A comparison of climate change impacts on park values on four Queensland World Heritage National Parks in Australia

Sherri L Tanner-McAllister, Jonathan Rhodes, Marc Hockings

Abstract

Protected areas will vary in how they respond to climate related threats and impacts. An important step in adapting protected area management to respond to climate change is identifying how protected areas and their values may be impacted. This requires an understanding of the ecological and social system impacting on the particular values so that consideration of management options and issues can be informed by this understanding. A set of Bayesian belief networks were developed to assess impacts and management issues for three key values (stream-dwelling frogs, cool temperate forest and recreational walking access) across four National Parks (Springbrook, Lamington, Mount Barney and Main Range) in Queensland, Australia. The aim was to assess how those values may be impacted by climate change, how the parks differ in relation to likely impact and options for management adaptation. We observed, depending on a protected area's physical and socio-ecological characteristics, that the values were likely to be differently affected across the parks and management responses will need to take account of these differences.

Introduction

Climate change is one of the most significant issues facing our natural environment (Sommer et al. 2010). Globally, there has been detectable increases in land and ocean surface temperatures, sea temperatures, ocean salinity and sea levels over the last three decades (IPCC 2013; Savage & Vellend 2015). Climate change projections of an increase in average temperatures are likely to exceed 1.5 - 2°C (relative to 1850 to 1900) by the end of this century (IPCC 2013). There are expected changes to the global water cycle, altering precipitation with an increase in intensity and frequency of precipitation events, and an increase in average global ocean temperatures and sea levels (IPCC 2013). These changes in climate are expected to have significant impacts on biodiversity (Sommer et al. 2010) including protected areas (Monzon et al. 2011).

Some protected areas are already experiencing climate change related impacts such as movement in a species' geographical distribution, local extinctions and ecosystem modifications (Hannah et al. 2007; Kitching et al. 2011; Monzon et al. 2011; Eigenbrod et al. 2015). Protected area management activities are generally focused on a static view of values and often managed in isolation from surrounding landscapes (Lemieux et al. 2011; Monzon et al. 2011). This contradicts many of the recommendations for improving climate change adaptation through managing for change and landscape scale strategies (Hobbs et al. 2006; Fischman et al. 2014). A key question therefore is how should existing protected areas be managed for climate change impacts in the future?

Protected areas generally require management to maintain or improve condition of the values that the park was originally set aside to conserve. In many situations, key park values are affected by some form of threat and require management intervention (Moore & Hockings 2013) to be sustained. However, limited resources, competing public interests, increasing and novel threats, changing political environments and a of the demands from a diversity of stakeholders can impede a manager's ability to manage parks effectively (Leverington et al. 2010; Bode et al. 2011; Swemmer & Taljaard 2011). The emergence of climate change as a factor likely to affect protected areas increases uncertainty around determination of appropriate management strategies and actions. Decision analysis and support systems can improve planning for management for park specific climate change impacts by increasing knowledge of potential threats and impacts, exploring and reducing uncertainty and providing a framework in considering stakeholder contributions (Cain et al. 2000; Addison et al. 2013; Fischman et al. 2014). There is a lack of knowledge of how local scale differences between broadly similar parks within a regional area might vary in terms of impacts and effective responses.

Bayesian Belief Networks (BBN) are an approach that is gaining traction as an effective tool to support decision making, particularly where there are interacting drivers, a lack of data and a high level of uncertainty (Cain et al. 2000). BBNs are effective because they utilise expert knowledge (Kuhnert et al. 2010) where data is lacking and can facilitate the practical application of adaptive management because models are easily updated as more information becomes available (Newton et al. 2007). They can also assist in communication and facilitate stakeholder involvement (Cain et al. 2000; Zorrilla et al. 2010). They provide support for management decision making by providing a visual way of representing uncertainty about the outcomes of management intervention and identifying which management responses are likely to be most effective (Newton et al. 2007).

Twelve BBNs were developed across four of Queensland's Gondwana Rainforest of Australia World Heritage listed protected areas based on three key values that are vulnerable to climate change; stream dwelling frogs, cool temperate forest, and walking tracks. The BBNs were developed to assess likely climate change impacts on these key values and compare the four parks to understand how they might differ from one another in terms of threats and impacts and likely effective management responses.

Methodology

Study site and protected area values

The Scenic Rim is a mountain system in southeast Queensland, Australia along the Queensland/New South Wales border extending westward from the Gold Coast (Queensland) hinterland. It includes the Gondwana World Heritage protected areas Springbrook, Lamington, Mount Barney and Main Range National Parks (Figure 1). Each park has similar values for which they were protected, however they vary in characteristics such as size, shape, surrounding land use and climate (Table 1).

