

Provision of ecosystem services by large scale corridors and ecological networks

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Abstract Large scale landscape transformation and contingent habitat loss are among the greatest threats to ecological integrity and ecosystem health. One of the mitigation approaches used to deal with these pressures is to leave interconnected corridors and nodes as remnant ecological networks (ENs) within the transformed landscape. The South African forestry industry has already allocated 500,000 ha, one-third of the plantation holdings, consisting predominantly of natural grassland, as ENs among and within timber plantations. These ENs are intended to maintain structural, compositional and functional biodiversity. However, little scientific research is available on the effectiveness of these huge ENs for biodiversity conservation and maintenance of natural ecosystem function, although initial findings are encouraging. While the local adverse effect of alien plantation trees on functional biodiversity is not in dispute, it is at the scale of the whole landscape where there is much interest in determining how effective these ENs are in maintaining the untransformed portion of the transformed landscape in a close-to-natural state. As these ENs are extensive, species beta diversity is a consideration in addition to alpha diversity. Initial findings reveal diminished ecological integrity in narrow corridors due in part to the adverse edge effect from the alien trees into the margin of the EN. Quality of the ENs is of great importance for maintaining functional diversity, with human disturbance reducing their effectiveness. First findings, and their application to the Framework for Ecosystem Service Provision, suggest that these ENs are significant for biodiversity conservation and for provision of ecosystem services. Nevertheless, still much more research is required on a greater range of taxa, and their interactions, to improve the design of these ENs for ecological and evolutionary processes.

Keywords Ecosystem services · Corridors · Ecological networks · Function · Grassland · Plantation forestry · South Africa · Mitigation

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Introduction

Creative management approaches are required to avert further loss of biodiversity and to maintain the functional integrity of ecosystems (MA 2005). Ensuring connectivity between habitat patches for organism dispersal is important for mitigating loss of habitat and for reducing the effects of isolation of remnant habitat patches (Fahrig 2003). Connectivity may be in the form of a physical linkage, or corridor (Bennett 1999). Such corridors are now being built into landscape design for biodiversity conservation in urban and agricultural contexts (Smith and Hellmund 1993; Burel and Baudry 1995; Rosenberg et al. 1997; Jongman and Pungetti 2004; Nasi et al. 2008). This approach is based on considerable theoretical discussion of the value of corridors (Forman 1995; Bennett 1999; Chetkiewicz et al. 2006; Hilty et al. 2006), and their practical value (Jongman 1995; Boitani et al. 2007).

A corridor has several functions for a species, which may vary from one species, and even morph, to another. A conduit for one may be a barrier for another, which may vary seasonally or according to a disturbance factor such as fire. In turn, different corridors in any one geographical area may have slightly different functions for the same suite of species.

Corridors may be relatively simple to define, say, as movement corridors for a focal species (Hilty et al. 2006). However, when overall biodiversity is being conserved, inherent biological complexity of whole ecosystems becomes a major consideration. In short, no one corridor will necessarily benefit all ecological integrity, nor all natural ecosystem functions. Corridors may also have ‘negative’ effects, by providing pathways for predators or pathogens. Conceptually, it is useful to know to what extent corridors within a transformed matrix can maintain biodiversity and whether they are sustaining the properties of dynamic ecosystems (i.e. durable, robust, stable and resilient; Dawson et al. 2009). Furthermore, with increasing demand for understanding the function and dynamics of socio-ecological systems (Rounsevell et al. 2009), we can apply conceptual frameworks which help define and structure those variables which are important for the sustainable management of corridors.

Two conceptual guidelines can serve as starting points in deciding what a corridor should accomplish:

Firstly, the landscape can be envisaged as a large continuous piece of land. The ideal, and perhaps theoretical, outcome from instigating a corridor within the transformed matrix (i.e. an alien timber plantation) would be where the corridor contains the same biodiversity and provides the same functions as a similar-dimensioned array of land in an untransformed matrix such as a neighbouring reserve (Fig. 1).

