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Condition Assessment Concepts and their Role in Facilitating Sustainable Range Management

R.S. Gibson, W.J. Allen, and O.J.H. Bosch,
Landcare Research – Manaaki Whenua, PO Box 276, Alexandra, New Zealand

Abstract : This paper reviews the development of the theories and concepts underpinning current understanding of vegetation dynamics in the world's rangelands. The influence these have had on the development of condition assessment techniques is also demonstrated. Unless they are placed in a context where they can aid decision-making, however, the results of monitoring have little meaning or use. The paper concludes by describing how monitoring techniques can be integrated into systems-oriented and community-based research to make maximum use of the information necessary for sustainable rangeland decisions.

Key words : Vegetation dynamics, rangelands, succession, monitoring techniques.

In general, the world's rangelands are grazed because they are not sufficiently productive for more intensive agricultural uses. Land managers must cope as best as they can with low or unreliable production, complex natural and semi-natural ecosystems and large management units. However, despite their importance to humanity, rangeland degradation can now be seen on every continent. Worldwide, it is estimated that about half the total area of grazed lands experience at least moderate degradation (Mabbutt, 1984). Nor is rangeland degradation limited to the Third World. In the United States, a 1987 survey reported 38 million hectares of government-owned rangeland that could only be classed as being in fair to poor condition (Brown, 1990). The economic and ecological sustainability of at least one-third of the South Island high country of New Zealand has been questioned by a recent ministerial review (Martin *et al.*, 1994).

Reversing the problems facing the world's rangelands requires the ability of both land managers and policy-makers to make wise management decisions. In turn, wise decision-making is dependent on the quality and availability of relevant knowledge. Therefore, an important role for range scientists, now and in the future, is to provide communities with the best knowledge available to help them manage their rangelands. As Provenza (1991) emphasises, range scientists must endeavour not only to understand the significant biological processes underlying rangeland production, but also to engage in research to apply that understanding to the development of new technologies and management applications.

This paper describes the development of the theories and concepts underpinning our current understanding of vegetation dynamics in the world's rangelands. Attention is also focussed on how this understanding has been used to develop condition assessment techniques. Clearly, in a review of this nature, it is not possible to refer to all techniques but enough examples are provided to illustrate the point. However, in reviewing the long-established tradition of rangeland science it is significant that there have been few recent innovations in research methodology other than the development of more sophisticated monitoring techniques. And this despite a growing recognition of the increasing complexity of rangeland problems and the changing nature of the rangelands themselves.

Accordingly, this paper argues that it is no longer enough for researchers to concentrate on developing more sophisticated techniques to describe what occurs on rangelands, while they continue to shrink each year. The results of monitoring have little meaning or use unless they can be placed in a context where they will help decision-making. The paper concludes by describing how monitoring techniques can be integrated into systems-oriented and community-based research to make maximum use of the information necessary for sustainable rangeland decisions.

The Concepts of Vegetation Dynamics

Succession theories

Before the start of the century, vegetation research centred around the recording of species occurrence over a broad area, with no demonstrable appreciation of the way vegetation changed or the significance of its pattern or composition. Vegetation classifications, if used, were on the basis of growth form or taxonomic group. Clements (1916) sparked considerable debate and scientific research early this century when he challenged the widely held opinion that vegetation was static and unchanging. His theory on succession suggested that vegetation was dynamic and constantly changing, but always followed a predictable pattern of development, the direction of which was controlled by climate (McIntosh, 1985; Joyce, 1993). The culmination of this single linear pattern of change was the formation of a stable climax community which was always the same for a particular climatic area.

In the period after Clements' major work was published in 1916, a substantial increase occurred in research effort and the number of papers published on the subject of succession and climax theory. Much of the work on these Clementsian ideas was carried out by co-researchers, and was substantially inward looking despite scientific works already critical of the narrow definition applied to succession by Clements. Criticism centred around his concept of a stable community and that climate alone controlled the direction of succession (Joyce, 1993). Key critiques were provided by Cowles (1911), Gleason (1917) and especially Tansley (after Joyce, 1993) who disputed the assumption that edaphic factors could not play a role in determining climax composition.

