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Do fire and rainfall drive spatial and temporal population shifts in parrots? A case study using urban parrot populations

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ABSTRACT

Populations of several species of native parrots have been increasing in many Australian cities since the 1980s contributing to a shift in the composition of urban avian communities. Anecdotal evidence suggests that some species of parrot may move into the urban landscape during environmental disturbances, such as wild fires or periods of decreased rainfall. This study seeks to determine the extent to which fire and rainfall explain changes in the abundance of parrots in urban Sydney. Multiple regression using the Akaike Information Criterion was used to analyse a 26-year data set, beginning in 1981, to measure the change in abundance of 13 species of parrot in response to wild fire and rainfall. Wild fire, within a radial distance of 100 km, significantly predicted changes in abundance of five species of parrot in urban Sydney. Local and/or inland rainfall significantly predicted changes in abundance of six parrot species in the urban landscape, with decreases in inland rainfall resulting in an increase in abundance in the urban landscape of parrots that traditionally inhabited inland areas.

1. Introduction

Urbanisation is one of the most dramatic transformations to shape the natural landscape (Lowry and Lill, 2007), and is considered one of the greatest threats to the conservation of biodiversity (Isaac et al., 2008). Whilst 51% of the global population is expected to reside in cities by 2010 (Garden et al., 2006; Isaac et al., 2008), Australia has already surpassed this global average with 90% of the population residing in urban and suburban areas (Isaac et al., 2008). Such a rapid rate of urbanisation has resulted in an abrupt change to the landscape, with continuous tracts of native vegetation transformed into complex spatial mosaics of buildings and bitumen, interspersed with fragmented and discontinuous remnant vegetation, parks and gardens (Catterall, 2004).

Urbanisation results in a profound restructuring of the landscape (Chamberlain et al., 2009) and has been described as catastrophic for some species of birds (Meyer-Gleaves and Jones, 2007), often resulting in the elimination of many indigenous birds from the urban landscape (McKinney, 2002; Shukuroglou and McCarthy, 2006). In Australia, however, there has been a recent increase in abundance of several species of native Australian parrots in suburban areas of Australian cities (Burgin and Saunders, 2007; Lowry and Lill, 2007; Shukuroglou and McCarthy, 2006; Veerman, 1991). In the city of Sydney, New South Wales, prior to 1920, Rainbow Lorikeets (*Trichoglossus haematodus*) were considered rare (Burgin and Saunders, 2007) however they are now one of the most frequently recorded species in Sydney (Major and Parsons, 2010). During the period between 1981 and 2002, four other species of parrot increased in abundance in urban Sydney (Burgin and Saunders, 2007). Whilst some of these species have always been present in the Sydney region, such as the Sulphur-crested Cockatoo (*Cacatua galerita*), other species such as the long-billed Corella (*Cacatua tenuirostris*) and the Galah (*Eolophus roseicapillus*) were historically known only from arid areas of inland Australia (Higgins, 1999). There are several factors that may be driving these changes in abundance, one of which is drought.

Drought results in long term changes to habitat and resources, and Australia regularly experiences drought cycles lasting ten years or more (Hunt, 2009; Ummenhofer et al., 2009). Surface water in the arid zone is normally naturally restricted (Fensham and Fairfax, 2008) and may become locally unavailable during these extended periods of drought, although for highly mobile species such as parrots, available drinking water may not necessarily be a limiting resource, given the widespread distribution of artificial agricultural watering points (Fensham and Fairfax, 2008). Foraging may become increasingly difficult, however, as plant flowering and seeding may be delayed, become dormant throughout the drought or aborted

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entirely (Ellis and Sedgley, 1992; Law et al., 2000), which may result in a resource-driven movement towards the urban landscape (Saunders, 1980; Smith and Moore, 1992).

