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Summary

Meeting all four natural criteria for United Nations World Heritage listing, the Wet Tropics World Heritage Area that covers 61% of the remaining vegetation of the bioregion conserves, on a biodiversity basis, habitats 'containing threatened species of outstanding universal value from the point of view of science or conservation'. As discussed in an accompanying paper by the same authors, the Wet Tropics Bioregion faces a level of habitat change unprecedented in threat and scale and manifested in the transition of sclerophyll forests and woodlands to closed forest habitats, a change attributable to the absence of fire or reduction in its frequency.

The implications of habitat change for certain threatened species and ecosystems present a challenge to conserving the ark of biodiversity the Wet Tropics represents. Evidence indicates that the dominant reason for these changes in vegetation patterns is the reduction in fire or its exclusion across a bioregion with the highest rainfall of the nation. It is clear that the bioregion is suffering and with present trends, will continue to suffer, a major loss of habitat diversity.

Keywords: management; vegetation; wildlife; biodiversity; habitats; ecosystems; fire; fire ecology; change; World Heritage Area; Queensland

Introduction

Within Australia, sclerophyll forests and woodlands are fire-evolved (Pyne 1991; Bowman 2000), reliant on a variable pattern of interval and intensity of fire to regenerate and maintain canopy, shrub and grass structural characteristics. Aboriginal burning provided these patterns and maintained open conditions and long-term stability in the landscape (Jurskis 2009; Gammage 2012). The Wet Tropics differs in no respect, though with the highest rainfall of any Australian bioregion the ways in which fire shapes ecotone boundaries and influences the survival and tolerance strategies of its flora and fauna species are perhaps more complex and subtle.

Transition from open to closed woodlands and forests within the Wet Tropics Bioregion is evident across a range of habitats from highland peaks to coastal lowlands, and the evidence that the absence or infrequent occurrence of fire is the dominant cause is strong. Most affected are those dominated by *Eucalyptus grandis* and *Syncarpia glomulifera*, generally referred to as wet sclerophyll forests, and the far more widespread tall forests dominated by various mixtures of three species, *E. pellita*, *Corymbia intermedia* and *E. tereticornis.* The invasive species involved in this transition process are sensitive to fire at the seedling stage, but later develop properties and strategies that give them a high level of tolerance to fire through a wide range of intervals and intensity (Williams *et al*. 2012). With the ability to develop a greater foliage cover than their sclerophyll counterparts, their progressive development by altering fuel conditions and the microclimate at ground level provides an increasingly fire-suppressive environment.

The level of change involved in various stages of the transition process, and the rapid pace of that change, poses a challenging and complex task when managing to maintain habitat diversity, particularly in relationship to judgments as to whether the transition process is reversible or not. Sound conservation and biodiversity principles endorse the frequent use of fire of low to moderate intensity to manage grassy sclerophyll communities. However, in the Wet Tropics Bioregion, widespread areas of forest and woodland are in transition to closed canopies in a process driven by reducing fire frequencies or, in most cases, the absence of fire. This is at the expense of a diverse representation of forest habitats.

Attempts to re-introduce fire into long unburnt habitats is proving difficult, if not impossible, in many situations, and can often only succeed under what, in the general region, may be conditions of high fire danger. This runs the risk of strong reaction from a public whose perception is that fire is invariably destructive of habitat and wildlife values. In these circumstances, the fire manager may be left wary of attempting to refine fire intervals and frequency across a broader range of fire conditions. In that event, fires within the bioregion will be dominated by wildfire events, rather than planned fire intervals, with fires confined to a much narrower seasonal band in the late dry season. Rather than addressing the problems of transition, this can increase the rate of change by slowing the regeneration of native grasses and decreasing their ability to compete with a range of pioneer tree species and shade-favouring shrub species such as *Melastoma affine* and *Breynia cernua.*

The mechanics of transition

As detailed in Stanton *et al.* (2014), there is a striking level of entrenched habitat transition mapped across the Wet Tropics Bioregion, with between 25% and 79% of individual forest types having undergone what was judged as irreversible change. Supporting the evidence provided by mapping is a wide range of observational evidence that the dominant reason for the recent rapid expansion of closed forest within the bioregion is the removal of fire from the landscape as a mechanism to regulate open forest structure. The term 'closed forest' is used because these young forests are neither sclerophyll forest nor rainforest in the sense that they have no equivalent in the classical rainforests described for the region. The mapping work and associated GIS analysis described in Stanton *et al.* (2014) illustrates that transition affects a diverse range of sclerophyll forests and woodlands and culminates in a closed forest which further inhibits fire by excluding more combustible fuel types. They are often poorer in plant diversity than the sclerophyll communities they replace because of the loss of ground cover, sclerophyll shrub species and various species of herbs, forbs and sedge, and their domination by a relatively small number of tree species.

Changing vegetation with a reduction in fire frequency or its exclusion is not a phenomenon unique to the Wet Tropics of Queensland and has been documented in ecosystems ranging from the fynbos biome of the western Cape of South Africa (van Wilgen 2013), the African savannah grasslands (Bond *et al*. 2005) to the North American forests and woodlands where remarkably similar trends have been reported in some forests (Ryan *et al.* 2013). These include major changes in ecosystem structure, composition and function, with an influx of fire-sensitive plants and a loss of animal species. Elsewhere in Australia, change has been documented in the south-western Australian tall open forests (Burrows and McCaw 2013) and the northern Australian savannas (Russell-Smith *et al*. 2013).