Regardless of the shortcomings of the various theories and concepts put forward during the next thirty years, the resulting scientific hypotheses, research and discussion created an appreciation that vegetation patterns are dynamic. This period can be regarded as one phase of growing scientific awareness that vegetation patterns are not static but develop and change in response to disturbance, edaphic and climatic factors.

Gleason (1939) considered the patterns of similarity between successional stages and climaxes to be largely a result of coincident properties of species and similar environmental conditions. Elger (1954) argued that the assumption of a single stable end-point or climax for any site is unproven. A number of publications regarding succession continued to evolve the concepts through to the modern understanding. Drury and Nisbet (1973) demonstrated that vegetation patterns following disturbances include not only successional replacements, but also cycles and divergences. Connel and Slatyer (1977) developed a three-way model which described different processes of vegetation change (inhibition, tolerance and facilitation), while Horn (1981) provided a Markovian model of replacement probability. Johnston's (1986) stochastic interaction model suggested that the interaction between invasion, maintenance and decline of species was reflected in the stability or instability of species at a location. The common theme throughout these theories is the Clementsian concept that vegetation succession is a reversible process.

New vegetation change theory

Of considerable significance in the field of vegetation dynamics has been the recent work of Laycock (1989) and Westoby *et al.* (1989). Their work provided an alternative to Clementsian succession which emphasised stable and predictable climaxes. Westoby *et al.* (1989) termed their model the State and Transition model, in which the states are recognisable and relatively stable groups of species occupy a site. The transitions refer to changes in state triggered by either management actions, such as grazing or the introduction of plants, or natural events, such as the weather or other natural phenomena.

Laycock (1989) described plant communities that remained unchanged in species composition for considerable periods of time as "suspended stages of succession". The concepts of thresholds have also been explored by a number of other authors such as Hurd and Wolf (1974), Bosch (1989) and Friedel (1988, 1991). Hurd and Wolf described an unstable state as one that does not return to the original level after significant disturbance but crosses a "threshold" and continues to be deflected toward some new state. Bosch and Kellner (1991) identified the development of new domains of attraction along a degradation gradient. These domains are created when a particular threshold has been crossed (e.g., irreversible changes in soil condition).

Bosch and Kellner (1991) further developed and brought together the concepts of stability, direction of succession, state, domain of attraction, as well as the earlier concepts of succession and thresholds of change. Their paper, while recognising Westoby's States and Transitions model also, significantly, recognised that states and transitions for a particular area can still be placed within a successional framework. The identified states are associated with different parts of the succession gradient, and a particular part of the successional framework may have more than one state associated with it (Fig. 1).

The Use of Vegetation Dymamic Concepts in Range Condition Assessment

"The ability to assess and monitor the condition or conservation status of the vegetation of a particular area and to interpret the assessments ecologically, is a prerequisite for rangeland planning and sound management systems" (Bosch and Gauch, 1991). "Even when management is based on detailed inventories and carefully considered management prescriptions the achievement of management objectives usually requires a trial and error approach of adjustment and fine tuning of the management applied" (Smith, 1989). These statements outline the importance of providing a monitoring system that is objective. An important question in designing a monitoring system must always be "... are the results and interpretations of evaluation available to the user in an understandable and useable form?" (Bosch, 1989).

Condition Assessment Based on Classical Succession Concepts

The application of these succession theories to condition assessment was initiated as early as 1917. Sampson (1917, 1919) applied the concept that successional stages could be used to detect overgrazing and that key plants of these successional stages could be used to identify both stages and overgrazing. Clements (1916) also acknowledged that livestock grazing could be an initiator of secondary succession. Sampson (1923) went further to suggest how research into the interaction between grazing management and succession could be used, among other things, to promote the successional replacement of undesirable (non-palatable and poisonous) plants by palatable, nutritious and high yielding species (Joyce, 1993).