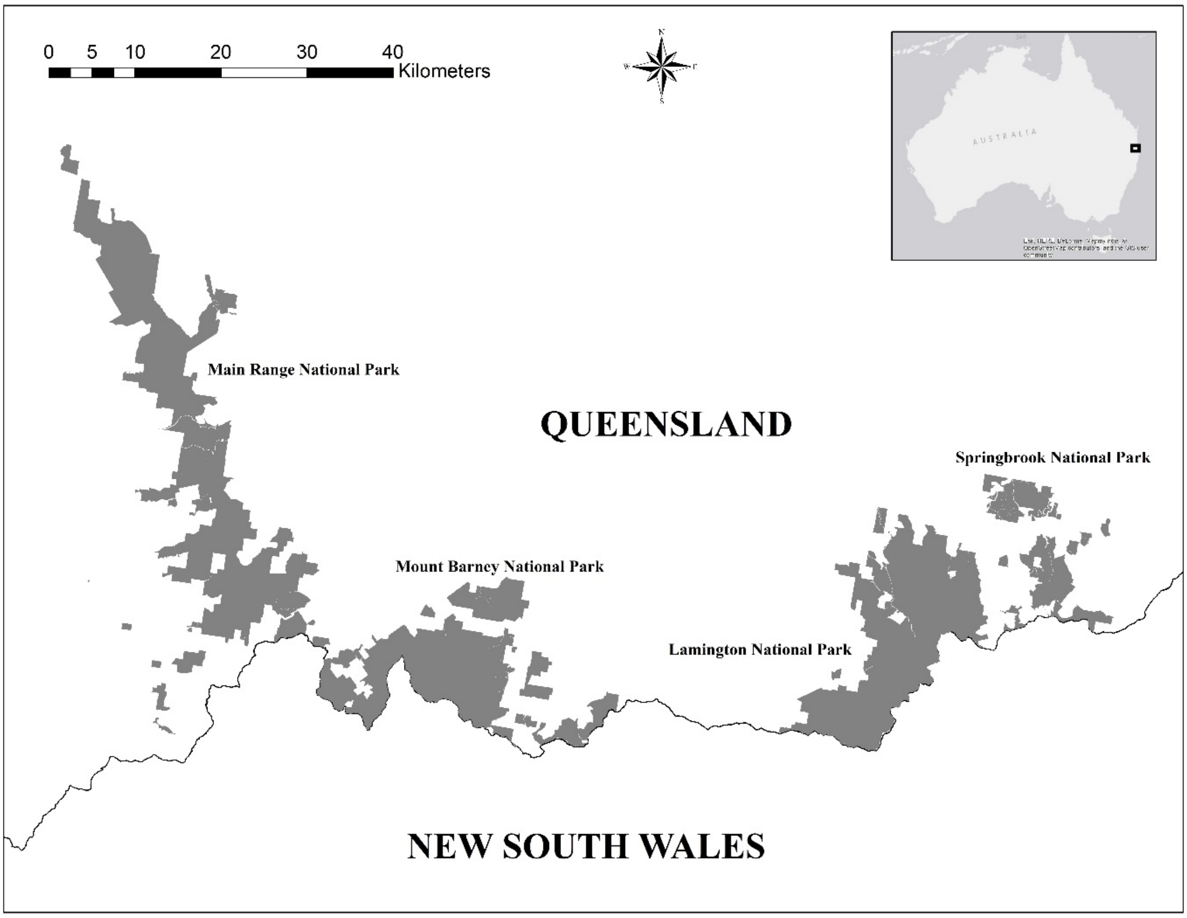

Figure 1 Location of Gondwana Rainforests of Australia World Heritage parks in Queensland, Australia.

Table 1 Attributes of four of Queensland's Gondwana Rainforests of Australia World Heritage listed national parks.

	Springbrook	**Lamington**	**Mount Barney**	**Main Range**
Park size (ha)	6 555	20 590	17 660	30 274
Boundary (kms)	235	200	267	419
Altitude - highest peak (m)	1000	1150	1359	1375
* Surrounding landuse (%)				
Compatible	11	23	28	2
Semi - compatible	63	36	31	38
Non - compatible	26	51	41	60
**Current precipitation (mm)	2052	1807	921	
**Current temperatures (C)	12.6 – 25.3	12.6 – 25.3	9.5 – 23.8	9.5 – 23.8
***Current # severe storms	3.4	1.4	1.7	2.2
Walking tracks – graded class 1-4 (approx. km)	27	140	14.2	65
Cool temperate forest (approx. ha)	3	519	98	672

* Surrounding landuse was categorised into compatible (National park, dam/reservoir, production forestry), semi-compatible (plantation forestry, residual native cover) and non-compatible (residential, livestock grazing cropping, intensive animal production).
** Current precipitation and temperatures were taken from the closest weather station to the National Park from the Australian Bureau of Meteorology
***Severe storms baseline data are based on the Australian Government's Bureau of Meteorology's Storm Archive. This is a record of severe thunderstorm and related events. Many storms are not recorded, for a number of reasons, therefore this is a guide only and not necessarily the exact number. The figure represents severe storms (severe rain events, hail, severe wind events and tornados) recorded on or in close vicinity to the protected area.

The parks are predominately rainforest and wet sclerophyll forest, with many of their values considered to be under threat from climate change (Australian National University 2009; Tanner-McAllister et al. 2014). The region is expected to experience an average annual decrease in precipitation, increase in storms and extreme weather events, and an increase in average temperature (Dowdy et al. 2015). An increase in fire risk, and rise in orographic cloud level is also anticipated (Australian National University 2009; Dowdy et al. 2015).

This research focuses on a group of species (stream dwelling frogs), an ecosystem (cool temperate forest) and visitor value (walking tracks), all expected to be subjected to climate change impacts. Frogs are particularly susceptible to climate change and are experiencing declines worldwide (Barrett et al. 2014; Penman et al. 2015). Stream dwelling frogs (i.e., *Mixophyes fleayi*, *Philoria loveridgei, Litoria pearsoniana*) are sensitive to changes in environmental conditions, and likely to be impacted by reduced rainfall, increased temperatures, changes in fire regimes, and increasing storm events (Hoskin et al. 2013).

The high altitude forests of Gondwana comprise of cool temperate forest and support many endemic species that rely on high moisture habitats from both precipitation and mist from cloud cover (Pounds et al. 1999; Laidlaw et al. 2011). Cool temperate forest are found across all four parks, typically dominated by Antarctic beech (*Nothofagus moorei*) on Springbrook, Lamington and Mount Barney National Parks, and Lilly pilly (*Acmena smithii*) on Main Range (Hunter 2004). These cloud forests and cool temperate forest habitat dependent species are highly vulnerable to climate change and expected to be impacted from loss of moisture and rising orographic cloud cover (Laidlaw et al. 2011; Oliveira et al. 2014).

The Gondwana parks are heavily used by visitors for nature based recreation, particularly Springbrook and Lamington National Parks due to their close proximity to the Gold Coast, a densely populated city and international tourist destination (Tourism Research Australia 2013; Queensland Government Statistician's Office 2015). Walking tracks are a significant recreational feature of all four parks. The walking tracks have already experienced an increase in climate change impacts from drought and increased storm activity resulting in landslides and other impacts such as erosion and tree falls. Tracks have been frequently closed for significant periods of time because the requirements for track reconstruction exceed the management staff and resources available (pers. comm. QPWS, walking track workshop participant, 2015).

Development of the models

Conceptual models were developed for each value following guidelines in Marcot et al. (2006). Draft models were created based on the literature and interviews conducted in previous research (see (Tanner-McAllister et al. 2014) and then distributed to experts for comment. Discussions were held over the phone or in person for input by experts to further develop and finalise the conceptual models. The aim of the models were to explain each value in a simple format, the major drivers of the system and how they relate to each other.

Experts were chosen based on their knowledge of the value and of the protected areas. Four experts were interviewed for the stream dwelling frog model. A total of eight experts were interviewed for the cool temperate forest models, four rainforest ecologists and four fire experts. Six QPWS rangers from across the region with very good, long term knowledge of the protected areas were consulted for the walking track models.

The conceptual models were then converted to BBNs in Netica (Norsys Software Corporation 2010). BBNs and decision networks are graphical and probabilistic models based on Bayesian probability theory, developed to assist decision making under uncertain conditions (Cain et al. 1999). They can quantify the relationship between variables (Walshe & Massenbauer 2008; Liedloff & Smith 2010) and be used for prediction and diagnostic analysis (Liedloff & Smith 2010).

