Solving problems of conservation inadequacy for nomadic birds

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ABSTRACT

Nomadic birds move around the landscape in complex, irregular patterns, making it difficult for conservation managers and planners to decide where and how to act to mitigate threatening processes. Because of this uncertainty, nomadic species are poorly represented in protected areas in Australia. We outline approaches to discover nomadic species distributions, their dynamics and their consequent vulnerability to extinction. Using citizen science initiatives like eBird Australia and the BirdLife Australia Atlas, combined with new ways of applying species distribution modelling that take into account temporal patterns of movement driven by weather and productivity, we demonstrate how to map and predict the key sites for conservation action for nomadic species. We explore recent advancements in decision–support tools to incorporate species movements into systematic conservation planning, and highlight challenges in traditional approaches for protected area designation for conserving nomads. Due to the spatio–temporal dynamism of nomadic species distributions, the projected costs of managing nomads across Australia using traditional, static, protected areas are prohibitive. Landholders, including graziers and indigenous landholders, will play a key role in safeguarding these species on pastoral lands into the future, and future conservation efforts should be focussed on these stakeholders, through a combination of community engagement, market–based incentives (such as biodiversity farming or payments for artificial water source and ephemeral wetland management), cross–boundary and cross–agency collaboration policies, and new legislative instruments. Accounting for the movements of nomadic species and incorporating new approaches to integrated land management will help design conservation solutions that are effective, cost–efficient, and robust to uncertainty in this rapidly changing world.

Key words: spatial conservation planning, migratory species, nomadism, extinction risk, threatened species policy, decision theory, dynamic systems

Introduction

Many Australian birds show some form of nomadism (Chan 2001; Griffioen and Clarke 2002), moving around the landscape in complex and irregular (though not necessarily unpredictable) patterns, commonly associated with highly fluctuating resources and opportunistic breeding or foraging (Dean 2004). Some species undertake nomadic movements only at times when resource availability across the wider landscape is low, tracking resource hotspots (Cheke *et al*. 2007; Perfito *et al*. 2007; Roshier *et al*. 2008; Wyndham 1982) or moving to exploit better resources elsewhere (Dean and Milton 2001). Others nomads undertake random movements in good conditions and become sedentary and contract to refugia when conditions degrade (Bennetts and Kitchens 2000). In extreme conditions such as severe drought, a nomad's previous knowledge about the location of resources and refugia would confer significant advantage over continuing to undertake random movements, and

gaining this knowledge in times of high landscape–wide food availability will have lowered cost to the individual. Nomadism remains a highly complex and little understood ecological response.

Nomads occur across bird families, and in many different habitats. Such species include the blossom–following Swift Parrot *Lathamus discolour* (Webb *et al*. 2014), the insectivorous Orange Chat *Epthianura aurifrons* found in the chenopod shrublands of inland Australia, or the mistletoe–dependent Painted Honeyeater *Grantiella picta* (Barea and Watson 2007). For many species, including those above, nomadic movements can be overlaid on larger scale (often north–south) migration patterns. However, the exact patterns of nomadic movement are rarely known, and for the majority of species, we have only a rudimentary understanding of what places are most important to them, and what drives their movements around the landscape.

The lack of knowledge on nomadic species distribution patterns, consequent population trajectories and the impacts of threatening processes, makes it difficult to decide where and how to act to mitigate threats. Despite the wide geographic ranges of many nomadic species, they are rarely habitat generalists. Nomads instead can have highly specific habitat needs, keying in to environmental conditions such as vegetation seeding or flowering events (Pavey and Nano 2013; Tischler *et al.* 2013; Webb *et al.* 2014; Ziembicki & Woinarski 2007), which may make them less resilient to environmental change than sedentary, generalist species. Additionally, unlike conventional migration, site use and the linkages between sites used by nomads are dynamic, changing from year to year and season to season. This is because many Australian nomadic birds follow resource pulses which in turn are driven by irregular pulses of rainfall. Bird movements or changes in bird abundance may coincide with flowering or fruiting in favoured plant species, or irruptions of native mammals. For example, dynamics in the Letter–winged Kite *Elanus scriptus* are linked to irruptions of the native Long–haired rat *Rattus villosimus* (Pavey & Nano 2013). At any given point in time only a small part of a nomad's range may contain suitable resources for the species. In response to this, the distribution of some nomadic bird species fluctuates by an order of magnitude or more, and may sometimes become highly spatially constricted (Runge *et al.* 2015). The consequences of not knowing the location and timing of these constrictions could be wasted conservation resources in places where the birds no longer occur, but also loss of key refugia if we fail to protect the right places at the right time.