Secondly, Hess and Fisher (2001) provide a very useful conceptual framework for corridors based on six ‘functions’ or attributes: (1) conduit (2) habitat (3) filter (4) barrier (5) source, and (6) sink. These functions may not be mutually exclusive, and depend on which species, even which morph or ecotype, is being considered, on the spatial scale being stipulated, and over a particular time scale. A focal corridor should be defined in terms of these functions, in relation to the focal species, or community. Generally, the aim of a functioning corridor is to promote the attributes of conduit, habitat and source, and not the other attributes.

Improving connectivity for all species in an area, and their interactions under varying weather and climatic conditions, as well as maintaining long term evolutionary advantage, is a challenging task. One way to tackle this complexity and its variation over time is to establish a network of corridors, with the addition of nodes where they interconnect and

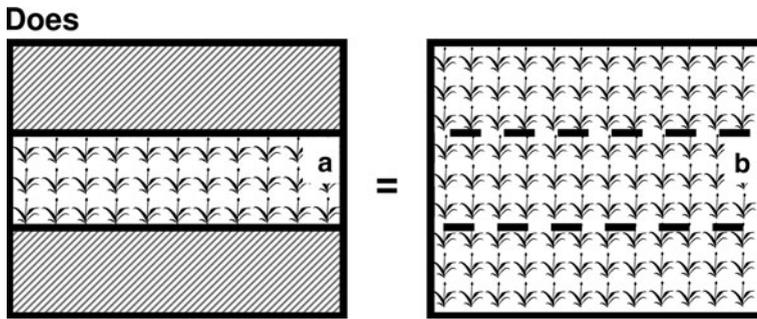


Fig. 1 A conceptual diagram showing the functional approach being used to introduce large scale corridors in South Africa. The corridor is considered not just simply a linear landscape element in a disturbed afforested landscape (a), but a functional section of an extensive natural landscape (b) (hatched areas represent a transformed landscape, plants a natural untransformed area). Nodes within the ecological network, as well as adjacent to natural reserves, are part of this landscape-to-regional scale approach. The question is whether, in reality, this is the case. Research to date shows that it is, provided the corridors are at least 250 m wide

with inclusion of particular landscape features or ecosystems (e.g. a hilltop, natural forest patch, or a wetland, in a grassland corridor). Such networks of corridors and nodes, and where possible, buffer zones (Jongman and Pungetti 2004) are referred to as ecological networks (ENs) (Fig. 2). While these are essentially at the landscape spatial scale, they can also be joined to form an extensive regional network.

ENs are more than simply a set of corridors. They have emergent properties and functions beyond those of a set of corridors, and are used to improve the persistence of a wide range of populations and can be used to stem the loss of biodiversity across an extensive landscape. However, there is a conceptual dilemma surrounding ENs. They are a structural component of the landscape yet they are intended to provide a function: that of conservation of compositional, structural and functional biodiversity. Whether they succeed in this should not be assumed, but rather measured scientifically. One approach for doing this, while at the same time taking into consideration socio-ecological systems, is by applying the Framework for Ecosystem Service Provision (FESP) (Rounsevell et al. 2009, this volume).

We examine here the possible value of the FESP framework for practical conservation using results from corridors and ENs in South Africa.

Historical context of ENs in South Africa

The ENs are scattered throughout the afforested areas of eastern South Africa. However, not all the plantations currently have ENs, but the proportion of afforested areas supporting them is increasing. ENs provide an opportunity for determining the extent to which this EN design feature fulfills a functional purpose, and whether it is a good model for extrapolation to other areas of the world.

The first large scale, exotic plantation forests were established in South Africa in the 1890s (Tewari 2001) in response to the insufficient natural wood sources in the country (the forest biome covers only 0.02% of South Africa's land surface area (Mucina and Rutherford 2006)). The majority of suitable land for forestry is within Mpumalanga and

