A PROBLEM TREE TO DIAGNOSE PROBLEM BUSH

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ABSTRACT

The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse a sequence of events that leads to a problem (such as bush encroachment in rangelands). A problem tree is useful because the consequences of different interventions can be visualised and understood more easily in diagrammatic form, thereby guiding management decisions regarding the problem. A problem tree was constructed to show multiple causes of bush encroachment. It was generalised by considering many possible causes, and not only those applying to particular areas of encroachment or specific species of bush. If the problem tree is to be useful in decision-making, one needs to determine which of the multiple pathways are of greater significance in any particular situation. Management decisions are bound to be more effective in the long run if they address causes higher up in the tree and closer to the root causes, than the proximate causes or symptoms at the bottom of the tree.

INTRODUCTION

Problem trees

The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse a sequence of events that eventually leads to a problem (Fussel, 1995). The tree is usually built upside down, with its roots, representing the root causes, at the top. When drawing a problem tree, the symptom is noted at the bottom of the diagram or page with its proximate cause immediately above it, and with a short arrow pointing downwards, from cause to symptom. The cause is determined by the question, "Why does this symptom occur?". This procedure is repeated until the root cause is reached, towards the top of the page. Since ecological interactions tend to be complex, with multiple determinants, the arrows in an ecological problem tree tend to grow out into branches.

The drawing of problem trees facilitates accurate diagnoses and guides the effective management of problems. Not all branches of a problem tree are relevant to every situation and land users need to identify which branches have the greatest relevance to their problems. Management decisions that address causes higher up in a problem tree, closer to the root causes, are likely to be more effective in the long run than those that address proximate causes or symptoms at the bottom of a tree.

Bush encroachment

Bush encroachment occurs in about 260 000 km^2 of Namibia (Bester, 1999), or about 30 % of the surface area of the country. Species of indigenous bush that contribute to bush encroachment include *Acacia mellifera*, *A. reficiens*, *A. luederitzii*, *A. erubescens*, *A. fleckii*, *A. nilotica*, *Colophospermum mopane*, *Dichrostachys cinerea*, *Terminalia prunioides*, *T. sericea* (De Klerk, 2004); *Grewia flava* and *A. tortilis* (Moleele, Ringrose, Matheson & Vanderpost, 2002). Widespread and excessive bush density seems to be a problem resulting largely from mismanagement of rangeland (De Klerk, 2004). However, bush encroachment can also be viewed as a natural patch dynamic process (Britz & Ward, 2007; Meyer, Wiegand, Ward & Moustakas, 2007), with the landscape consisting of many patches in different states of transition between grassy and woody dominance.

METHODS

Problem trees were constructed for various environmental problems, as teaching exercises during environmental awareness workshops. The bush encroachment problem tree was started with the symptom "bush encroachment". The tree was developed by repeatedly asking "Why does this symptom occur?" until the root causes were reached. The tree produced during the workshops was developed further through informal discussions with farmers as well as the authors' research. The problem tree was generalised by considering all possible causes, and not only those applying to a particular bush-encroached area or a particular species of bush. Diverse views on the causes of bush encroachment were considered, including well-established, speculative, controversial and anecdotal views.

RESULTS

The problem tree appears in Figure 1. The causal linkages below are numbered; the numbers in brackets refer to the numbered arrows in Figure 1.

DISCUSSION ON PROBLEM TREE CONSTRUCTION

Availability of soil water

Bushes encroach when established bushes grow bigger (1), and when new bushes are recruited (2). The growth of previously established bushes occurs every year, although more so in years of good rain. If more soil water is available to bush roots (without prolonged waterlogging), bushes grow more vigorously (3). Greater soil water also allows more bush seedlings to establish (4), provided there are enough viable seeds (5). If more soil water is available to *Acacia mellifera* roots, more pods with viable seeds are produced (6) (Joubert, Rothauge & Smit, 2008). In fact, there is generally no production of viable seeds in below average rainfall years, whereas very many seeds are produced in exceptionally high rainfall years.