Systematic conservation planning is the science and art of choosing conservation actions in space and time, and doing so in a way that maximises both their efficiency and effectiveness. The past two decades have seen the growth of systematic conservation planning, in both theory and practice (Moilanen *et al.* 2009a). This science operates within the paradigm that we live in a world where conservation must compete with other human demands on natural resources and space; answering a basic question: How do we choose where to focus our conservation investments? Conservation science has traditionally tended to assume that the targets of management, such as species or ecosystems, are static in space and time (Moilanen *et al.* 2009a). Accounting for the dynamics and uncertainty of nomadic species distributions across space and time is not easy using traditional conservation planning frameworks based around this assumption and therefore rarely done. However, mobile species are subject to the same pressures and threats as their sedentary counterparts, and many are in decline (Butchart *et al.* 2004; Sanderson *et al.* 2006; Szabo *et al.* 2012). Crucially, both migrants and nomads depend on a chain of intact habitats (though not necessarily spatially linked) across the areas traversed during their migrations (Figure 1), making them vulnerable to habitat degradation or loss at any part of their movement cycle, and in need of management to prevent further declines.

Dynamics across space and time in the occurrence and abundance of nomadic species present four challenges for conservation planners. Firstly, difficulty in monitoring nomads means that we must deal with poor or uncertain information about the movements, ecology and population dynamics of species (Runge *et al.* 2015; Tulloch and Szabo 2012). This limits our understanding of which sites and parts of the nomadic cycle might require conservation action, though there are some exceptions (e.g. Australian inland waterbirds, where tracking studies and long–term population monitoring are providing valuable conservation information (Kingsford *et al.* 2010)). Secondly, the spatial and temporal configuration of conservation actions for species persistence may involve protecting or managing not only one type of habitat or resource, but several, which need to yield suitable resources at the appropriate time and to have the right spatial configuration, making prioritisation of areas for conservation action a complex problem. Thirdly, the large scale movements of mobile species, and the reliance on multiple sites throughout their lifecycle, require us to account for the connections between sites in the way we prioritise conservation across species; in the design of conservation networks, and in the implementation of conservation actions (e.g. Nicol *et al.* 2015). Lastly, conservation objectives for nomads are poorly defined, meaning that we have little guidance about whether it is best to protect the minimum requirements, the most–used areas, or complementary sites across time or space. New thinking and approaches are needed to plan for nomadic species and answer the question, where and how much should we protect to ensure persistence of species with uncertain distributions across space and time?
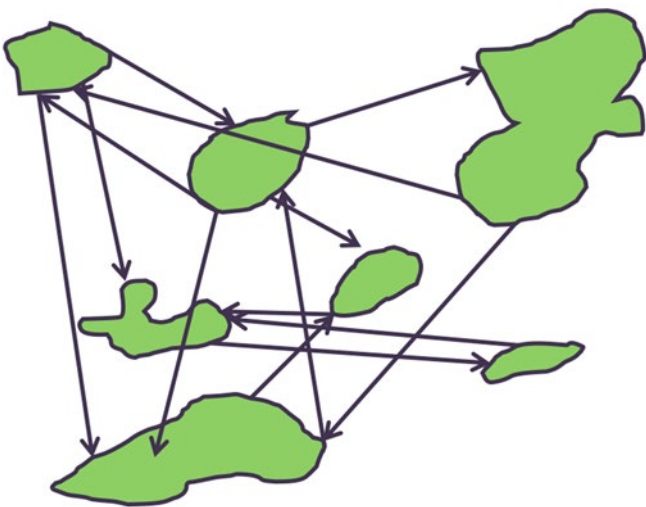