The tree species that dominate the transition process vary with latitude and altitude, but in the earliest stages at least the most common are various species of A*lphitonia*, *Alstonia muelleriana*, *Commersonia bartramia*, *Guioia acutifolia*, *Macaranga* spp., *Mallotus* spp., *Melicope* spp., *Homalanthus novoguineensis*, *Polyscias australiana*, *Polyscias elegans* and *Trema tomentosa.* In lowland transition forests, common species include *Chionanthus ramiflora*, *Carallia brachiata*, *Cyclophyllum coprosmoides*, *Mallotus philippensis*, *Cryptocarya hypospodia* and *Endiandra hypotephra.* As the transition forests thicken, grasses are replaced with shade-tolerant sedges and, commonly, ground cover of little more than leaf litter.

As transition becomes more entrenched, species more commonly associated with rainforest become prominent in a canopy in which remnants of the original sclerophyll community can still be found. They can also be observed forming a distinct subcanopy under a forest of tall eucalypts. An example is the occurrence, in some areas, of *Flindersia brayleyana* as a distinct age class of 20–39 years in forests dominated by canopy and emergent species such as *E. tereticornis* and *C. intermedia.*

There is a range of forests of simple or single-species canopy composition which are widespread in the bioregion and which were identified as distinctive vegetation types, yet which are clearly young forests representing an advanced stage in the transition process. Their origins can easily be traced in surrounding vegetation where their canopy species can be observed at various stages of out-competing for canopy dominance less vigorous species of the early transition process. In these forests, the eucalypts of the original community have gone or are reduced to isolated remnants, and they appear to be in a relatively stable condition with no evidence to be found in other vegetation types of what their next stage might be. Examples are found in the tall single-species-dominant closed forests of *Blepharocarya involucrigera* and the medium closed forests of *Syzygium forte* on broad low dunes of coastal areas. There are also significant areas of closed forest where several species of acacia can be found at various stages of replacing the original eucalypts in the canopy. Examples are forests where dominant or co-dominant canopy species are *Acacia mangium*, *A. celsa* and *A. polystachya.*

Another impact of Wet Tropics transition is witnessed through 'fire shock'. This can sometimes be expressed in forests long unburnt but in the earlier stages of transition, where amassed fuel may be suspended, aerated and cured to the extent that full canopy scorch occurs when fire returns in very dry weather conditions. Such fires, where they occur with an intensity that exposes mineral earth, can retard epicormic growth, or grass stolon re-shooting, for several months after fire. This, in contrast to the desirable fine-scale mosaic of unburnt refugial pockets and quick canopy recovery witnessed with planned burning, can result in the transition process becoming more entrenched. Pioneer rainforest transition species, such as those from the genera *Alstonia*, *Alphitonia* and *Polyscias*, which employ post-fire adaptations such as basal re-shooting, are observed to accelerate in growth, taking advantage of a bare forest canopy and removal of competition from a grass layer now forced to rebuild from the soil seed bank or subsurface rhizomes rather than to recover from above-surface stolons, or to spread from unburnt refugial pockets left with mosaic burning.

A major impediment to the expansion of rainforest is recurrent fire, and theories to explain the uneasy interaction between the two have focused on mechanisms involving the rainforest edge and regulation by biophysical factors or fire. It has long been proposed that rainforest could invade adjacent communities by a process of marginal expansion, and there is ample evidence for this in the North Queensland situation (Ash 1988; Unwin 1989; Harrington and Sanderson 1994; Tng *et al*. 2010). Unwin recorded an advance of a closed rainforest edge at an average rate of 1.2 m horizontal distance per year and inferred, from the presence of old eucalypts scattered within young rainforest, that the location of the rainforest–eucalypt forest boundary was capable of changes across tens to hundreds of metres within the lifespan (estimated at 100–400 years) of a mature eucalypt tree. Even the maximum postulated rate, however, cannot explain the observed and documented rapid expansion of rainforest across wide areas of landscape, both in the Wet Tropics Bioregion and on Cape York Peninsula.

Russell-Smith *et al.* (2004a, 2004b) showed that at Iron Range on Cape York Peninsula rainforest was expanding into open forest by three successional processes: margin extension in which rainforest seedling densities declined with distance from mature rainforest margins; nucleation, where seedling densities were positively correlated with the presence of tall trees; and a process that was termed irruption, where seedling densities neither correlated with distance from mature rainforest margins nor with vegetation structural features. It was concluded (Russell-Smith *et al.* 2004a, p1293) 'that under conditions conducive to growth (moisture, substrate), low fire disturbance, and maintenance of diverse dispersal processes (high frugivore richness), rainforest can rapidly invade regional landscapes'. The work demonstrated the capacity of rainforest species propagules to be widely dispersed across the open forest landscape. This capacity corresponded with a high proportion of vertebrate-dispersed species in the rainforest, and a rich frugivore fauna of mammals and birds. Effective dispersal of even large (>25 mm) fleshy fruits was observed even at an early stage of succession. This was considered to be a result of the activities of the southern cassowary, which largely feeds on fresh fruit from the rainforest, and at Iron Range (and in the Wet Tropics) can be observed to range widely across open forest habitats. In addition to the above, a few wind-dispersed canopy trees were found to be common at all stages of successional development. These were confined to several species of *Alstonia*, *B. involucrigera* and *Toona ciliata.*

