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A north Australian perspective

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TROPICAL SAVANNAS CRC

Cooperative Research Centre for the Sustainable Development of Tropical Savannas

Defining and measuring the health of savanna landscapes: A north Australian perspective

Tropical Savannas CRC Discussion Paper

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Tropical Savannas Cooperative Research Centre

The Tropical Savannas CRC (TS–CRC) was established in 1995 as a cooperative of resource management and research agencies, all publicly funded, with a brief to undertake research and education relating to the sustainable development of Australia's savannas. The Australian tropical savannas are landscapes of dense grass and scattered trees that stretch across northern Australia from Broome to Townsville. They cover a huge area—around 1.9 million square kilometres—or around a quarter of mainland Australia's land area. The dominant land use is extensive pastoralism. Tourism, based largely on wildlife and other natural values and focused mostly on a few major parks and reserves, is the largest employer. Aboriginal people own a large proportion of the savannas and retain some rights to traditional use of many other areas. Intensity of development is variable across the savannas, being most concentrated in parts of Queensland, but rates of change are accelerating in many other regions.

The TS–CRC's distinctive role—the special value it adds to the work of its individual partners—is to integrate research outcomes from a variety of disciplines to produce management tools accepted and used by a wide range of stakeholders. The TS–CRC's vision is summarised in a *Strategy Statement* (Anon 1998) produced through a consultative process involving representatives of industry, government, land owners and managers, and conservation interests.

The statement identifies several key areas where the TS–CRC must produce results if it is to meet its broad charter. These include:

- *Definitions of healthy landscapes at space and time scales that are useful to land holders, managers and users.*
- *Methods for assessing landscape health which incorporate landscape processes and resource status at a range of space and time scales.*

Several features of these statements are important in the context of this discussion. First, they explicitly seek application of the health concept in ways that are accessible and relevant to a wide range of stakeholders. The audience we seek to support and influence includes land managers with little or no formal scientific education, but long experience and often profound knowledge of many aspects of the systems they manage.

Second, the identification and measurement of attributes of healthy landscapes is to extend beyond physical status to include processes ultimately influencing status. Third, the concept is expected to apply across a wide range of spatial and temporal scales. These statements have challenged TS–CRC partners to specify the types of management outcomes they seek from their participation, and the types of human-caused change in savanna systems they regard as sustainable and hence consistent with the maintenance of savanna health.

Summary

Participants of the Tropical Savannas CRC have sought to develop performance benchmarks by defining healthy savannas and their attributes, and identifying indicators of health. They propose that:

A healthy savanna:

- *maintains basic functions (including but not confined to nutrient cycling, water capture, provision of food and shelter for fauna) at all spatial scales;*
- *maintains viable populations of all native species of plants and animals at appropriate spatial and temporal scales; and,*
- *reliably meets the long-term needs (spiritual, aesthetic and material) of those with an interest in the savannas.*

Key features of this definition of savanna health are that:

(i) attributes considered important extend beyond basic processes such as nutrient cycling to include features such as biological and landscape diversity that may make little direct contribution to production; and

(ii) attributes considered integral to health may vary across spatial scales.

In taking this broad view of application of the term health to landscapes, participants chose to avoid theoretical and semantic debate and focus instead on the primary goal: to clarify the sorts of resource management outcomes to which the TS–CRC will be seeking to contribute. While this approach requires that we embrace some diversity of views, we consider that attempts to closely circumscribe ideas at this stage in the development of the savanna health concept would be premature and potentially counter-productive.

Therefore the suite of attributes identified also varies somewhat according to prevailing land use; they are identified separately for Aboriginal, conservation, pastoral and more intensive agricultural use. However, attributes tend to converge and be less dependent on narrower sectoral goals at larger spatial scales. Proposed indicators all identify potentially measurable aspects of savanna state or process, but many require further work to simplify, verify sensitivity and cross-validate. In addition to technical validation of indicators, future research should include analysis of processes that most effectively encourage application of such benchmarks by land managers and other decision-makers.

Introduction

Improved standards of environmental and natural resource management are stated goals of governments, non-government organisations and resource users at many levels (e.g. WCED[1] 1987). Global acknowledgment of the obligation to improve the way natural systems are used and conserved has spawned many attempts to establish coherent frameworks for promoting improvement and monitoring change.

For example, Australian Governments at State and Federal levels have endorsed a National Strategy for Ecologically Sustainable Development (Anon, 1992). The strategy emphasises, *inter alia*, integration of development and conservation actions over large spatial and temporal scales. Recently, the principles underpinning that strategy were incorporated in relevant Federal legislation: the Environment Protection and Biodiversity Conservation Act 1999. By executive fiat, government agencies in the United States have adopted ecosystem management as a paradigm for management of public lands and their resources (Christensen et al., 1996). Within the ecosystem management framework, management decisions are to be informed by considering interactions among the many elements of natural systems; a perspective that cannot be attained through resource-by-resource, species-by-species, or localised site-by-site approaches (Franklin, 1993). Related initiatives in the US include legislated goals for maintenance and restoration of biological integrity of waterways and catchments (Karr, 1993).

These statements of intent to improve management performance—often through a shift in focus from individual resources to entire systems—have attracted a good deal of support from institutions and individuals (e.g. Dombeck, 1996). However, warm embrace of the principle has, as yet, generated little operational practice. It remains unclear how specific management targets, means of addressing those targets or of monitoring outcomes under the new paradigms would vary from those developed under other conceptual frames (Grumbine 1994, 1997; Czech and Krausman, 1997). Turning broad statements of intent into operational responses directed at achievable targets remains a major challenge (Regier, 1993; Whitehead, 1999). Even such basic issues as the meaning of the term sustainability and the capacity of science to contribute to resolve ambiguities remain in doubt (Lele and Norgaard, 1996; Bell and Morse, 1999). Many question the value of such superficially simple and hence politically attractive statements of intent in the absence of coherent scientific theory to guide their application, or debate the suitability of the vocabulary (e.g. Wicklum and Davies 1995; Callicott et al. 1999).