Wild fire, which is a frequent occurrence among the sclerophyllous forests and woodlands of the New South Wales coast, is another factor that may account for temporal change in Sydney's parrot community and may result in an increased abundance of local species in the urban landscape immediately following large fires (Recher, 1997). Following a small fire, surrounding vegetation may offer enough food resources so that only local evasive movements by birds are necessary. The effects of large fires (fires that burn in excess of 10,000 ha (Keane et al., 2008)), however, are twofold. There is an immediate effect of the fire itself, where populations of (vertebrate) fauna are often depleted, either as a function of mortality or through dispersal/escape mechanisms (Bradstock, 2008), and a longer term effect that is a function of changed habitat resources, such as food or cover (Whelan, 1995).

It appears that certain species of Australian Psittaciformes may be responding to such environmental events as drought and rainfall, and may be entering the urban landscape in search of shelter or food resources that are limited or unavailable in the surrounding natural vegetation. This study aims to document changes over a 26 year period in Sydney's parrot community and to determine the extent that drought and wild fire explain annual variation in parrot abundance. The specific aims are to:

1) analyse population dynamics of 13 parrot species in the Sydney region, New South Wales Australia over a 26 year period;
2) determine the extent to which rainfall explains patterns of abundance of urban parrot populations; and
3) determine the extent to which fire explains patterns of abundance of urban parrot populations.

If large wild fires are a driver of changes in parrot abundance in the urban landscape, we predict an increase in abundance of species that have traditionally been present in the Sydney urban landscape (such as the Rosellas (*Platycercus* spp.) and Australian King Parrot (*Alisterus scapularis*)) immediately following large wild fires. If rainfall contributes towards changes in abundance in the urban landscape, we predict an increase in the abundance of arid zone species (such as Corella species and the Galah) in the Sydney urban landscape up to two years following decreases in inland rainfall.

2. Materials and methods

2.1. Study site

The study site encompassed the Sydney urban region on the east coast of New South Wales, Australia. Sydney extends over an area greater than 12,000 km^2 and is characterised by a warm, temperate climate. It is an urban island, bounded by the Pacific Ocean to the east and three major national parks to the north, south and west (Fig. 1). The area of natural vegetation within these parks surrounding Sydney exceeds 2700 km^2 and is predominantly dry sclerophyll woodland or forest, and heath (Keith, 2006). Sydney and its suburbs contain numerous recreational parks and gardens as well as a number of small remnants of native vegetation (shaded in Fig. 1) which provide habitat for a range of native bird species (Parsons et al., 2003).

