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Fire exclusion and the changing landscape of Queensland's Wet Tropics Bioregion 1. The extent and pattern of transition

Peter Stanton[a], David Stanton[b], Mike Stott[c] & Mark Parsons[d]

[a] PO Box 154, Redlynch, Queensland 4870, Australia

[b] 719 Logan Road, Greenslopes, Queensland 4120, Australia

[c] GIS Section, Wet Tropics Management Authority, PO Box 2050, Cairns, Queensland 4870, Australia

[d] Department of National Parks, Recreation, Sports and Racing, PO Box 1293, Ingham, Queensland 4850 Australia

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Peter Stanton[1], David Stanton[2], Mike Stott[3] and Mark Parsons[4]

[1]PO Box 154, Redlynch, Queensland 4870, Australia
Email: psec@cairns.net.au
[2]719 Logan Road, Greenslopes, Queensland 4120, Australia
[3]GIS Section, Wet Tropics Management Authority, PO Box 2050, Cairns, Queensland 4870, Australia
[4]Department of National Parks, Recreation, Sports and Racing, PO Box 1293, Ingham, Queensland 4850, Australia

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Summary

The vegetation and geology of the Wet Tropics Bioregion of North Queensland, covering 1 998 150 ha, were mapped at a scale of 1:50 000. The resulting geographic information system (GIS) data base provided an unprecedented opportunity to examine vegetation condition across the entire bioregion. Mapping used colour aerial photography at 1:25 000, informed by ground truthing. Vegetation type, nature of the understory and ground cover, degree and type of disturbance, and the presence of secondary vegetation were described by a coding system, with codes marked directly on the aerial photos.

Analysis of these data has confirmed a picture, which emerged from ground truthing, of large areas of sclerophyll woodland and forest being invaded by a rainforest understory that prevents regeneration of the sclerophyll canopy. Fifty-three per cent of the native vegetation of the bioregion consists of non-rainforest vegetation types, dominated in both area and number by sclerophyll woodlands and forests. Seventeen per cent of the 735 713 ha of sclerophyll woodland and forest types were assessed as having suffered irreversible change. Between 25% and 79% of individual forest vegetation types were judged to have been affected by irreversible change. No climatic changes, or changes in the environment, apart from those related to changing fire regimes, were identified as causative factors. Changed fire regimes, predominantly fire exclusion, are considered to be the most likely cause.

Keywords: geology; mapping; geographical information systems; habitats; regions; forests; rainforests; fire; fire regimes; fire effects; change; Queensland

Introduction

During 52 years of intermittent work in Queensland's Wet Tropics, PS observed that rapid change was taking place within much of its large area of sclerophyll vegetation and that much of it was irreversible. The prime, if not the only, cause of that change was perceived to be the loss of a regime of regular fire, largely replaced by no fire at all. In a global context the World Heritage fynbos biome of the western Cape of South Africa (van Wilgen 2013), the African savanna grasslands (Bond *et al.* 2005), the Great Plains biome of northern America (Twidwell *et al.* 2013), North American forests and woodlands (Ryan *et al.* 2013), the south-western Australian tall open forests (Burrows and McCaw 2013) and the northern Australian savannas (Russell-Smith *et al.* 2013) also share comparable issues of change wrought by a reduction in fire frequency. Climate change is forecast to alter vegetation composition through an increase in woody cover, grass species composition and the influence of introduced high-biomass exotic grasses, though the exact nature of change including impact on fire regimes (Bradstock *et al.* 2012) is very difficult to extrapolate from those forecasts.