The relationship between condition and succession was researched extensively during the 1930s and 40s. This research, in turn, led to attempts to formalise the relationship between grazing and succession. Some of the methods and systems of classification that arose were considered by Dyksterhuis (1949) to "no longer have the original ecological basis". Other methods included categorising vegetation into groups (e.g., desirable, less desirable and undesirable) and were aimed at classifying plants with similar potential usefulness for grazing together.

A major development in the concept of condition assessment occurred when Dyksterhuis (1949) published his quantitative approach for range condition based on plant species' response to grazing. Three classes (decreasers, increasers and invaders), which correspond to different parts of the succession gradient from disturbed to climax, were used as a standard for comparison. Dyksterhuis considered that change in species composition along this gradient was continuous. Accordingly, measuring the proportions of the three classes present at a particular site allowed the site, after comparison with standard values

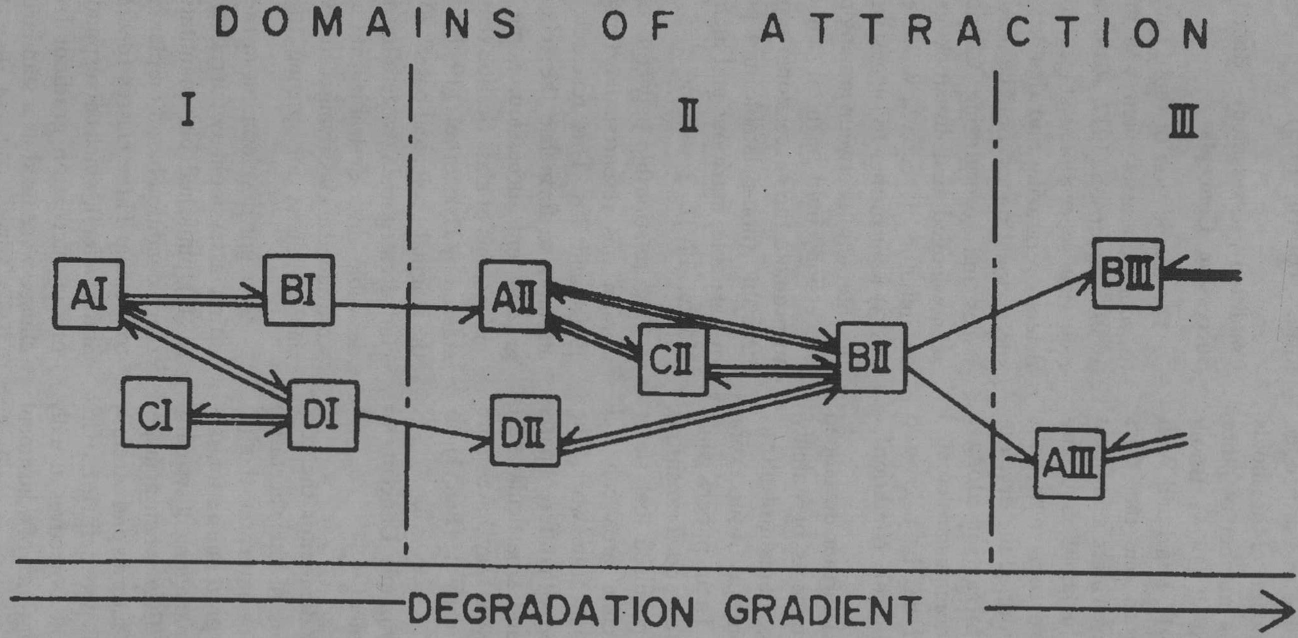

Fig. 1. *Diagrammatic illustration of the directional characteristics of transitions during the process of degradation and recovery. An-Dn: compositional states; =: reversible transitions; –: irreversible transitions. (Source: Bosch and Kellner, 1991).*

for the area, to be placed on the succession gradient.