Figure 1. Movements of a hypothetical nomadic species between resource patches or habitats

Here, we outline some existing approaches to discover nomadic species distributions, their dynamics and their consequent vulnerability to extinction. We then explore recent advancements in decision–support tools to incorporate species movements into conservation planning, and discuss possible ways to ensure greater likelihood of successful nomad management. We demonstrate new thinking about accounting for uncertainty and risk in conservation planning for nomads, to ensure the best possible outcomes under limited budgets and uncertainty.

Conservation planning for nomads

1. Where do nomads occur? Using existing tools to discover species dynamics and distributions

One of the most basic pieces of information required for conservation is an understanding of where the species is to be found. Species distributions are often conceptualised and treated as static. However, nomadic movements can lead to substantial temporary expansion and contraction of geographic distributions, which may be combined with longer term range shifts associated with changes in climate, threat distribution and habitat loss. These shifting distributions have implications for the way we prioritise and conserve nomadic species: presenting challenges for extinction risk assessment, population monitoring, identifying conservation actions and deciding when and where to take those actions.

Identifying distributions across time can be challenging in dynamic species, particularly for areas and species where data are limited. However, recent advances in species distribution modelling and the availability of increased computing power mean the mapping of dynamic species distributions and identification of refugia across short time periods is now possible (Reside *et al.* 2010; Runge *et al.* 2015; Webb *et al.* 2014). Rather than aggregating environmental conditions across time, these approaches match environmental conditions at the time of each species record to create a model of species environmental niche – neatly summarised by Reside *et al.* (2010) as using 'weather, not climate'. This model is then projected across different time periods to provide time–sliced estimates of species distributions. Such approaches use short–term variables (i.e. weekly or monthly measurements of vegetation greenness and land temperature) as an alternative to long–term climate variables such as average annual rainfall used in conventional species distribution models, to provide greater predictive accuracy in the estimates of species ranges and habitat use throughout time. The increased availability of remotely–sensed environmental data products over the past two decades (ie http://modis.gsfc.nasa.gov/), and post–processed and ground–truthed data products such as Photosynthetic Vegetation Index (http://www.auscover.org.au/; (Guerschman et al.

2009)) provide high–resolution data on short–time–scale environmental conditions even in the remote areas of Australia.

A dynamic modelling approach was recently used to predict time–sliced distributions for 43 nomadic birds found across the arid and semi–arid parts of Australia (Runge *et al.* 2015). The data used to populate these models were citizen science records over the past decade – a resource that has in the past been discounted by researchers over traditional localised long–term monitoring protocols, but shows promise as one of the best (and possibly only) ways to explore nomadic distributions over large poorly–surveyed areas such as the arid interior of Australia (Tulloch *et al.* 2013a). By linking productivity and weather to nomadic species' habitat requirements, existing knowledge of the extent and location of resources required by Australian
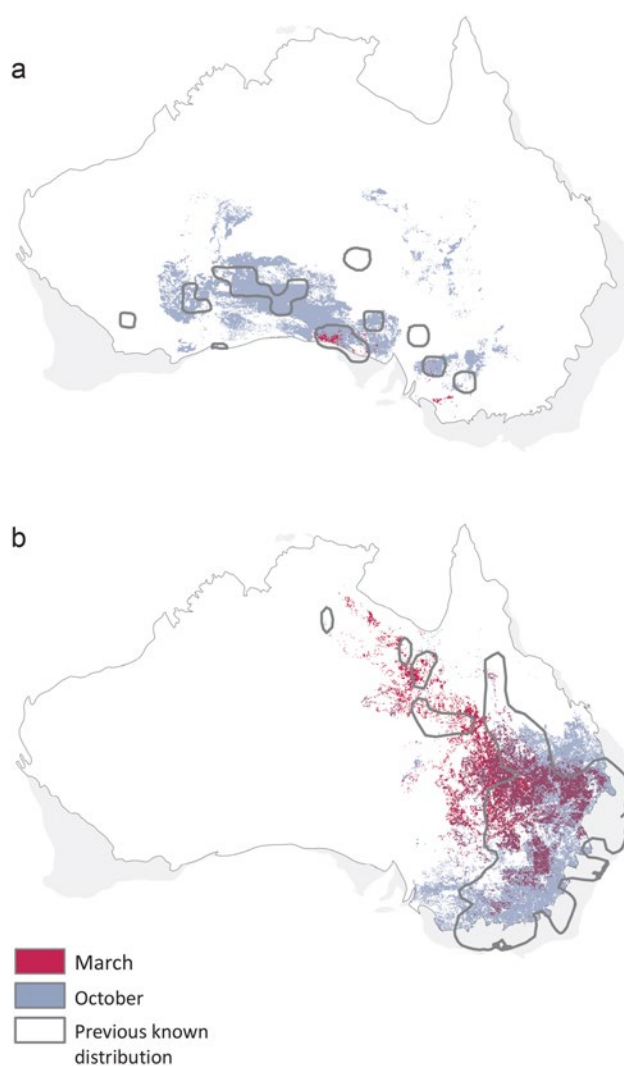