There is widespread denial in the conservation and academic communities, and even among professionals in government agencies charged with management of the Wet Tropics World Heritage Area, that change is occurring or that prescribed fire has any legitimate role in its management, despite the evidence provided by the memoirs and photographs of early settlers, and the accounts of early European explorers. These described tracts of open woodland, forest and grasslands in areas that are now closed forest. In the scientific literature the only documentation of large-scale change within the bioregion comes from the work of Harrington and Sanderson (1994). Tng *et al.* (2010) provided evidence of limited expansion of rainforest edges near the western boundaries of the bioregion, while Jackson (2011) provided evidence of change in a small area of lowland sclerophyll habitat. On a nation-wide basis the historian Gammage (2012) presents an enormous amount of evidence to support his thesis that the pre-European environment of Australia was shaped by the purposeful and meticulous use of fire by Aborigines and that dramatic landscape-scale changes have followed the removal of that influence. Outside the Wet Tropics Bioregion, but involving very similar vegetation types, landscape-scale loss of sclerophyll and grassland habitats transitioning to closed forests through rainforest irruption has been documented at Iron Range on Cape York Peninsula (Russell-Smith *et al.* 2004a, 2004b).

Detailed vegetation and geological mapping of the Wet Tropics Bioregion was carried out by PS and DS under contract to The Wet Tropics Management Authority between 1997 and 2004.

This work provided for the first time an opportunity to fully document habitat change across the bioregion.

Description of the bioregion and some relevant aspects of its history

The regional ecosystems of the Wet Tropics Bioregion of Queensland (Stanton and Morgan 1977; Sattler and Williams 1999) have been assigned a conservation status under the Queensland *Vegetation Management and Other Legislation Amendment Bill 2004*, based on putative pre-clearing vegetation distribution and on more contemporary threats to biodiversity within each ecosystem, such as altered fire regimes or weed invasion.

The bioregion covers mountainous country and coastal plains between latitudes 15°36′S and 19°20′S, stretching about 415 km between Cooktown and Townsville, and varying in width between 23 km and 65 km (Fig. 1). It embraces Queensland's highest mountain, Mount Bartle Frere, which reaches 1615 m, and many peaks above 1200 m. It also embraces a number of offshore islands including the 39 588 ha Hinchinbrook Island. It is geologically diverse, with the dominant rocks including granites, metamorphics, basic and acid volcanics, minor sedimentary and residual formations, and recent alluvium. Soils are predominantly deep although extensive areas of skeletal soil do exist, particularly on steep granite slopes at the southern end of the bioregion, including those of Hinchinbrook Island and its opposing slopes across the Hinchinbrook Channel.

The bioregion is defined by climatic factors, essentially its high rainfall, generally between 2000 mm and 4000 mm per annum, but rising to a 40-year average of 8154 mm at a recording station on the top of Mount Bellenden Ker, and falling to about 1500 mm in some coastal areas where the ranges are aligned almost parallel to the prevailing south-east winds, and a low of about 1200 mm in the rainshadow of the western margins. The region comes under the influence of the inter-tropical convergence zone (north-west monsoon) and the south-east trade winds driven by the passage of winter high-pressure systems across southern Australia. Under the influence of tropical lows and cyclones that form in both the Coral Sea and the Gulf of Carpentaria, orographic uplift where south-easterlies drive moisture across the ranges, and convectional uplift, the region occupies part of the extreme wet spectrum in comparison with other areas of tropical rainforest, and is subject to some of the highest rainfall intensities by tropical as well as world standards (Bonell *et al.* 1991). The distribution of the rainfall is highly seasonal with 60% or more of the average annual rainfall occurring in the months December to March.

