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Perspective

Plant colour as a visual aspect of biological conservation

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ABSTRACT

Plant colour has not been specifically considered as part of biological diversity. The absence of visual attributes in discussions of biodiversity and its conservation appears to have arisen due to the confinement of conservation to the disciplinary territory of science and to the protection of species. This essay draws attention to the need to consider colour as an aspect of biological diversity in need of protection and management. It focuses on the colour of plants which we see, and what plant colour means to us as a representation of local place or biogeographical region; it is not concerned with the visual abilities of the human eye. The distinctiveness of the colours of regional plant species and changes in plant colour in landscapes undergoing urbanisation are discussed. Plant colour as an aspect of visual diversity needs to be considered for conservation as a component of the diversity of biogeographic regions, and visual diversity acknowledged in ecology as an important aspect of biology not just worthy of conservation, but helpful to conservation ambitions.

Contents

1. Introduction

The diversity and distribution of plant species can be represented or analysed by species lists and quantitative figures from biologists, but diversity of plant species is also experienced visually by all humans. Currently, colour is absent from ideas of conservation, and this appears to be due to conservation being the disciplinary territory of science. Within science, colour is discussed with caution because colour is not considered immutable. Colour is also noted within botany and zoology at the scale of species, not at the scale of a region. Yet if we pick a green leaf, what colour green is it? The answer will depend on where you are regionally, or in what biome. Intuitively, we might suppose that the green in Australia's sclerophyllous woodlands is different from the green of a beech woodland, but how is it different? Does the colour of green we see represent or suggest to us the biological diversity of species of a particular place? I argue that the difference in colour is important to human 'sense of place' and suggest that if a local green is replaced by a non-local green our sense of place is altered. There are implications for conservation in 'sense of place'.

As we walk down the street everything we see determines our experience of that place. 'Place' has been discussed as an idea by Antonsich (2010), and defines much of our personal and social identity, our sense of self, our 'rootedness', and our responses to a sense of region. While humanist geographers tend to ignore the physical landscape in notions of 'sense of place' – noted by Antonsich (2010) as "elusive, ill-defined and controversial"—the geologist and writer Seddon (1972) treated 'sense of place' in a manner likely to be more comfortably understood by conservation ecologists, as he treated 'sense of place' to include landform, soils, plants and the human community, and our responses to a landscape; it is the definition I use here. 'Sense of place' surely suggests that what we see in our physical world has a cultural impact. The

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colour of plants is a component of our understanding of our part of the world and is likely to engage the public, not just scientists.

2. How biologists and ecologists have and have not studied colour

Colour in biological species has long been studied, such as in shells (Sheppard, 1823; Grier, 1920), bird eggs (Martínez- Padilla et al., 2010), warning colours (aposematism) in butterflies (Mallet and Singer, 1987), tulips (Raamsdonk, 1993; Torskangerpoll et al., 2005), bacteria (Pridham, 1965), snakes (Shine et al., 2010), reef fish (Marshall et al., 2003), stink-bugs (Musolin et al., 2010), bees associating warmth with floral colour (Dyer et al., 2006), and leaves (Lee, 2007). Evolutionary biologists and the public have been excited at revelations of dinosaur colours (Zhang et al., 2010; Wogelius et al., 2011) and some articulation of the evolution of structural colour in beetles (McNamara et al., 2011). Ridgway's (1912) book of 1115 colours has been used extensively in ornithology. Soils continue to be readily analysed and compared for colour, with the Munsell soil color charts; sands are noted for colour differences (e.g. Welland, 2009), and diamonds coded according to colour from pure white to yellow. Colour has been used as a parameter to establish, measure, and discuss features of global change biology. Changes in satellite colour data have been used to classify ocean environments for monitoring inter-annual change in the oceans (Esaias et al., 2000), and changes in plant cover in the Amazon (Malmer et al., 2005), and aerial photography used to determine forest cover types in New England, USA (Hershey and Befort, 1995). Coral bleaching data have been used as an indicator of coral health (Donner et al., 2005), and Margalit et al. (2010) modelled the propagation of green light through grana and inter-grana components of chloroplasts. Colour has been central to recent advances in understanding chlorophyll degradation (Hörtensteiner, 2006) and images from space of seasonal greening in the northern hemisphere (Scaaf, 2007; Zhou et al., 2007). Barry (2009) noted that the diversity of plants is partially manifested by pigments.