At Iron Range, seedlings of rainforest woody species were observed to establish in open forest far from the mature rainforest margin and were observed over the full length of all sampled transects. Their ability to rapidly develop a dense understory to open forest after a few years' absence of fire indicates an ability to persist after establishment that raises questions about the acceptance of models that portray them as fire-sensitive with an inability to survive frequent fire. While the ability of rainforest species to recruit new plants after fire as seedlings and root suckers has been demonstrated (Stocker 1981; Unwin 1983; Williams 2000), the work of Williams *et al.* (2012) has identified the capacity of a wide range of rainforest species to persist through a regime of frequent fire intense enough to scorch their full canopy. He rejected the concept of 'fire-intolerant rainforest versus fire-tolerant eucalypt forest flora' and found little difference between eucalypt forest and rainforest plants in their ability to survive in frequently burnt areas. The key difference between them was demonstrated to be the inability of rainforest species to maintain their height after canopy scorch—always returning as ground level coppice shoots—while eucalypt tree species were able to re-sprout via epicormics from branches and trucks. Thus while recurrent fire maintains an open forest or woodland landscape by 'ground-keeping' pioneer species back within the ground cover, pioneer transition species retain an ability to convert that landscape towards a closed forest in the longer absence of fire, and where fire frequency is allowed to extend out to a point where pioneers begin to shade out ground cover, to consequently lower fire intensity and further entrench transition. The critical factor in preventing the initiation of irreversible change in an open forest situation to a closed forest one is the maintenance of a grassy ground cover and this can only happen in the presence of regular fire. Grasses disappear when the shade of a developing understory reaches a critical level and this can be reached in a period as short as 10 years without fire. From that point, fires penetrate with increasing difficulty, and when they do, a grassy ground cover is slow to re-establish, requiring, as demonstrated in an experimental area near Paluma, repeated fires at 2- to 3-year intervals, to prevent the re-establishment of shading. This observation demonstrates a satisfactory explanation for why much of the bioregion is experiencing a widespread irruption of rainforest across broad areas of open forests and woodland within the bioregional landscape in the absence of regular fire.

In the North Queensland situation, the *E. grandis* forests would appear to be the ecological equivalent of the mountain ash (*E. regnans*) forests of Victoria and Tasmania. Both are often referred to in the literature (e.g. Florence 1996) as wet sclerophyll forest, and there is a belief commonly held by ecologists and similarly interested others that they share similar regeneration strategies. There is a general acceptance that the *E. regnans* forest was maintained through periodic stand-replacing wildfires. This belief is entrenched by the observed high fire-sensitivity of *E. regnans* and its inability to regenerate through the production of lignotubers, and the high frequency, since European settlement, of wildfire events that have completely killed large areas of forest. It is debatable, however, that this was the universal regeneration strategy of the species pre-settlement. Lindenmayer (2009) pointed out that the impacts of fire in a regrowth forest will be very different from those of similar intensity in an old-growth stand, and Turner *et al.* (2009) reported that a study of wet eucalypt forest in Tasmania demonstrated that most old-growth stands of *E. regnans* were multi-cohort.

The common belief that the regeneration strategies of *E. grandis* are similar to those of *E. regnans* is often advanced as a reason for lack of concern for the fate of sclerophyll communities being invaded by rainforest. There is, however, no evidence to support a theory of fires of catastrophic intensity at long intervals driving sclerophyll recruitment in the North Queensland situation. While even-aged stands do occur, they are uncommon, and they are invariably regeneration from logging operations. As observed for *E. regnans* forests by Turner *et al.* (2009), most old-growth stands of *E. grandis* are multi-cohort. Nowhere in living memory in the Wet Tropics Bioregion have severe wildfires been noted as destroying undisturbed rainforest beyond the death of some trees on the margin. Nor is rainforest expansion confined to the *E. grandis* forests: it is a process that affects most woodland and forest vegetation types across the lowlands to the western fall of the ranges of the bioregion. Providing further evidence against the scenarios described above are numerous observations, including the aftermath of fires in post-cyclone Yasi debris in the Paluma area, that *E. grandis* is often tolerant of high-intensity fires, contrary to descriptions of wet sclerophyll forest, including *E. grandis* unable to survive other than low-intensity fires (Ashton 1981; Ash 1988). The widespread occurrence of dead and dying trees of *E. grandis* and other eucalypts within and above the canopy of young rainforests leaves little room for doubt of the inability of wildfire to rescue the sclerophyll forest once rainforest capture is well advanced.

While well established for the broad description of sclerophyll communities in southern Australia, the categories of wet and dry sclerophyll may not be useful in the Wet Tropics Bioregion and may obscure recognition of the way in which differences of climate and recent fire history have shaped them differently from comparable communities further south. Historical evidence in the form of photographs and descriptions by early settlers, as well as that provided by aerial photographs taken in the early 1940s, indicates that even in the tallest forests in the wettest areas, a grassy ground cover was their general condition. Aboriginal burning ceased here much later than it did in southern areas, and some important climatic differences have vastly lowered the possibility of stand-replacing wildfires. Even the driest parts of the bioregion have relatively high rainfalls in relation to other parts of continental eastern Australia, and summers are invariably wet. Sustained winds from the inland, temperatures approaching 40°C and 3:00 pm humidity below 40%, are rare to extremely rare events.

Conversely, the impact of tropical cyclones such as Tropical Cyclone Yasi of February 2011 appears to be the main environmental cyclical disturbance which operates both on rainforest and sclerophyll forests. Rainforests, particularly ecotonal and transition types, appear particularly susceptible to catastrophic wind damage, whereas mature, emergent sclerophyll trees appear to have a greater resilience. Catastrophic damage in this context may offer a competitive advantage to sclerophyll species by offering them a suddenly open habitat in which to recruit.

In contrast to the view of the catastrophic role of fire in southern Australia, the work of Williams *et al*. (2012) has demonstrated that Wet Tropics rainforest species can be as resilient to fire as most sclerophyll species, and that only regular fire can inhibit their occupation of a site to below a tipping point of transition to the formation of a closed stratum. Within a period as short as 20 years without fire, the process of rainforest invasion appears to be irreversible in many closed forest habitats, as the recent experience of rare hot fires which failed to penetrate (Mt Fox 2003, 2009; Taravale 2003) has demonstrated. Post-fire inspections of both localities in which there were severe wildfire events showed sharp boundaries where the fires had self-extinguished in the ecotone at the closed forest margin. As grasses disappear with increasing shade, the ground cover is depleted and simplified in composition, favouring shade-tolerant sedges and ferns, and an increasing ability to retard the intrusion of fire. Once rainforest species share the canopy with sclerophylls, there is rapid attrition of the latter.