The establishment of new bush seedlings tends to be an extremely episodic event, occurring on average once every few decades. This is particulary true for *A. melllifera* (Joubert *et al.*, in press). A good rainy season leads to prolific flowering during the following dry season, after which viable seed is produced in the next rainy season. This seed also needs good rain to ensure survival after germination. A third good rainy season may be needed to ensure successful establishment of the small seedlings from the previous season. Hence recruitment of *A. mellifera* may require two or three consecutively good rainy seasons (7), for linkages (4), (5) and (6) to take place.

Although there is no arrow in the problem tree pointing towards the box with successive good rainy seasons, this is not a root cause, but rather a rare environmental prerequisite for the establishment of bush seedlings of certain species, if at least one of the root causes has taken effect. Other species such as *D. cinerea* may be able to establish with one season of exceptional rain, since they produce viable seed banks (due to hard seed coats) (Bell & Van Staden, 1993). There is a distinction between species such as *A. mellifera*, which have seeds that cannot survive in the soil from one season to the next and species such as *A. tortilis* with small seeds and hard testa that survive for many years in the soil seed bank. Establishment of *A. tortilis* seedlings therefore do not require an initial wet season for seed production.

The soil water available to bushes is directly related to the water that is removed by grass roots (8). If grasses are dense and/or vigorous, less water is available (Mworia, Mnene, Musembi & Reid, 1997) (9). This is straightforward competition between bushes and grasses, regardless of whether their roots occupy two different layers in the soil as postulated by Walter (1971). This competition is also influenced by differences in osmotic potential and wilting points between woody plants (that use the C3 photosynthetic pathway) and grasses (that use the C4 photosynthetic pathway). Generally grasses utilise soil water faster than woody plants, but reach wilting point sooner, with soil water at a higher matrix potential above the wilting point of woody plants (Smit & Rethman, 2000).

Grazing herbivores

Perennial grasses evolved under conditions of severe grazing followed by periods of long rest. They can become weakened by extremes in either direction, namely by overgrazing or overresting. Both conditions can occur on the same rangeland, if animals are stocked lightly and continuously or under fast rotation with short rest, as occurs on many commercial farms. The most palatable grasses, especially those closest to the water point, then become overgrazed (10), while the less palatable species, especially those further from the water point, become over-rested (11), both resulting in lowered grass vigour (McNaughton, 1979). Historically, under natural conditions, the predominant species of wild herbivores remained tightly bunched in large herds controlled by predators. Permanent water sources created ideal opportunities for predators to ambush prey and it is unlikely that herbivore herds would have remained in the vicinity for long periods. Wherever the herds grazed they are likely to have fouled the rangeland with their dung, making it unsuitable for regrazing until cleaned by dung beetles and rain, by which time the severely grazed and trampled grasses would have replenished root reserves and would thereby have been ready to be regrazed (Savory, 1999). The natural movements of animals were disrupted by pioneer farmers who replaced the wild herbivores with domestic livestock; controlled the predators; changed the natural range by sinking boreholes and putting up fences; and thereby allowed overgrazing and undergrazing to become widespread (12) and (13), thus contributing to the root causes of bush encroachment.