Artists have employed colour palettes with colour descriptions often named after the colours of biological parts such as Emerald Green from "beauty spot on wing of teal duck" (Syme, 1814). The botanical artist Ferdinand Bauer, who accompanied James Cook and Joseph Banks on the Royal Navy-Royal Society voyage to the South Pacific in 1768–1771, used an extensive colour number system which enabled him to colour his drawings with accuracy in London years later (Hewson, 1999; Pignatti-Wikus et al., 2000). More recent colour systems include those of the Pantone series, the Royal Horticultural Society, and the Natural Colour System of Sweden. The colours of building facades and regional colour schemes for built form have been analysed in French villages (Lenclos and Lenclos, 1982; Lenclos, 1989), British towns and other European cities (Lancaster, 1996), the interaction of colour and architecture in Moscow described (Semenova, 2007), colours for websites set out (Holzschlag, 2001), and the use of colour in design discussed (Klanten et al., 2007). Lancaster (1996) termed the expression 'colourscape' to describe the variety of regional colours in both built and natural forms.

The difficulties of colour description for plants have been noted for centuries (Waller, 1686; Syme, 1814; Gage, 1993), with issues of plant age, light and sun angles, adjacent colours, and leaf thickness, texture and surface coatings being considerations for plant colour—all reasons for science to be cautious of colour as an aspect of conservation.

Difficulties with colour come from the heart of scientific nomenclature. Before the 18th-century natural historians noted colour as closely as they could, with both form and colour together seen as a "*more Compleat reading*" of a subject (Syme, 1814). However, since Carl Linnaeus's *Species Plantarum* of 1753 (Blunt, 2001), botanists have not annotated colour as a determinant of species because colour is not immutable, and to a large extent only immutable features such as sexual parts determine species in the Linnaean catalogue. Other mutable features in plants exist, and the problem of description of plant features is not confined to colour. Traiser et al. (2005) note that there are still no "unequivocal and undisputed definitions" of some leaf architectural characters. However, other mutable features such as variations in plant height are dealt with in the literature statistically, while there is no established comparative analysis for colour. Thus we have been left with a difficulty of discussing colour in better terms than 'duck egg green'. Examining just one book on eucalypts (Chippendale, 1973) we find examples of the difficulty of comparative description of leaf colour, as leaves are described as green (e.g. *Eucalyptus erythrandra*), deep green (*Eucalyptus oleosa* var. *oleosa*), glossy green (*Eucalyptus dundasii*), dull green (*Eucalyptus oleosa var. plenissima*), dark green (*Eucalyptus flocktoniae*), dull yellow-green (*Eucalyptus ewartiana*), grey-green (*Eucalyptus orbifolia*), pale green (*Eucalyptus formanii*), light green (*Eucalyptus foecunda*), bright green (*Eucalyptus tetraptera*), dull grey-green (*Eucalyptus drummondii*), as well as 'paler below' (green) on the abaxial surface (*Eucalyptus uncinata*). Such descriptions are no better than the 'duck egg green' of the seventeenth century, for what is the difference between dull green and grey-green, in reality, or in the eye of one beholder, or in the eyes of different beholders? Poor descriptions prevent us from assessing plant colour and then defending the conservation of regional or biome colours against the globalisation of new plantings in urban design, or against invasive species.