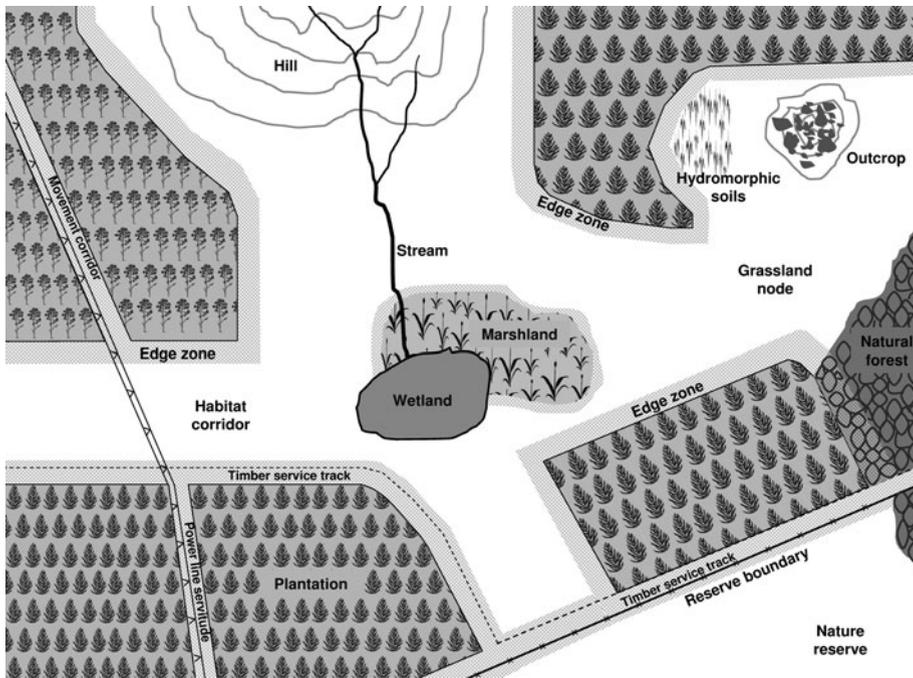


Fig. 2 A conceptual diagram illustrating the emergent properties (over simply corridors) of large-scale ecological networks (ENs) designed to function like the equivalent and adjacent natural reserve area. The EN here is set in the context of afforestation with alien plantation trees. ENs are much more than just a set of corridors. They include nodes which are extensive areas, often at the intersection of large corridors (habitat corridors), special ecosystems (such as wetlands and marshlands), special features (such as outcrops), while enabling natural ecosystem functioning such as water catchment and run off. Small corridors, which may for example be power line servitudes or timber vehicle tracks are a necessary part in the whole design, and yet can also function as movement corridors. The plantation tree patches inevitably have an edge zone which tends to be impoverished in biodiversity compared to the interior of the large, habitat corridors. Hydromorphic soils are not planted to improve overall hydrology. In one of the most advanced of the ENs in South Africa, at iSimangaliso World Heritage Site, the fence between the reserve area and the adjacent EN has been taken down, allowing game animals, even elephant and white rhino, to wander throughout the area

KwaZulu-Natal (KZN) provinces, within the severely threatened grassland, wetland and indigenous forest biomes (Eeley et al. 2002; Neke and du Plessis 2004; DWAF 2006), and in an El Niño-prone area where there is indication of evolutionary adaptations at least by insects to such climatic events.

Today, this timber industry occupies 1.8 million ha, or 1.5% of the surface area of the country (DWAF 2006). Of this, 1.3 million ha are planted to alien *Eucalyptus*, *Acacia* and *Pinus* species (Kirkman and Pott 2002). A further 500,000 ha are maintained mostly as conservation areas of protected grassland, wetland and indigenous forest, but also with some firebreaks, power lines and vehicle tracks. On average, one-third of a given plantation remains unplanted to timber, and it is these unplanted areas which form the ENs of interconnected corridors, nodes and special landscape features, especially hilltops and wetlands (Fig. 3) (Kirkman and Pott 2002; Samways 2007a, b).

In the mid-1990s, and in anticipation of global consumer demand for products that are produced in a biodiversity and socio-economically friendly way, the large forestry



Fig. 3 A portion of the 500,000 ha grassland ecological networks already instigated in South Africa as a biodiversity mitigation measure for commercial forestry

companies with markets in Europe began to seek certification. By 1995, both Mondi and Sappi, the largest private growers in South Africa, had implemented ISO 14001 or Forest Stewardship Council (FSC) international standards (Kirkman and Pott 2002). The FSC is a stakeholder-owned, non-profit organization which accredits private companies around the world to conduct the FSC certification process on sustainable forestry and annual audits (FSC 1996).

