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Novel ecosystems resulting from landscape transformation create dilemmas for modern conservation practice

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Abstract

Introduction: Novel ecosystems occur when new combinations of species appear within a particular biome due to human activity, environmental change, or impacts of introduced species. **Background:** Managing the trajectory of ecosystems toward desired outcomes requires an understanding of the means by which they developed. To facilitate this understanding, we present evidence for the development of a novel ecosystem from a natural experiment focusing on 52 woodland remnants surrounded by maturing stands of exotic radiata pine. **Results:** Bird community composition changed through time resulting in a unique blend of tall closed forest and open-woodland birds that previously did not occur in the study area, nor in the region's tall closed forest or open-woodland biomes. **Conclusion:** Novel ecosystems will become increasingly common due to climate change, raising complex management and ethical dilemmas for policy makers and resource managers.

Introduction

Unprecedented transformation of landscapes worldwide (Foley *et al.* 2005; Millennium Ecosystem Assessment 2005) is leading to unpredictable changes to communities, posing new challenges to traditional thinking in conservation and resource management. Novel ecosystems that do not fall along the traditional gradient of pristine to degraded landscapes contain "new combinations of species that arise through human action, environmental change, and the impacts of the deliberate and inadvertent introduction of species" (Hobbs *et al.* 2006:1). In novel ecosystems, species "occur in combinations and relative abundances that have not occurred previously in a given biome" (Hobbs *et al.* 2006:1).

Introduced and invasive species are the usual drivers of novel ecosystems (Hobbs *et al.* 2006), although rapid climate change may also produce these ecosystems through associated changes in the occurrence and distributions of many species (Parmesan 2006). Research into paleoclimatic conditions and pollen records of the last 18,000 years suggests that during interglacial transitions, plant species moved at different rates and directions (Overpeck *et al.* 1991). This process led to plant communities with no historical equivalent. These findings are likely precursors to what will occur in many ecosystems over coming decades (Parmesan 2006; Williams *et al.* 2007), as novel ecosystems become increasingly common worldwide (Hobbs *et al.* 2006).

The increasing incidence of novel ecosystems is leading to calls for: (1) greater understanding of these systems so that we can predict their future state, and (2) the instigation of adaptive ecosystem management (*sensu* Walters 1986) so that the trajectories and desired outcomes of these systems can be proactively managed (Chapin *et al.* 2006; Seastedt *et al.* 2008). Both our ability to predict where novel ecosystems are heading, and the proactive management of these trajectories, require an understanding of the means by which novel ecosystems develop. In this article, we document the development of a novel ecosystem in southeastern Australia