The important concepts that Dyksterhuis brought to condition assessment were that: i) site condition was not dependant upon current vegetation; ii) forage production was considered a basis for range condition classification; iii) the recording of plants according to taxonomy or other categories not related to their ecological and successional status was abandoned; and iv) the widely-used concept of forage density was replaced with "the quantitative relations of vegetation based on total forage production". The disadvantage of Dyksterhuis's method is that it still necessitates a high degree of taxonomic skill, requiring the identification of all plants present at a site. Nonetheless, in the southern African rangelands a number of developments arising from Dyksterhuis' methods have been used to improve techniques for monitoring condition assessment. These (Foran *et al.*, 1978; Vorster, 1982; Hurt and Bosch, 1991) provide good examples of the progress of methods for estimating the condition of sites.

Foran *et al.* (1978) proposed the Bench Mark Method, which operated by comparing a site to bench mark sites that had been subjectively selected previously to represent sites in excellent condition. A bench mark site could be selected to represent any management objective. All species within the bench mark site would be subjectively classified into one decreaser and three increaser groups, based on the assumed responses to grazing management. A condition index value could then be calculated for a sample site based on its relative composition of these groups to the bench mark site (Hurt and Bosch, 1991).

Vorster (1982) described a method of calculating an "Ecological index" which is the sum of the products of species abundances plus the weightings assigned to those species on the basis of a subjective judgement of the successional status (increaser, decreaser, etc.). The method uses all species at a sample site to calculate an index which is independant of any bench mark site. Index values for sample sites can then be compared with bench mark sites.

Degradation Gradients and Key Species

The theories that bring together the concepts of thresholds, stable states and transitions have considerable potential for condition assessment. They explain why observed changes in vegetation condition induced by grazing disturbance are not simply reversed or improved by the removal of grazing once a threshold has been crossed. When a site has crossed a threshold into a new domain it may continue to be attracted towards a new stable state of vegetation composition regardless of the removal of grazing. The implications of these theories, through their relationship to management and grazing, have enormous significance for land managers.

The Degradation Gradient Method proposed by Mentis (1983) and Stuart-Hill *et al.* (1986), and further modified (Bosch and Kellner, 1991; Bosch and Gauch, 1991), is based on this combination of theories. It uses an ordination model of deteriorating ecological condition along a grazing gradient as the basis for condition assessments. New samples are introduced to the ordination and their position along the degradation gradient used as a condition value. Noisy species (species that do not have a measurable response to grazing) are removed from the ordination model in the process of defining the gradient. This method also measures how well the site fits the ordination model, and is therefore a confidence estimate of the accuracy of the condition value.

A number of authors (e.g., Foran, 1976; Mentis, 1983; Hardy and Hurt, 1989) have noted that some species do not respond to grazing, and that the inclusion of these species in calculating an index of condition may make the index insensitive to changes induced by grazing. Heard *et al.* (1986) recognised this by using subjectively selected key species to calculate an index of range condition. Using only species known to be responsive to grazing provides an index value which reflects the grazing history of the site.

A further development of the key species method (Heard *et al.*, 1986) is the Weighted Key Species Method. To calculate condition, this method uses weightings obtained objectively from the abundances of key species at a sample site. The weightings given to each species reflect the position that species occupy along a known grazing gradient. Ordination techniques can be used (Hardy and Hurt, 1989; Hurt and Hardy, 1989) to identify the key species which are most responsive to grazing along the gradient of grazing intensity. The advantage of this technique is that accurate weightings can be identified from the ordination scores, and the final weighted average or condition index ignores noise introduced to the data if non-responsive species are used. The weighted average can then be used to monitor species composition and temporal changes induced by grazing.

Condition assessment methods, such as the Weighted Key Species Method and Degradation Method that exclude noise introduced to the data by species unresponsive to grazing have been identified (Bosch *et al*., 1989; Mentis, 1983; Hardy and Hurt, 1989) as the most appropriate for southern African grasslands. In these comparative studies other methods were found to be lacking sensitivity to grazing influence. These two methods are also most readily interpreted in terms of modern succession theory. Bosch and Kellner (1991) identified domains of attraction and multiple stable states along the gradient so that the concepts of stability and threshold, as well as the interaction of other edaphic factors, are incorporated. These may help avoid unreal expectations of recovery or response to grazing management, as well as warn of impending irreversible change (Friedel, 1991). In addition, these models recognise that different levels of palatability and productiveness may be associated with different parts of the degradation gradient and that the most ecologically stable level may not necessarily be the optimum position.