Today, forestry is the single most regulated land use in South Africa (DWAF 2006). The Department of Water Affairs and Forestry (DWAF) oversees all plantations, and in 2005, began to implement the Principles, Criteria, Indicators and Standards (PCIs) which were provisioned for by the National Forests Act of 1998 (Lawes et al. 1999). The PCIs stipulate documentation and monitoring of the known rare, threatened and endemic species of an area, forest layer integrity, rehabilitation of degraded forests, mitigation of water pollution, and water quality assessments (DWAF 2005). In addition to these mandatory steps, many forestry companies, particularly the large corporations, voluntarily certify their plantations through the FSC to maintain their biodiversity conservation *bona fide*. Certification by the FSC requires annual environmental impact assessments of indigenous forests and wetlands within a plantation (FSC 1996).

Neither DWAF nor the FSC regulate all plantations within grasslands (Jackelman et al. 2006). National FSC standards are being written at present to rectify this loophole. They aim to include small and medium growers, as well as the large-scale operations which do comply, and to cover all growers, even those who do not export their products to Europe.

Issues of spatial scale: the small and the large

Spatial scale plays a crucial role in determining the efficacy of ENs for biodiversity conservation. An organism's ability to utilize an EN depends on its specific habitat requirements and mobility, as well as the geographic extent of the EN. Similarly, studies to

determine the efficacy of ENs, must choose an appropriate spatial scale depending on the research question being asked (see also Brockerhoff et al. 2008). Since the ENs are so extensive, species beta diversity must also be taken into account. For example, Pryke and Samways (2001) undertook an intensive survey of butterflies inside versus outside ENs adjacent to a large reserve area. While the ENs lacked two species of butterfly that were in the reserve area, the ENs in turn had two other species that were not inside the reserve. Thus, for these butterflies the functions of habitat and source vary as much across ENs as they do across extensive natural landscapes.

At the very small, local scale, the landscape can be envisioned as adjacent, individual patches of plantation and natural vegetation (e.g. grassland, wetland or indigenous forest). At this scale, plantation forestry (i.e. stands of alien trees) has been shown to be highly detrimental to biodiversity (Samways and Moore 1991; Armstrong and van Hensbergen 1994, 1996; Armstrong et al. 1998; Pryke and Samways 2009). Yet, within ENs, and at the same spatial scale, and in contrast to the plantation patches, an equivalent patch of remnant natural grassland is rich in local biodiversity.

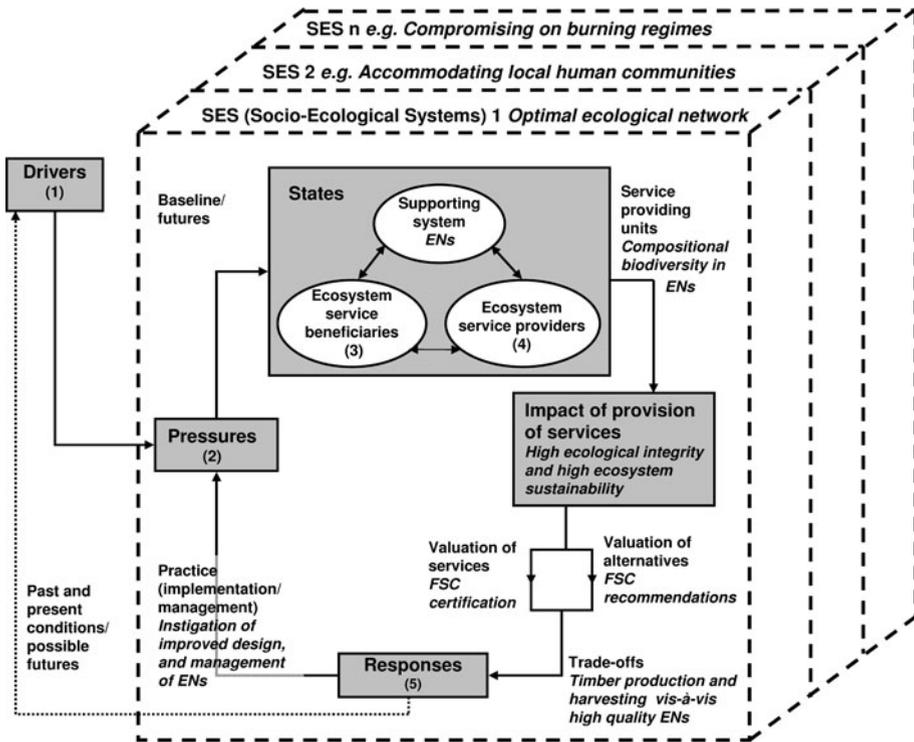
Then there is the other extreme of the very large regional or national spatial scale. While providing interesting information on the overall current state of timber-planted grassland, this very large spatial scale is often too coarse to see finer scale population patterns. Allan et al. (1997), working at the regional scale, found that grassland bird species diversity was negatively correlated with extent of afforestation. At the national scale, Reyers et al. (2001) found that plantation forestry was the largest threat to three out of ten vegetation types of highest conservation priority in South Africa. Neke and du Plessis (2004) noted that 3.3% of the grassland biome, regions containing the highest species richness of grassland birds, as well as rare, threatened and endemic birds, had been transformed by plantation forestry. However, all these studies included in their analyses the additional and extensive plantations that did not incorporate ENs. These large-scale figures do not realistically consider the intermediate, landscape-scale conservation approaches, i.e. where ENs have been instituted.