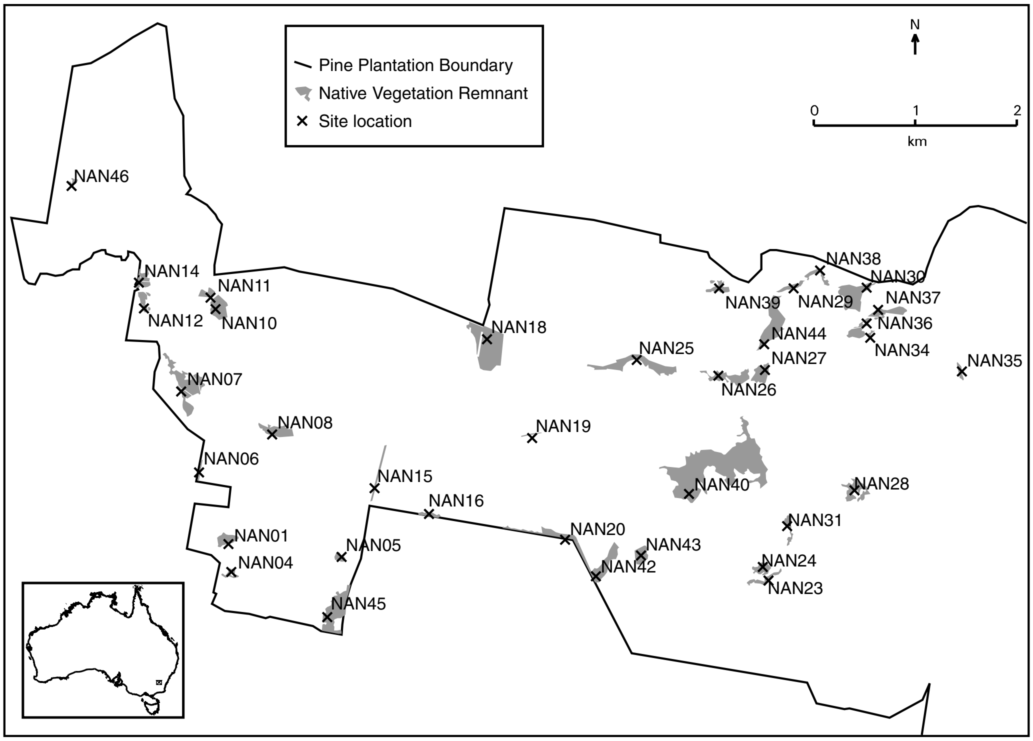

Figure 1 The location of open-woodland remnants (shaded) in the Nanangroe radiata pine plantation area.

using a 7-year dataset on changes in bird and reptile assemblages. We use the case study to illustrate the challenges for conservation posed by novel ecosystems and the proactive management of these systems.

Methods

We established a landscape-scale longitudinal "natural experiment" to quantify how the local bird and reptile assemblage responded to plantation establishment of the introduced plantation tree species, radiata pine, at Nanangroe, southeastern Australia (Lindenmayer *et al.* 2001, 2008). Nanangroe is 10–20 km southeast of the town of Jugiong in southeastern Australia. Approximately, 85% of the original temperate *Eucalyptus* open-woodland at Nanangroe was cleared in the past 170 years for livestock grazing. In Australia, tall closed forest and open-woodland are distinctly different vegetation types characterized by marked differences in tree height, tree spacing, length of boles, canopy development and spacing as well as a raft of other features (Specht & Specht 1999).

At the commencement of this investigation, our study area supported 70 remnant patches of native open-woodland (measuring 1–9.9 ha). These were surrounded by grazing pastures with scattered trees. No large open-woodland remnants were available for inclusion in the study. This was because of the extent of repeated land clearing events throughout the study region (Benson 1999), which has removed 95–99% of many types of open-woodland communities and left only small remnants (Prober & Thiele 1995; Gibbons & Boak 2002). Indeed, landscape clearing in the Nanangroe region has not been a single perturbation event, but rather a series of repeated phases of clearing and re-clearing over 170 years with the latest occurring in the mid 1970s.

In 1997 (and prior to plantation establishment), we randomly selected 52 open-woodland remnants from strata defined by vegetation class (three open-woodland types) and four patch sizes (0.5–0.9 ha; 1–2.4 ha; 2.5–4.9 ha; 5–10 ha). The 52 open-woodland remnants were retained at the time of plantation establishment (1998) (Figure 1), but the scattered trees surrounding them were removed and replaced with dense stands of radiata pine. In addition, the 18 other open-woodland remnants in the Nanangroe study area which were not selected in our experimental design also were subsequently cleared as part of plantation establishment. The area adjacent to the plantation had previously been cleared (during the past 170 years) and paddocks were typically dominated by large areas of exotic grasses. The levels of replication in the different size classes of the 52 open-woodland remnants that were selected in experimental design were as follows: 0.5–0.9 ha (13 remnants), 1.0–2.4 ha (20 remnants), 2.5–4.9 ha (17 remnants), and 5.0–10.0 ha (two remnants).

For the 39 open-woodland remnants larger than 1 ha, we established a 200-m-long permanent transect with steel markers at the 0, 100, and 200 m points. In the case of 13 open-woodland remnants smaller than 1 ha, a 100-m long transect was established with markers at the 0 and 100 m points. We recorded bird data at the marker points along the transect located within each of the 52 open-woodland remnants prior to plantation establishment, and for up to 7 years after plantation establishment (1998–2005). We completed 5-minute point interval counts (*sensu* Pyke & Recher 1983) at these points in early November for each of the survey years. For each point count, observers recorded the numbers of each bird species seen or heard within 50 m of the plot point. No surveys were conducted during days characterized by poor weather such as when it was raining or there was low cloud or high winds. In each survey year, sites were surveyed by at least two observers on different days, giving a total of up to six point counts and up to 30 minutes of surveys per site per year. Cunningham *et al.* (1999) showed that averaging the counts of two or more observers at the same site could compensate for extra variability due to observer heterogeneity. Surveying on different days also limited the potential for day effects to compromise data quality (Field *et al.* 2002).