If, as the evidence clearly suggests, this condition has been reached because of the exclusion of fire from the landscape, the loss of sclerophyll vegetation is exacerbated by another process which, in some vegetation types, is an even faster and more obvious result of the exclusion of regular fire, and that is invasion by the noxious weed lantana. Vast areas of woodland in the drier parts of the bioregion (<2000 mm y^{-1}), particularly at its southern end, have had their understory completely captured by this species, which out-competes the ground cover and other shrubs and denies the canopy species their ability to regenerate. Lantana also exacerbates the difficulty in restoring fire to these communities by being less flammable and by preventing the accumulation of more flammable fuel on the forest floor. It slows the transition process because of the difficulty that tree and shrub species have in regenerating through it, but ultimately does not prevent it, and is shaded out by it. By facilitating the accumulation of high levels of nitrogen in the soil and disrupting mild burning patterns, it contributes to the decline of sclerophyll systems that have developed in low-nitrogen environments (Jurskis *et al*. 2011; Jurskis 2012). Once rainforest species emerge through the lantana, however, high levels of soil nitrogen are likely to accelerate their development to canopy closure and ability to shade out the lantana.

The nature of the landscape changes and their speed

It is clear from evidence uncovered during the course of an exercise of mapping the Wet Tropics Bioregion that many of the sclerophyll habitats of the bioregion have suffered massive structural alteration in recent times. It was also clear that although some of these changes might have been in progress early in the twentieth century, most of them had begun in the last 60 years, with a rapid acceleration of the process during the last 30 years. In his own working experience in the area, which spans 53 years, PS has observed large areas of grassy forest and woodland change to closed forest.

Apart from the evidence from aerial photos taken over 30 years apart, and personal experience, there are numerous historical photographs and surveyors' reports which document open eucalypt communities in areas that are now rainforest. An example is the survey report of 1891 of an area north of Cape Tribulation. In an area which is now rainforest, the surveyor had made various notations on the plan, such as 'splendidly grassed open forest' and 'splendidly grassed, box, bloodwood and ironwood' (Fig. 1).

This process is not unique to the Wet Tropics Bioregion. Similar changes have been observed throughout the higher-rainfall (>1500 mm y^{-1}) areas of eastern Queensland. The dramatic speed at which it can happen was revealed to PS in 1964 when working as a forester in Mackay. Having discovered a photo of a scene near a resort on Long Island, in the Whitsunday Island Group, which had been taken by his parents in 1939, he noted that in 1964 the open grassy woodland shown in the photograph had been replaced by a closed forest of a wide range of rainforest species, with the original widely spaced eucalypts still in the canopy. Today, the area is a rainforest with evidence of the original sclerophyll species hard to find. Prior to its gazettal as a National Park in 1936, Long Island was a pastoral lease, and regularly burnt. Nor is transition uniquely a rainforest process. Along the eastern seaboard, coastal headland grasslands are being replaced by shrublands, predominantly banksias and casuarinas, as a consequence of reduced fire intervals.

A common reason advanced to explain the spread of closed forests across the bioregion is response to climate change, particularly an increase in rainfall in recent decades. The advance and retreat of rainforest across the landscape over tens of thousands of years, in response to fluctuating climate, has been well documented in the literature (Hopkins *et al*. 1990,

(a) (b)

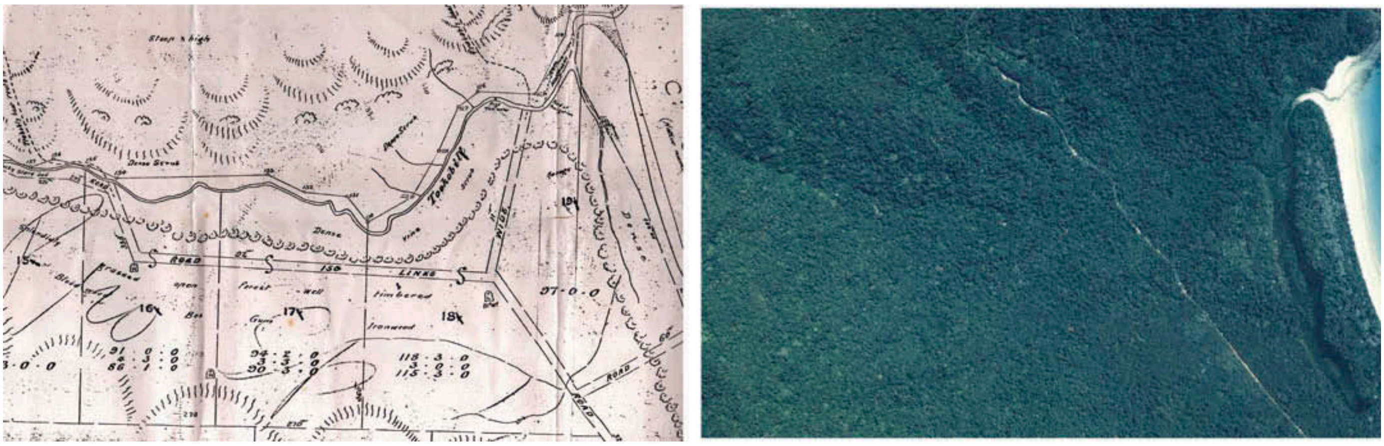

Figure 1. (a) Extract from a survey plan of a proposed settlement area north of Cape Tribulation, dated 2 September 1890. The surveyor's inscription to the south of the creek reads 'Splendidly grassed open forest, well timbered. bloodwood, box, gum, "ironwood" '. The rainforest boundary is marked below the inscription 'dense vine scrub' in the middle of the plan. It shows that 'vine scrub' occupies the northern half and eastern coastal strip of the area. (b) An enlarged section of an aerial photo taken in 2000, showing precisely the same area as Figure 1(a). It shows complete coverage by rainforest

1993; Kershaw 1994). These changes, however, have occurred over very long periods, and there is no known precedent for the present situation in which rainforest overwhelms sclerophyll forest habitats in time spans as short as 30 years.