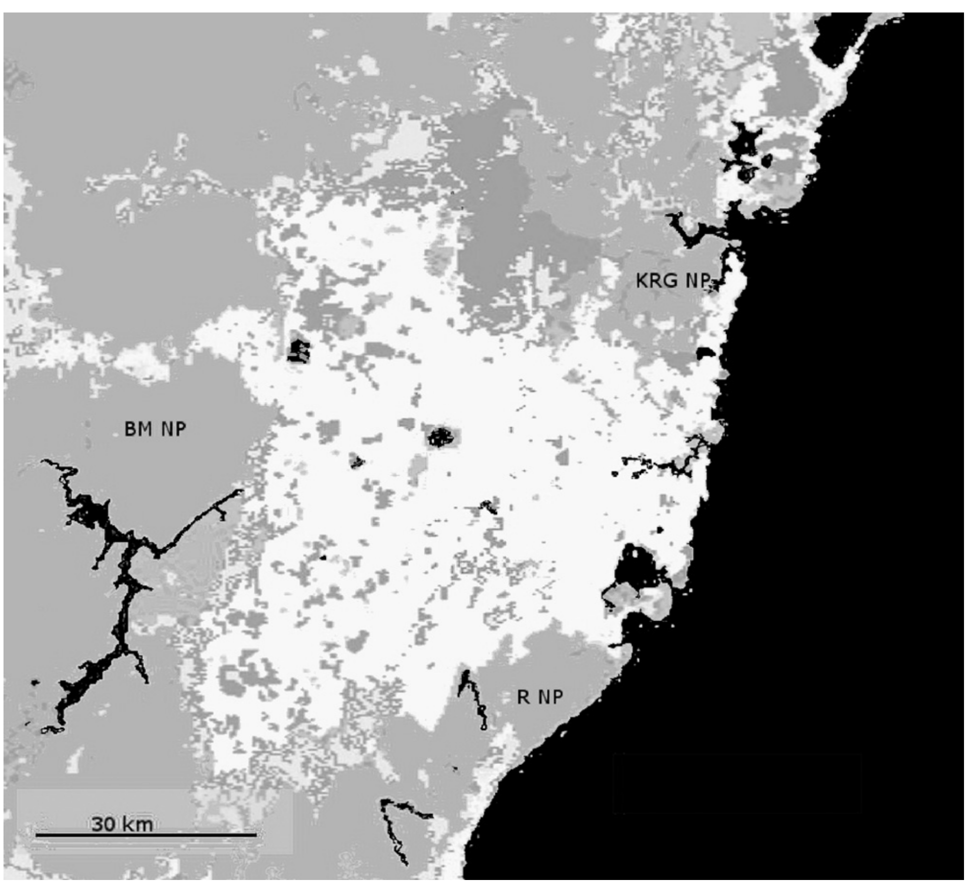

Fig. 1. Sydney, Australia, showing the Sydney urban landscape (white) and surrounding vegetation (grey) with Royal National Park (Royal NP), Ku-ring-Gai Chase National Park (KRG NP) and the Blue Mountains National Park (BM NP). Water is coloured black.

Table 1
Traditional range of each parrot species within the study and the general feeding guild to which each species belongs (Higgins, 1999).

Species	Traditional association	Main dietary classification
Australian King Parrot	Coastal/Sydney	Frugivore/Granivore
Crimson Rosella	Coastal/Sydney	Granivore
Eastern Rosella	Coastal/Sydney	Granivore
Galah	Inland	Granivore
Gang-gang Cockatoo	Coastal/Sydney	Granivore
Glossy Black-cockatoo	Coastal/Sydney	Granivore
Little Corella	Inland	Granivore
Long-billed Corella	Inland	Granivore
Musk Lorikeet	Coastal/Sydney	Nectarivore
Rainbow Lorikeet	Coastal/Sydney	Nectarivore
Scaly-breasted Lorikeet	Coastal/Sydney	Nectarivore
Sulphur-crested Cockatoo	Coastal/Sydney	Granivore
Yellow-tailed Black-cockatoo	Coastal/Sydney	Granivore

2.2. Bird atlas data

Bird data were obtained from the "Atlas of New South Wales Wildlife" (NSW National Parks and Wildlife Service), a government database that contains 5808 records of the target species within the study area since 1981. The atlas is limited in that it does not follow a standardised survey technique, but is primarily comprised of incidental sightings. Numbers of birds recorded in the atlas was therefore not consistent, or standardised, for area of search effort, hence only presence/absence information was used. The advantage of this data set, however, is that it contains continuous records from 1980 to the present day, unlike the more systematic Birds Australia Atlas Database (Barrett et al., 2003) that contains records only since 1998. Data were extracted for the years between 1981 and 2007 for ten species of parrot that have traditionally been recorded from Sydney and three species of parrot that have traditionally been associated with the inland (Table 1). The ten species of traditional Sydney parrots were the Australian King Parrot (*Alisterus scapularis*), Crimson Rosella (*Platycercus elegans*), Eastern Rosella (*Platycercus eximius*), Gang-gang Cockatoo (*Callocephalon fimbriatum*), Glossy Black-cockatoo (*Calyptorhynchus lathami*), Musk Lorikeet (*Glossopsitta concinna*), Rainbow Lorikeet (*Trichoglossus heamatodus*), Scaly-breasted Lorikeet (*Trichoglossus chlorolepidotus*), Sulphur-crested Cockatoo (*Cacatua galerita*), Yellow-tailed Black-cockatoo (*Calyptorhynchus funereus*). The three historically inland parrots were the Galah (*Cacatua roseicapilla*), Long-billed Corella (*Cacatua tenuirostris*) and the Little Corella (*Cacatua sanguine*). The Little Corella and the Long-billed Corella were pooled into one 'Corella' variable as the two species often flock together and are easy to misidentify.