We also completed detailed surveys of reptiles in the 52 woodland remnants surrounded by maturing pine stands. We did this by repeated annual area-constrained searches at each site as well as the establishment of three kinds of artificial substrates at the marker points along our transects: (1) three overlaid sheets of corrugated iron each measuring 1 m × 1 m in size, (2) a pile of hardwood timber off-cuts comprised four pieces of timber each measuring five 1 m long × 15 cm wide × 3 cm deep, and (3) a set of four standard (420 mm × 245 mm) roof tiles (Lindenmayer *et al.* 2001). Further details of the work at Nanangroe are described in Lindenmayer *et al.* (2001, 2008).

Statistical analysis

Initial exploratory data analyses on temporal changes in the composition of bird and reptile assemblages (normalized for survey effort) were conducted using Correspondence Analysis (Greenacre 2007). In the case of birds (for which our analyses indicated large changes in the composition of the bird assemblage between 1998 and 2005), we then conducted a chi-squared test of homogeneity across the survey years, considering all of 51 species of birds present in each of the six surveys and that were detected on average at more than 1/50 of point counts. In our cross-tabulation, each cell contained the number of point counts (normalized for survey effort) at which a given species was detected in a given year. Species were sorted in descending order by the cumulative proportion of detections in the three most recent surveys.

Results

At the commencement of this study (and prior to plantation establishment), the bird and reptile fauna at Nanangroe was broadly similar to that we have quantified elsewhere for typical grassy box-gum open-woodland environments on the nearby South West Slopes of New South Wales (Cunningham *et al.* 2007, 2008). That is, it was dominated by a range of individual species that are characteristic of open-woodland environments, with the exception (in the case of birds) of the highly aggressive noisy miner (*Manorina melanocephala*), which is largely absent from the Nanangroe region (Lindenmayer *et al.* 2008).

Correspondence Analysis revealed that the bird community composition in the open-woodland remnants at Nanangroe changed ($P < 0.0001$) through time as stands of surrounding radiata pine began to mature. This major change in bird community composition was confirmed by a chi-squared test of homogeneity across the six survey years ($\chi^2 = 1105.3$; 250 df, $P < 0.0001$; Figure 2). Some native bird species were lost from the landscape (e.g., speckled warbler [*Pyrrholaemus sagittate*]) or became extremely rare (brown treecreeper [*Climacteris picumnus*]), whereas others colonized the landscape (e.g., olive whistler [*Pachycephala olivacea*], satin bowerbird [*Ptilonorhynchus violaceus*], and superb lyrebird [*Menura superba*]).

Bird species experiencing the largest proportional increases in abundance were a unique blend of tall closed forest birds (e.g., white-eared honeyeater [*Lichtenostomus leucotis*], common bronzewing [*Phaps chalcoptera*]), and open-woodland birds (e.g., peaceful dove [*Geopelia striata*] and rufous songlark [*Cinclorhamphus mathewsi*]). Notably, many of the species combinations in this landscape were either extremely rare or not recorded in studies of nearby tall closed forest environments in the general region (Lindenmayer *et al.* 2002) or in studies of open-woodland sites throughout the nearby south west slopes region (Lindenmayer *et al.* 2007; Cunningham *et al.* 2008). The simultaneous increase in bird species typically associated with tall closed forests and in bird species typically associated with open-woodlands is consistent with novel ecosystem development (Hobbs *et al.* 2006).