Nor are the implications of future climate change fully understood. Whilst it is generally agreed that the tropical belt may receive the same or higher annual rainfall, this pattern may see a shorter intense wet season with a prolonged dry season. What influence this may have on ecotones is yet to be fully understood, but it may result in a longer fire season during the drier period, such as in 2009 when Cairns experienced 3 months in which the total rainfall was 17 mm. The authors do not dismiss that increasing rainfall could play a part in the observed phenomenon of rainforest expansion, but the patterns of expansion in relation to landscape features, some of which are referred to below, indicate that it could not be more than a minor contribution. Climatic fluctuation such as the extremely dry events of 2003 and 2009 bear this out, where in post-fire habitats the recoppicing of pioneer transition species was observed to continue relatively unimpaired while the recovery of native grasses was impeded due to very low soil moisture during and following the fire. Native grasses can be slow to recover in such dry soil conditions where the grass stolon is burnt to just below the soil surface. These observations would suggest that the sclerophyll vegetation now subject to transition to rainforest has been reflecting a fire disclimax which, with the removal of fire, has moved the vegetation along a gradient to more mesic types, reflecting more the mesotrophic nature of the soils than the influence of rainfall.

Some of the more striking evidence for the role that the removal of fire has played in habitat change is presented as follows.

Eucalyptus grandis

Eucalyptus grandis communities occupy a narrow band along the western margin of the rainforest from Mount Windsor Tableland to Paluma and are confined by their need for deep well-drained soils of at least moderate fertility. In the face of a westward expansion of rainforest into their habitat, they have no capacity to similarly respond by a westward expansion. Rainforest, however, can develop on soils that the *E. grandis* forest cannot occupy, and can occupy adjoining sclerophyll habitats leaving the *E. grandis* stranded in a sea of rainforest. Long, sinuous patterns of emergent *E. grandis* trees with a dense mesophyll and notophyll mid-canopy, aligned approximately north–south, can be detected on the aerial photos in

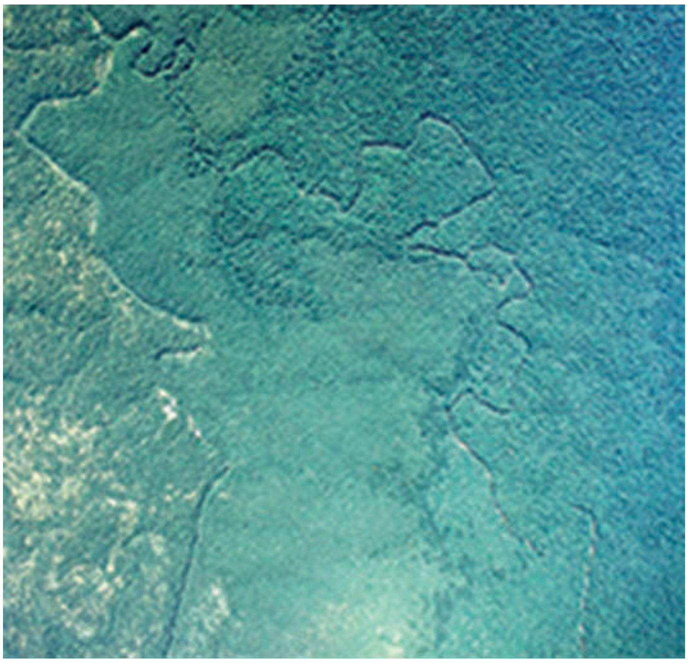

Figure 2. The dark north-to-south shadow near the centre of the photo is a tall forest of *Eucalyptus grandis* marking the former long stable edge of the rainforest. It now lies stranded in rainforest that has expanded westwards to the line of a creek that has blocked fires from the west

many locations (Fig. 2). They mark former rainforest margins and represent the crumbling ghosts of one of the grandest forests of eastern Queensland, deserted by the regular fire intervals that once sustained them, and no longer able to recruit new cohorts in the fire-excluding environment of a dense cloaking rainforest ground cover.

Upper Daintree River

The pattern of rainforest capture of sclerophyll habitats bears a stronger relationship to features of the landscape than to any other feature. Regular fires now burn only where they sweep into the bioregion from pastoral areas either adjacent to or within the western, southern and northern extremities of the bioregion. In these areas, dramatic changes in habitat occur along landscape features, usually stream lines, and these changes can be related to no other factor than the impediment these features present to the passage of fire. A striking and large-scale example of this is provided along the upper Daintree River where it pursues a north–south course through sclerophyll communities for over 20 km (Figs 3 and 4). Fires, until recently, have regularly come from the west and burnt to the western bank of the river. To the west of the river is a grassy woodland dominated by the bloodwood *Corymbia nesophila.* Its eastern side is occupied by closed forests in the canopy of which *C. nesophila*, with trees at the same canopy height and spacing as in the woodlands of the western side, can still be seen. It is clear from the bloodwoods' form that they have developed and grown in an open community. In other areas, similar patterns have developed on either side of fire breaks, or even vehicle tracks where milder fires predominate.