Integrating Condition Assessment and Management Decision-making

As demonstrated above, there has been considerable progress in the scientific understanding of rangeland vegetation dynamics and in the development of methods for assessing rangeland condition. However, despite all the efforts invested in rangeland science over the last decade, the world's rangelands are continuing to shrink in area through processes of degradation and desertification. In African countries, conservation attempts have largely been ineffective (Bosch, 1989), and in New Zealand O'Connor (1986) noted the slowness with which landuse and land administration have responded to changes in ecological conditions.

In many cases, the problem is not so much that the science is lacking, but that scientific understanding has not been translated into practical application. The apparent inability on the part of land managers to make use of range condition knowledge must, at least partly, be attributed to what appears to be a lack of tools to make sense of and interpret monitoring data in a useful and efficient way. For example, the Nevada Rangeland Monitoring Handbook (1984) amply describes monitoring methods and techniques, as well as providing definitions of terms used in range condition assessment. Unfortunately, little or no space is devoted to explaining what to do with the data or how to interpret it once it has been collected.

An integrated system for plant dynamics

However, recent research on the sustainability of range management in an African context (e.g., Bosch, 1989; Lane and Scoones, 1993) makes the point that the determination of range carrying capacity cannot be based solely on botanical considerations, but must also take account of the management objectives of rangeland users. In South Africa, the development of the computer software Integrated System for Plant Dynamics (ISPD) represented an important first step in integrating condition assessment techniques and a management decision support system within a single user-friendly decision support system (DSS) for farmers and land managers. The program has analytical ordination tools for scientific identification of degradation gradients. However, unlike other ordination packages, it goes further and processes the scientific results into a form that is readily available and useful for land managers and farmers. It provides modules for interpreting not only the condition of sites, but also the grazing capability of the land.

The condition assessment module incorporates both the Degradation Method (Bosch and Gauch, 1991; Bosch and Kellner, 1991) and the Weighted Key Species Method (Hurt and Hardy, 1989) in a user-friendly, efficient program that provides a graphic as well as numeric condition description for a sample site. Once this ecological condition is known, the capability of the site can be calculated through an inference tree for which the structure and formulae are entered and/or altered by the researcher. The parameters used in the inference tree can be varied to run different scenario's (e.g., the effect of rainfall) to gauge the effect on the grazing capability of the site (Bosch *et al.*, 1992).

Integrated system for knowledge maximisation

A further related strand of evolving agricultural research design builds on the early work of operational researchers in the United Kingdom (e.g., Ackoff, 1974; Checkland, 1972, 1981), and argues for involving the community in future rangeland research (e.g., Bawden *et al.*, 1984; Ison and Ampt, 1992; Ison, 1993). This research approach recognises that rangelands management is a "human activity system", and that issues and problems are seen and interpreted differently by the various actors involved. This community-based research is future-oriented, and focusses on identifying and improving problem "situations". Ideas on system functioning in the field of ecology are also changing - towards the view that the structure and function of natural ecosystems are largely driven by disturbances and driving factors determined outside the system (e.g., Hadley, 1993; Solbrig, 1993; Kay and Scheider, 1994). These approaches, based on concepts of open and evolving systems, are necessarily broad and multi-disciplinary. The health of the rangelands is accordingly evaluated not only in terms of economic and productive criteria, but also in terms of environmental integrity and social sustainability.