Ecological networks and ecosystem services

Rounsevell et al. (2009) describe a framework for consolidating knowledge on the effects of various drivers of change on ecosystem services (the Framework for Ecosystem Service Provision; FESP). The framework is based on an integration of three existing concepts: the Drivers-Pressures-State-Impact-Response framework (DPSIR; EEA 1995), the concept of Socio-Ecological Systems (SES; Berkes and Folke 1998) and the Service Providing Unit concept (SPU; Luck et al. 2003, 2009). If ENs are considered to provide the service of biodiversity conservation, then application of the FESP to large-scale ENs in South African plantation forestry can help to define and understand the dynamics and interactions between relevant socio-ecological systems (Fig. 4).

We now dissect and assess the impacting forces in and around ENs, and explore the FESP conceptual basis for implementation of high-quality ENs. In addition to the global economy which dictates the price of timber, and the growing wood requirements of an increasing human population, the exogenous *Drivers* which effect change on these timber production landscapes are environmental regulations, both mandatory, such as those enforced by DWAF, and voluntary, such as FSC certification.

There are numerous endogenous *Pressures* within the timber production landscape, affecting the internal environment, biodiversity, and socio-ecological systems. For



(SES) Socio-Ecological Systems

- (1) Wood requirements of society; global economy (price of wood); national legislation; voluntary regulations (Forestry Stewardship Council certification.)
- (2) Habitat loss and fragmentation; land use change; alteration of soil conditions; ground water depletion; edge effects from plantation trees; fire; invasive alien plants.
- (3) Timber companies; local human communities
- (4) Compositional biodiversity of the ecological networks (ENs) in plantation forests
- (5) Research; management (delineation, fire, grazing, mowing, removal of invasive alien plants); optimization of ENs; policy.

Fig. 4 Application of the Framework for Ecosystem Service Provision (FESP) (see Rounsevell et al. 2009) to the provision of ecosystem services by the extensive ecological networks (ENs) in and among South African plantation forestry

instance, forestry leads to altered soil chemistry and depletion of groundwater which exacerbate existing Pressures on already stressed systems (Armstrong and van Hensbergen 1996). The change from indigenous grassland to alien plantation forest (Neke and du Plessis 2004), the extent of conversion (Armstrong and van Hensbergen 1996) and the resulting habitat loss and fragmentation (Fahrig 2003) are all Pressures. The timber production landscape is situated in a fire-prone area (some 10 lightning strikes/year/km²) and fire can be an endogenous, ‘positive’ Pressure which shapes the natural biotic communities when used at the correct frequencies and time of year. Exclusion of fire is a ‘negative’ Pressure (in the context of maintaining indigenous grassland) which leads to seral succession to woodland and enables invasion by alien plants into the ENs, further shaping the system from within.