In a paper to *Nature* more than 100 years ago Pillsbury (1895) detailed that the introduction of colour standards would make possible the discussion of colour in a definite language, a sentiment echoed by Archetti (2009), who noted that a combination of direct observation by human eye and spectral data would be welcome. Without a standard colour system comparable to the Munsell Color System for soils, botanists have not been able to articulate accurately plant colors to someone elsewhere (Grose, 2007), unless we resort to the spectrophotometer. Although it will give us a certain type of comparative data, a reflectance reading is unlikely to mean much to someone who is not a scientist, to someone who just looks at the world walking down the street. This is the world that most of us live in, scientists and non-scientists alike. Visual appearance—the colours of your beech trees in autumn or my eucalypts in summer—do speak of plant diversity in particular parts of the world, and suggest a need to be alert to the conservation of locally endemic plant colour. It is possible that the detailed analysis of plants, whether by microscopic images or mathematics, has denied the plant as we see it—as a coloured object in space. We have appeared to ignore the *visual* variety of the biological world, and in doing so have ignored a major component of plant diversity, complexity, and evolution.

3. The meaning of greens to conservation

Importantly, does colour diversity matter, and does it matter to conservation ambitions? To answer these questions it is first necessary to ask what physiological features in a plant set-up the colour differences which we see. Gumbert et al. (1999) noted that "seemingly trivial questions such as...'what is the biological meaning of the diversity of flower colours we see?' remain unanswered", then partly answered that question for flowers. If we ask 'what is the biological meaning of the colour green in leaves?', the answer to this is in both structural and biochemical features in the realm of leaf thickness, density and the proportions of

Fig. 1. Just add water: Smooth-barked trunk of *Corymbia maculata* [syn. *Eucalyptus maculata*] in Melbourne, Australia, pictured after rain, when its spotted grey trunk transforms into very different colours from grey, showing the mutability of colour underlying the rejection of colour as a criteria in the Linnaean classification. This south-eastern Australian species is planted extensively as a street tree across other biomes in Australia due to its upright growth form.

mesophyll, epidermis, sclerenchyma and vascular bundles (Garnier et al., 1999), as well as chloroplasts, plastids, chlorophyll types, photosystems I and II (Barber, 2008), chlorophyll development in expanding new leaves, and pigment extraction by plants to create deciduous autumn colours (Wilkinson et al., 2002; Hörtensteiner, 2006). Chloroplasts and thus the colour green also occur in stems and trunks, a feature common in eucalypts which have low leaf area indexes (Tausz et al., 2005) such as the spotted gum shown in Fig. 1.

Leaves evolved with two distinct surfaces approximately 420 million years ago (Beerling, 2007), and it might be expected, as in leaf morphology, that they have diversified in their biological components which give us green. How did the internal workings of the leaf come to diversify into what we see as many hues across different species? Was there one 'original structure', and thus one 'original green' from which all subsequent physiological evolutions produced a range of hues? Since leaf structure has evolved to deal with climate and light intensities across drifting continents, are green hues regionally distinct, either now or previously? Is there global convergence for colour-light intensity or colour-climate responses, such as that for leaf margin teeth (Greenwood, 2005)? Currie and Paquin (2004) consider that species richness in trees is principally a function of varying amounts of energy available, suggesting the importance of light and responses to light in leaf structure. Such responses will determine leaf colour in biomes. Detailed information about comparative plant colour will contribute to an understanding of visual biodiversity, the visual qualities of biomes, and how conservation also means conserving the visual attributes of a region or biome.

4. How colour matters to us and to conservation

It is well known that other animals have different colour vision to us, and see the world differently. However, what we humans see is important to us. Plant colour is surely a factor which places us in a recognised part of the world. The colour of your leaf—perhaps orange, or fallen and absent—intrinsic to the perception of your place or your region of the world, and my leaf—ever grey-green—speak of our biomes in the world. The colours which we see are important to us socially and emotionally, and this can be gleaned by considering three situations—an invasive plant, a hypothetical scenario, and plants introduced into designed landscapes.

First, heather, *Calluna vulgaris*, was introduced into New Zealand in the nineteenth century, and is one of New Zealand's' most invasive weeds (Owen, 1998). The issue of heather for New Zealanders is not only what it is doing in terms of ecosystem alteration, but what it looks like—it is not the colour of New Zealand as she once was, and it seems that New Zealanders would like to see the heather removed as much because of the colour dominance it gives over endemic flora than what it does ecologically.