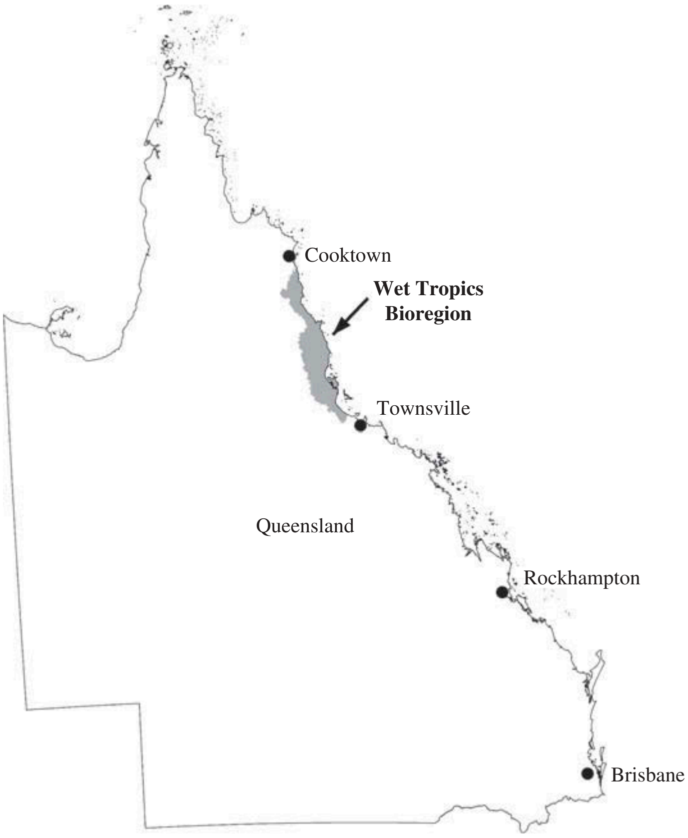

Figure 1. The Wet Tropics Bioregion

The vegetation of the region was classified according to the systems of Webb (1959) for rainforest and related types, and of Specht (1970) for other communities. The vegetation varies through a wide range of rainforest types from vine thickets to tall complex forest, and an equally wide range of sclerophyll woodlands, forests and shrublands, as well as mangroves, grasslands and sedgelands.

The Wet Tropics Bioregion was first settled by Europeans in 1863 with the establishment of a community at Cardwell on its southern coastline. Early development focused on the exploitation of mineral and timber resources, and the first assault on the rainforests began with the cutting of large stands of red cedar along the Mossman and Daintree Rivers and in the Cairns hinterland (Frawley 1983). The first land development began in the early 1880s with the opening of land on the lowlands for sugar cane and for dairying on the basalt soils of the Atherton Tableland. By the 1920s most of the better soils throughout the bioregion had been selected, but large-scale clearing on the poorer soils continued until the 1960s.

Up to that point, land-use conflict involved competition between land alienation for agriculture and pasture versus forest conservation for timber production. The legacy of that period includes tens of thousands of hectares of abandoned land with regrowth forest at various stages. Since that time public attention has focused on the intrinsic environmental values of the remaining forests. Identification of their national and international significance finally led, in 1988, to an area of 894 420 ha within the bioregion being listed under the United Nations' World Heritage Convention after it was accepted as meeting all four natural criteria for World Heritage listing. A concurrent proclamation under Commonwealth legislation brought an end to all timber extraction in the area, most of which is now either national park or progressively being converted to that or other conservation tenures. Within the 1 998 150-ha bioregion, 555 958 of the remaining 1 450 378 ha of natural vegetation is outside the World Heritage Area. It encompasses a range of tenures including freehold, various forms of leasehold including pastoral leases and crown land.

The Wet Tropics Management Authority was established to ensure Australia's obligation under the World Heritage Convention would be met in relation to the area. It reports to both the state and

Commonwealth governments and is a body corporate with statutory powers. The Authority's functions are, among many others, to rehabilitate and restore the area, to gather, analyse and disseminate information on the area, to monitor its condition and to support relevant research.

The declaration of the Wet Tropics of Queensland World Heritage Area brought to an end over a century of land use within the area based largely on exploitation of its timber resources. It has been hailed for its significance in providing a guarantee that its outstanding biological values will be adequately protected and transmitted undiminished to future generations. At the time of its declaration, however, there was little evidence to support an assumption that guarantee was being met or could be met. Subsequently, however, a large body of research and monitoring work has been stimulated, some of which has investigated the status of various species. The work reported here was designed not only to record the status of various vegetation types but to provide a methodology that would allow detection of trends. Previous broad-area mapping within the bioregion was confined to an overall classification of vegetation types as a series of maps at 1:100 000 completed by J.G. Tracey of the Commonwealth Scientific and Industrial Research Organisation (Australia) (CSIRO). Published in 1975 they described 57 vegetation types and provided an ecological framework from which many studies of the Wet Tropics since then have followed and adopted. A subsequent publication, Tracey (1982), provided a more definitive statement of vegetation complexity within the bioregion. However it was supported by few resources and is inadequate to meet current demands of precision.