Data for four similarly sized urban-resident birds, that were not expected to respond to fire and drought, were used as an index of survey effort. The Australian Magpie (*Cracticus tibicen*) and the Laughing Kookaburra (*Dacelo novaeguineae*) are both native carnivorous species, commonly found in both the urban and non-urban landscapes (Higgins, 1999; Slater, 1995). The Noisy Miner (*Manorina melanocephala*) is a native nectarivore that has recently increased in abundance throughout urban landscape (Keast, 1995) and the Common Myna (*Acridotheres tristis*) is an exotic species that is common throughout the urban and rural landscape (Barrett et al., 2003; Martin, 1996). All four reference birds occur throughout the same inland and coastal regions as the 13 selected parrots, are considered sedentary and, except for the Laughing Kookaburra, are among the top ten most frequently cited birds within the urban area (Higgins, 1999; Major and Parsons, 2010). The abundance of each species was expressed as the relative percentage of the yearly total of all reported sightings for all 17 species. All records were mapped into a Geographic Information System (ArcMap 9.2) and the report locations were validated to ensure that the majority of records were not collected from only a few locations.

2.3. Fire data

Data sets containing information on each wild fire in New South Wales between 1980 and 2007 were obtained from the NSW Department of Environment and Climate Change and mapped into ArcMap 9.2. The number of hectares burnt in each wild fire occurring in national parks within a radial distance of 100 km from the Sydney GPO was calculated. Only wild fires that burnt greater than 100 ha were included and these were summed to provide the total number of hectares burnt for each year between 1981 and 2007. A variable was also created that lagged data by one year and two years respectively to account for indirect effects of fire.

2.4. Rainfall data

Annual rainfall (in mm) records were obtained from the Bureau of Meteorology for both the local coastal area (Observatory Hill: 33.85°S, 151.21°E) and inland area (Temora: 34.41°S, 147.57°E). Coastal Sydney rainfall was strongly correlated with rainfall in western Sydney and thus the one rainfall record for Sydney sufficed. Drought was defined as any year where rainfall was below the average annual rainfall for the rainfall zone. Lags of one and two years respectively were applied to rainfall data to account for delay in landscape changes and resultant species responses (see Ellis and Sedgley, 1992; Law et al., 2000).

2.5. Analysis

All data were tested for homogeneity of variance using Levines test and, where homogeneity was not met, data were log-transformed for analysis. Data for any species that still had a small to moderate degree of skewness or kurtosis (values less than 2) were analysed with an alpha equal to 0.01. Data were then analysed using multiple regression.

Curve estimation was undertaken in SPSS 17.0 to determine whether a relationship over time existed for each species. General linear modelling using the step function was then undertaken using *R* (version 2.9.0, 2009) to determine the influence of rainfall and fire on each species. As not all effects were expected to be linear, curvature was assessed for each variable and, when curvature existed, both linear and quadratic terms were entered into the model and the Akaike Information Criterion (AIC) was then employed to select the best models (Manning et al., 2007; Pearce and Ferrier, 2000). ΔAIC values were calculated as the difference between a candidate model's AIC and the lowest AIC value, and AIC weightings (w_i) were calculated for each model to determine the likelihood that each candidate model was the best model (Mazerolle, 2006). ΔAIC values less than 2 indicate substantial support for the model and thus only models with ΔAIC values less than 2 are presented.