Figure 3. An aerial photo (year, 2000) of the Upper Daintree River showing how landscape features that impede the passage of unmanaged fire and create 'fire shadows' of destabilised vegetation, with rapid change to closed forest. As recently as 50 years ago both sides of the river supported a tall grassy woodland of *Corymbia nesophila*. This has been maintained on the western side by fires sweeping in from pastoral country. The eastern side of the river is now a closed forest

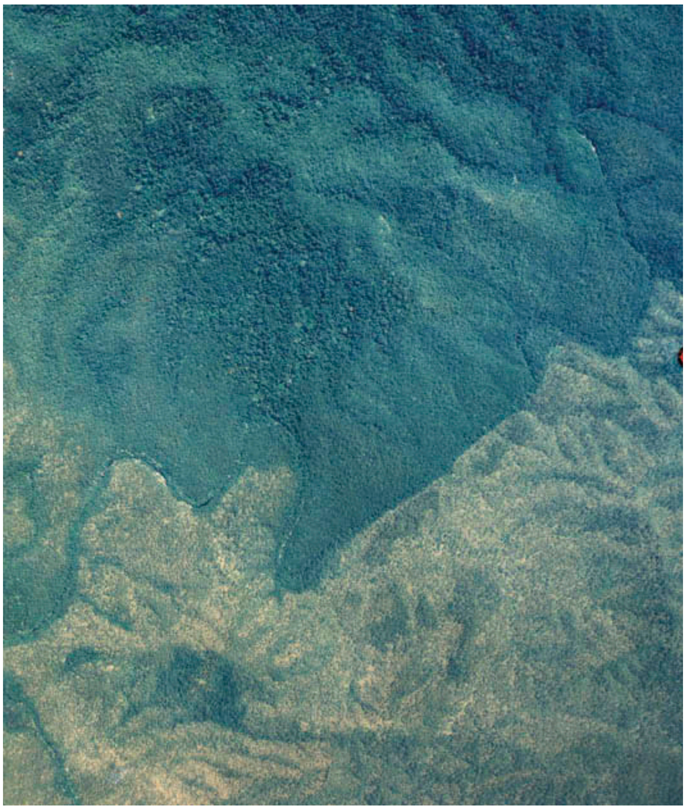

Figure 4. A sharp divide between rainforest and regularly burnt sclerophyll forest along Boolbun Creek, a tributary of the Daintree River. A young rainforest (<50 years old) has developed just to the north of the creek in an area of former eucalypt woodland. Regular fires to the south of the creek have maintained the woodland

Sclerophyll forest pockets

Throughout the bioregion, there are numerous pockets of sclerophyll woodland and forest that are surrounded by rainforest (Fig. 5). They have not been counted, but it is estimated that they would number in the thousands, and range in size from a few to hundreds of hectares. In all but a few cases where they are still regularly burnt, they have been captured by rainforest invaders—either an understory or co-dominant canopy species. As it has never been possible for external fires to penetrate these areas, it has to be concluded that they were maintained by aboriginal burning, possibly as camp sites and for promoting grazing by marsupials. A number of them are occupied by groves of cycads, the fruits of which are known to have been an aboriginal food resource. In the face of rates of change in which closed forests can occupy these habitats within 20 years of the cessation of burning, one can only marvel at the thoroughness and scale of aboriginal land management that would have so regularly tended these areas for thousands of years.

A clear illustration of the extent of individual Aboriginal stewardship and diligent maintenance of every part of the landscape is found in the journals of the explorer Christie Palmerston (Savage 1989). Near the top of Queensland's highest mountain (Mount Bartle Frere, 1615 m), in the wettest part of Australia, are open areas of granite boulders and dense sprawling ferns with scattered shrubs (Fig. 6). Their total area is 44 ha. Walls of low vine thicket surrounding them provide clear evidence that

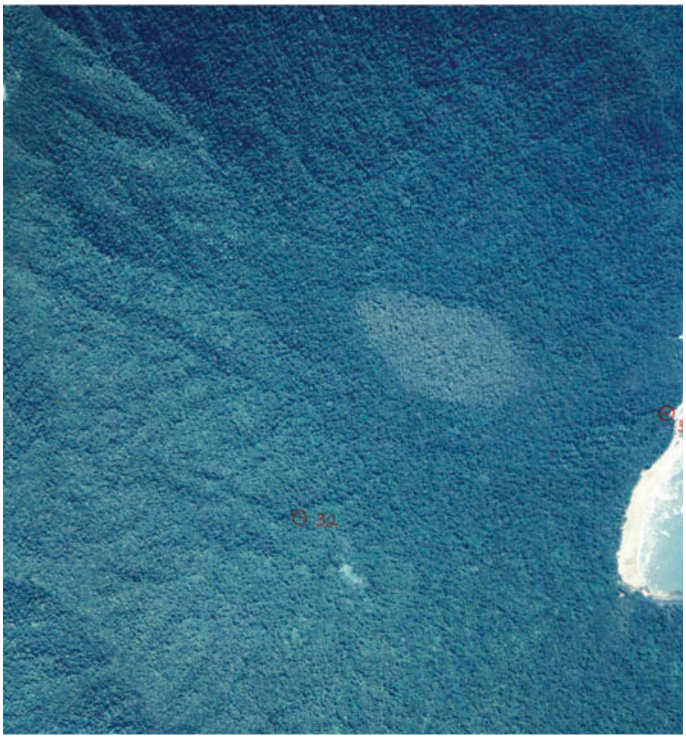

Figure 5. An aerial photo (June 2000) showing a 20-ha pocket of eucalypt forest within tall complex lowland rainforest in the Cedar Bay National Park. There are no soil differences that would explain the existence of this forest. It does, however, contain cycad groves which are believed to have been a food source for aboriginal people. It remains today because it is still regularly burnt, most recently by the National Park Service

they have shrunk in recent times. In a journal entry of 26 October 1886, Palmerston (quoted in Savage 1989, p219) describes an expedition to the summit of Mount Bartle Frere in the company of aborigines. In his description of the approach to the summit, he writes:

> we soon entered Choor-a-chellem opening that ends a little short of the greatest elevation. Its upper part is free of rocks, and, indeed of everything else, it having been burnt in the early part of this year by an old aborigine named Wallajar, to whom it belongs.