The challenge of moving beyond vague concepts to operational responses must be met sooner rather than later. Otherwise, opportunities presented by institutional and professional acceptance of the need for better natural resource management may be forfeit. None of the basic ideas underpinning these re-articulated management frames is new (see Leopold 1941, 1949). But the effort made by the committed to re-invigorate them by re-statement in contemporary language does create new opportunities. It would be a travesty if conservationists, resource managers and research scientists squandered enhanced public and institutional interest by substituting, for genuine efforts to advance practice, a sterile debate about the relative merits of different epistemologies, theories, or vocabularies.

General ecological theory—as distinct from high-quality natural history and detailed autecological studies—has not been able to generate the quality of prediction needed to address most environmental policy issues (Shrader-Frechette and McCoy 1994). Existing economic theory and practice is driving much adverse environmental change (Callicott and Mumford 1997). To insist that serious issues of environmental management await the protracted development and acceptance of appropriate new theory, not only within inherently conservative disciplines but also crossing a number of disciplinary boundaries, is unrealistic at best and, less charitably, arrogant and irresponsible.

If sensibly handled, a new vocabulary may be a useful precursor to change (Norton 1977). However, in addition to the risk of ideas being degraded by rhetoric or specious intellectual rigour decoupled from serious action, highly developed technical language may actually inhibit acceptance of the new, especially if the vocabulary is captured by special interest groups or over-elaborated by professional elites.

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[1] WCED: World Commission on Environment and Development

Ecosystem Health Concept

It is essential that accessible language be found for dealing with complex systems and communicating with all of those who have a hand in managing them. Metaphors are often used to facilitate the exploration and transfer of new ideas, and the attempt to promote improved management of living and non-living natural resources has generated a number of models. One of the more resilient has been the analogy drawn between the health of individual organisms and the health of natural systems, which has generated a large literature dealing with ecosystem health (e.g. Constanza et al. 1992), extending as far as the consideration of such issues as 'clinical ecology' (e.g. Rapport et al. 1998).

The attraction of the concept of ecosystem or landscape health as a metaphor to promote good land management is obvious. All of us have some experience of ill health. We are aware that impairment of a part can affect the function of the whole, can identify a suite of vital signs to detect malfunction, have experienced successful treatment or witnessed self-repair and benefited from preventative medicine. All of these observations have their counterparts in the status of ecosystems and their management.

Some have criticised the notion that natural systems should be described in terms of their health, arguing that the analogy is imperfect. For example, it is obvious that temporally dynamic ecosystems do not maintain the same quality of homeostasis as individual organisms, nor die in the same way as individual organisms once homeostasis breaks down (e.g. Wicklum and Davies 1995). However, we consider such criticisms to be rather pedantic reactions to a misapprehension of the purpose and usefulness of analogy. A perfect metaphor is an oxymoron: all analogies break down at some point, and should not be judged by some arbitrary 'goodness-of-fit', but how well they facilitate exploration of ideas. During such exploration, consideration of differences between metaphorical and 'real' systems may be as revealing as similarities.

Callicott et al. (1999) included ecosystem health among what they describe as "a plethora of ill-defined normative concepts . . . now in circulation". Some attempts to move beyond analogy to operational definitions of ecosystem health have indeed been clumsy. For example, Haskell et al. (1992: page 9) provide the following 'operational' definition:

> *An ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable (that is, if it is active and maintains its organisation and autonomy over time and is resilient to stress.*

The weakness of such a definition is obvious; it depends on shared understanding of other terms at least as obscure as the concept which it seeks to clarify. What is 'distress syndrome'? How is stability defined given the highly dynamic nature of ecosystems? What are the characteristics of a sustainable system? What is an autonomous system, given that we are often seeking to deal with human impacts on links among landscape elements? To what levels and kinds of stresses should the system be resilient?

The various failings of the multiplicity of concepts and vocabularies employed to provide strategic directions for better-integrated conservation and production, documented by Callicott et al. (1999), should not be exploited as excuse for inaction. Their number and the persistence of their advocates illustrate the strong and continuing public demand for effective action to halt environmental degradation, and the associated obligation of those supported by the public purse to seriously pursue genuine advances. Rather than retreat to further abstract contemplation, those seeking improved resource management outcomes must choose a vehicle that the group they seek to involve is prepared to board. We believe that a thoughtful application of the savanna health concept offers such a vehicle.

Approach

We offer this paper as part of a process for describing Australia's tropical savannas, the management challenges they face, and options for improving management. As a first step, we identify attributes that characterise healthy savannas and ways to monitor those attributes.

The views of a substantial number of TS–CRC participants were obtained during 1999 through facilitated workshops with the following primary objectives:

- to document attributes considered to characterise a healthy savanna, together with potential indicators of savanna health for assessing current status, monitoring trends, diagnosing likely causes of change, or providing early warning of adverse change;
- to produce a draft CRC definition of healthy savannas; and
- to develop a process for refining characterisations of savanna health, including the incorporation of wider stakeholder views, and for incorporating the health concept in education, training and extension programs.

Disciplinary backgrounds of participants were predominantly the biophysical sciences. However, orientation differed significantly, ranging from those engaged primarily in wildlife and landscape protection to those seeking to improve production. Aboriginal stakeholders were also represented.

The Concept Defined

Definition of Savanna Health

Participants defined savanna health as follows.

> *A healthy savanna:*
>
> - *maintains basic functions (including but not confined to nutrient cycling, water capture, provision of food and shelter for fauna) at all spatial scales;*
> - *maintains viable populations of all native species of plants and animals at appropriate spatial and temporal scales; and,*
> - *reliably meets the long-term needs (spiritual, aesthetic and material) of people with an interest in the savannas.*

This definition constitutes a succinct statement of the mix of values that the participants have brought to the Centre and its work.