Browsing herbivores

Another reason why bushes flourish is because of a reduction in browsing animals which allows more pods to be produced on bushes (14), more seedlings to establish (15) and established bushes to grow more vigorously (16). Browsing, mainly by kudu, goats and impala, was found by Roques, O'Connor & Watkinson (2001) to impact on encroachment, mainly on *Dichrostachys cinerea*, and only in the early stages of encroachment. Although browsing by ruminants may actually stimulate bush growth (Scogings, 2003; Stuart-Hill, 1988), megaherbivores such as elephant and black rhino previously played an especially important role by keeping bush growth in check (Grossman & Gandar, 1989). These large megaherbivores have been seriously depleted due to the construction of fences and hunting (17). Small browsing herbivores such as hares, squirrels, gerbils and bruchid beetles feed on bush seeds and/or seedlings. In fact, small browsers may be more important regulators of bush densities than previously recognised (Ostfeld, Manson & Canham, 1997; Weltzin, Archer & Heitschmidt, 1997). A decline in small browsers allows more seedlings to establish (18). Declining grass cover may be responsible for the decline in some small browsers (19), which is due to perennial grasses being fewer and weaker, thereby rejoining the main trunk of the problem tree (20). Bush seedlings of some species increase because large herbivores browse the pods and disperse the seeds (21) (Coe & Coe, 1987). This applies especially in the dry season when palatable grasses are in short supply, to bush species with tasty pods and seeds with hard testa that can survive animal digestive systems. *D. cinerea* and *A. tortilis* are dispersed in this way, especially if there is insufficient palatable grass available, forcing grazing animals to feed more on pods (22). However,