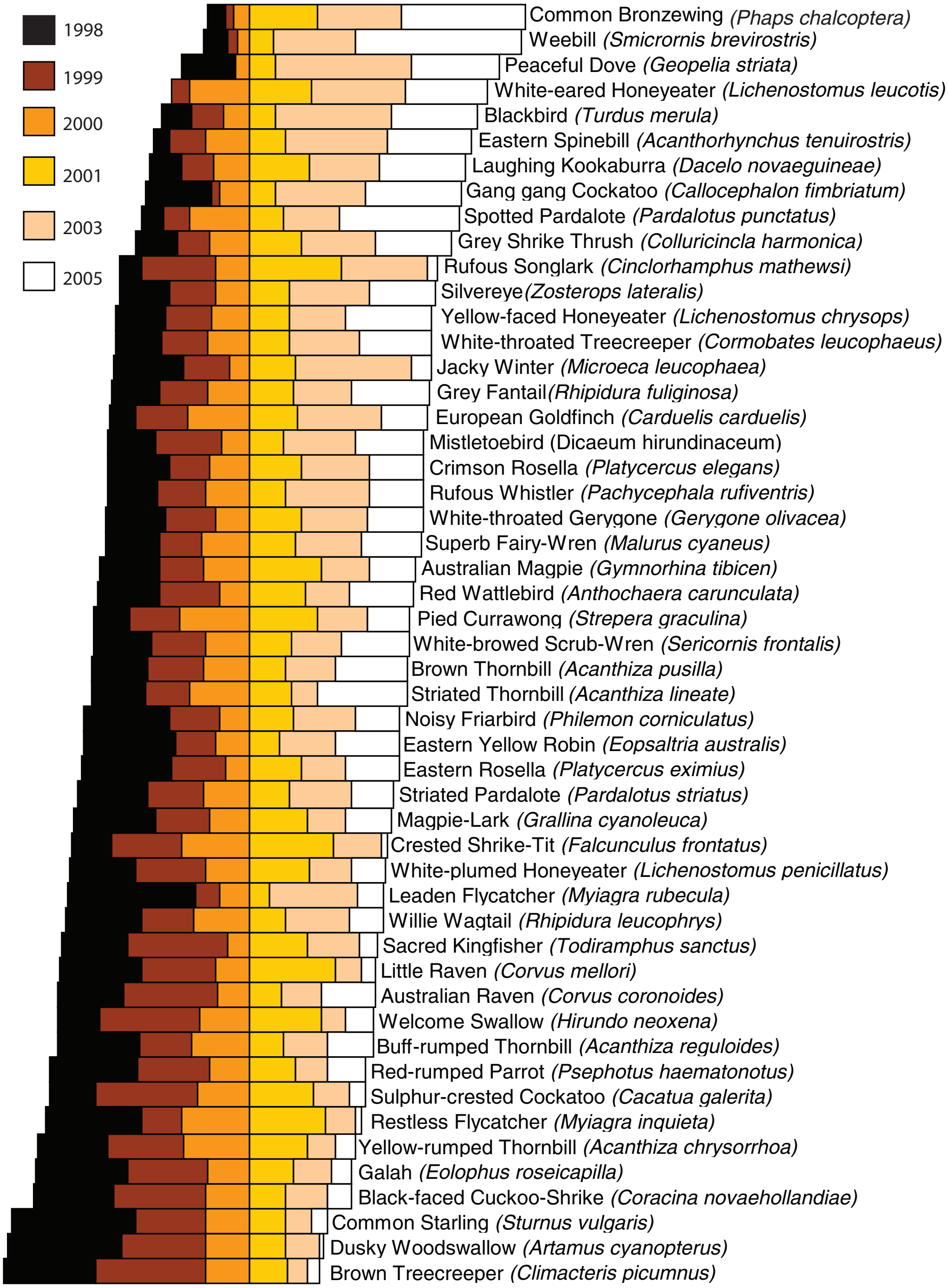

Figure 2 Proportions of detections for 51 species across six surveys. All species detected at more than 1/50 of all point counts, and detected in all survey years, are shown (total number of point counts = 1949). From left to right, the segments of a given species' horizontal bar correspond to the years 1998, 1999, 2000, 2001, 2003 and 2005. Detection rates were standardized for survey effort. The solid vertical line marks the year 2000.

We recorded 14 species of reptiles in the 52 open-woodland remnants (Table 1) and detections of a number of individual taxa have increased in abundance over time (Lindenmayer *et al.* 2008). However, although the reptile assemblage has varied from year to year, Correspondence Analysis revealed that the reptile assemblage in 2006 was not significantly different ($P = 0.41$) from what it was at the start of the study in 2000. No primarily tall closed

Table 1 Temporal patterns in mean values of occupancy by reptiles in 52 woodland sites surrounded by maturing stands of radiata pine.