A BBN was developed for each value for each of the four parks in the study area, i.e., total of 12 models (all BBNs and details are included in the supporting documentation). Due to a lack of quantitative data, expert elicitation was used to populate the conditional probability tables with the same procedure used for each model. Conditional probabilities were gathered through individual interviews for the stream dwelling frog and cool temperate forest models, and a workshop was conducted for the walking track models. A workshop was required for participating park rangers with less scientific background, and to promote discussion about parks that rangers were less familiar with (McBride et al. 2012).

Conditional probabilities for each child node of the BBNs were gathered using Microsoft Excel. Bar graphs representing figures provided a visual representation to assist expert input and reduce errors. For the individual interviews, group averages and standard deviations were calculated from the initial estimates. These were then made available to the experts, who then had the option of adjusting their original estimates (Linstone & Turoff 1975; Martin et al. 2012; McBride et al. 2012). Final averages were used for the conditional probability tables in the BBNs (Martin et al. 2012). The workshop for the walking track models gathered the conditional probabilities in a similar manner. Each ranger populated individual conditional probabilities into Microsoft Excel. Averages and standard deviations were then presented to them in the second half of the workshop upon which they made adjustments to their original figures they felt were warranted. Final figures were then averaged and used for the BBN conditional probability tables. (Martin et al. 2012; McBride et al. 2012).

Once the BBNs were completed, each model was tested by trying different combinations by altering the status of various nodes and observing their response to assess for any unrealistic behaviours. For example, the literature maintained that moisture and orographic cloud cover was a large influence on the presence of cool temperate forest, so there was the expectation that changes to the cloud immersion node would influence the cool temperate forest health node. Secondly a sensitivity analysis was run using calculations of variance reduction and entropy reduction to verify the model structure and parameterisation (Marcot et al. 2006). Again, based on literature and interviews with the experts and park managers, expectation of which nodes should be most sensitive were established to assess any unusual behaviours.

Analysis of the models

A sensitivity analysis calculating variance of belief was undertaken for each of the 12 models on the final output nodes. Each sensitivity analysis was carried out under a ‘best case’ and ‘worst case’ scenario to assess the sensitivity of the final output nodes to different elements of the models. ‘Best’ and ‘worst case’ scenarios were established by setting all nodes to the optimal or worst condition.

The models were then used to process a number of scenarios to predict possible outcomes under different management situations to give an indication of how the values on each park may be impacted and may respond to climate change. Models were first run as a ‘best case’ scenario (i.e., current climate and good management) to assess how final output nodes respond to a range of scenarios. Different nodes were altered to reflect variations in management to investigate changes in final node probabilities. Different combinations of management nodes were also performed under ‘moderate’ and ‘substantial’ climate change scenarios.

Results

For the analysis, groups of nodes (climate and management variables) were used to represent current, moderate and substantial climate change; good and poor management; and 'best' and 'worst case' scenarios. Detailed information for each model is included in Table 2. For example, climate variables (light grey nodes Figure 2, Figure 3, Figure 4) were grouped according to current, moderate and substantial, and park management variables (dark grey nodes Figure 2, Figure 3, Figure 4) were set to good or poor. A 'best case' scenario consisted of current climate variables and good management, and 'worst case' scenario set to high climate change and poor management. For example, a 'best case' scenario for the stream dwelling frog model consisted of current climate; good management; current surrounding land use; chytrid - present; no captive breeding. Detailed information for each BBN is included in supporting documentation.