The *State* which results from the combined action of the Drivers and Pressures on two-thirds of the timber production landscape (the plantation patches), is generally an inhospitable, unnatural land use, containing impoverished biodiversity. For example, pine plantations have a proven deleterious effect on a variety of taxa such as grasshoppers (Samways and Moore 1991) birds and small mammals (Armstrong and van Hensbergen 1994, 1995). Furthermore, the ‘hard edge’ of timber adjacent to grassland causes severe edge effects for butterflies (Pryke and Samways 2001) and grasshoppers (Samways and Moore 1991). Also, alien plants adversely affect hydrology (Le Maitre et al. 1996), biodiversity (Samways et al. 2005) and ecosystem services (Van Wilgen et al. 2006). Therefore, the remaining one-third of semi-natural land, the ENs, have been instituted to sustain the properties of dynamic ecosystems, including durability, robustness, stability and resilience.

ENs as supporting systems

The ENs are the *supporting system* within the States box (Fig. 4), i.e. they support the maintenance of compositional biodiversity in the plantation forests, which provides the service of biodiversity conservation. To illustrate this, Bullock and Samways (2005) found that plant-arthropod associations, were maintained at any depth within a plantation, as long as the EN was sufficiently wide to exclude edge effects. Similarly, for butterflies, the distance to an outside source site did not matter, as long as the EN was of good quality (Pryke and Samways 2003). Almeida Vieira and Carvalho (2008) similarly found that pollination of a Brazilian tree continued in high-quality forest corridors at a landscape scale, while in an experimental landscape, Townsend and Levey (2005) demonstrated that corridors facilitate pollen transfer.

The two main obstacles adversely affecting the functioning of ENs as supporting systems are disturbance (Pryke and Samways 2003, Kinvig and Samways 2000) and size. Several studies have linked the size of a remnant natural patch or width of a corridor to the function of the EN. Field (2002) found that isolated, and especially small patches of natural grassland surrounded by pine afforestation showed an overall decline in seed set per flower for 94% of plant species in comparison with those in an extensive neighboring grassland. For butterflies, 250 m-wide corridors were a habitat, source and conduit. This was the case in parts of the EN even deep within the plantation landscape (Pryke and Samways 2001). In contrast, narrow corridors (<50 m wide) acted principally simply as conduits, with butterflies flying overall 13 times faster along these corridors than in the wide ones. This meant that the narrow corridors were unsuitable as habitats but were nevertheless effective movement corridors for butterflies (Pryke and Samways 2003).

These results on wide corridors functioning as habitats per se are among a suite of findings elsewhere in the world where some general principles are beginning to emerge. Hill (1995), for example, found 200 m-wide corridors were necessary as habitats for dung beetles in tropical Australian forest, while Berggren et al. (2002) found that in Fennoscandian corridors, bush crickets walked and dispersed more slowly in good quality, wide corridors than in poor quality, narrow ones. What this means in terms of function is that width is a highly significant variable, with 200 m beginning to emerge as the minimum width at which a corridor in a grassland EN can start to function as a habitat over simply a conduit, at least for invertebrates. However, we must emphasize that this includes the edge zone which runs along the edges of the grassland corridors. This edge zone physically *looks like* just the edge of the corridor, as it is simply a continuation of the grassland

(Fig. 5). The critical point though, is that it is not *functioning* in the same way as the grassland *interior* because the plantation trees are having an edge effect. An additional consideration is that many factors may affect the size of the edge zone, such as the ENs vegetation structure and type, age of plantation, aspect, gradient and plantation tree species.

The ENs provide several ecosystem services, besides biodiversity conservation, with two distinct beneficiaries. Local human communities utilize the grassland ENs for grazing land and for harvesting for thatching grass. Honey bees are numerous in the natural forest patches within ENs, and local people harvest the honey for sale and private consumption. Firewood is also collected in these natural forest patches, especially as many of the plantations/ENs are located in remote, rural regions where some communities have no electricity. Timber companies are the other significant ecosystem beneficiary, utilizing grasslands for useful compositional biodiversity (e.g. pollinators, natural biocontrol agents), nutrient cycling, natural water filtration, and firebreaks. The grasslands in ENs are also used to improve hydrological catchment function. This is done through the activity of delineation, which involves not planting, or removing planted, trees on hydromorphic soils so as not to interfere, or to restore, the natural hydrological processes (Dye and Jarman 2004).