Methods

The Wet Tropics Management Authority obtained current 1:25 000 colour aerial photography. Vegetation (white) and geological (black) boundaries were marked directly on the photos, codes for each vegetation type were marked in black ink (Fig. 2).

Aerial photo interpretation

Vegetation types were separated by features of the canopy which could be seen under the stereoscope, and boundaries between them were marked in ink by lines generally 0.5 mm or less in width, allowing clear delineation of areas even as small as a hectare. Features used were canopy height (the estimation of which from stereoscopic examination of aerial photos was regularly checked by field observations) and canopy coverage, which was also estimated from the aerial photos but calibrated by field observations and canopy floristics. In relation to the latter a wide range of species could be identified by their colour at the season of photography, the characteristic colours of new leaf flushes or flowers, the shape and texture of their crowns, and their shape as revealed by shadows. Problems arose with the definition of vegetation types that were clearly in a state of transition and that involved a range of structural types that at the extremes were as wide as from grassy open forest and woodland to closed forest and woodland. So extreme were these transitional changes observed to be that at an early stage in the mapping exercise numerous checks were made against previous aerial photography (mostly black and white photography at the same scale as the current photography, and captured during the 1960s and 1970s) and regular checks continued throughout the exercise.

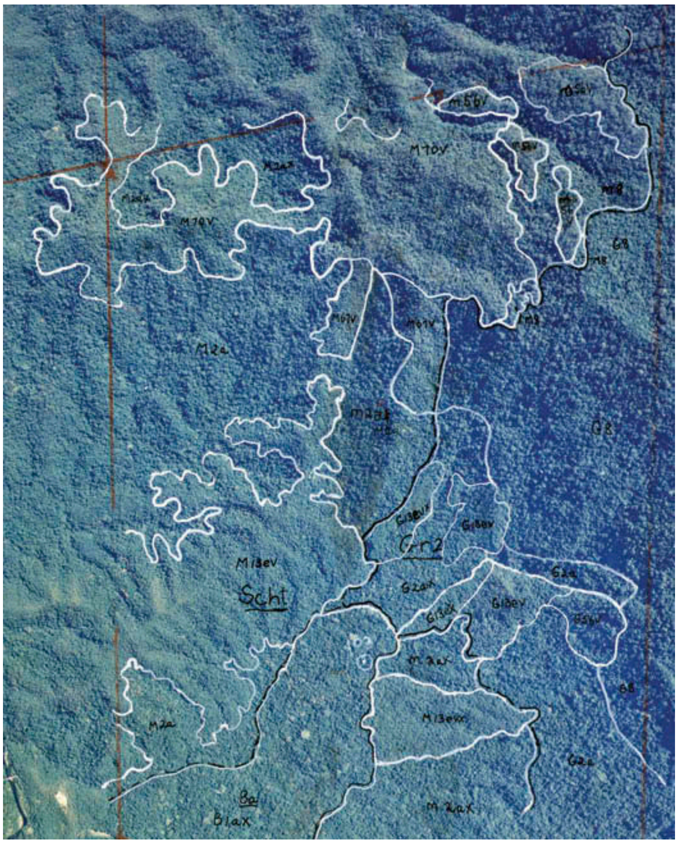

Figure 2. Section of an aerial photo with linework

Considering the observed speed of the transition from sclerophyll to rainforest communities, and the fact that the aerial photography was but a snapshot in time, it was judged that it would not be a useful exercise to separate the manifest structural changes of this process as separate vegetation types. To do so would be to obscure the basic relationships between vegetation and its environment, and to ignore the powerful evidence of change provided by the successive aerial photo records. Hence a decision was made that no matter how advanced the transition to rainforest of any sclerophyll habitat was, that as long as the sclerophyll species remained in the canopy, vegetation typing would be based on those species, and that the presence of the rainforest species would be acknowledged by a symbol appended to the main code (referred to earlier as a suffix). Where doubt remained from current aerial photography alone as to the original community from which the rainforest–sclerophyll mix was derived, the matter was generally settled by reference to historical photography without the need for field checking. Thus for any particular vegetation type that was in transition to rainforest, the mapping allowed the delineation of three variants of the type, according to the ground-cover, understory, and sub- or co-dominant canopy species. These were a grassy stage, a shrubby understory stage and a stage that encompassed either a well-developed rainforest understory or a closed forest with various mixtures in the canopy of rainforest and sclerophyll species.

All parts of the bioregion have been captured by intermittent state aerial photography at 1:25 000, beginning in the 1950s, and some by 1943 military photography. These show widespread habitat change across the bioregion as dramatic as change from open grassy woodland to closed forest, and that these changes, which have been extensive and rapid since about 1970, were rarely related to marginal expansion of rainforest, but involved an irruption of rainforest understories on a landscape scale (see Fig. 3).

Each polygon was marked with a vegetation code. The codes included a geology prefix; a vegetation type and an associated suffix that denoted canopy disturbance; and for sclerophyll woodlands and forests, the nature of the understory and/or sub-canopy. Disturbance suffixes were qualified by bracketed symbols to indicate the cause of the disturbance (e.g. logging or cyclonic winds). Separate codes were used to identify areas that were essentially regrowth from complete or partial clearing. These were further classified according to whether they were regrowth from former sclerophyll or rainforest communities.

The complete mapping exercise processed over 4000 interpreted, marked-up aerial photographs, which included 90 000 vegetation polygons, and covered, in whole or part, 53 standard 1:50 000 map sheets. Two hundred and fifty separate vegetation types were identified that were further subdivided on the basis of their underlying geology. The mapped polygons included areas as small as 1 ha.