Figure 2: Predicted habitat suitability for a) Scarlet–chested Parrot *Neophema splendida* and b) Painted Honeyeater *Grantiella picta* in March and October 2010 (Runge *et al.* 2015). Grey lines show the extent of the previously mapped distribution (BirdLife International and NatureServe 2012). Dark grey areas fall outside the bounds of the modelled area.

nomads was improved, and range maps were refined to more accurately reflect when and where species might occur over time and space.

2. How vulnerable are nomads? Characterising species vulnerability

The distributional dynamics of nomadic birds have consequences for the way we estimate their vulnerability to extinction. Geographic range size (the extent of a

species' distribution) is often treated as a fixed attribute of a species for the purposes of calculating extinction risk; species occupying smaller geographic ranges are assumed to have a higher risk of extinction, all else being equal (Gaston and Fuller 2009; IUCN Standards and Petitions Subcommittee 2014). However, when a species is nomadic within its overall distribution, estimates of geographic range size based on pooling observations across time will often be larger than the geographic range size at any one point in time. This could lead to an erroneous conclusion that a nomadic species is safe from extinction when it is not. A recent study by Runge *et al.* (2015) suggests that threat assessments (e.g. IUCN Red Listing) based on geographic range size may underestimate extinction risk in nomadic species if such assessments are based on pooled occurrences across time, and they suggest instead that extinction risk be assessed on minimum range size.

For instance, the Scarlet–chested Parrot *Neophema splendida* is currently listed under IUCN guidelines as Least Concern because the population is thought to be stable and occupy a large area (EOO 262,000 km^2; (BirdLife International 2013)), though the accuracy of population estimates is acknowledged to be poor (Figure 2a). However, modelled distribution maps indicate that this species' range size may repeatedly drop below the 2000 km^2 threshold given by IUCN guidelines for classification as Vulnerable (Figure 3) (IUCN Standards and Petitions Subcomittee 2014; Runge et al. 2015). Additional extreme fluctuations in geographic range size displayed by
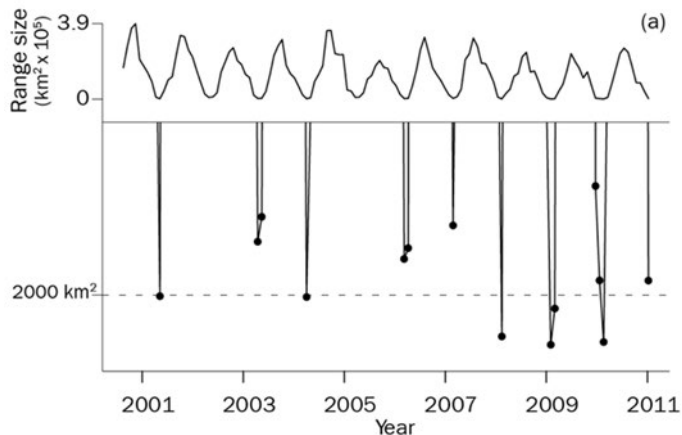