Salient features are that:

- maintenance of basic savanna function (and hence ecosystem services related to production) is only part of the management obligation, which extends to the maintenance of viable populations of native plants and animals;
- valued savanna attributes extend beyond the strictly utilitarian to include intangibles;
- savanna health should be assessed at a range of spatial scales;
- humans and their needs are inseparable from the savanna landscape;
- all use of savanna resources should be sustainable (meet needs over the long term).

The definition is valuable, not because it circumscribes the notion of savanna health, but because it clarifies and expands previous statements of the contribution that TS–CRC participants expect to make to the development of savanna management systems. Clearly they bring a strong commitment to maintain processes, structures and species of plants and animals that give the savannas their particular character. However, there is also a recognition that meeting the needs of savanna residents may involve change, and apparent acceptance that loss of natural values is inevitable at some, especially smaller, spatial and time scales. There was debate about the extent to which savanna managers should respond to interests from outside the region (notably residents of major urban settlements in temperate Australia). Some considered that giving credence to the views of non-residents invited uniformed and misguided intrusion. However, the majority considered that there was an obligation to deal with the range of expectations of those whose support will be needed to support change.

Attributes of Savanna Health

The second step in the workshop process was to identify attributes that participants considered characterise a healthy savanna. It was recognised from the outset that achievable management goals, and hence desirable attributes, would be likely to vary across ecosystem types and spatial scales, and that it would therefore be useful to identify attributes at a range of scales. For example, small highly modified sites used for intensive cropping could not sustain the full range of values that might be maintained at a large regional scale.

It was also accepted that, at least early in the process of developing norms of savanna health, stakeholders from different sectors would vary in their assessment of the features that should be maintained in a healthy system. Thus it was agreed that, as a first step, attributes of health would be identified separately for a number of the dominant sectors and the perspectives they bring to land use. Those sectors were pastoralism, cropping, indigenous use, and conservation. Thus attributes were initially identified in an orthogonal matrix of different spatial units and sectoral interests. The outcomes from that process are shown in Table 1.

Several important features can be gleaned from this summary.

1. Retention of basic function such as nutrient (including water) capture is considered essential for health in all lands and in the smallest management units, regardless of land use.
2. Production-oriented participants tend to emphasise maintenance of function, including basic and universally important processes, such as capture and retention of water and nutrients, at smaller scales. However, they also recognised the obligation to maintain elements of the landscape and biota that may have no strong connection to production values at larger spatial scales, significantly including the property scale. They were prepared to promote retention of viable areas of wildlife habitat as an important management goal for individual properties.
3. Regardless of dominant land use, all participants considered habitat and wildlife diversity to be essential attributes at catchment/ bioregional or larger spatial scales.
4. Aboriginal stakeholders often described savanna health in terms of the health of its human occupants, rather than emphasising particular biophysical attributes.
5. Minimisation of off-site effects through movement of residues (including excessive sediment) is accepted as a necessary attribute of healthy savannas.

We draw two generalisations from these patterns. First, TS–CRC participants regard the maintenance of basic function across the entire landscape as an absolute minimum requirement for savanna health. Second, they reject the notion that savanna health can be defined entirely in terms of nutrient cycling and like measures of landscape function (*sensu* Ludwig et al. 1997 and Tongway and Hindley 1995). While there was unanimity about the need to incorporate structural and compositional values (*sensu* Callicott et al. 1999), views diverged somewhat regarding the smallest spatial scale at which maintenance of biological and structural diversity should be regarded as an indispensable feature of a healthy savanna landscape.

Indicators of Savanna Health

In the case of indicators of savanna health that could actually be measured, the range proposed by workshop participants (Table 2) could be loosely grouped into four categories.

1. **Landscape function** These indicators deal with fundamental physical and biological processes and states, including hydrological function, nutrient cycling and soil condition and stability. The TS–CRC has actively contributed to the development of methods, collectively described as Landscape Function Analysis (LFA: Tongway and Hindley 1995), as well as simplification to permit application by landholders outside the research framework. Associated research directed at assessment of land condition by remote sensing provides the potential to extend assessment from small to very large scales (R. Karfs, unpublished).
2. **Pasture condition** Direct measures (frequency and cover) of the representation of important fodder species were proposed. Information on frequency and size of grass clumps is also picked up in LFA. As for LFA, work is in progress to validate use of satellite imagery to assess trends in pasture condition, based in part on change related to the relative abundance of annual and perennial grasses.
3. **Landscape structure** This group of indicators measures variation in the configuration of landscape elements. Examples include measures of the fragmentation of woodland, forest or other significant vegetation remnants, proportion of riparian corridors protected, and proportion of area beyond grazing range from watering points.
4. **Components of biological diversity** Indicators include measures of the abundance and range of selected species (plants or animals) at a range of spatial scales. Other related measures include the proportion of vegetation associations occurring locally that remain on sites of various sizes.

Features of the Savanna Health Concept

Savanna Health Attributes

It is unsurprising that basic processes such as nutrient and water capture should be identified by resource managers from all sectors as essential to maintain savanna health. Severely dysfunctional landscapes cannot support production, let alone offer other less tangible values. Similar unanimity in identifying non-production values as important at larger spatial scales—including the property level—was less predictable.

The perspective of contributors to the Tropical Savannas CRC has previously been set out in a variety of documents, all of which have been endorsed by its stakeholders in one form or another. Core partners have entered into contractual agreements with the Commonwealth Government, and other stakeholders have been involved in establishing strategic directions. These processes have affirmed the Centre's interests in going beyond the maintenance of function that is an explicit requirement of sustainable development, to embrace a wider mandate for the protection of less tangible environmental and social values.

In these workshops TS–CRC participants re-iterated that perspective, and proposed a set of specific attributes that captured features of savanna structure and composition, without necessary linking those attributes to the maintenance of production values. In taking this position, the CRC is acting consistently with many international, national, State and regional statements of society's environmental management goals.

In looking beyond the functional, the TS–CRC's definition of savanna health and identification of related attributes depart somewhat from more academic treatments. For example, Callicott et al. (1999) argue that the ecosystem health concept and terminology should be strictly confined to basic ecosystem functions.