3. Results

3.1. Change over time

Sulphur-crested Cockatoo relative abundance increased linearly in the Sydney urban landscape from 1981 to 2007 (R^2 = .38, $F_{1,25}$ = 15.38, p = .001; Fig. 2a) whereas relative abundance of the Gang-gang Cockatoo has declined linearly throughout the same period (R^2 = .51, $F_{1,25}$ = 25.86, p < .01; Fig. 2b). A positive quadratic relationship existed for both the combined Corella species (R^2 = .61,

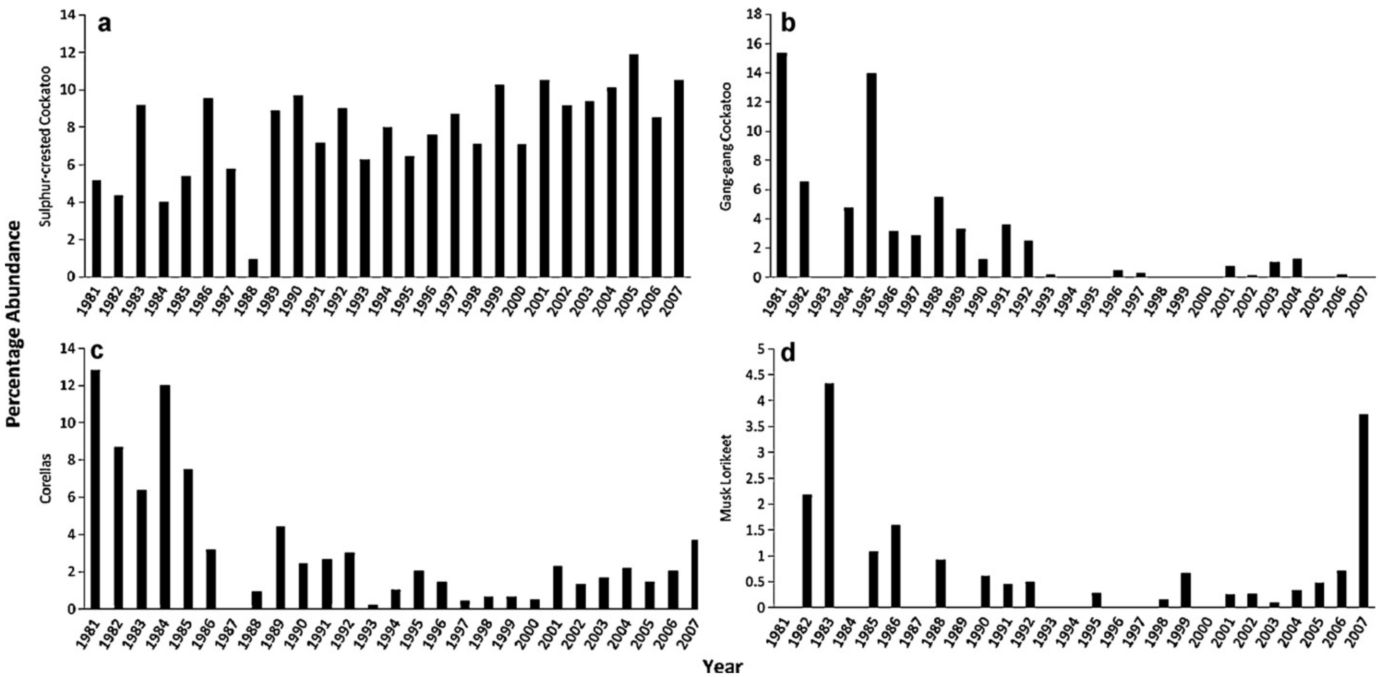

Fig. 2. Change in the percentage relative abundance between 1981 and 2007 for the (a) *Corella* sp., (b) Gang-gang Cockatoo, (c) sulphur-crested Cockatoo and (d) *Musk Lorikeet*.

$F_{2,24} = 18.99$, $p < .01$; Fig. 2c) and the Musk Lorikeet ($R^2 = .28$, $F_{2,24} = 4.58$, $p < .05$; Fig. 2d), with both species increasing since 2000. No other species showed significant change in relative abundance through time.

3.2. Response to fire and rainfall

Six out of 12 species of parrot showed a relationship with fire and/or rainfall. Models for these species are shown in Table 2 along with ΔAIC and w_i values. None of the reference birds showed any significant relationship with fire or rainfall.