Determining the threshold at which adequate biodiversity conservation is provided at a level demanded by the timber companies, or the legislation which affects them, needs further investigation. This defines the Service Providing Unit (Luck et al. 2003, 2009) which can be characterized as the minimum (threshold) quantity of biology required to supply a service at the desired level (Rounsevell et al. 2009, this volume). That is, the minimum biotic component which makes up a functionally natural EN. A good quality EN provides, for example, natural hydrological conditions, as well as highly exportable timber products that can be certified as having been grown in a sustainable way. The benchmark or reference condition of an EN equates to the equivalent structural, compositional and functional biodiversity in an adjacent reserve area.

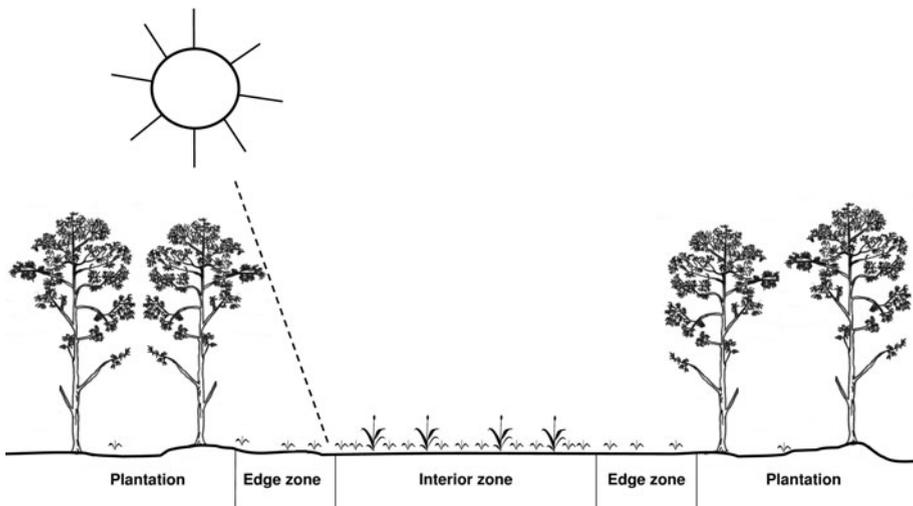


Fig. 5 Cross-section of an ecological network showing the edge zone between the plantation stand and the interior zone (zone of highest quality habitat). In this example, habitat quality is reduced in the edge zone of the ecological network by the shading effects of the alien trees, thus reducing habitat quality in this zone. Other variables, both direct and indirect, may add to this edge effect

Impacts and responses

The current State of the timber production landscape (ENs included) has many *Impacts* on local human communities and ecosystems. Extensive plantations result in reduced availability of suitable grazing land, leading to higher grazer density in the ENs than would otherwise occur. Indeed, human disturbance, particularly excessive cattle grazing and the impact of invasive alien plants has a detrimental effect on the ENs fauna and flora (Pryke and Samways 2003; Kinvig and Samways 2000).

The value of the service provided by ENs to timber companies is related to FSC certification. This is an all-or-none phenomenon: the markets are lost should FSC certification be lost. Thus, the only valuable ENs are those that enable timber production while at the same time maintaining structural, compositional and functional biodiversity. This is a stimulus to seek an optimal design for ENs, where good biodiversity conservation translates into highly exportable timber.

Not every corridor in an EN is of equal value. Design is important, as optimal EN design involves, for example, focusing on good quality, large habitat corridors and important nodes which deliver the important functional attributes. Lesser credence is given to smaller and disturbed corridors.