Figure 3: Geographic range size dynamics for Scarlet–chested Parrot *Neophema splendida.* Dashed lines indicate Vulnerable threshold under IUCN Red List guidelines B2ii Area of occupancy, AOO: VU < 2000 km and the minima are magnified below each plot. Adapted from Runge *et al.* (2015).
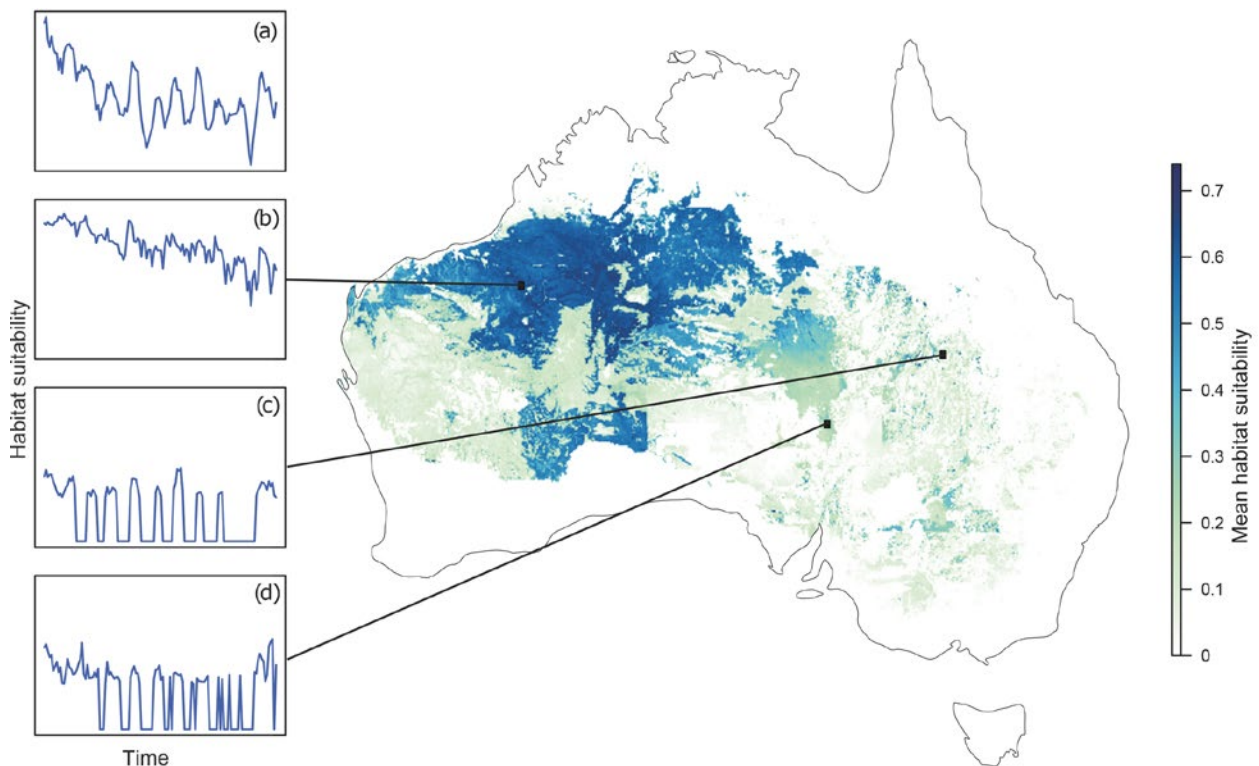

Figure 4: Theoretical outcome of population monitoring by geographic location for Black Honeyeater *Sugomel niger*: (a) overall trend and (b) population dynamics at the core and (c–d) edges of the species' overall range. A linear relationship between probability of habitat suitability and population size is assumed. Adapted from Runge *et al.* (2015).

this species provide a case to increase the threat category of this species (Runge *et al.* 2015). In doing so, this species has a greater chance of being included in government– and non–government conservation planning aimed at protecting or managing threatened species.