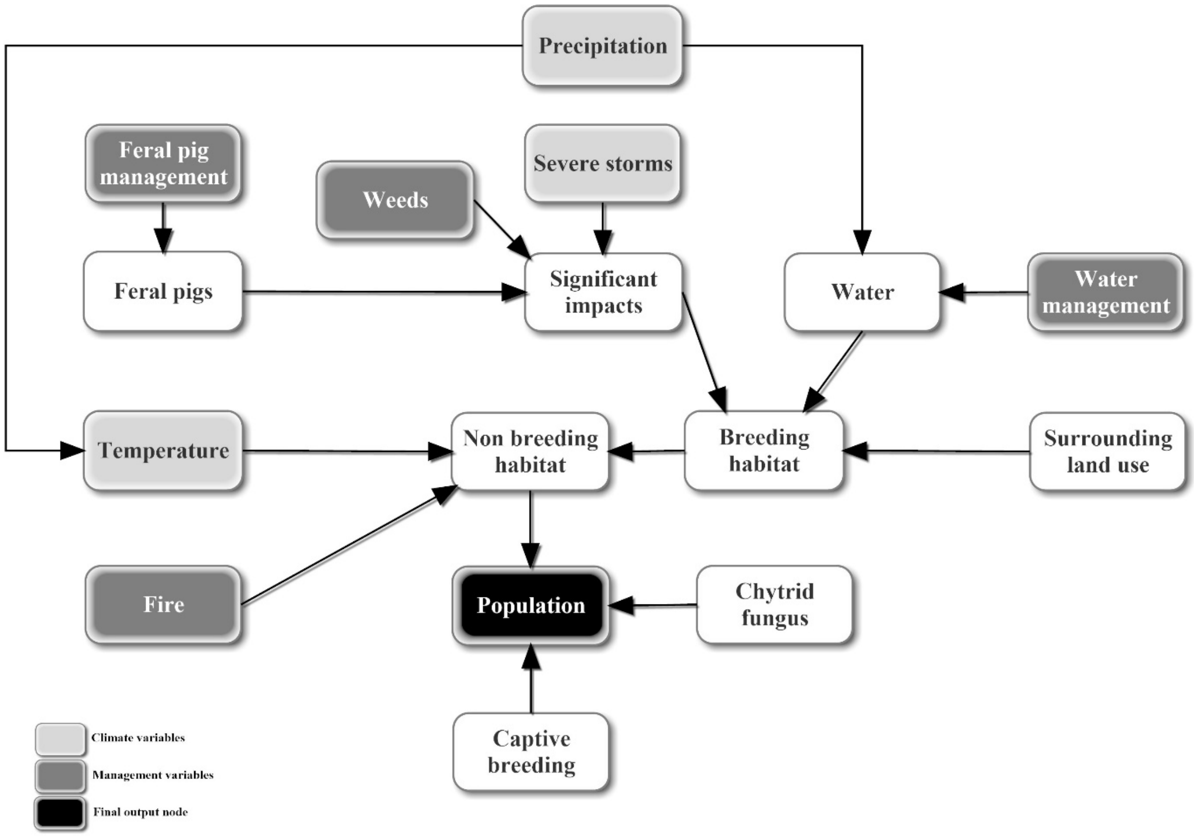

Figure 2 Conceptual model for stream dwelling frogs

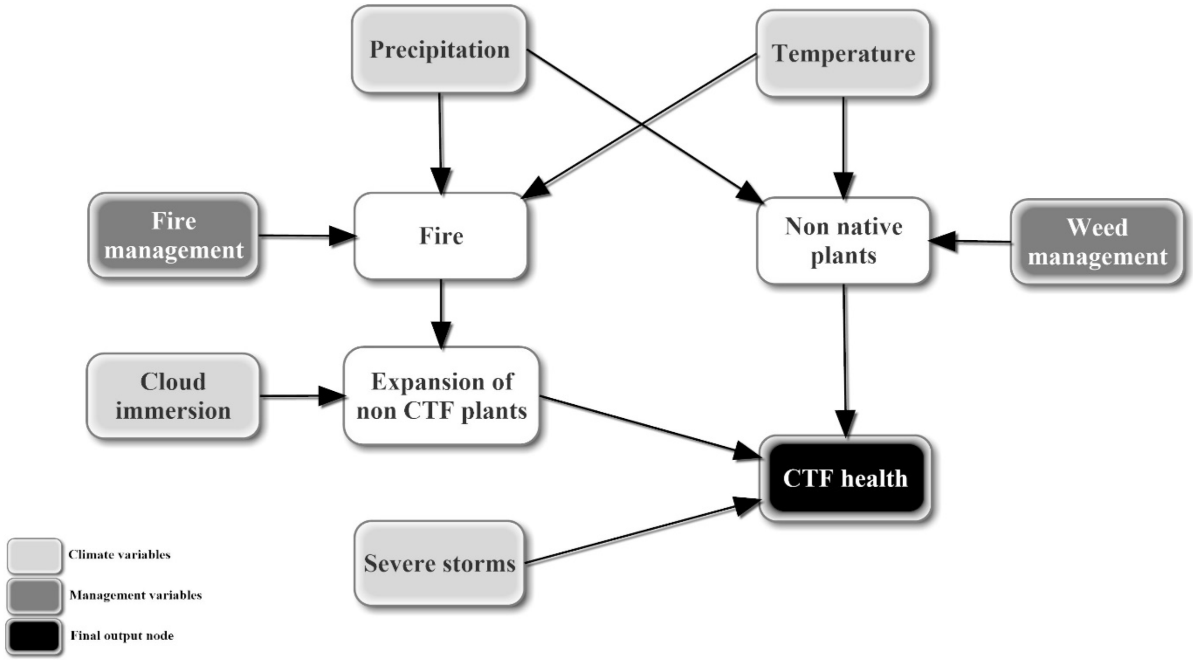

Figure 3 Conceptual model for cool temperate forests (CTF)

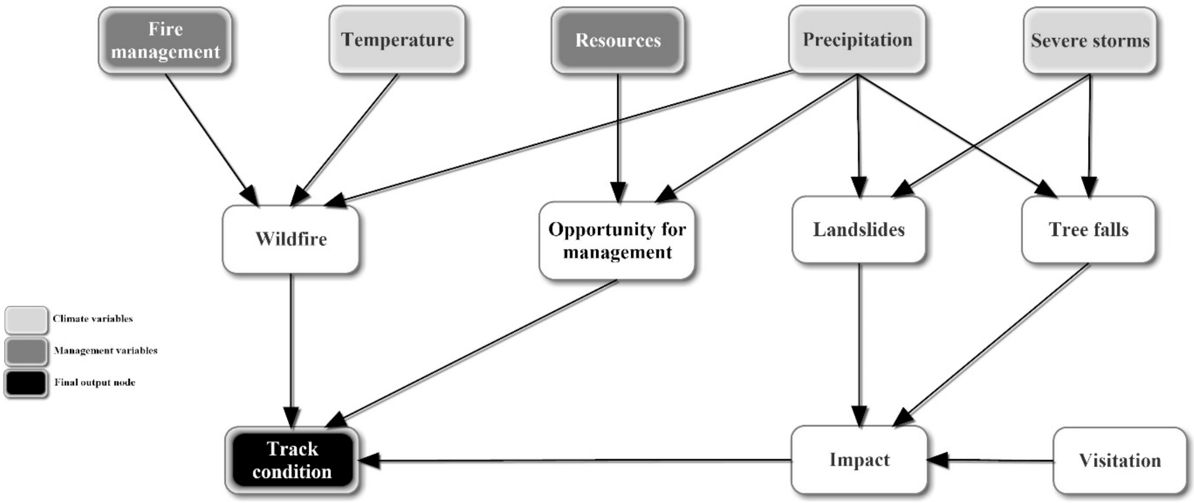

Figure 4 Conceptual model for walking tracks

Table 2 Groupings of conceptual model and BBN nodes used for the analysis.

		Stream dwelling frogs	**Cool temperate forest**	**Walking tracks**
CLIMATE VARIABLES	Current climate	Current precipitation; current severe storms; current temperature	Current precipitation; current severe storms; current temperature; current cloud immersion	Current precipitation; current severe storms; current temperature
	Moderate climate change	Low decrease in precipitation; low increase in severe storms; low increase in temperature	Low decrease in precipitation; low increase in severe storms; low increase in temperature; moderately higher cloud immersion	Low decrease in precipitation; low increase in severe storms; low increase in temperature
	Substantial climate change	High decrease in precipitation; high increase in severe storms; high increase in temperature	High decrease in precipitation; high increase in severe storms; high increase in temperature; substantially higher cloud immersion	High decrease in precipitation; high increase in severe storms; high increase in temperature
MANAGEMETN VARIABLES	Good management	Water management - appropriate; feral pig management - yes; fire - planned; weeds - low	Fire management - good; weed management - good	Fire management - appropriate; resources - appropriate
	Poor management	Water management - not appropriate; feral pig management - no; fire - wildfire; weeds - high	Fire management - poor; weed management - poor	Fire management - not appropriate; resources - not appropriate
ANALYSIS SCENARIOS	Best case scenario	current climate; good management; current surrounding land use; chytrid - present; no captive breeding	current climate; good management	current climate; good management; suitable terrain; low visitation
	Worst case scenario	high climate change; poor management; current surrounding land use; chytrid - present; no captive breeding	substantial climate change; poor management	high climate change; poor management; not suitable terrain; high visitation

Stream dwelling frogs

All parks showed a lower probability of an increasing population and higher probability of a decreasing population under increasing climate change (increase in temperature, increase in severe storms, decrease in precipitation) with ‘good management’ (Figure 5).