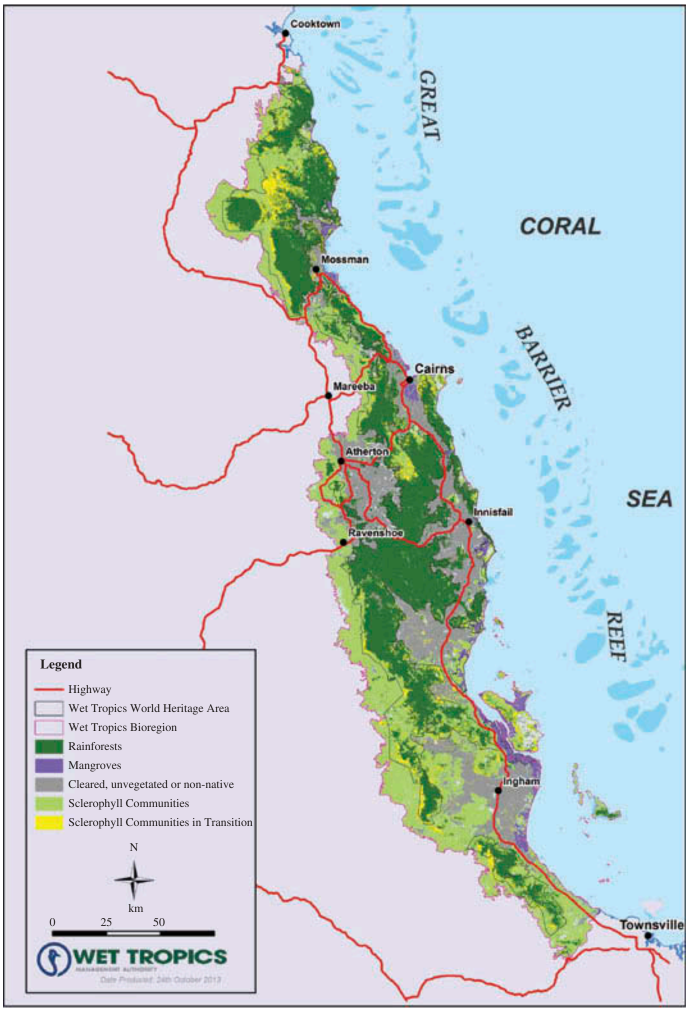

Figure 3. Broad vegetation groups and sclerophyll communities in transition

GIS mapping

A digital elevation model (DEM) of the land surface was created using 1:100 000 contour and drainage data. Each marked-up aerial photo was scanned and 'ERDAS Imagine' software was used to isolate the linework from the image. The critical process of orthorectification of each of the aerial photos for terrain distortion was performed with the aid of the DEM. Spatial accuracy was further refined using drainage data correction. The resulting accuracy was 0.5 mm at the 1:25 000 (or 12 m on the ground). Each individual scanned orthorectified air photo was then subsetted to minimise radial distortion. ArcInfo software was used to produce GIS polygons of the photo-interpreted vegetation communities.

Presenting all this data in a cartographically correct and aesthetic way was an enormous challenge. For example, the human brain would struggle to decipher all the individual colours needed to show all vegetation types. We chose to group the data hierarchically, and to use a smaller colour palette to describe broad forest types, while providing information at the individual polygon level by developing a well-structured legend specific to each map sheet. Some vegetation types were ordered in the legend to achieve a 'higher the darker' hypsometric colour effect. As distinct rainforest vegetation types vary with elevation, and fern complexes are always near mountain tops, this type of biotic and abiotic knowledge in conjunction with topographic hill shading was used to help model the landscape and make it easier for the informed user to 'navigate the data' visually.

GIS analysis of data

The GIS data were examined to determine the extent and distribution patterns of transitional vegetation types, and their relationship to rainfall patterns and geology. The scale of vegetation change within zones of mean annual rainfall was analysed. Within each zone the area of sclerophyll communities, and the area of sclerophyll communities in transition, was