Some of these patches survive today because a walking track to the mountain's summit passes through this locality and they have been burnt by at least two escaped camp fires in the last 30 years. In this environment of low temperatures, extreme rainfall and shallow infertile soils, these fires have been effective, in spite of the long intervals between them, in preventing any further encroachment of the clearings by vine thicket.

Changing land use in agricultural and urban areas

In the 1970s, there were large areas of open woodlands and forests on hillslopes and flats of the coastal lowlands, adjacent to sugar cane fields. At a time when cane fields were burnt prior to harvest, it was a common practice among farmers to ignite these areas at the end of the cane harvest season. With the cessation of pre-harvest burning in the 1980s, the focus shifted to preventing fires rather than to lighting them, and rainforest invasion of these formerly open areas is now at an advanced stage. A similar progression has taken place where urban subdivision has replaced cane fields in the foothills.

Eubenangee Swamp

The Eubenangee Swamp National Park, at 1900 ha, is the largest remaining lowland swamp habitat; it provides a significant example of the importance of regular fire in maintaining non-rainforest habitats in the bioregion (Fig. 7). It is a complex of rainforests, melaleuca forests, open sedgelands and grasslands, all of which are subject to inundation during prolonged heavy rainfall.

The park contains the only surviving examples of grasslands dominated by *Hemarthria uncinata* which formerly occupied large areas of the Tully and Herbert River valleys. Concerned by the invasion of the grasslands and open sedgelands by melaleucas, the Queensland Parks and Wildlife Service initiated

Figure 6. Fernland with shrubs near the summit of Mount Bartle Frere shortly after it was burnt in a wildfire in November 1995

Figure 7. *Melaleuca quinqueneria* invading native grassland in Eubenangee Swamp National Park

Figure 8. Prescribed fire in Eubenangee Swamp in October 1991, burning in sedgeland, grassland and melaleuca forest. At the time of the fire, there was shallow water in the melaleuca forest and the sedgelands, while the grasslands were dry

regular burning programs across the swamp in 1982 (Fig. 8). The experience of the programs revealed some surprising aspects of the ecology of the grassland that could not have been anticipated, and that were vital knowledge for long-term maintenance of this most endangered of the bioregion's habitats.

Briefly, it was discovered that after 3 or 4 years without burning the grassland collapsed in numerous small areas and quickly rotted, leaving bare areas that were often invaded by sedges. Where the sedges built up at the expense of the grass, fire frequency was reduced as the sedges were difficult to burn. *Melaleuca* seedlings, which easily established among the sedges, were frequently protected by them long enough to establish. These, if established in sufficient density, can have the longer term consequence of converting the grassland to a paperback woodland.

Before being declared a national park, the grassland areas of Eubenangee Swamp were subject to grazing, which clearly provided an effective substitute for burning in the maintenance of the grassland. Without a decision to commence a burning program soon after gazettal of the national park, the threatened grassland community of the park may have had no future.

The implications of habitat change for iconic threatened wildlife

As an Australian fire ecology principle, the cycle of burn and recovery appears to favour native fauna if a stable pattern of between-fire interval and fire intensity to which the fauna has adapted is reached (Catling and Newsome 1981; Woinarski *et al*. 1997; MacHunter *et al*. 2009). That is, although the passage of fire and the subsequent recruitment themselves provide dramatic habitat changes as short-term stochastic events, their regularity, particularly where refugial elements (either transient or permanent) are retained, provides a means to replenish habitat features including logs, hollows, seed sources, litter and humic layers, and specific resources such as mycorrhizal truffles.

For the Wet Tropics, the process of transition appears to narrow the ability of the regulating influence of fire to retain habitat condition in a variety of states. In contrast to the specialised adaptation and utilisation of habitat by both rainforest and sclerophyll fauna of the bioregion, closed forests present as simplified ecosystems that offer lesser value to either rainforest or sclerophyll forest fauna species. With the loss of open sclerophyll forests, fauna species reliant on this habitat lose out due to gradual entrenched changes which lower adaptive evolutionary values or alter the availability and distribution of reduced food resources, leading to a process of being eventually displaced or replaced by species able to exploit a simplified habitat community.

Transition is likely to introduce gradual, inexorable pressure against fire-adapted species being able to continue to exploit a less than suitable habitat than that with which they are otherwise associated. 'Displacer' species are those that lose out in a process of change that displaces species from their habitat niche by directly affecting resources. An example is the northern bettong (*Bettongia tropica*)—rainforest and casuarina-influenced transition appears to greatly reduce the distribution of cockatoo grass (*Alloteropsis semialata*) or alter the suite of mycorrhizal truffles towards a point where, due to impacts on the distribution and presence of key food resources, these bettongs appear to less frequently occupy those forests than when they were in a former, more open state.

'Replacer' species are those that, in the face of transition, lose their competitive evolutionary advantage in exploiting habitat and moving within it. Both the mahogany (*Petaurus gracilis*) and yellow-bellied (*P. australis* var. *reginae*) gliders are examples where the adaptation of gliding is favoured by open forest strata and is reflected in the considerable home range and foraging distance of these species. Transition towards a closed forest state is most evident within the mid-stratum, where a thicker screen of vegetation can begin to act as a barrier to gliding efficiency, and where sympatric species such as the smaller sugar glider (*P. breviceps)*, the brush-tailed possum (*Trichosurus vulpecula*) and striped possum (*Dactylopsila trivirgata*) may have a greater ability to move through habitat (Figs 9 and 10).

Transition does not automatically lead in all cases to the absence or decline of these affected species, for individuals may still be observed to occur within, pass through or use features of this increasingly unsuitable habitat. Occupation, presence and utilisation, however, typically gradually decline to much lower levels.

Within the Wet Tropics Bioregion, the process of transition is reducing the ability of those species adapted to sclerophyll habitats to continue to exploit them. Just as sclerophyll trees emergent from a closed forest canopy bear witness to a former open habitat, isolated populations of open forest-evolved fauna may indicate the last stages of the narrowing or loss of the fire-maintained ecotones that once supported them.