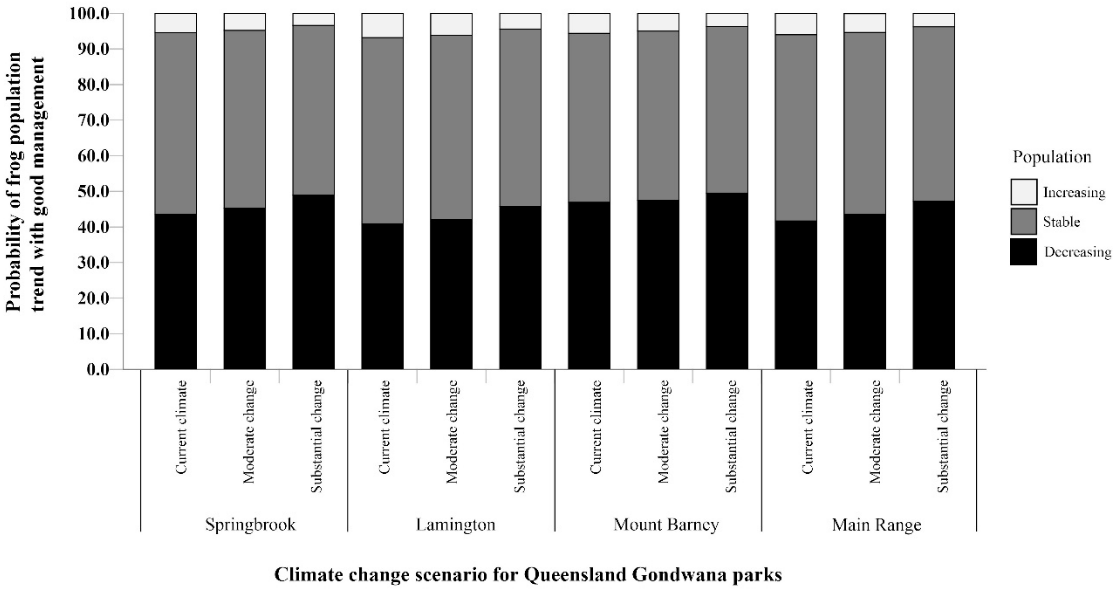

Figure 5 The probability of increasing, stable and decreasing stream dwelling frog population under ‘current’, ‘moderate’ and ‘substantial’ climate change scenarios under ‘good management’.

Reducing feral pig or weed management, or implementing inappropriate water management made no major difference to the ‘good management’ scenario. However, increasing the presence of wildfire had a negative effect on the stable and decreasing population under climate change. Springbrook, Mount Barney and Main Range had a much higher probability of a decreasing population under a ‘substantial climate change’ scenario with the introduction of wildfire. Springbrook and Main Range also showed a slightly higher probability of a decreasing population size under a ‘moderate climate change’ scenario. Under a ‘substantial climate change’ scenario, Main Range, Mount Barney and Springbrook all resulted in over a 50% probability that there would be a population decrease. The change in probabilities of negative effects on frog populations with the introduction of wildfire increased as climate change increased (Figure 6). The largest changes in probabilities were for increasing populations, particularly under substantial climate change.

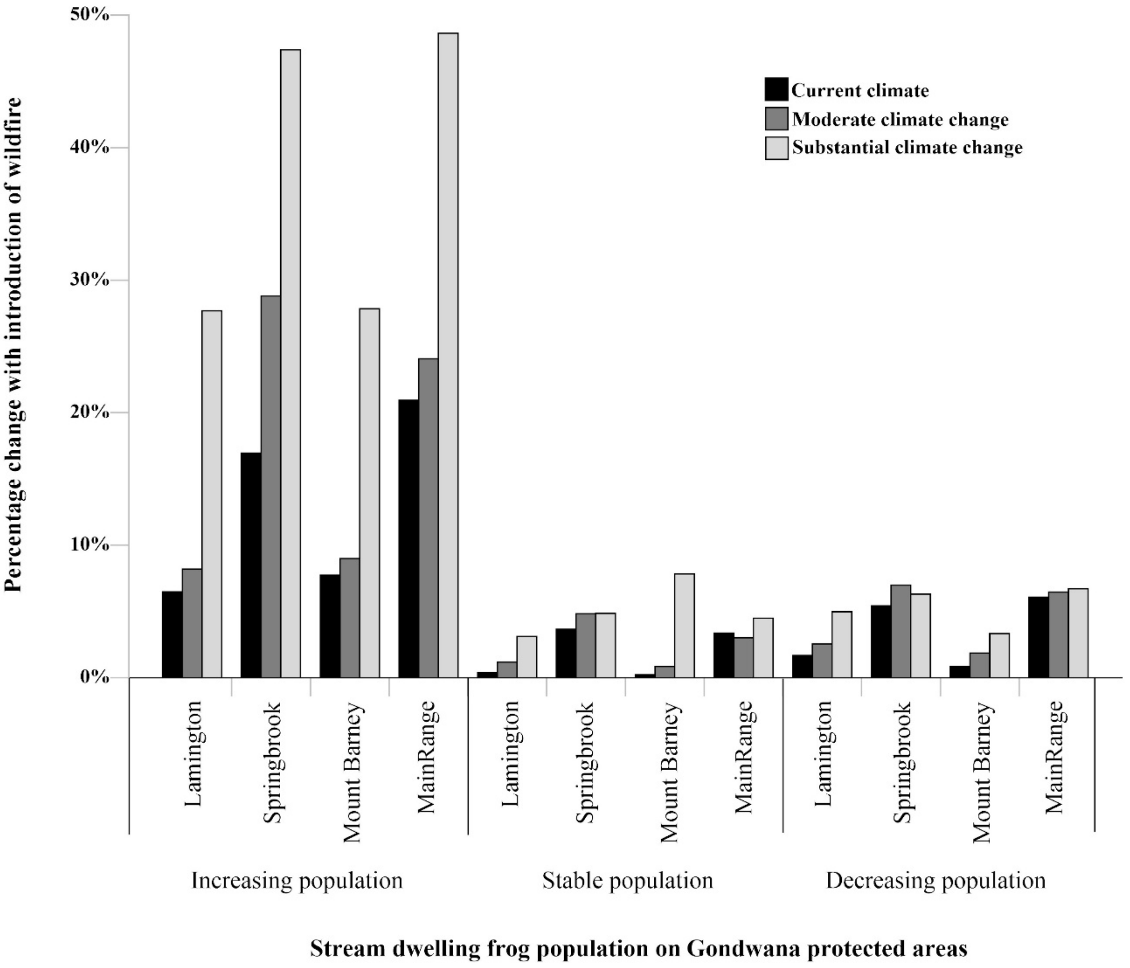

Figure 6 Graph showing the percentage change in probabilities of increasing, stable and decreasing populations with the introduction of wildfire.