One thing to note here is that extinction risk in a nomadic species as measured by minimum range size is not necessarily the same as that of an otherwise identical sedentary species (Maron *et al.* 2015). While a nomad and an equivalent sedentary species could be at equally high risk from threats whilst occupying a bottleneck or refugial site, the ability of nomads to expand in distribution (and population) when environmental conditions improve may buffer them from stochastic threats over the long term because they can move on and take advantage of good conditions elsewhere (Dean 2004). However, movement itself could be risky in the sense that locations and timings of suitable resources are unpredictable and irregular (Mac Nally 2009). Additionally, in some cases, threats can be concentrated into precisely the areas to which nomadic species contract (Stojanovic *et al.* 2014); for example, both invasive predators and livestock grazing converge on sites with recent rainfall, particularly during conditions of widespread below average rainfall (Greenville *et al.* 2014; Reid and Fleming 1992).

Nomadic movements limit our ability to determine population dynamics and consequently our ability to estimate extinction risk on that basis (Runge *et al.* 2015). Many migratory species can be surveyed annually because of predictable movements to and from breeding grounds, which allows reasonably accurate measurement of population change and extinction risk (e.g. Wilson *et al.* 2011). However, for nomadic species, when and where we monitor may dramatically influence our estimates of both population abundance and trend (Figure 4). Geographic range size determination thus seems the most tractable way to assess extinction risk in many nomadic species, despite its reliance on a (as yet untested) theoretical relationship between habitat availability and population size.

3. How do we prioritise conservation actions? Using decision–support tools to incorporate species movements into conservation planning

Choosing areas to protect or manage for nomadic species requires an approach that accounts for movement processes across time and space rather than a simple focus on static maps of species distributions (Rondinini *et al.* 2006). Choosing conservation areas for sedentary species commonly involves identifying the locations that collectively, at least cost, contain the greatest number of species or largest amount of suitable habitat (Moilanen *et al.* 2009b). Site selection for more mobile species, such as nomads, is necessarily more complex. Spatial conservation planning in nomadic species must deal with (a) uncertainty

around where they are and where their refugia are (if they use refugia at all), and (b) identifying flexible and responsive conservation actions that account for dynamic movements across space and time (Bolger *et al.* 2008; Martin *et al.* 2007). Such dynamics can be significant for any attempts to conserve mobile species including nomads (Runge *et al.* 2014). Failing to protect critical sites, including refugia, may result in irreparable population declines or extinction (Reid and Fleming 1992). However, critical refugia or bottlenecks may only be utilised by species during extreme climatic events, making it difficult to justify protection of these sites to decision makers in political jurisdictions where a precautionary approach is not taken. Effective conservation planning for nomadic species therefore requires information on the location of important sites and their functional significance, as well as tools to incorporate that knowledge into prioritisation approaches.

Classic migrants have relatively predictable patterns of movement, and there has been much recent progress in understanding how to incorporate such movements into spatial conservation planning (Beger *et al.* 2010; Iwamura *et al.* 2014; Klaassen *et al.* 2008; Kool *et al.* 2013; Linke *et al.* 2011; Moilanen *et al.* 2008; Nicol *et al.* 2015). However, many species show much less predictable patterns of movement and the irregular movements of nomadic species make their conservation a particular challenge. As a consequence, little or no attention has been paid to the need for protection of nomads in particular parts of their lifecycle or across resource hotspots (Gilmore *et al.* 2007; Venter *et al.* 2014; Watson *et al.* 2011). We are only aware of one attempt where the dynamics of nomadic species have been considered in a prioritisation scheme. Fahse *et al.* (1998) examined alternative configurations of theoretical protected areas for a nomadic lark in the Nama–Karoo, South Africa by using a spatio–temporal model to estimate the survival of flocks given known ecological relationships with seasonal rainfall patterns (Fahse *et al.* 1998). They found that these nomadic birds were best protected by a series of sites spread across the study region, spatially focused on areas of high resource availability. Their study sought to inform the single–large–or–several–small (SLOSS) debate on optimal protected area configuration rather than a systematic conservation plan, and therefore did not incorporate cost or feasibility. Runge and colleagues (2016) progressed this field by expanding protected area selection to account for between– and within–year distribution dynamics of 42 highly mobile Australian birds, as well as the costs of converting land that is mostly privately held for agriculture to public conservation reserves for nomads. These two studies remain the only examples where distributional dynamics have been incorporated into a prioritisation for a nomadic species.