calculated. For that analysis vegetation types were grouped into formations (see Table 1). Sclerophyll communities included the vegetation formation grouping fernlands, rock pavement complexes, shrublands and heathland, and the formation coastal beach complexes. These inclusions result in a slightly lower figure for the fraction of the area that is in transition within each rainfall zone than would be the case if only the woodlands and forests were considered, but this is not significant given the overwhelmingly greater area of the latter compared to the former.

Harrington and Sanderson (1994) stated that 'a superficial examination of rainfall records does not indicate a wetter trend during the progress of this century'. An examination of all Bureau of Meteorology rainfall records for two selected recording stations, Cairns and Innisfail, similarly failed to find any evidence of wetter (or drier) trends. Analyses of these records over 10-year periods (Cairns) and 30-year periods

Table 1. The number of vegetation types mapped by formation and groups of formations

Formation	Number of vegetation types
Rainforest	69
Sclerophyll forests and woodland	126
Riparian and wetland complexes (excluding swamp forests)	7
Mangrove forests and herblands	6
Fernlands, rock pavement complexes, shrublands and heathlands	21
Coastal beach complexes	3
Grasslands and sedgelands	13
Secondary successional complexes	5
Total	250

Table 2. Cairns Airport rainfall records (analysis of data from Bureau of Meteorology 2013)

Period	Mean annual rainfall (mm)
1943–1952	1812
1953–1962	1968
1963–1972	2079
1973–1982	2253
1983–1992	1917
1993–2002	1936
2003–2012	2133
All years	2014

Table 3. Innisfail rainfall records (analysis of data from Bureau of Meteorology 2013)

Period	Mean annual rainfall (mm)
1881–1910	3753
1911–1940	3537
1941–1970	3445
1971 + 1986–2001	3601
2002–2012	3470
All years	3576

(Innisfail) are presented in Tables 2 and 3. The present recording station in Cairns has records going back to 1943, while Innisfail records go back to 1881, with a gap from 1971 to 1985.