They propose that other terms, like ecological integrity (Woodley et al. 1993), should be used when considering issues of biological and structural diversity that have no demonstrated functional role. However, we do not consider these distinctions and resultant increase in complexity of terminology to be useful in developing and communicating the TS–CRC's contribution to improved savanna management.

Our processes were not designed to elicit statements of social and economic attributes of healthy savannas, and most participants did not offer them. Nonetheless, their proposals regarding biophysical attributes clearly embodied particular values strongly influenced by social and cultural backgrounds. The Aboriginal perspective straddled cultural values and biophysical attributes, reflecting the inseparability of land and people; land without its people was incomplete and hence, by definition, unhealthy. Key features of the Aboriginal definition of savanna health related to predictability in the availability of resources (historically a life or death issue), meeting obligations to the land in both ceremonial and management senses (particularly in regard to the use of fire), and the linked needs for free access and coordination of management of sites and use of resources with neighbouring clans. Articulating an equivalent non-Aboriginal perspective on social attributes of healthy savannas will follow review of the present treatment.

Spatial Scale and Savanna Health

The spatial units within which we have considered attributes of health are rather loosely defined, and variable (e.g. property size) across the savannas. Our choices have been influenced by the need to communicate clearly and simply with stakeholders. The most appropriate way to do this is to structure descriptions in common management units rather than arbitrary categories of area. However, this decision does raise questions about the achievability of goals relating to viable patches of natural ecosystems on properties (Tables 1 and 2). It is possible that at some sites, even an entire property may not be large enough to support a viable area of one or more regionally significant ecosystem types. In these cases, maintenance of viable samples of natural ecosystems must be treated as a multi-property or regional goal.

In our view it does not follow that within-property maintenance of habitat diversity should cease to be recognised as a valuable attribute that contributes to the ecological health of the property. Rather this 'gold standard' should be supplemented by recognition of other means of making useful contributions to the same goal at somewhat larger scales, such as the maintenance of small patches or corridors of native woody vegetation that can be linked to similar structures on neighbouring properties. Consequently we regard the articulation of attributes and indicators in a spatial hierarchy as a useful approach that enables stakeholders (especially landholders and managers) to place their properties—and the contribution they can make to regional environmental goals—in a wider context.

Savanna Health Indicators

Indicators of Basic Function

Indicators of functional attributes were those derived from landscape function analysis (Tongway and Hindley 1995; Table 3). However, it was recognised that such indicators are laborious to measure, and are best applied to recognised problem areas or sites subject to more intensive use. Even here, TS–CRC participants took the view that application of the suite of techniques making up the LFA package is unlikely to be widely adopted in whole by stakeholders, and a simplified set of validated measures is needed. Work has begun to produce such a simplified but robust procedure (Tongway and Hindley, unpublished). At larger spatial scales, participants preferred measures of health that provide a spatially and temporally integrated view, such as the condition of waterways.

Such functional measures were also less emphasised in regard to conservation lands, where management goals mostly seek maintenance of biological assemblages. Direct comparisons between the biological assemblage present at the site of concern and reference sites can provide a meaningful and integrated measure of condition (see below). However, direct application of LFA techniques and hence use of LFA indicators may be appropriate for protected lands requiring rehabilitation, specifically for tracking effectiveness of rehabilitation methods and their application.

The need for such intensive measures of function may also be reduced when remotely-sensed indicators of condition at large spatial scales (R. Karfs, unpublished) are validated against LFA and other finer-scale measures of health, including those based on aspects of habitat and biological diversity. Work to provide this validation is currently a high priority for the TS–CRC.

Indicators of Diversity

Two principal classes of non-functional attributes and indicators were identified. One of these related to the condition of different landscape elements, vegetation types or habitats and their size and configuration, and the second to the size and hence viability of the wildlife populations these natural habitats are able to support. Identification and monitoring of indicator species was also proposed.

There may appear to be potential for considerable redundancy in such a diverse group of indicators. A basic assumption underlying selection of sites for biodiversity protection using the most commonly applied methods (e.g. Pressey et al. 1993) is that adequate surrogates (e.g. vegetation: Woinarski and Braithwaite 1993) for biodiversity can be identified. Thus, measures of native vegetation cover, changes in which can be monitored by remote sensing (e.g. Graetz et al. 1995) might be treated as indicators of savanna health at a range of spatial scales. However, the reality is that for large parts of northern Australia, patterns of use of landscapes and their resources by fauna are poorly understood. It will be some years before surrogates are validated, and details of configurations of those surrogates favouring maintenance of diverse wildlife assemblages are known.

In addition, surrogates indexing gross structure rather than condition may not adequately capture environmental variation important to some faunal groups. For example, the TS–CRC is studying granivorous birds, which declined across much of northern Australia prior to extensive land clearing (Franklin 1999). Gross measures of vegetation structure will not provide adequate surrogates for health in terms of the land's capacity to maintain this large suite of species, as required by the definition of savanna health. It has proved necessary to improve understanding of the group's interactions with the landscape at a range of spatial scales. This work is intended to culminate in simple but robust indicators of habitat suitability measurable from paddock to property scales.

For many other faunal groups, monitoring programs may have to be based on suites of initially unvalidated indicators. There may be few options but to apply these broad landscape descriptors, measures of landscape condition, as well as the distribution and relative abundance of individual plant or animal species, and test their performance through experience.

Quality of Indicators

A good deal has been written about the characteristics of informative indicators (e.g. Bell and Morse 1999).

Features of good indicators that recur repeatedly in the literature, or capture the essence of detailed treatments, are:

1. **Conceptual soundness (Munn 1993; Keddy et al. 1993; Walker et al. 1996; Fisher 1998**) While the detail of ecosystem function is often unknown, indicators that are connected to fundamental ecological processes are more likely to provide for meaningful assessments of health.
2. **Valued ecosystem components (Munn 1993)** Indicators should measure attributes valued by stakeholders in the status of savannas and quality of their management.
3. **Simplicity (Keddy et al. 1993; Harger and Meyer 1996)** Indicators should be as simply described and measured as is consistent with their remaining relevant.
4. **Reproducibility (Munn 1993; Schreuder and Czaplewski 1993)** Measurements should be consistently and objectively obtained and perceived to be so by stakeholders.
5. **Sensitivity (Harger and Meyer 1996**) Indicators should be sensitive to change in the attributes of interest. However, interpretation of sensitive indicators will require that sources of natural change and measurement error be well understood.

