitoring effort flagged for that attribute. This feature, combined with the focussing of monitoring effort on the attributes at greatest risk or on the threats that pose the greatest risk, make the approach an efficient and cost-effective way to design a suite of monitoring programs.

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Appendix 1

GLOSSARY

Assessment endpoint: a formal expression of the environmental attributes or values to be protected (Suter 1989, cited in Suter & Barnthouse 1993).

Consequence: the outcome of an event expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain. There may be a range of possible outcomes associated with an event (SA/SNZ 1999).

Ecological risk assessment: a set of formal scientific methods for estimating the likelihoods and magnitudes of effects on plants, animals and ecosystems of ecological value resulting from the release of chemicals, other human actions or natural incidents (SA/SNZ 2000).

Event tree analysis: a technique that describes the possible range and sequence of the outcomes that may arise from an initiating event (SA/SNZ 1999).

Event: an incident or situation which occurs in a particular place during a particular intervalof time (SA/SNZ 1999).

Fault tree analysis (FTA): A systems engineering method for representing the logical combinations of various system states and possible causes which can contribute to a specified event, called the top event (SA/SNZ 1999). FTA is usually represented by a logic diagram beginning with an undesired consequence, and systematically deducing all the different possible root causes of action leading to the outcome or ëtopí event (SA/SNZ 2000).

Frequency: a measure of likelihood expressed as the number of occurrences of an event in a given time (SA/SNZ 1999). See also *likelihood* and *probability*. Frequency may also be expressed in other suitable measures, such as per million units, per head of population, per thousand births (SA/SNZ 2000).

Hazard: a source of potential harm, or a situation with a potential to cause loss or adverse effect (SA/SNZ 2000).

Likelihood: used as a qualitative description of probability or frequency. It refers to both the event and its associated consequences (SA/SNZ 1999).

Measurement endpoint: a quantitative summary of the results of a monitoring study, intended to reveal the effects of a hazard (after Suter 1993b).

Probability: the likelihood of a specific outcome, measured by the ratio of specific events or outcomes to the total number of possible events or outcomes. Probability is expressed as a

number between 0 and 1, with 0 indicating an impossible outcome and 1 indicating that an event or outcome is certain (SA/SNZ 1999).

Qualitative risk assessment: Where the likelihood or the magnitude of the consequences are not quantified, the risk assessment is referred to as qualitative (SA/SNZ 2000).

Quantitative risk assessment: risk assessment where the probability or frequency of the outcomes can be estimated numerically and the magnitude of consequences quantified so that risk is calculated in terms of probable extent of harm or damage over a given period (SA/SNZ 2000).

Risk: the chance of something happening that will have an impact upon objectives. It may be an event, action, or lack of action. It is measured in terms of consequences and likelihood (SA/SNZ 1999).

Risk analysis: a systematic use of available information to determine how often specified events may occur and the magnitude of their consequences (SA/SNZ 1999). The component of risk assessment that is devoted to calculations (Beer & Ziolkowski 1995).

Note that in the USA, risk analysis is the overall process, which includes risk assessment (Beer & Ziolkowski 1995).

Risk assessment: the process of risk analysis and risk evaluation (SA/SNZ 1999).

Note that in the USA, risk assessment refers to the component of the overall process that is devoted to the calculations (Beer & Ziolkowski 1995).

Risk evaluation: the process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels, or other criteria (SA/SNZ 1999).

Risk management: the culture, processes and structures that are directed towards the effective management of potential opportunities and adverse effects (SA/SNZ 1999).

Risk management process: the systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk (SA/SNZ 1999).

Risk perception: the way in which individuals estimate risk. Risk perception cannot be reduced to a single parameter of a particular aspect of risk, such as the product of the probabilities and consequences of any event. Risk perception is inherently multi-dimensional and personal, with a particular risk or hazard meaning different things to different people and different things in different contexts. (Pidgeon *et al*. 1992).

Semi-quantitative risk assessment: Where qualitative estimates of likelihood and the magnitude of the consequences are assigned values which are then used to calculate risks on a numeric scale, the risk assessment is referred to as semi-quantitative. This type of assessment is not designed to produce quantitative estimates of risk, simply to produce scores for ranking of the risks (SA/SNZ 1999).

Uncertainty: a lack of knowledge arising from changes that are difficult to predict or events whose likelihood and consequences cannot be accurately predicted (SA/SNZ 2000).

Parks Victoria is responsible for managing the Victorian protected area network, which ranges from wilderness areas to metropolitan parks and includes both marine and terrestrial components.

Our role is to protect the natural and cultural values of the parks and other assets we manage, while providing a great range of outdoor opportunities for all Victorians and visitors.

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