These findings are supported by the sensitivity analysis (Table 3) with population health being most sensitive to the non-breeding (drier woodland ecosystems) habitat which is highly influenced by fire.

Table 3 Sensitivity analysis for the final output node 'population' for stream dwelling frogs under a 'worst case' scenario, variance of beliefs ranked highest to lowest sensitivity.

	Springbrook	Lamington	Mount Barney	Main Range
Non-breeding habitat	0.0068747	0.0058587	0.0036479	0.005789
Breeding habitat	0.0001645	0.0002010	0.0000568	0.0001853
Water	0.0000649	0.0000713	0.0000200	0.0000669
Significant threats	0.0000069	0.0000096	0.0000023	0.0000076
Surrounding land use	0.0000035	0.0000006	0.0000001	0.0000002
Feral pigs	0.0000002	0.0000002	0.0000001	0.0000000
Severe storms	0.0000000	0.0000000	0.0000000	0.0000000
Chytrid fungus	0.0000000	0.0000000	0.0000000	0.0000000
Captive breeding	0.0000000	0.0000000	0.0000000	0.0000000
Temperature	0.0000000	0.0000000	0.0000000	0.0000000
Fire	0.0000000	0.0000000	0.0000000	0.0000000
Water management	0.0000000	0.0000000	0.0000000	0.0000000
Precipitation	0.0000000	0.0000000	0.0000000	0.0000000
Weeds	0.0000000	0.0000000	0.0000000	0.0000000
Feral pig management	0.0000000	0.0000000	0.0000000	0.0000000

Cool temperate forest

The models for all four parks showed a decrease in the probability of very good forest health under increased climate change. All parks also showed an increase in the probability of poor and very poor forest health as climate change increases (Figure 7). Introducing 'good management' produced no significant improvement under increased climate change. The sensitivity analysis (Table 4) supports these views with the forest health being most sensitive to expansion of non-cool temperate forest which is primarily driven by loss of cloud cover and precipitation and increase temperatures (Foster 2001; Laidlaw et al. 2011).

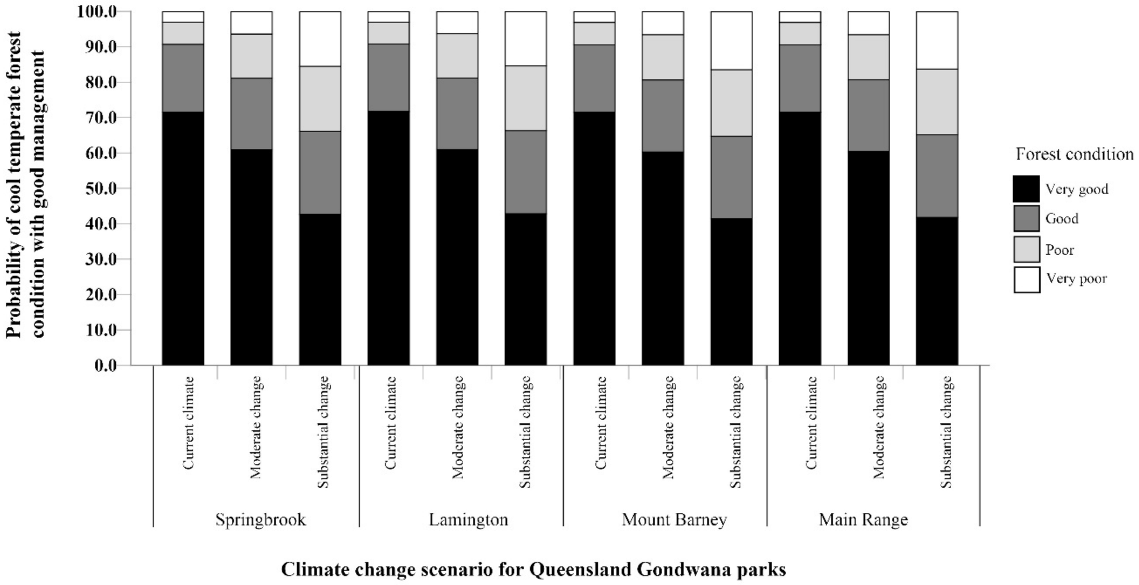

Figure 7 The probability of very good, good, poor and very poor cool temperate forest condition under 'current', 'moderate' and 'substantial' climate change scenarios. Comparison of Lamington, Springbrook, Mount Barney and Main Range National Parks under 'good management'.

Table 4 Sensitivity analysis for the final output node 'cool temperate forest (CTF) health' for cool temperate forest under a 'worst case' scenario, variance of beliefs ranked highest to lowest sensitivity.

	Springbrook	Lamington	Mount Barney	Main Range
Expansion of non CTF	0.0034322	0.0037593	0.0031337	0.0033220
Non-native plants	0.0012847	0.0012799	0.0016626	0.0013523
Fire	0.0000124	0.0000059	0.0000283	0.0000232
Weed mgt	0.0000000	0.0000000	0.0000000	0.0000000
Severe storms	0.0000000	0.0000000	0.0000000	0.0000000
Cloud immersion	0.0000000	0.0000000	0.0000000	0.0000000
Precipitation	0.0000000	0.0000000	0.0000000	0.0000000
Temperature	0.0000000	0.0000000	0.0000000	0.0000000
Fire mgt	0.0000000	0.0000000	0.0000000	0.0000000

Park management (fire and weed management) had very little influence to the probabilities of maintaining a healthy cool temperate forest when impacted by climate change. Slight improvements were seen with enhanced weed management on Lamington and Springbrook National Parks under both 'moderate' and 'substantial climate change', and on Mount Barney and Main Range National Parks under 'substantial climate change'. After expansion of non-cool temperate forest, forest health was most sensitive to non-native plants (Table 4) which is in accordance with the model outputs of slight improvements with better weed management.

With an increase in storms, all parks showed a considerable decrease in the probability of very good health under all climate change scenarios. All parks showed a minor increase in the probability of very poor health under current and moderate climate change, and a more considerable increase under 'substantial climate change' with an increase in storms.

Walking tracks

The track condition was assessed under a variety of conditions. All parks showed very subtle changes in the probabilities of the condition of tracks under climate change with a general decrease in desirable track condition (Figure 8). This was dependant on the type of terrain, park management and visitation.