The Australian King Parrot exhibited a negative response to large wild fires, with the strongest relationship detectable two years following large wild fires (Table 2). The Galah, Rainbow Lorikeet and Scaly-breasted Lorikeet also exhibited a negative response to large wild fires, with the strongest relationship for the Galah and Rainbow Lorikeet detectable in the year immediately following large wild fires and in the second year following large wild fires for the Scaly-breasted Lorikeet (Table 2).

The Crimson Rosella was the only species that exhibited a positive response to large wild fires, with the strongest relationship detectable in the year immediately following large wild fires. The association continued beyond the first year with significant Sydney rainfall effects detectable both one and two years following increased rainfall (Table 2).

The Rainbow Lorikeet, Scaly-breasted Lorikeet and Sulphur-crested Cockatoo exhibited a positive response to local Sydney rainfall (Table 2). The Rainbow Lorikeet exhibited the strongest relationship in the year immediately following local rainfall whereas the Scaly-breasted Lorikeet and Sulphur-crested Cockatoo displayed the strongest relationship with local Sydney rainfall two years following rainfall (Table 2).

The Sulphur-crested Cockatoo, Galah, Rainbow Lorikeet and the Australian King Parrot displayed a negative response to inland rainfall. The relationship was strongest for the Rainbow Lorikeet and Sulphur-crested Cockatoo in the year immediately following decreases in inland rainfall whereas the strongest relationship for the Australian King Parrot and the Galah was apparent two years following decreases in inland rainfall (Table 2).

Table 2
Candidate best AIC models with ΔAIC < 2.0 and corresponding weights (w_i). A '1' or '2' after the variable denotes a lag of either one or two years. RainSyd indicates annual rainfall in Sydney; RainIn indicates inland annual rainfall. The numerals 0–2 beside variables indicate the lag period in years. A superscript of 2 denotes the relationship is a quadratic relationship.

Variables in model	ΔAIC	w_i
Australian king parrot		
−Fire2 − RainIn2	0	0.48
−Fire0 − Fire2 − RainIn2	0.43	0.2
Crimson Rosella		
Fire1 + RainSyd2^2	0.05	0.23
Fire1 + RainSyd1^2 + RainSyd2^2	1.45	0.12
Galah		
−Fire1 − RainIn2^2	0.47	0.19
Rainbow Lorikeet		
−Fire1 + RainSyd1^2 − RainIn1	0	0.3
Scaly-breasted Lorikeet		
RainSyd1 − RainSyd2	0	0.3
−Fire2^2 − RainSyd2 + RainSyd1	0.52	0.23
Sulphur-crested Cockatoo		
RainSyd2 − RainIn1	0	0.37
RainSyd1 − RainIn2 − RainIn1	1.6	0.17

4. Discussion

Large wild fires significantly predicted changes in relative abundance of four species of parrot that have traditionally been present in the Sydney urban landscape, with one species increasing in relative abundance in the urban landscape following large wild fires and three other species decreasing. Decreasing inland rainfall resulted in the significant increase in relative abundance of two species of inland parrot in the urban landscape. Three species of parrot also responded to local rainfall, increasing in relative abundance in the urban landscape as local rainfall increased. Three species of parrot increased in relative abundance over time in the urban landscape, independently of wild fires or rainfall, and one species has significantly declined over time.

4.1. Change over time

The increase in relative abundance of the Sulphur-crested Cockatoo and the pooled Corella species in the Sydney urban landscape is concordant with the results of Burgin and Saunders (2007) who reported a higher encounter probability in 2002 than in 1981, using data from an independent source (Cumberland Bird Observers Club database). Whilst Burgin and Saunders (2007) demonstrated increases in the abundance of these two species between two discrete years, our study encompasses a continuous 26 year period. Both studies suggest that the Sulphur-crested Cockatoo and the Corellas are increasing in the urban landscape, although it appears from our study that the Sulphur-crested Cockatoo has increased steadily over the 26 year period, whereas the Corellas declined until the year 2000, and have only increased in relative abundance since then.