These related shifts in recent thinking have several implications for rangeland science and management. In particular, they highlight that the issues facing the management of these agro-ecosystems are complex and inevitably involve many social perspectives. These systems are continually evolving in response to management, economic forces and climatic factors. Given these uncertainties, and the fact that we can never have complete management knowledge, successful resource management must be based on an adaptive or opportunistic approach (Walters and Hilborn, 1978; Westoby *et al.*, 1989; Danckwerts *et al.*, 1992). Given the ecological and climatic variability within the world's rangelands it is physically impossible to undertake a rigorous experimental approach that continually tests different grazing regimes under all environmental conditions. However, active adaptive management is what land managers do every day, and is little different from the approach taken by the experimental scientist who applies different treatments under different conditions and measures the outcome. Range managers implement a strategy, observe or measure the outcomes and adapt their management accordingly. Monitoring, whether carried out formally or informally, is therefore an integral part of the adaptive management process. It provides not only a basis for decision making, but also for maximising the development of new knowledge.

Accordingly, if land managers can become formally involved with the interlinked processes of monitoring and adaptive management, the local knowledge base held collectively by the community increases significantly (Bosch *et al.*, 1995). Combining this local knowledge base with the scientific knowledge system allows a community to maximise available knowledge to make wise management decisions.

An attempt to facilitate adaptive management has been made in the South Island high country of New Zealand (Bosch *et al.*, 1995). A research framework has been designed that can allow continually for "learning by doing" (Walters and Holling, 1990) (Figure 2). Such a framework needs to be able to capture the existing knowledge, both scientific and local, held within the community. This information must be presented in a form that allows stakeholders direct access to the knowledge base for decision making. The process also has to provide for new knowledge to be added as it becomes available, and it must recognize and address the multiple social perspectives that characterise rangelands throughout the world.

As Figure 2 illustrates, these efforts are designed to maximise the knowledge available to decision-makers at any time. The first challenge is to share existing knowledge. This requires amalgamating information held by both the community and science into a single accessible and structured database, or knowledge pool. Ongoing community dialogue ensures that the information is understood in the context in which it was provided, and makes it possible to develop a comprehensive management-decision support system (DSS). These community discussions are designed to reduce conflict through clarifying issues and encouraging a "learning" environment which will lead to constructive and voluntary change. New research initiatives will often develop from this process.

Importantly, the process is ongoing and allows the substance and context of the required information flows to be rethought and reprovided as society, the economy and the environment co-evolve. As land managers adopt new strategies and measure the results of their actions, they will continually take information from - and gain new information to add to - the management DSS. In a similar way, research organisations can use the information base to help define research priorities; and research results can also be effectively transferred to the end user.

This systems-based approach represents an effort to design for uncertainty and to obtain benefits from the unexpected. Through participatory research it offers an educational experience which serves to determine community needs, as well as to motivate the community to develop solutions to their own problems (Anyanwu, 1988). Providing greater understanding of the system helps the community adapt to change. It can also help target research priorities better by determining those components most affected by change (Stuth *et al.*, 1991). In turn, this understanding allows the scientist to shift from a reactive position to a proactive position. Because this represents a process of actively designing a more sustainable future, rather than accept that our future will be determined by the status quo, new demands are placed on individual land managers, the community and science.

Concluding Remarks

There are many more good techniques available for rangeland condition assessment than could be mentioned in a paper of this nature. While it is important that rangeland science continues to develop the theories and concepts of vegetation dynamics that underpin these techniques, a more immediate challenge lies in making existing techniques readily available to those entrusted with the management of the world's rangelands.

In order for the results of monitoring to be useful they must be able to be interpreted in a way that helps decision-making. The process of adaptive management hinges on being able to measure the outcome of management practices, and quickly and efficiently adapt future management accordingly. The evaluation of management practices through monitoring also leads to a greater scientific understanding of rangeland systems, and this, in turn, contributes to better management practices.

Participation in the processes of monitoring and adaptive management means that individual land managers acquire greater technical expertise - building on both collective local knowledge and an associated scientific awareness of their particular physical environment. At the same time, by improving their resource position through the collective effort, land managers develop greater confidence, and that, in turn, ensures the successful continuation of the whole process.