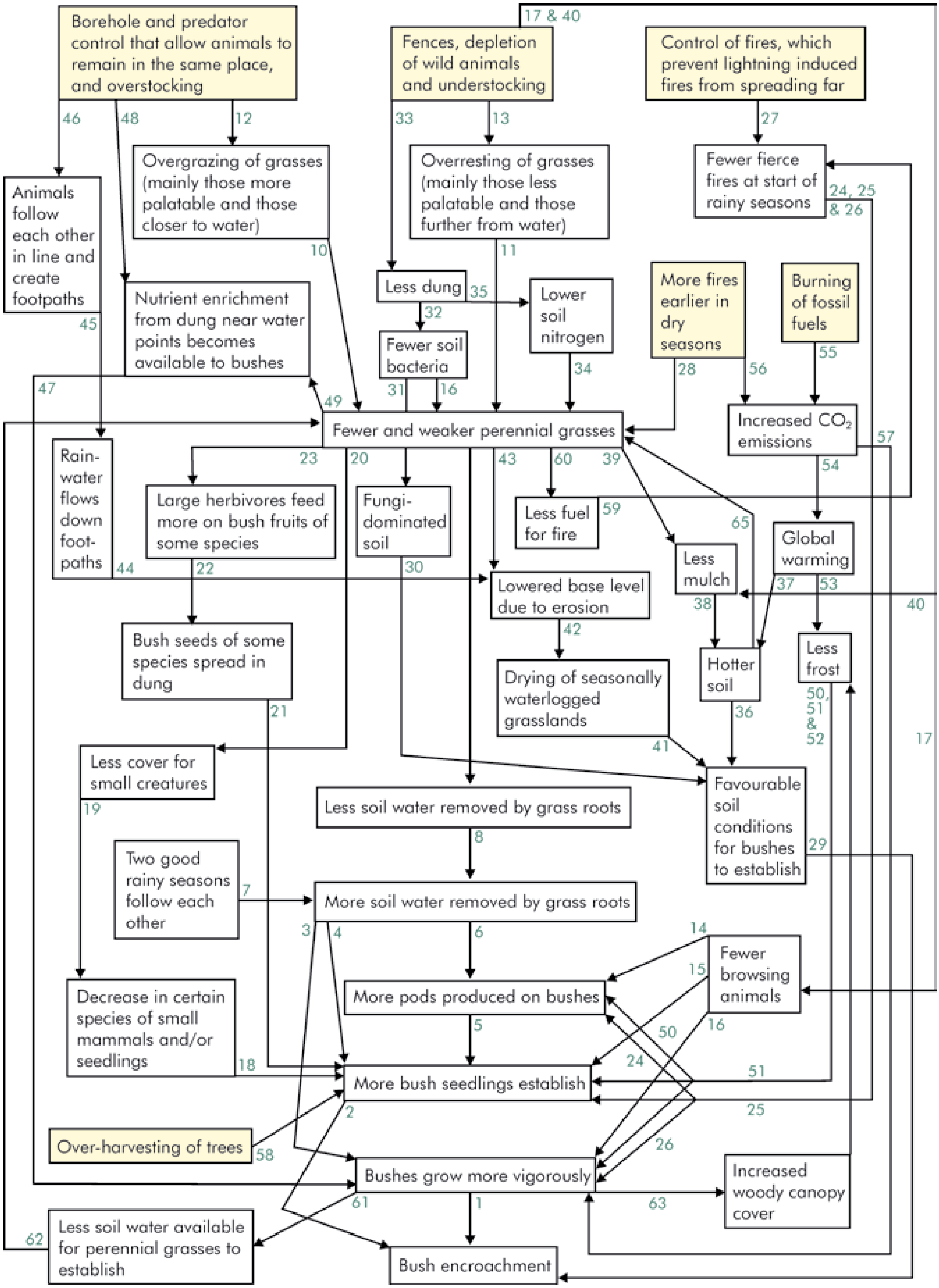

Figure 1. A diagnostic problem tree for bush encroachment, with root causes shaded and numbers providing references to text.

the seeds of other woody species (such as *A. mellifera*) which do not have hard testa, cannot survive, and cannot be dispersed in this way. The lack of palatable grasses again leads back to the main trunk of the problem tree through fewer and weaker perennial grasses (23).

Fire

Bushes also flourish because of fewer hot fires at the start of the rainy season, when bush stems are more sensitive, having broken dormancy so that their phloem is active and buds are exposed. Fierce fires tend to burn in years following high rainfall when a high fuel load is produced and there are fewer large herbivores to reduce the fuel by grazing. After good rains the bushes produce many pods, which are consumed by the fire (24), preventing them from producing viable seed. Small bush seedlings and saplings are sensitive to fire; they are probably also destroyed in fires of lower intensity (25). Well-established bushes usually only suffer top kill from hot, high intensity fires, although they may be weakened due to loss of food reserves (26), especially if their regrowth is browsed (Trollope, 1980). Lightning often causes natural fires at the start of rainy seasons. These fires occur during the short window period when the availability of dry fuel overlaps with the occurrence of thunderstorms. However, effective fire fighting by commercial farmers over the past decades has resulted in such fires being quickly extinguished or contained within firebreaks (27), further contributing to bush encroachment.

Despite fewer fires at the start of the rainy season, there has been an increase in fires earlier in the dry season, usually as a result of negligence or vandalism. Perennial grasses evolved under the selective pressure of fire at the start of rainy seasons. They are thus not well equipped to deal with fires early in the dry season (or in winter), which tend to weaken the grasses (28). These early fires break the dormancy of the grasses, exposing their new shoots to unfavourable conditions (dryness, continuous grazing and possibly frost). These hardships are ameliorated at the start of the rainy season but impose their toll if the rainy season is still far away. Bushes on the other hand, are far less affected by fires early in the dry season, since they are dormant with inactive phloem and buds well protected by bark. Therefore, the balance between bushes and grasses tends to favour bushes if a fire burns early in the dry season, contributing to the root causes of bush encroachment.

Soil conditions

Some soil conditions, other than those related to competition for soil water mentioned above, may also favour bush encroachment (29). Soil dominated by fungi favours bushes (30) while soil dominated by bacteria favours grasses (31) (Kingdon, 2005). Dung is dominated by bacteria so less dung results in fewer bacteria in the soil (32). Less dung is produced if large herbivores are fewer (33), one of the root causes of bush encroachment already mentioned. Lack of dung beetles to process dung, resulting from the use of chemicals to control parasites, which simultaneously contaminate dung, can lead to fewer bacteria in the soil.

C4 grasses are in greater need of soil nitrogen than leguminous C3 bushes that house nitrogen-fixing bacteria. Lowered soil nitrogen may therefore weaken grasses (34) more than bushes (Kraaij & Ward, 2006). Soil nitrogen is lower if there is less dung (35).