The influence of geology is exercised through the soils that are developed on the various rock types but, as soils were not mapped, geology was the only available surrogate. That posed a difficulty because of the great range of rock types represented in the various categories, and therefore in the soils developed from them. For the purpose of analysis four geological groups were chosen and these are described in Table 4.

Table 4. Geological groupings

Geological group	Description
1. Granites and rhyolites	Acid and intermediate plutonic rocks including granites, microgranites and granodiorites
2. Basalts	Basalts and greenstones
3. Metamorphics	Amphibolite, schists, phyllites, serpentinites, quartzite hills, quartzose sands
4. Alluvium	Alluvium, colluvium, minor areas of laterite

Some of the inclusions in these groups are there for convenience because of the relationship of the soils developed on them to other soils found on rocks within that group, but because their areas are relatively small these will not significantly bias the analysis. An example is the grouping of meta-basalts (greenstones) with basalts.

Results

Of the formations and groups of formations in Table 1, only the sclerophyll forests and woodlands, and the coastal beach complexes, were identified as having significant areas in an advanced stage of capture by understories of rainforest species. Such areas are referred to here as transition forests. Habitat change was also identified in the grasslands and sedgelands, but the change in these habitats was from invasion by sclerophyll shrubs, predominantly melaleucas, and they were excluded from the analysis of habitat change but equally demonstrate a loss of biodiversity and habitat worthy of further investigation. The coastal beach complexes consist of intimate mixtures of woodlands, forests, shrublands, sedgelands, grasslands, herb fields and bare ground too complex to allow mapping of individual formations, and they have also been excluded from the analysis. A total of 735 713 ha were occupied by sclerophyll forests and woodlands. Of these 124 335 ha or 17% of the total were mapped as being in a state of advanced transition. Habitat change, however, was not uniformly spread throughout the forests and woodlands, being most advanced in the forests. Table 5 shows the situation in the major forest vegetation types, where between 25% and 79% of individual vegetation types were identified as transition forest. Of particular note is the tall forest type of *Eucalyptus grandis*, commonly referred to in eastern Queensland and New South Wales as wet sclerophyll forest. A total of 12 119 ha, representing 76% of the Wet Tropics Bioregion distribution of this vegetation type, is considered to be in a condition where it cannot regenerate to sclerophyll forest. In summation, the data from the GIS support the conclusions from field observations that major change in vegetation composition and structure has occurred in the Wet Tropics Bioregion since the 1950s.

Table 6 shows that the percentage of transition forest in each rainfall zone progressively increased with rainfall, with 6% in the very dry zone, 10% in the dry zone, 14% in the moist zone, 32% in the wet zone and 34% in the very wet zone. The designation of rainfall zones follows Tracey (1982). Table 7 illustrates that habitat change is occurring most extensively in Group 3 (metamorphics). The percentage of the sclerophyll communities within each group that are subject to advanced transition is lowest on the basalts (2%) and highest on the metamorphics (28%).

Table 5. Rainforest capture of major sclerophyll forest types in the 1600 to >3000 mm zone

Brief description of forest types[a]	Area (ha)	Area captured by rainforest (ha)	Fraction captured (%)
Forest dominated by *Eucalyptus pellita*	31 175	24 715	79
Medium to tall forests of *Corymbia intermedia*	11 105	7195	65
Tall forests of *Eucalyptus grandis*	15 890	12 120	76
Tall forests of *Eucalyptus resinifera*, *C. intermedia* and *Syncarpia glomulifera*, with or without *E. grandis* and *Callitris macleayana*	37 940	9445	25
Medium to tall forests of *Eucalyptus tereticornis*	33 925	15 085	45
Tall forests dominated by *S. glomulifera*	4175	3275	78
Medium to tall forests of *S. glomulifera*, *C. intermedia* and *E. pellita*	3750	2760	74

[a] Medium and tall are defined according to Specht (1970). Medium = 10–30 m tall. Tall = greater than 30 m tall.