6. Generality (Keddy et al. 1993) Indicators should be measurable and interpretable over a range of relevant circumstances, including across different biological communities.

Many indicators of savanna health identified by TS–CRC participants cannot be shown to meet these criteria, mostly because they have yet to be specified in sufficient detail to properly examine their credentials (Table 3). In general all proposed indicators require further examination to confirm their simplicity, sensitivity, reproducibility and generality.

Indicators as Thresholds for Action

Detecting trends in measures of savanna health is one thing, but determining when trends demand management responses is quite another. Management authorities will probably be most comfortable using indicators that show regions of rapid change separating quanta indicating high levels of health from quanta indicating substantially lower values. Indicators showing this sort of behaviour are likely to be relatively uncommon. In addition, efforts to combine indicators covering different classes of attributes, to give a single measure of system condition, have in general failed (Bell and Morse 1999).

Thus, it is more likely that decision-makers will be faced with a wide range of indicators, presented to summarise trends in a more or less integrated way. Bell and Morse (1999) present a plausible methodology for presenting and interpreting complex mixes of monitoring data and summaries of system status to a range of stakeholders. They suggest presentation of indicators relating to a range of influences on management behaviour (including economic, social, and environmental considerations) in a single diagram called an AMOEBA (Ten Brink 1991). In this diagram the current value of all indicators is shown relative to agreed 'zones of equilibrium' within which sustainability is thought to be achievable. A time series of these diagrams then provides a succinct statement of trends in sustainability or, in the terminology adopted by the TS–CRC, savanna health, and hence a basis for focussing on problem areas and assisting decision-making by stakeholders.

Relationships to State of Environment Indicators

Australia has devoted considerable effort to the development of indicators to be used in State of the Environment reporting (ANZECC 1998). Savanna indicators are matched to SOE indicators in Table 4. Differences relate primarily to the scale at which indicators are applicable and the extent to which they index effect rather than cause. Many of the SOE core indicators relate to broad-scale measures of actions with gross effects on landscape structure. In our view the proposed savanna indicators complement these measures by proposing and indexing attributes at smaller spatial scales, while also more directly addressing the effects giving rise to public concern about the state of the environment. A range of TS–CRC research indicates that more diffuse effects, which involve no dramatic structural change, can have major impacts on status of large suites of native plants and animals (Franklin 1999). The proposed savanna indicators are more likely to reveal and track trends in such important processes.

Implications for the TS–CRC Research Program

The Tropical Savanna CRC's research program includes a number of projects that seek to relate various measures of the status of flora, fauna or abiotic features to each other. For example, sites used for on-ground Landscape Function Analysis (Tongway and Hindley 1995) are included in regions for which satellite imagery is being used to index pasture condition over large areas (R. Karfs, unpublished). Generalised biological surveys of invertebrate and vertebrate animals and flora are also being conducted over the same sites. Fire histories are being related to floristics and cover of both ground layers and overstorey in savanna woodland. These closely linked studies should permit identification, clarification and validation of additional parameters that also index a number of the savanna attributes identified as important by TS–CRC participants. Progress with these studies will be important to refine the indicators of savanna health and validate them against more direct measures of desired attributes.

But as suggested above, perhaps the greatest challenge will be to develop methods for refining, testing, organising and presenting these indicators in ways that optimise their relevance for savanna stakeholders. Regardless of technical quality, definitions and suites of indicators are ultimately meaningless until they are shown to have influenced management behaviour. Wilcove and Blair (1995) argue that "ecosystem management will ultimately be defined in actions, not words". The same can be said of the notion of savanna health. Utility will be measured by its contribution to improved outcomes for the savannas. Programs to expose landowners and land managers to measures of savanna health, demonstrate their utility, and to modify them after joint evaluation, should become an important component of TS–CRC activity. Documenting the human processes leading to widely accepted and effectively applied systems should also form part of the TS–CRC's research program.

We strongly endorse Yaffee's (1999) analysis of the path taken in developing approaches to ecosystem management. He argues that a preoccupation with definition and premature demands for a single best approach are likely to be counter-productive. Such broad initiatives require action from a wide range of interests, some of whom may be excluded or deterred by discipline-based boundaries. Some early looseness is actually an important strength that allows a range of interests to come together and so provides opportunities to refine understanding through shared experience (Whitehead 1999). Persistence and commitment are more important attributes than pedantry.

We offer this view of the healthy savanna in that spirit. Working with stakeholders to test its relevance through application will be the most effective way to enhance this initial statement.

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Table I

Attributes of healthy savannas identified by researchers and land managers associated with the Tropical Savannas CRC. Horizontal arrows join similar attributes across scales. Vertical arrows link attributes that are to some degree dependent on each other or otherwise interact strongly. Note some attributes can be applied at more than one scale.