Second, if we were to take all the American maples out of Vermont and replace them with British deciduous trees such as limes and beeches, would the people of Vermont notice and care? Yes they would, but why would they? Is it the colour that tells where they are, and partly or largely defines their sense of place?

Third, colour transformations can occur very rapidly with transforming landscapes, such as those undergoing major suburban expansions into bushland. For example, the Southwest Australian Floristic Region (SWAFR) (Hopper and Gioia, 2004) is a global Hotspot (Myers et al., 2000) under threat from suburban development around the capital Perth (EPA, 2007). *Banksia–Eucalyptus* woodlands in this Mediterranean biome have taken the brunt of suburban development, and non-local species are now dominant in urban areas (Farrelly, 2003). Such species change is not new in Australia, particularly in those cities where older planting referenced another place, or the 'home country' of England, such as the English elms planted extensively in Melbourne, or the London Plane Trees planted in the SWAFR. But European or Asian exotics planted in Australia are likely to have a greater evolutionary 'gap' with local species, including plant colours, than a British tree planted in Italy or Massachusetts because Australia has been until recently far more isolated. Thus with land transformation, the colour of the flora in the SWAFR is being changed to something markedly different visually from previous, as seen in Fig. 2. If plant colour is threatened to be changed with land transformation, should we actively conserve endemic colour? Does the colour of the eucalypt educate us subtly about the SWAFR—do the grey-greens of the *Eucalyptus–Banksia* woodland say something about the physiologic responses to water, sunlight, aridity, and poor soils *for these plants, in this biome*, all together? Importantly, how do endemic fauna respond to what a new colour is, and what it represents (e.g. predation risk)? Colour change can thus be seen to represent an altered ecological state, and as a warning for conservation.

Colour can warn us about conservation because we can see it. The colours of our major plant species tell us something about

Fig. 2. Two greens in the South West Australian Floristic Region: In the foreground is the introduced Indian Coral Tree *Erythrina indica*, and in the background the locally endemic 'Tuart' *Eucalyptus gomphocephala*. What are the implications for insect feeding guilds and predation of the alteration of colour with replacement of one species with another?

our place, our landscape, our geographic region; the colours are likely to be distinct and different from other places, whether subtly or greatly. If we look out the window, colour is a major component of our view, and likely to be capable of quietly educating us about the biological diversity underpinning our senses of place. If we look out the window and ask what we would like to see there in 50–100 years we will see what we might hope to conserve. But conservationists tend to talk of species loss, not visual loss.

Echoing Seddon's 'sense of place', the landscape architect Meyer (1997) noted that design needed to be "grounded", and experiential, with designs for biodiversity or resilience or conservation which are also beautiful. Meyer (2008) noted beauty as a forgotten aspect of sustainability, and comments that "it will take more than ecologically regenerative designs for culture to be sustainable, that what is needed are designed landscapes that provoke those who experience them…to care". This idea is important for the science of conservation because to engage the public in conservation they need to care about species and places, and there is a need for scientists to engage in wider sectors of society in ways that are easily understood (Bickford et al., 2012). Understanding a place is very much determined by our visual experience. Yet ecologists talk largely to themselves and appear to have forgotten the visual 'Compleat reading' of the pre-Linnaean world which could be used to provoke people to care about conservation.

5. Conclusions: the need for conservation to engage the visual

Colour continues to be seen as mutable and thus outside of ecological concern, even in transforming landscapes or in regard to invasive species. However, colour can be seen as an aspect of biological diversity which is readily approachable and understood by non-specialists, and could contribute to understanding the significance of local and regional biodiversity and its conservation. Ecologists and landscape architects are not simply engaged in restoration or improving the habitat or green spaces of cities, or assisting with the creation of new green spaces, but are also working in a colourscape which might have 'grounded' regional aspects worthy of conservation for world biodiversity. Importantly, urban landscapes are where most people see and experience 'nature'. It is timely to call for a re-assessment of mutable plant colour, and its role in educating us all about place, plants, our 'sense of place', and the conservation of those places and the species within.

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