	2000–1	2000–2	2001	2003	2006
Species					
Bassiana playnota	0	5.7	0	5.4	3.6
Carlia tetradactyla	0	8.6	6.1	12.5	16.1
Christinus marmoratus	5	2.9	14.3	8.9	19.6
Ctenotus robustus	0	2.9	0	1.8	1.8
Ctenotus taeniolatus	0	2.9	2	3.6	3.6
Egernia striolata	0	0	0	0	1.8
Eulamprus heatwolei	0	0	2	5.4	3.6
Hemiergis decresiensis	20	31.4	24.5	39.3	51.8
Lampropholis delicata	0	5.7	10.2	3.6	1.8
Lampropholis guichenoti	5	2.9	2	7.1	3.6
Leiolopisma duperreyi	0	2.9	0	7.1	1.8
Morethia boulengeri	5	11.4	4.1	8.9	7.1
Niveoscincus coventryi	0	0	0	0	1.8
Pogona barbata	0	0	0	1.8	0
Tiliqua scinicoides scinicoides	0	0	2	0	1.8

forest-associated reptile taxa have colonized the system to date.

Discussion

At commencement of the study and prior to large-scale plantation development, the bird and reptile assemblages at Nanangroe were typical of open-woodlands environments in the region (Cunningham *et al.* 2007, 2008). Over subsequent years, we documented the rapid development through time of a novel ecosystem (*sensu* Hobbs *et al.* 2006) because the establishment of the introduced radiata pine plantation has resulted in: (1) the loss of some bird species and the gain of new ones in the open-woodland patches surrounded by plantation stands, (2) new combinations of bird species that previously did not co-occur in the Nanangroe study area, and (3) combinations of bird species that did not occur in neighboring regions within the same biome. In addition, several species of tall closed forest bird taxa are now cooccupying the open-woodland remnants with open-woodland reptiles. These combinations of open-woodland reptiles and the mixture of open-woodland bird and tall closed forest birds have not previously been recorded in our earlier surveys in the tall closed forests of the nearby Tumut region (Fischer *et al.* 2005) or in the nearby open-woodland environments of the South West Slopes (Cunningham *et al.* 2007, 2008; Lindenmayer *et al.* 2007). Hence, there is potential for new dynamics in pollination and seed dispersal between tall closed forest birds and open-woodland plants, as well as new types of species interactions, such as predation of open-woodland reptiles by tall closed forest birds that were previously separated taxa.

We suggest that our basic understanding of novel ecosystems may be insufficient to facilitate and guide the ecological changes that are occurring in them. For instance, while the bird assemblage has undergone a radical change allied with the landscape transformation, the composition of the reptile assemblage has changed little in our study area. Inconsistency in the responses of different broad taxonomic groups through time to landscape transformation suggests a need to increase our understanding of the processes leading to the development of novel ecosystems. Without this understanding, our ability to manage novel ecosystems in line with societal expectations will be curtailed.

Our study highlights the need for long-term landscape scale studies from which to extract empirical data needed to understand better how species respond through time to landscape transformation and novel ecosystem creation. Indeed, the novel ecosystem we have quantified is unlikely to be a static entity. Rather, there may continue to be marked temporal changes in some assemblages at Nanangroe, particularly the bird assemblage. This is, in part, because the sizes of the open-woodland remnants in this investigation were small—larger ones were simply not available to study because of repeated past extensive and intensive land clearing (Gibbons & Boak 2002). Given such small patch sizes, we anticipate that ongoing maturation of the radiata pine matrix will continue to exert a substantial influence on the species assemblages occupying the open-woodland remnants. We plan many more years of careful monitoring to quantify such changes.