Similarly, the increase in the Musk Lorikeet in the Sydney urban landscape is similar to that reported in Melbourne, Australia (Smith and Lill, 2008), where Musk Lorikeets have increased in abundance since the 1970s. This increase in abundance has been partly attributed to the planting of nectar-producing ornamental street trees (Smith and Lill, 2008), which serve as a prolific and reliable food source.

The decline in the Gang-gang Cockatoo may be due to loss of habitat throughout the urban landscape. The Gang-gang Cockatoo is an altitudinal migrant that breeds in the coastal lowlands during winter (Higgins, 1999). Gang-gang Cockatoos require large tree hollows to breed and a lack of suitably sized hollows, due to clearing and wild fire, may be contributing to the decline of this species. However, if loss of large hollows is the cause of decline of Gang-gang Cockatoos, this is inconsistent with the increase in relative abundance of Sulphur-crested Cockatoos, which also require large hollows. As would be expected from their opposite temporal trends in relative abundance, post-hoc analysis revealed a significant negative correlation between the Sulphur-crested Cockatoo and Gang-gang Cockatoo ($r = -0.578$, $p < .01$). It is conceivable that competition for limited nest sites may be contributing to the decline of this species if it is an inferior competitor. Interestingly, we detected no increases in the relative abundance of the Rainbow Lorikeet or Galah, two species which have previously been reported to be increasing in the urban landscape (Burgin and Saunders, 2007). This may be due to the temporal range of the data set used in this study, which encompassed a continuous 26 year period, whereas previous studies have compared abundance between discrete years. This study may include a pattern of fluctuations in populations whereas the previous study may only detect one aspect of that fluctuation.

4.2. Response to fire

The Crimson Rosella was the only species whose post-fire pattern of abundance supported our initial prediction of an increase in the relative abundance of coastal species in the urban landscape following large wildfires. This species nests in hollows of Eucalyptus trees surrounded by dense shrubs and trees (Penck, 1992 cited in Higgins, 1999) and, since the urban landscape is generally protected from large wild fires, it may offer nesting and feeding resources that may have become locally limited in surrounding vegetation following wild fires.

Decreases in abundance of birds in the urban landscape following wild fire may be accounted for through mechanisms of either mobility or mortality. Whilst the Crimson Rosella is a mostly sedentary species (Higgins, 1999), both Rainbow Lorikeets and Galahs are capable of long distance movements (Higgins, 1999; Schodde and Tidemann, 1986; Shukuroglou and McCarthy, 2006). It is possible that they, along with other species of parrots, move between both the urban landscape and the surrounding national parks, frequently or periodically, entering the urban landscape to feed, roost or nest. If these birds are unable to escape the fire front and perish during large wild fires, this may account for the decrease in the abundance of certain species in the urban landscape. Such decreases in parrot abundance following wild fires have been reported, with decreases in abundance of over 70% in the area burnt (Loyn, 1999). Three of the fires during the study period burnt more than 374,000 ha, 173,000 ha and 360,000 ha, respectively. Whilst emigration to surrounding unburnt areas is possible, given the size of the area burnt, and that multiple fire fronts would have been burning simultaneously, it is more likely that many birds succumbed to either flames or smoke. This appears to have been the case following an extensive wild fire in south eastern Australia, where over 48% of avian mortalities recorded post-fire were parrots or other large hollow-nesting birds (Reilly, 1991).

An alternative explanation for decreasing abundance in the urban landscape following wild fires is that birds may make resource-related movements towards the burnt area post fire (Woinarski, 2005). For example the Galah, which decreased in relative abundance in this study, is a ground forager (Higgins, 1999) and has been observed feeding in increased numbers in burnt areas (Woinarski, 2005) due to the easier access to seed afforded by the burnt canopy and shrub layer (Espeland et al., 2005; Orians and Milewski, 2007; Woinarski, 2005). The Crimson Rosella however, whilst still feeding on seeds, consumes a broader diet of fruits and other plant material, and mainly forages in the shrub and tree layer (Penk, 1995; cited in Higgins, 1999) rather than on the ground, and may move to the urban landscape where food resources are more readily available.