Higher soil temperatures seem to favour the establishment of bushes (36) (Labuschagne, pers. comm.). Soil temperatures increase as a result of global warming (37) and when there is not enough mulch to cover and shade the soil (38). A scarcity of mulch results if grasses are fewer and weaker (39), and if there are fewer animals to trample down dry grass stands (40).

Soil conditions in specific locations can influence the growth of bushes. For example, seasonally waterlogged soils tend to be dominated by a good grass cover because bushes suffer if waterlogged. Although covering only a small proportion of Namibian rangeland, these hydromorphic grasslands are key habitats that provide important resources for livestock and game. Bushes are likely to flourish if water is drained from waterlogged soil (41) as a result of erosion that lowers the base level (42), which formerly held the water back (Pringle, Watson & Tinley, 2006). According to Pringle (2008), "base level incision is clearly etching away some of Namibia's most productive, drought-buffering landscapes at very local to whole of catchment levels of ecological organisation". The base level erosion is usually a result of depleted perennial grass cover (43) and often of water flowing down footpaths (44); brought about when herbivores (cattle) slowly follow each other (45), especially when walking to and from a water point supplied by boreholes (46) in the absence of large predators. Another local effect is that established bushes often grow vigorously near water points, often developing into valuable shade trees. Animals rest under these trees and devour the masses of pods that are normally produced. The trees/bushes benefit from nutrient enrichment of the soil from dung (47) of animals attracted to the water point (48) (Moleele & Perkins, 1998). There is no competition from grasses (49), since they do not survive due to continuous trampling by animals. Dung from animals supplemented with phosphate lick is likely to improve soil fertility even more, considering the low availability of phosphorous in Namibian soils; however, much of it is wasted if allowed to accumulate in the sacrifice zone around water points, benefiting only a few desirable large shade trees.

Climate change

Warmer temperatures result in fewer bush pods being killed by frost (50), fewer seedlings being killed by frost (51) and fewer established bushes experiencing top kill (52), especially of the more frost-sensitive species such as *Dichrostachys cinerea*. In encroached stands the bushes are less susceptible to damage by cold (frost), compared to more open stands, since many bushes in close proximity to each other are somewhat protected (Smit, 1990). Less frost may result from global warming (53), caused by increased carbon dioxide and other greenhouse gas emissions (54), and the burning of fossil fuels (55) and bush fires (56).

Increased carbon dioxide emissions favour the growth of C3 plants, including bushes (57), over C4 plants, including grasses of semi-arid rangelands (Midgley, Bond, Roberts & Wand, 2000), especially under xeric, rather than mesic conditions (Palmer & Eamus, 2008).

Loss of large trees

The loss of large trees due to harvesting for fence posts or charcoal/firewood, or through indiscriminate/non-selective bush-control measures, is a root cause of bush encroachment (58). Large trees outcompete smaller bushes (Smit, 2004), and when large trees are cut down, the smaller bushes increase in size.

Positive feedback

The problem tree has four positive feedback loops that reinforce some of the causal linkages, further favouring bush encroachment. Fewer and weaker perennial grasses result in less fuel for fire (59), reinforcing fewer fierce fires at the start of rainy seasons (60). Increasingly vigorous bushes remove water from the soil (61), leaving less for perennial grasses, thereby reinforcing fewer and weaker perennial grasses (62). The increasingly vigorous bushes also provide greater canopy cover (63), which creates a microclimate with less frost (64). Hotter soil reinforces fewer and weaker perennial grasses (65) due to poor germination of perennial grass seeds in soil much exposed to the sun, while favouring the germination of weeds such as *Tribulus terrestris* and bush seedlings (Labuschagne, pers. comm.). The increase of biological soil crusts under impenetrable *Acacia mellifera* bushes (Thomas, Dougill, Berry & Byrne, 2002) may also provide a positive feedback loop by restricting water infiltration to grass roots (Eldridge, Zaady & Shachak, 2000). However, there may also be negative feedback since the density and vigour of annual grass under bushes is often greater than between bushes, so the benefits of shade and leaf mulch provided by bushes may outweigh the disadvantages of some biological soil crusts. In addition, the crusts that tend to develop on soil under bushes may contain more beneficial organisms that fix nitrogen, protect soil from wind erosion and possibly enhance water infiltration, since biological soil crusts can be extremely diverse in both species composition and properties (Eldridge & Greene, 1994). Because the role of biological soil crusts in bush encroachment is not entirely understood, they have not yet been added to this problem tree; however, this can be done once this issue has been clarified.