Our case study has also highlighted some substantial ecological, management and ethical challenges for conservation biologists, managers of natural resources, and policy makers. For example, novel ecosystems may be dominated principally by exotic species (here radiata pine) with high potential to be invasive taxa (Richardson *et al.* 1994), yet still able to provide valuable ecosystem services (e.g., plantation establishment in agricultural areas can help to reduce damaging levels of soil salinity (Stirzaker *et al.* 2002). Similarly, while novel ecosystems may provide habitat for regionally declining species, as we have documented (in Figure 2) for the rufous whistler [*Pachycephala rufiventris*], they may lead to the decline or even the local extinction of other species of conservation concern. This occurred in the case of the brown treecreeper which has suffered local extinction in our natural experiment (Lindenmayer *et al.* 2008, Figure 2). Novel ecosystems may also alter the distribution of patterns of some species, but the consequent altered interactions between taxa may not always have beneficial outcomes. For example, the novel ecosystem that has developed at Nanangroe has facilitated the westward expansion of native bird species such as the superb lyrebird and the olive whistler into nationally endangered open-woodland vegetation types where they never previously occurred. This may have negative consequences for native flora as the superb lyrebird is threatening the persistence of rare plant species in parts of southern Australia, which it has recently colonized (M. Brown and S. Munks, personal communication). Thus, novel ecosystems present major challenges to traditional thinking in conservation ecology, such as the focus on species extinctions as the usual response to landscape transformation, the simple binary classification of transformed landscapes as either habitat or nonhabitat, and the attempted eradication of exotic species once they inhabit new areas.

While the concept of novel ecosystems is comparatively new (Hobbs *et al.* 2006), the actual existence of novel ecosystems is not. For example, many landscapes characterized by a prolonged human presence such as those in Europe and elsewhere support groups of species that may not have lived together without human influence (Vera 2000; Laiolo 2004). Nevertheless, the concept of novel ecosystems raises important issues for the modern discipline of conservation biology. For example: when and where are novel ecosystems appropriate? What can we do about changes deemed inappropriate? When does the preservation of a novel ecosystem become a conservation concern? If a novel ecosystem is a dynamic entity (see above), at which point might conservation interventions be warranted? How long does an ecosystem have to exist for it to be considered novel? The answers to these questions are not always straightforward and we suggest that to address them, we need to set clear objectives about the relative advantages and disadvantages of specific representatives of these kinds of ecosystems within different landscape contexts.

In the specific case of the landscape at Nanangroe, we believe there are important management actions that land managers can undertake to maintain particular elements of the biota. First, remnants of native vegetation need to be retained, irrespective of whether they occur within traditional grazing lands or locations designated largely for plantation establishment. Indeed, a monoculture landscape of either grazed paddocks or of pine stands would likely support only a small proportion of the many species of birds and reptiles recorded in our study. Second, the majority of species of conservation concern in the broader region are typically open-woodland birds, most of which respond negatively when the remnants they occupy are surrounded by maturing plantation trees (Lindenmayer *et al.* 2008). Thus, an important conservation strategy must consider land cover patterns at a regional scale and ensure that not all semi-cleared agricultural landscapes are converted from being grazing-dominated to plantation-dominated. The maintenance of a range of landscape types, thereby giving rise to regional-level heterogeneity would ensure that species associated with open-woodland remnants in traditional grazing systems can persist in some landscapes whereas in others declining taxa which can colonize landscapes where open-woodland remnants are surrounded by maturing pines (e.g., the rufous whistler) can find suitable habitat. Finally, the potential for altered species interactions in the Nanangroe landscape highlights the critical importance of targeted monitoring. The aim of that work would be to ensure the early detection of negative interactions between species that previously did not occur with the potential for intervention if they arise (e.g., the removal of newly colonizing native species).

Circumstances similar to those we have documented at Nanangroe, in which patches of remnant native vegetation are surrounded by expanding exotic plantation forests, are increasingly common around the world (Zanuncio *et al.* 1998; Estades & Temple 1999; Wethered & Lawes 2003; Barlow *et al.* 2007). Similarly, the potential for major shifts in the distribution of many species as a consequence of rapid climate change (Parmesan 2006; Williams *et al.* 2007) means that the likelihood of novel combinations of species is extremely high (Opdam & Wascher 2004). New conservation paradigms coupled with new on-the-ground strategies for conservation management may be needed to address the issue of how we value ecosystems without a historical analogue, and how we can guide these systems toward desired ecological states.

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Editor: Corey Bradshaw

Correction added after online publication 4 July 2008: Editor Corey Bradshaw's name was previously misspelled