Table 6. The patterns of transition in sclerophyll forest and woodland in relation to rainfall

Rainfall zone	Average annual rainfall (mm)	Total area (ha)	Area in transition (ha)	Fraction in transition (%)
Very wet	>3000	19 607	6717	34
Wet	2000–3000	210 786	67 123	32
Moist	1600–1999	169 865	24 383	14
Dry	1300–1599	162 713	15 589	10
Very dry	<1300	172 743	10 779	6
All zones		735 713	124 591	17

Table 7. The relationship of patterns of transition in sclerophyll forest and woodland with geological substrate

Substrate	Total area (ha)	Area in transition (ha)	Fraction in transition (%)
Alluvium	115 537	17 347	15
Metamorphics	166 121	45 954	28
Basalts	7953	171	2
Granites and rhyolites	446 397	58 722	13

Discussion

The patterns of transitional forest distribution in relation to rainfall and geology do not, alone, elucidate the matter of a possible link between vegetation change and environmental factors, but are explicable when combined with knowledge of land-use changes, most particularly the way in which fire is now used in the landscape. In areas surrounded by rainforest, or largely protected by belts of rainforest, habitat change would have been initiated on the cessation of aboriginal burning. Within the state forests, Forestry Department practice, if not policy, over a long period of time, was to exclude fire from stands of commercial timber where it affected adjoining protected areas. This was not always successful, but served to reduce fire frequency. Within the grazing industry, the introduction of a new breed of cattle and the practice of supplementary feeding with molasses and urea, as well as reduced interest in grazing in the more rugged country, has led to a rapid decline in regular grazier-lit fires. In coastal areas adjacent to cane fields, where the practice was to burn cane prior to harvest, fires were deliberately lit, or allowed to escape, in surrounding land at the end of every cane harvesting season. This practice abruptly ceased in the early 1980s with a move by farmers to green harvesting. The only areas in which fires now regularly or occasionally burn are along the western margins of the bioregion where intact vegetation is continuous with that of grazing country outside the bioregion, in a small moist zone along the coast north of Cairns, and in a large moist zone at the southern end of the bioregion south of Cardwell, and on the large Hinchinbrook Island.

Within the southern moist zone and on Hinchinbrook Island some extensive prescribed burning programs are now carried out by the Queensland Parks and Wildlife Service to ensure that fire occurs with such regularity that the process of transition is arrested. Other than where those programs are carried out, fires are now infrequent. The lower prevalence of transition forests within the very dry, dry and moist zones can be explained by the fact that these zones lie within the fire-prone areas identified above. Within the wet and very wet zones, large areas of sclerophyll communities in total are protected by belts of rainforest, or occur in numerous small pockets surrounded by rainforest and are not subject to the chance incursions of external fires. Large areas also occur on coastal lowlands or foothills adjacent to cane farms where fire is no longer used, or where urban areas have replaced the cane farms. Similarly, the proportionately greater area of metamorphics dominated by transition communities can be explained by the fact that the metamorphics occur most extensively in wet and very wet zones on the lower slopes of the mountains at elevations of about 400–500 m and lower, while the very dry, dry and moist rainfall zones of the western margin of the bioregion are generally at higher altitudes than that, and are largely characterised by plutonic and volcanic rocks.

The almost complete absence of transition forest on the basalt soils is explained by the fact that the only areas of basalt which once supported sclerophyll forest and woodlands, and remain uncleared, are small in extent and located in the very dry zone, where they are subject to regular fire. In the light of the above, and the lack of evidence in the rainfall records of any wetter trends over the last 70 or more years, changing fire regimes, including those in large areas where fire is now excluded, provide the most plausible explanation for the massive recent habitat changes revealed by field observations and the GIS data. The dynamics of transition forests and implications for their management are explored in a complementary paper, Stanton *et al.* (2014).

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