4.3. Response to rainfall

The response of both the Galah and the Sulphur-crested Cockatoo supported our prediction of an increase in relative abundance of arid zone species in the Sydney urban landscape up to two years following decreases in inland rainfall. The relationship between declining inland rainfall and increasing relative abundance of the Galah and the Sulphur-crested Cockatoo in the urban landscape suggests that these species may move towards the urban landscape in search of more readily available food resources and is concordant with such rainfall related movements reported for Carnaby's Cockatoo and Corella species in Western Australia (Saunders, 1980; Smith and Moore, 1992). Surprisingly, the Rainbow Lorikeet and the Australian King Parrot exhibited the same relationship even though their foraging is more closely associated with canopy resources in more mesic areas, suggesting that a number of drivers may be correlated with broad scale climatic patterns.

Unlike the studies in Western Australia, the temporal change in the relative abundance of Corella species showed no relationship with inland rainfall. The significant increase in relative abundance, particularly since the year 2000 would, however, suggest that factors other than rainfall appear to be driving increases in abundance of Corella species.

Whilst decreasing arid rainfall appeared to result in the movement of several arid species into the urban landscape, consistent with our second prediction, changes in local rainfall resulted in fluctuations in the relative abundance of species already present within the urban landscape. The increase in these species of parrot that have traditionally been present in the Sydney urban landscape, up to two years following increases in local rainfall, suggests that feeding resources may be greater in the urban landscape following periods of above average rainfall than in surrounding natural vegetation. Decreases in rainfall can delay or even abort flowering in *Myrtaceous* species (Ellis and Sedgley, 1992; Law et al., 2000) the principle food source of lorikeets (Higgins, 1999) however, the frequent watering and fertilising of parks and gardens (Burgin and Saunders, 2007) as well as prolifically flowering street trees in the urban landscape (Smith and Lill, 2008) provide a buffer against decreases in rainfall. In combination with above average rainfall and elevated temperatures in the urban landscape that often result in prolonged flowering (Lu et al., 2006; Mimet et al., 2009), this results in an increased abundance of food resources that may be greater than that provided in surrounding natural vegetation.

5. Conclusion

In conclusion, patterns of wild fires surrounding Sydney may explain changes in relative abundance of species of parrot that have traditionally been present in the Sydney urban landscape; however responses to wild fire appear to be complex and are most likely linked to the feeding ecology and mobility of individual species. Decreasing inland rainfall resulted in increases in relative abundance of one inland species within the urban landscape, suggesting that mobile inland birds may make resource-driven movements towards the coastal or urban landscape during drought or following periods of below-average rainfall. Rainfall also appears to drive changes in relative abundance of species of parrot traditionally present in the urban landscape, once again probably as a function of feeding resources, with these birds increasing in relative abundance in the urban landscape following increased periods of local rainfall. The urban landscape appears to not only offer an immediate refuge during wild fires but also offers a more stable environment post fire or during periods of below average rainfall when habitat and food resources may be temporarily limited or unavailable elsewhere.

The utilisation of the urban landscape by native fauna is a consideration that should therefore be taken into account by both urban landscape designers and planners. As the probability of wildfire and drought events is projected to increase with the changing climate, we may see a greater number of species using cities and urban landscapes as a stable resource which provides refuge among the dynamic and unpredictable natural environment. As urban areas continue to expand globally, it is important to ensure that future urban planning protocols provide resources for native species through maintenance of existing remnant vegetation and incorporation of park, street side and garden landscaping within newly developed estates. There is also scope in older cities and their suburbs, particularly those cities in regions prone to wildfire or cities in drier climates, for planners to encourage the proliferation of resources such as native gardens, nesting boxes or suitable water sources in public parks and reserves to ensure available resources for species that use cities as an urban refuge.

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