DISCUSSION ON MANAGEMENT APPLICATIONS

It is necessary to determine which of the multiple pathways in the problem tree are of greater significance in any particular situation, if the tree is to be useful in decision making. Pathways will differ, depending on factors such as land-use and rainfall history, agro-ecological zone, soil conditions and the species of bush that are considered problematic. For example, Midgley and Bond (2001) suggest that fire contributes more significantly to bush dynamics in higher rainfall areas while rainfall contributes more significantly in lower rainfall areas. They further suggest that herbivores in higher rainfall areas exert their influence on bush dynamics largely by consuming fuel load, which in turn reduces the occurrence, extent and effectiveness of fire. In lower rainfall areas herbivores probably influence the dynamics largely by feeding on bush seedlings and saplings. The problem tree has five shaded boxes containing root causes. It is unlikely that more than three of them would apply to a particular situation, and most likely that one will be of overriding importance. If management is applied within the problem tree, at an intermediate cause, then the arrow pointing down to that cause will show which factors, above it, are likely to counter the effectiveness of the management efforts. Final problem trees for specific circumstances will appear less complicated than the large, generalist problem tree in Figure 1. Even if specific trees appear complicated at a glance, they become ever clearer when interpreted one step at a time. A Powerpoint presentation is ideally suited to this purpose, as small amounts of information are released at intervals, making the construction of the complete tree easier to follow. If farmers are involved in the construction of a problem tree, discussion is stimulated and a more holistic understanding of the problem develops.

Treating the symptom

Farmers commonly react to bush encroachment by wanting to treat the symptom, usually by means of a "quick fix", such as the application of arboricide. Observations in the field show that widespread aerial application of arboricide appears to result in other "problem" species becoming dominant after the targeted bushes have died. For example, *Laggera decurrens* has been observed to replace dead *A. mellifera* and *D. cinerea* thornbush. Apart from the high cost of this "solution", it may simply bring temporary relief until the root causes (still in place) result in further bush encroachment. However, if the root causes have indeed been addressed, the simultaneous treatment of the symptoms may be justified to ensure a quicker recovery of the rangeland.

If arboricide is opted for, application costs can be minimised by selective application, at critical times, such as when bushes failed to produce viable seed. This would prevent the sprouting of masses of seedlings after the parent bushes had died. It may be more economical to apply arboricide as a follow-up treatment some years after another method has been used. The arboricide then only needs to be applied to those target bushes that were not sufficiently weakened by the previous treatment. Arboricide may also be applied to cut stumps in conjunction with selective chopping, to prevent regrowth. Selective thinning can structure the surviving bushes in such a way that their roots will suppress the re-establishment of excessive replacement bushes while encouraging grasses (Smit, 2004).

With increasing worldwide demand for energy it is likely that manual chopping will become a viable option for many farmers. There is a risk that chopping will be insufficiently selective, or favour the chopping of bigger bushes over smaller ones to maximise wood yield per unit of effort. This may lead to rangeland degradation due to exposed soil, as does the non-selective application of arboricides.