Management scale

Stakeholder group	Paddock/Place	Property/Clan Estate/ Protected Area	Bioregion/ Catchment/ Language Group	Savanna-wide
Aboriginal ***Vision: Country is clean and people healthy***	Predictable availability of one or more important resources	Predictable, year-round availability of a wide range of resources	Additional resources shared with neighbouring clans	
	Spiritually significant sites undisturbed	People active in their country	Connections among sites and associated ceremony maintained	
	Access protected and sites properly maintained		Land management coordinated among neighbouring estates	
	Mosaic of important landscape elements is maintained People, plants and animals are in their customary place			
		Clean water available year-round		
Conservation ***Vision: Diverse landscapes and diverse biota***	Effective resource capture and retention			
	Essential ecological processes are maintained	Viable populations of resident/ territorial species	Viable populations of species for which bioregion is significant	Wildlife populn's linked by favourable landscape configuration
		Landscape complexity maintained		
		Viable remnants of natural communities	Species diversity maintained Endemics effectively protected	
	Low impact from functionally significant exotic species			
				Carbon balance maintained

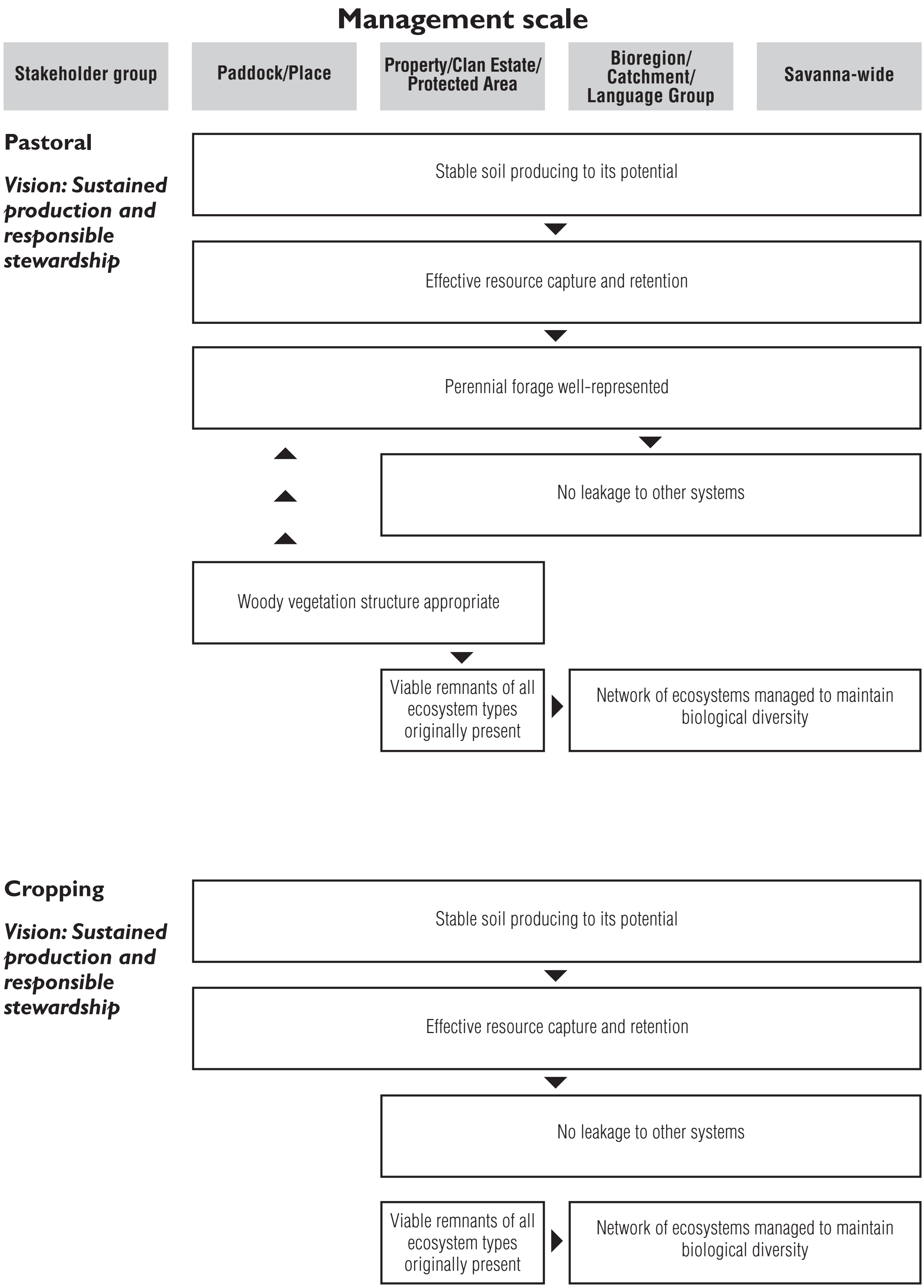
Management scale
Stakeholder group
Paddock/Place
Property/Clan Estate/ Protected Area
Bioregion/ Catchment/ Language Group
Savanna-wide
Pastoral
Vision: Sustained production and responsible stewardship
Stable soil producing to its potential
Effective resource capture and retention
Perennial forage well-represented
No leakage to other systems
Woody vegetation structure appropriate
Viable remnants of all ecosystem types originally present
Network of ecosystems managed to maintain biological diversity
Cropping
Vision: Sustained production and responsible stewardship
Stable soil producing to its potential
Effective resource capture and retention
No leakage to other systems
Viable remnants of all ecosystem types originally present
Network of ecosystems managed to maintain biological diversity

Table 2

Attributes of healthy savannas (taken from Table 1) and measures (indicators) of performance identified by researchers and land managers associated with the Tropical Savannas CRC. Attributes are shown in clear boxes and indicators in black boxes. Indicators marked (*) are under active study within the TS–CRC research program.

Management scale

<table>
<tr><th>Stakeholder group</th><th>Paddock/Place</th><th>Property/Clan Estate/ Protected Area</th><th>Bioregion/ Catchment/ Language Group</th><th>Savanna-wide</th></tr>
<tr><td rowspan="9">Aboriginal
Vision: Country is clean and people healthy</td><td>Predictable availability of one or more important resources</td><td>Predictable, year-round availability of a wide range of resources</td><td>Resources shared with neighbouring clans</td><td></td></tr>
<tr><td>Availability of key resource (identified by local community) reliably meets subsistence and trade needs</td><td>Availability of key resources (identified by local community) reliably meet subsistence and trade needs</td><td>Availability of regionally important resource meets subsistence & trade needs of locals and neighbours</td><td></td></tr>
<tr><td>Spiritually significant sites undisturbed</td><td rowspan="2">People active in their country</td><td colspan="2">Connections among sites maintained</td></tr>
<tr><td>Access protected and sites properly maintained</td><td colspan="2">Land management coordinated among clan estates</td></tr>
<tr><td colspan="4">Mosaic of important landscape elements is maintained
People, plants and animals are in their customary place</td></tr>
<tr><td>No evidence of physical damage to sites
Human health maintained</td><td colspan="3">Ceremony conducted
Fire regimes accord with plans
Human health maintained</td></tr>
<tr><td></td><td colspan="3">Clean water available year-round</td></tr>
<tr><td></td><td colspan="3">Human health maintained</td></tr>
</table>