Research itself is one of the *Responses* in the FESP. Each negative Impact or Pressure is addressed in the form of altered management activities of the ENs and plantations. These responses include delineation. Fire management is also practiced to simulate natural and disrupted processes, with the burning of narrow corridors in the ENs being particularly delicate in the face of the financial risk of spread of fire to the commercial tree stands. Narrow corridors can be actively maintained by monitoring stocking rates of grazing livestock or large herbivores or mowing to provide defoliation in sites where burning is impractical. A further Response is optimization of existing EN design to connect between isolated fragments, or enlarge corridors in key locations, while allowing others to be afforested. A Response, such as the removal of invasive alien plants, reduces the Pressures by improving the ENs. Ultimately, the appropriate Response to the legislation Drivers are high-quality ENs (with high ecological integrity and ecosystem sustainability) which equate to the natural landscape in both the shorter and longer term.

Alternate socio-ecological systems (SES)

In principle, several alternative SESs are possible, as outlined by Rounsevell et al. (2009). As regards these ENs, arguably there is one optimal SES, and that is to establish ENs which optimize production without compromising biodiversity and natural system function. However, this is an ideal where there are essentially only two elements: timber production and conserving structural, compositional and functional biodiversity. In reality, there are other elements which must also be brought into the picture and which constitute alternative SESs. These other elements include the indigenous human communities and associated infrastructures. Within a single EN, this may mean setting aside certain parts of the EN to accommodate housing and traditional agricultural and pastoral activities, especially cattle grazing. This feeds back into revising the design of the ENs with a focus perhaps on several types of corridors and nodes, ranging from high-quality, functionally natural, large habitat corridors and nodes to partially degraded, narrow, pasture areas. Thus, the alternative SESs would depend on the level of indigenous human occupation and the subtending needs. In turn, for SESs at the larger spatial scale, which can be translated

into contiguous ENs with an evolutionary and climate change mitigation function in addition to an ecological function, it is essential to consider the adverse dissecting effects of major roads (McKenna et al. 2001). Some organisms and their propagules can cross roads, while others cannot, depending on type of road and traffic density, as well as type of organism. This means that roads act as a differential filter and therefore lessen the positive effect of the Response in the framework.

Conclusions

That the South African forestry industry has already set aside 500,000 ha for ENs is a major commitment. Initial research results suggest that this initiative has been successful for the conservation of biodiversity and the provision of ecosystem services. Already there are some clear pointers as to what design features of ENs are effective for biodiversity conservation and ecosystem service provision, and which are not. Firstly, it appears that large corridors in the ENs (about 250 m wide) satisfy Hess and Fischer's (2001) positive functional attributes of conduit, habitat and source, with narrow corridors fulfilling the function of only conduit. This clearly has important planning implications. Corridor width is important here, with wide corridors having considerably more important functional value than narrow ones. This is further emphasized by the fact that the EN/plantation tree boundary is very hard, with both little perforation of the plantation tree boundary by grassland EN-inhabiting species. Furthermore, there are considerable influential adverse effects by plantation trees (pines in particular) on the first few metres of the margin of the EN (the edge zone).

In addition, the initial results also clearly indicate that the quality of the corridors, as well as the width, is also very important. To be of high value, the ENs are required to be habitats and not just conduits, so that they function as a source and not just sink to enable long term maintenance of biodiversity and ecosystem function. This emphasizes that they must have a matching role to an equivalent piece of land in a natural system. When large, high-quality ENs are instigated, it means that larger-scale issues, such as species beta diversity, are also incorporated. At the even larger spatial scale, they would, through joining of a group of ENs, accommodate gamma diversity.

A particularly encouraging finding is that greater 'interiority' (increasing distance inside the plantation/EN from the outside, natural reserve area), did not lead to a decrease in biodiversity, compositional or functional (Pryke and Samways 2001, 2003; Bullock and Samways 2005). This is very strong support for the high value of these ENs across their entirety.

There is no dispute that alien plantations are generally detrimental to many taxa, and therefore, by extrapolation, unquestionably adverse for functional diversity at the local level. The question remains as to whether these large ENs are providing sufficient mitigation. Although the results to date are relatively sparse, they nevertheless do support the fact that these large ENs are indeed a mitigating factor for biodiversity conservation, and ecosystem function such as hydrological processes and pollination, in the plantation tree landscape. Clearly however, there is still much we can learn from the current and future results to improve the design and management of the ENs for long term, sustainable maintenance of biodiversity in the production landscape.

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