Treating root causes

Since the root causes of widespread bush encroachment are related to human interference in nature, treatment would mean reverting to nature. This could only be achieved if neighbouring farmers were to join forces to form large conservancies, temporarily close down water points, removing fencing and re-introducing megaherbivores and other wild animals exterminated in recent centuries to their farms. Since the above is highly impractical, the next best alternative would be to treat intermediate causes as close as possible to the root causes. The root cause that is the easiest to treat is the disruption of natural fire regimes, through the combination of regular fire control and the infrequent application of strategically timed burning. The root cause of over-harvesting would require lengthy treatment if few or no trees remain, requiring protection for tree seedlings over the decades as they are sensitive to browsing.

Focusing on perennial grass

The box with fewer and weaker perennial grasses features prominently in the problem tree and it holds the key to bush encroachment through a multitude of pathways, and to its management. Perennial grasses can be kept healthy by alternating short grazing periods with long rest periods in the growing season, allowing grasses time to replenish their food reserves. Vigorous perennial grass cover may weaken bush seedlings and saplings through competition for water, but whether it prevents the establishment of the young bushes or not is still debatable (Kraaij & Ward, 2006; Joubert *et al*., 2008). A soil rich in manure, well worked in by dung beetles, seems to favour grasses while causing premature weakening of mature bushes by fungal disease, as indicated by the sound of a hollow thud when striking the main stem with a heavy stick (Richardson, pers. comm.).

Reversing rangeland desiccation

Where there is massive loss of water from the rangeland as a result of soil erosion, instead of slow infiltration, the root causes need to be addressed, but it is important to treat the symptoms at the same time. If a gully is eating its way towards a seasonally waterlogged grassland, repair of the gully will save the grassland from bush encroachment (Pringle, *et al*., 2006). A gully system can be healed by the strategic placement of filters to slow down flowing water and trap sediment, provided that the root causes of the gullies have also been addressed. In cases where dense bush grows nearby, this problem can be converted into a solution, by providing filter material for the gully system (Shamathe, Pringle & Zimmermann, 2008).

Occasional use of fire

There are many risks associated with the use of fire, including the accidental spread of fire to other areas and the possibility that there will be insufficient rain after the fire to allow proper recovery of the burnt grass. One way to minimise the latter risk is not to use fire unless the residual soil water from the previous season is sufficient to allow the grass to recover, even without follow-up rain (Labuschagne, pers. comm.). Since fire consumes organic matter that would otherwise be added to the soil, it may be wise never to use fire unless sufficient organic matter has built up in the soil over previous years.

Situations where burns may be warranted are: after exceptionally heavy rains resulting in high grass yields that cannot be consumed by available animals; where it may be beneficial to open up bushy areas; or to remove the threat of mass seed production by bushes. Perhaps the most important role that fire can play is to kill off a mass emergence of bush seedlings to prevent a new wave of encroachment during the limited time that bush seedlings and saplings are sensitive to burning (Joubert *et al*., 2008).

CONCLUSION

The problem tree is one of several tools that can assist decision making on appropriate rangeland management. The constructed tree is by no means inflexible, and can be revised as new information becomes available. It can be more effective if used in combination with other tools, such as a state and transition model (Joubert *et al*., 2008); a decision support system for rangeland management (Joubert, Zimmermann & Graz, 2008), accessible at http://chameleon.polytechnic.edu.na/wiki/; and a farmer's conceptual model of rangeland dynamics (Zimmermann & Smit, in prep.).

The problem tree is based on a wide range of information sources including informal observations. Some aspects thus need further research before assertions can be verified. For this reason, greater emphasis should be placed on research into the dynamics implicated in the overall process of bush encroachment in Namibia, such as the demographic studies proposed by Midgley & Bond (2001).

Since problem trees are aimed at controlling problems, there is a risk that bush, rather than excessive bush, will be perceived as the problem. In their natural environment all species of bush, whether encroachers or not, perform useful ecological functions. Most rangeland management aims at achieving a reasonable balance between bushes and grasses, so that each may contribute to a healthy and productive rangeland.

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