Legend

Attribute
Indicator

Management scale

Stakeholder group	Paddock/Place	Property/Clan Estate/ Protected Area	Bioregion/ Catchment/ Language Group	Savanna-wide

Conservation

Vision: Diverse landscapes and diverse biota

Effective resource capture and retention

****Landscape Function Analysis (LFA)***

****Remote sensing of landscape condition***

Water quality measures in streams and lakes

Essential ecological processes are maintained

Viable populn's of resident/ territorial species

Viable populations of species for which bioregion is significant

Wildlife populations are linked by favourable landscape configurations

****Trends in abundance of selected species***

Viable remnants of natural communities

****Trends in range of selected species***

****Measures of landscape fragmentation***

Landscape complexity maintained

% site retaining native vegetation

% regional vegetation types retained on site

Size and configuration of remnants

Species diversity maintained
Endemics effectively protected

% of riparian habitat length protected

% of area beyond grazing range from watering points

Area of identified critical habitats protected

****Trends in abundance and range of selected species***

****Measures of landscape fragmentation***

Quality of protected lands' network

Complementarity of protected lands with off-reserve landscape condition

Low impact from functionally significant exotic species

Number and spatial distribution of exotic species

Trends in distribution of species of concern

Number and identity of exotic species

Trends in number of exotic species on site

% cover of nominated exotics

Carbon balance maintained

****Net contribution to atmospheric CO_2***

Legend

Attribute

Indicator

Table 2 cont.

Attributes of healthy savannas (taken from Table 1) and measures (indicators) of performance identified by researchers and land managers associated with the Tropical Savannas CRC. Attributes are shown in clear boxes and indicators in black boxes. Indicators marked (*) are under active study within the TS–CRC research program.

Management scale

<table>
<tr><th>Stakeholder group</th><th>Paddock/Place</th><th>Property/Clan Estate/ Protected Area</th><th>Bioregion/ Catchment/ Language Group</th><th>Savanna-wide</th></tr>
<tr><td rowspan="13">Pastoral

Vision: Sustained production and responsible stewardship</td><td colspan="4">Stable soil producing to its potential</td></tr>
<tr><td colspan="4">Effective resource capture and retention</td></tr>
<tr><td colspan="2">*Landscape Function Analysis
Transect based measures</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="3">Water quality measures
*Remote sensing of land condition</td></tr>
<tr><td colspan="4">Perennial forage well-represented</td></tr>
<tr><td rowspan="3">*LFA
*Quadrat-based measures of perennial grass frequency and cover</td><td colspan="3">*Remotely-sensed measures of trends in pasture condition</td></tr>
<tr><td colspan="3">No leakage to other systems</td></tr>
<tr><td colspan="3">Water quality measures (including sedimentation rates)</td></tr>
<tr><td colspan="2">Woody vegetation structure appropriate</td><td colspan="2"></td></tr>
<tr><td colspan="2">*Trends in density of woody stems</td><td colspan="2"></td></tr>
<tr><td></td><td>Viable remnants of all ecosystem types originally present</td><td colspan="2">Network of ecosystems managed to maintain biological diversity</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">% site retaining native vegetation
% regional vegetation types retained on site
Size and configuration of remnants</td><td colspan="2">% of riparian habitat length protected
% of area beyond grazing range from watering points
Area of critical habitats protected</td></tr>
<tr><td colspan="2">*Measures of landscape fragmentation
Quality of regional protected lands network
Complementarity of off-reserve management with protected lands</td></tr>
</table>

Legend

Attribute
Indicator

Management scale

Stakeholder group	Paddock/Place	Property/Clan Estate/ Protected Area	Bioregion/ Catchment/ Language Group	Savanna-wide

Cropping

Vision: Sustained production and responsible stewardship

Paddock/Place to Savanna-wide:

- Attribute: Stable soil producing to its potential
- Attribute: Effective resource capture and retention

Property/Clan Estate/Protected Area to Savanna-wide:

- Attribute: No leakage to other systems
  - Indicators: ***Water quality in streams and lakes***; ***Sedimentation rates***

Property/Clan Estate/Protected Area:

- Attribute: Viable remnants of all ecosystem types originally present
  - Indicators: ***% site retaining native vegetation***; ***% regional vegetation types retained on site***; ***Size and configuration of remnants***

Bioregion/Catchment/Language Group to Savanna-wide:

- Attribute: Network of ecosystems managed to maintain biological diversity
  - Indicators: ***% of riparian habitat length protected***; ***% of area beyond grazing range from watering points***; ***Area of critical habitats protected***
  - Indicators: ****Measures of landscape fragmentation***; ***Quality of regional protected lands network***; ***Complementarity of off-reserve management with protected lands***

Legend

- Attribute (white box)
- ***Indicator*** (black box)

Table 3

Analysis of the match of health indicators proposed by TS–CRC participants to the criteria for successful indicators summarised in the text. Three ticks indicate a good match, two ticks medium and one tick minimal. A question mark indicates that it is currently unclear whether there is likely to be a match, and an (*) indicates no match.