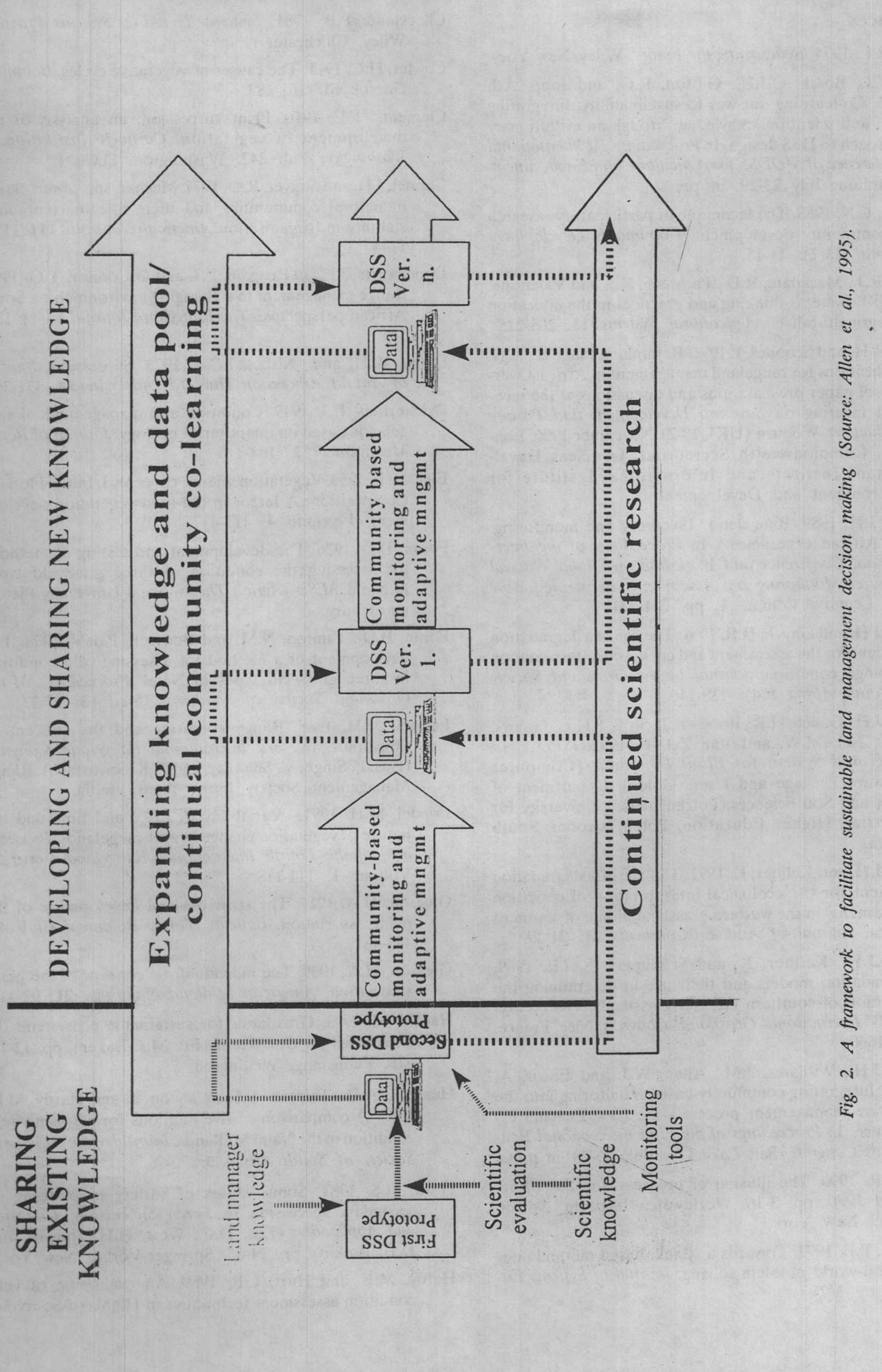

Fig 2. A framework to facilitate sustainable land management decision making (Source: Allen et al., 1995).

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