Figure 9. Pioneer sapling mid-stratum within *Eucalyptus grandis* forest, Mount Carbine Tableland, November 2012. With no history of logging disturbance but a low frequency of fire in the past 30 years, Mount Carbine clearly demonstrates how the absence of fire has advanced transition. No recruitment of *E. grandis* saplings is evident in the cohort of pioneer sapling transition throughout this former tall grassy open forest

Figure 10. Mount Windsor Tableland, October 2010. Regularly burnt *Eucalyptus grandis* tall forest with a mixed age class of *E. grandis* sapling recruitment and a high diversity of shrubs, grasses, herbs and forbs

Discussion

Declaration of the Wet Tropics of Queensland World Heritage Area recognised among its 'outstanding universal values' the significance of its habitats for in-situ conservation of biological diversity. The Wet Tropics Management Authority was established to ensure Australia's obligations under the World Heritage Convention would be met in relation to the area. The Authority's functions, among many others, are to rehabilitate and restore the area, to gather, analyse and disseminate information on the area, to monitor its condition and to support relevant research. One of the guiding principles of the Wet Tropics Conservation Strategy (2004, p3) developed by the Authority is that 'Conservation management should maintain biological diversity within intact, fully functioning ecosystems, both now and for future generations'. Unrecognised or unacknowledged at the time of declaration of the World Heritage Area were the significant and widespread changes occurring in many of these habitats and the need for active management to maintain them. The mapping work described in Stanton *et al*. (2014) demonstrates that widespread habitat change was under way long before the declaration of the World Heritage area and has continued since then. It has become irreversible over large areas and has caused significant loss of habitat diversity. World Heritage declaration has changed land uses within the area from those based largely on the exploitation of a limited number of resources to those where preservation takes precedence. In spite of that, it has failed to guarantee the survival of a wide range of its sclerophyll habitats.

The role of fire in shaping and maintaining some of the sclerophyll habitats of the Wet Tropics Bioregion, of which the World Heritage Area represents 61%, has been largely unacknowledged in defining the direction of its management. In meteorological circles, the concept of rain shadows generally describes areas whose habitats are sheltered on the leeward side of imposing barriers and are depauperate in many respects in relation to their surrounding climes. Similarly, within the Wet Tropics Bioregion what have emerged due to a reduction in fire frequency, or its elimination, are fire shadows, with sclerophyll open forests and woodlands slowly but irreversibly engulfed by a transition towards a closed forest structure. With a rich and complex biodiversity, the Wet Tropics Bioregion is unique, not only for what it preserves but also for the challenges facing the maintenance of its integrity. Unlike other threats to world heritage values which typically arise externally, the problems posed by changing fire regimes are internal ones, and restoration of adequate fire regimes across complex landscapes, where habitats demonstrate high levels of change and loss, presents difficult problems with no clear direction of action in many cases.

Objectives for fire management are often set at a single-event level, to implement a planned burn or to respond to a wildfire and contain its spread. Recognition of the scale of change (some 17% of sclerophyll habitat is now considered lost) requires a finer understanding of the shaping and regulating role of fire in the maintenance of habitat integrity than that involved in recognising simply that fire has been removed from the landscape. Addressing forest transition in an effort to halt or hinder its progress should be understood to involve a series of prescribed fires with a long-term objective of representing habitats at various states, except of course where change is entrenched to a point of no recovery, and where key icons are displaced or replaced.

While it has long been recognised that rainforest is expanding into adjacent habitats, the common belief that this is happening by a process of marginal expansion cannot explain the scale and speed of rainforest expansion across the landscape. That a nascent rainforest can emerge from the grassy ground layer and irrupt across the landscape in only a few years belies the reputed sensitivity of these species to fire. As identified by Williams *et al*. (2012), it is the inability of rainforest species to maintain their height after being fully scorched that cedes the competitive advantage to sclerophyll species which have the ability to re-sprout along branches and stems by epicormic shoots. Without fire, the competitive advantage turns against the sclerophyll species and a fast-developing rainforest understory progressively inhibits the ability of fire to penetrate.

The question arises 'should we care'? Should we not be pleased that rainforests are burgeoning in one small part of Australia where they still remain a dominant part of the landscape? Within the community, and including the academic community, there is still doubt that the processes described above are happening. Where it is acknowledged there is generally little concern, with a common response being expressed to PS by a prominent scientist in the words 'The world needs more rainforest, there is plenty of eucalypt forest elsewhere in Australia'. In PS's opinion, such a response is an inappropriate value statement, given that the data show us that, excluding mangroves and secondary communities from the calculation, 768 700 ha or 53% of the 1 450 377 ha of the remaining vegetation of the bioregion is occupied by non-rainforest communities, and that some of these are unique to the Wet Tropics Bioregion.

Their expansion, however, is part of a process that is leading to the demise of a range of sclerophyll forests and woodlands that have evolved alongside the rainforests. These are eucalypt-dominated habitats that cannot be seen as just a trivial variant of such habitats that dominate so much of the Australian landscape. They are important contributors to the biodiversity values of the World Heritage Area. These are habitats that have developed under conditions of climate and soil that are unique on the continent and subject to a greater disturbance and pressure through not only reduced fire regimes but also weeds, fragmentation and clearing, than the more resilient Wet Tropics rainforest communities of Australia. Equally deserving as upland rainforest in protection of their world heritage values, they require the regulating mechanism of fire to maintain their integrity and habitat condition. They are being replaced over large areas by a range of closed forests that are still in transition and which, at the present stages of their development, have no equivalent to other closed forests of the bioregion. We believe that we should care, that the loss of habitat diversity is a major cause for concern for those charged with protecting its world heritage values, and that the highest management priority for the bioregion should be to maintain the presence of fire in those habitats that are still considered capable of supporting it.

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