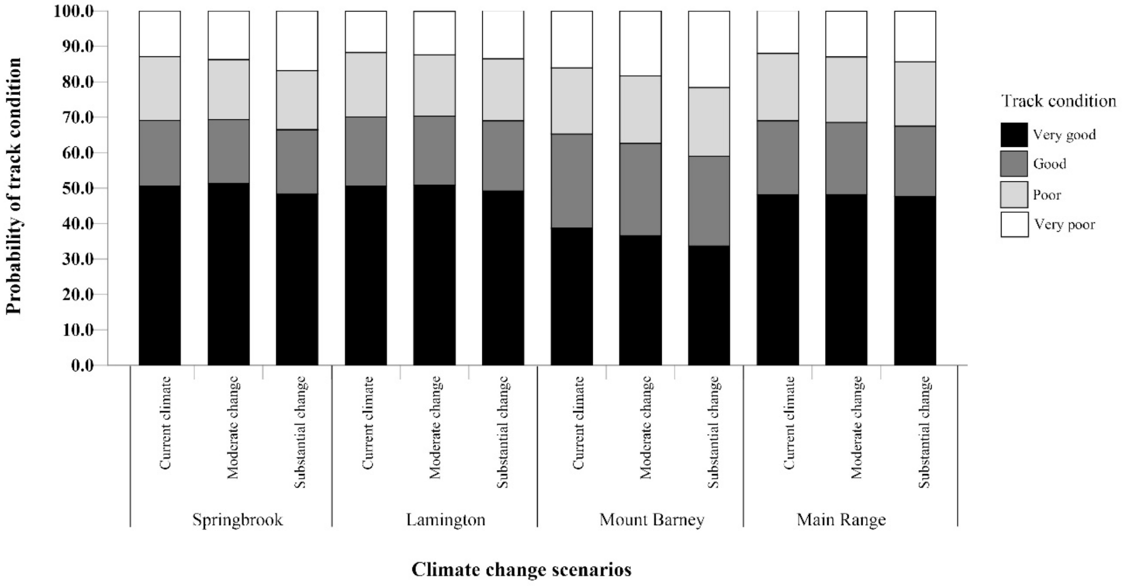

Figure 8 Bar graph showing the probability of track condition on each protected area with 'poor management' under 'current climate', 'moderate climate change' and 'substantial climate change'.

There is a positive change in track condition when ‘good management’ is introduced. The positive change was greater as climate change increased. Figure 9 shows the change in walking track condition probability from ‘poor management’ to ‘good management’. All changes represented an improvement in desirable track condition (i.e., an increase in very good or good condition or a decrease in very poor or poor condition), except for the change in good condition on Springbrook, Lamington and Main Range National Parks. These however, were outweighed by the increase in desirable conditions. This was reflected in the sensitivity analysis (Table 5) with the track condition node being most sensitive to opportunity for management which is largely influenced by resources.

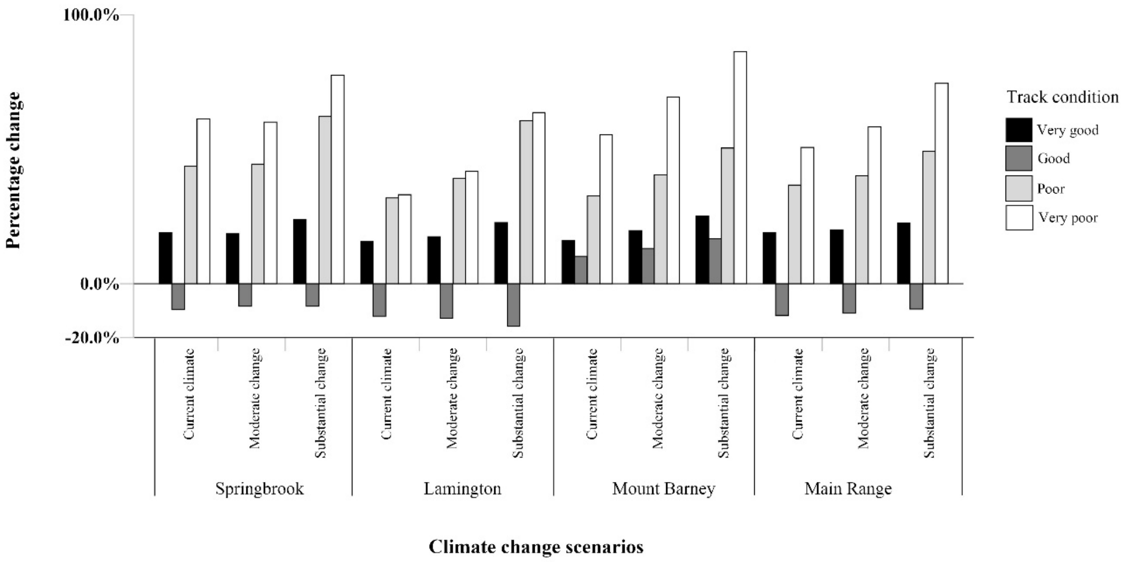

Figure 9 Bar graph representing the percentage change in the probabilities of very good, good, poor and very poor track condition from ‘poor management’ with the introduction of ‘good management’. All changes represented an improvement in desirable track condition (i.e., increase in good and very good condition, decrease in poor and very poor condition). Changes below the 0% on the x-axis represent a reduction in desirable track condition.

Table 5 Sensitivity analysis for the final output node 'track condition' for walking tracks under a 'worst case' scenario, variance of beliefs ranked highest to lowest sensitivity.

	Springbrook	Lamington	Mount Barney	Main Range
Opportunity for management	0.0233972	0.0227071	0.0121099	0.0268079
Impact	0.0033857	0.0032940	0.0015773	0.0029351
Landslips	0.0003212	0.0003437	0.0001696	0.0002969
Wildfire	0.0010933	0.0000466	0.0005684	0.0009588
Tree falls	0.0000598	0.0000790	0.0000372	0.0000631
Visitation	0.0000000	0.0000000	0.0000000	0.0000000
Terrain	0.0000000	0.0000000	0.0000000	0.0000000
Severe storms	0.0000000	0.0000000	0.0000000	0.0000000
Resources	0.0000000	0.0000000	0.0000000	0.0000000
Precipitation	0.0000000	0.0000000	0.0000000	0.0000000
Fire management	0.0000000	0.0000000	0.0000000	0.0000000
Temperature	0.0000000	0.0000000	0.0000000	0.0000000

Discussion

Our results indicate that protected areas within a local region may respond differently to climate change and require different strategies for effective management. In order for park managers to understand how and why particular attributes or values (including species) may be differently affected by climate changes, they must investigate how parks differ in physical attributes, park values, external influences and climatic variables. Springbrook, Lamington, Mount Barney and Main Range National Parks have many common values for which they were designated and are located within the same region. The cool temperate forest models for all parks showed very similar results in terms of both impacts and effectiveness of management strategies under increased climate change. Stream dwelling frog models on the other hand, demonstrated different population sensitivities to various drivers. Stream dwelling frog populations in Lamington were less sensitive to wildfire. This is likely to be due to the park's larger size and smaller boundary/area ratio than Springbrook, and occurrence of moister ecosystems than in Main Range and Mount Barney that would buffer frog populations from the impact of fire.