Indicator	Criteria satisfied		
	Conceptual soundness	Valued ecosystem components	Simplicity
Availability of key resources	✓	✓✓	*
No evidence of physical damage to important sites	✓	✓✓✓	*
Human health is maintained	?	?	?
Management responsibilities are met • ceremony conducted • fire regimes conform to plans	✓✓	✓	✓
Landscape function (LFA) indicators	✓✓✓	✓✓	*
Water quality (WQ) indicators Rates of sedimentation	✓✓✓	✓✓✓	✓/?
Remote sensing of land condition (including pasture condition)	✓✓✓	✓✓✓	*
Trends in density of woody stems	✓✓✓	✓✓✓	✓
Species of perennial grass present Density of valued (palatable or ecologically significant) perennial grasses	✓✓✓	✓✓✓	✓
Size and configuration of landscape elements - % site retaining native vegetation - % regional vegetation types retained on site - size and configuration of remnants - % of riparian habitat length protected - % of area beyond grazing range from watering points - area of critical habitats protected - measures of landscape fragmentation - quality of protected lands network - complementarity of off-reserve management with protected lands	✓✓✓	✓✓✓	*
Trends in abundance of selected species	✓✓✓	✓✓✓	*
Trends in range of selected species	✓✓✓	✓✓✓	*
Number and spatial distribution of exotic species in region	✓	✓✓✓	✓
Trends in number and identity of exotic species on site	✓	✓✓✓	✓
Cover of nominated exotics on site	✓✓	✓✓✓	✓✓
Net contribution to atmospheric CO_2	✓✓	✓✓✓	✗

Criteria satisfied			Comments
Reproducibility	Sensitivity	Generality	
?	?	✓	Specific resources and variation among communities needs clarification
*	*	✓✓✓	Nature of sites and significance of change variable among sites and clans
?	?	?	Direct links between aspects of human health and landscape condition unexamined
✓	?	?	Wider acceptance requires linkage to values that human presence is needed to maintain
✓✓✓	?	✓✓✓	Simplified and validated suite of indicators required
?	✓/?	✓✓✓/?	Criteria for physico-chemical measures of water quality are well-established, but biological indicators (e.g. AUSRIVAS) require validation in north Australia
✓	?	✓✓	Requires validation in different ecosystem types under wide range of conditions
✓	✓	✓	Adequate theoretical base and methodologies under development
✓	?	✓	Has been validated as indicator of rangeland condition in other studies, but requires linkage to work on granivorous birds.
?	?	✓	Specific configurations of habitat needed to maintain wildlife populations and ecological functionality unknown. Relationships between habitat condition and status of wildlife populations unresolved for many species. Critical habitat types require identification. Most useful measures of landscape configuration (fragmentation) require further study and validation.
✓	?	✓	Criteria for choice of indicator species undetermined
✓	?	✓	Selection of indicator species requires validation Criteria for timely identification of significant decline require validation
?	?	✓✓✓	Criteria required for identification of exotics of particular concern (functionally significant)
?	?	✓✓✓	
✓	?	✓✓✓	
✓	?	?	Large task to which the TS–CRC is making some contribution through studies of woody vegetation dynamics

Table 4

Links between indicators of savanna health proposed by TS–CRC participants and core Environmental Indicators for reporting on the State of the Environment developed by the Australia and New Zealand Environment and Conservation Council.

Savanna Attribute	Savanna Indicator	Related SOE Core Indicator		Comments
		Pressure	Response	
Landscape Function Effective resource capture and retention	Landscape function (LFA) indicators	Changes in land use Potential for erosion Extent of potential perennial vegetation cover	Area revegetated Area of land under best practice management	SOE indicators emphasise 'large scale' measures assumed to be causally related to land condition, whilst TS–CRC indicators emphasise process and are applicable to smaller scales
Stable and productive soil condition	LFA indicators	Changes in land use Potential for erosion Extent of potential perennial vegetation cover	Area revegetated Area of land under best practice management	
Absence of leakage/ Clean water	LFA indicators Water quality (WQ) indicators Rates of sedimentation	Changes in land use Volume of biocides sold Point source discharges Diffuse source discharges	Area of land under best practice management Area revegetated Waste water treatment Implementation of stormwater controls	Savanna indicators focus on direct measures of landscape condition (including measures of infiltration and nutrient trapping) and water quality
Diversity Measures Viable representation of relevant ecosystem types	Proportion of original ecosystem types retained Size and configuration of remnants	Native vegetation clearing	Terrestrial protected areas Area revegetated	Savanna indicators focus on results of pressures and assessing continued functionality as well as indexing change
Woody vegetation structure	Density of woody stems	Fire regimes		Savanna indicators focus on results of pressures and assessing continued functionality as well as indexing change
Landscape complexity	Size and configuration of landscape elements	Habitat fragmentation	Area revegetated	Savanna indicators focus on results of pressures and assessing continued functionality as well as indexing change
Low impact of functionally significant exotic species	Trends in number and distribution of exotic species Density of exotic species in sample plots	Introduced species		Savanna indicators focus on species likely to threaten values and are applicable at a finer spatial scale
Perennial grasses well represented	Number of species of perennial grasses Density of valued (palatable or ecologically significant) perennial grasses	Extent of perennial catchment vegetation cover		Differences are scale and resolution related

Savanna Attribute	Savanna Indicator	Related SOE Core Indicator		Comments
		Pressure	Response	
Diversity Measures Viable remnants of natural communities	% site retaining native vegetation % regional vegetation types retained on site Size and configuration of remnants	Native vegetation clearing Habitat fragmentation	Area revegetated Recovery plans (for species) Terrestrial protected areas	Savanna indicators are designed to measure effects rather than index cause, and some are applicable at finer spatial scales than SOE indicators
Landscape complexity maintained	% of riparian habitat protected Measures of landscape fragmentation Quality of protected lands network	Native vegetation clearing Habitat fragmentation	Terrestrial protected areas	Savanna indicators cover greater range of measures at finer spatial scales
Carbon balance maintained	Net contribution to atmospheric CO_2.	Native vegetation clearing	Area revegetated Terrestrial protected areas	
Socio-economic Predictable availability of resources	Availability (including guarantee of access) meets landowner needs	Nil	Nil	SOE does not seek to address social indicators
Special sites are properly maintained	No evidence of physical damage Human health is maintained	Nil	Nil	
Human presence is maintained	Management responsibilities are met • ceremony conducted • fire regimes conform to plans	Nil	Nil	