Springbrook which is a smaller, fragmented park compared to the three other parks in this study exhibited high sensitivity to surrounding land use in the stream dwelling frog model. This supports the argument that larger parks with lower boundary/area ratios are more resilient to external impacts and that smaller parks have less capacity to buffer external influences (Maiorano et al. 2008).

Additionally, topography can play an important role in resilience to climate change impacts. The region has provided refuge sites for species and ecosystem protection under past climate change (Shoo et al. 2014). Lamington protects the largest area of cool temperate forest out of the four parks and the plateau topography of Lamington may provide small refuge sites in cool, moist valleys for the cool temperate forest ecosystem. Likewise, Mount Barney appears to be more resilient for the stream dwelling frogs. This park has the largest altitudinal range of the stream dwelling frog habitat in the region and resides higher up in the catchment with virtually no external negative impacts on their habitat.

Topography and catchment location can also affect an area’s resilience to external impacts (DeFries et al. 2007). Springbrook showed a high sensitivity to the stream dwelling frog’s wet breeding habitat and water. The park is surrounded by higher density residential and farming land uses than the other parks and as is positioned lower in the catchment and suffers from downstream impacts of external land use. Lamington has some adjoining land uses above the stream dwelling frog habitats, however much less than Springbrook. It has been suggested Lamington may experience effects from water extraction which may well be a factor in the models results of this park’s high sensitivity to water under a ‘worst case’ scenario (stream dwelling frog model participant pers. comm., 2015). Increasing density and depth of pools as well as connectivity has been shown to likely reduce tadpole mortality from drying effects under climate change (Scheele et al. 2012), therefore additional removal of water under drier conditions may increase climate change impacts on frogs.

Implications for park management

There will be some climate change impacts that are not easily managed and will prevent park managers from meeting their goals (West et al. 2009). Direct impacts, in many cases will not be easily managed. For instance, an increase in temperate and decrease in precipitation and/or moisture that have direct impacts on cool temperate forest are relatively out of a park manager's control. Loss of cloud cover and moisture is deemed to be one of the major impacts of climate change on mist forests across the globe (Krishnaswamy et al. 2014). It is an important factor for cool temperate forest health, and a decrease in cloud cover may push this ecosystem out of its ecological niche (Still et al. 1999; Oliveira et al. 2014). In this study area, a reduction in orographic cloud cover is highly likely to result in an expansion of drier rainforests and woodland ecosystems and a reduction or loss of moist, cool rainforest ecosystems. Cool temperate rainforests are probably the most susceptible of the park ecosystems to direct impacts of climate change. The models in this study showed that possible management responses made very little difference to maintaining a healthy cool temperate forest as cloud cover and precipitation reduced on all four parks. There is little evidence that park management may be able to stop reduction or loss of cool temperate forest in these four parks. These issues have implications for protected area management, particularly where park values are highly significant and loss of species or ecosystems may result in irreversible outcomes such as extinction. Decision making will need to include options such as managing for change and prioritisation (Bottrill et al. 2008; Wilson et al. 2009; Iwamura et al. 2010).

There are some direct impacts however that are more manageable. Extreme weather events such as severe storms can directly impact species and ecosystems through damage to forest structures. All models exhibited these direct impacts as a result of increased storms, for example the significant damage as seen in 2013 with Cyclone Oswald where large tracks of forest were destroyed (rainforest ecologist model participant pers. comm., 2015). Storms and associated consequences such as tree falls and landslips also pose a direct threat to visitor infrastructure such as walking track systems. Impacts to the tracks have already been observed on all four parks, particularly Springbrook and Lamington. Lamington has over 150 kilometres of graded walking tracks (Queensland Government 2011). Most of these tracks are in areas of the park that are difficult to access and can be challenging to manage. Lamington's track condition showed it was the most sensitive park to landslips and tree falls under a 'best' and 'worst case' scenario. The BBNs indicated that resources play an important role in maintaining walking tracks in good or very good condition and all four parks displayed a positive effect with the introduction of appropriate resources.

Many of the indirect impacts may be more within a park manager’s control. As the Scenic Rim becomes warmer and drier, fire risk will increase. Fire has shown to be one of the most sensitive factors for the non-breeding areas of stream dwelling frogs and indirect impacts of altered fire regimes and reduction of habitat from climate change are of particular concern (Penman et al. 2015). Fire management will increasingly play an important role in dealing with those habitats and reducing the risk of wildfire. Springbrook is surrounded largely by residential land use. Protection of life and property are a very high priority in the Queensland Government’s fire policy (Queensland Parks and Wildlife Service 2013) and close neighbouring residential areas may see ecological burning take a ‘back seat’ (Tanner-McAllister et al. 2014). Some frog species that require fire adapted ecosystems for habitat are particularly sensitive to climate change and its interaction with fire (Penman et al. 2015). The results indicated that the stream dwelling frogs on Springbrook were very sensitive to the changes in their dry, non-breeding habitat. It is likely that the risk of wildfire will increase with climate change due to the parks smaller size and reduced buffering.

As moister ecosystems transform to drier types, fire management will become even more significant. Springbrook, Mount Barney and Main Range appeared more affected by fire than Lamington for all three key values and managing fire appears more imperative on Main Range and Mount Barney. These parks have more open woodlands and a drier climate making them more susceptible to wildfire. However, both parks are surrounded by land use comprising largely of grazing. Opinions differ whether this may act as a benefit or a risk. Graziers tend to burn more frequently to maintain grassland systems, which in turn may reduce fuel loads and the risk of wildfires. However, an increase in fire in the region also increases the chances of escaping wildfires. Surrounding grazing land use though may make it easier for park managers to focus more on ecological style planned burning.

Conclusion

BBNs proved useful in assisting protected area managers to understand how their protected area may be impacted by climate change. They provide a basis for discussions on options for response and directions for park management into the future. For the purposes of protected area management decision making, they are not designed to give definitive answers but to provide support to begin dialogue and reduce uncertainty for managers in how best to proceed with adapting management for climate change.

Limited funding and competing interests compels park management to become more efficient, but still remain effective in their management. The cost of implementing some management strategies to combat climate change may make them unpractical.

Historically, park management agencies have focused on individual park management with an intention to maintain existing park values. With climate change, decision making will need to begin making decisions such as accepting loss or change to some park values. This will be the reality that managers must face as many impacts may be outside their ability to manage.

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