Conservation planning problems are typically formulated as either a 'minimum set' (meet conservation targets using minimal resources (i.e. area, money)) or 'maximal

coverage' (maximize conservation benefits given a fixed amount of resources) problem (Moilanen *et al.* 2009b; Possingham *et al.* 2006). Regardless of the approach, using a static range map that overestimates the habitat needs for a species would most likely focus prioritisation on the cheapest places regardless of whether or not those places are used more often than others, and risks ignoring key sites used by nomads if they are more expensive (Runge *et al.* 2016). A dynamic approach allows planners to discover and account for the places that are important across different times (e.g. when different resources are available), with lowered risk of protecting areas of low value for nomads. There are currently only a few examples of conservation planning specific to migratory species (Grantham *et al.* 2008; Iwamura *et al.* 2013; Klaassen *et al.* 2008; Martin *et al.* 2007; Sawyer *et al.* 2009; Sheehy *et al.* 2011; Singh and Milner–Gulland 2011) though the theoretical framework for dealing with these issues is improving rapidly (Hodgson *et al.* 2009; Hole *et al.* 2011). These approaches can be adapted to account for the more complex movements of nomadic species.

For instance, the Scarlet–chested Parrot *Neophema splendida* appears to contract to a set of very small areas during the summer/autumn months (Figure 2a). Ignoring the dynamics of this species by treating the species distribution as static would miss these critical refugia. Management of this species may involve monitoring these refugia to determine the key requirements of the species during these times and identify potential threats and corresponding management actions. Using these data, a graph theoretic approach, as used by Iwamura *et al.* (2014), could be used to prioritise sites for conservation action and determine the population consequences of loss of these sites. A less data–intensive approach could be used for the Painted Honeyeater, which migrates from breeding grounds along the inland slopes of the Great Dividing Range to semi–arid regions of central–eastern Australia (Figure 2b). Most of its habitat is on private land (just 2.4% is protected; (Runge 2015)) and persistence of these birds will be unlikely without conservation action in both breeding areas, where much of the habitat has been reduced to ageing, isolated trees, and in the non–breeding areas, where ongoing clearing for agriculture is a continual threat. For species such as the Painted Honeyeater that do not have clear refugia, conserving sites across both regions should be sufficient to ensure their persistence. Although this approach ignores connections between patches and makes the assumption that individual birds will move to any available habitat patch, this is likely to succeed provided the amount of habitat under conservation action is large enough to allow the birds to move to avoid resource shortages. Conservation targets should be set with sufficient redundancy to maintain the desired population during resource–limited times (e.g. based on carrying capacity during drought rather than average carrying capacity or allowing for random events to knock

out a proportion of normally suitable habitat). This approach can be easily implemented in an adaptation of existing prioritisation decision–support tools (e.g. Marxan (Ball *et al.* 2009), Zonation (Moilanen *et al.* 2012)), by treating non–breeding grounds and breeding grounds separate species (Runge *et al.* 2016).

One consideration for conservation planning for nomads that has received little attention is the difficulty in designing conservation actions for species whose refugia are not in fixed sites, or that do not use refugia at all. Whilst information on the most–used places at a particular point in prior history is useful for learning about habitat and resource requirements, it may not be useful for designating where to act if the animal no longer returns to that place, or if spatial patterns of habitat use change in the future. Additionally, although we have good data on some nomadic species such as birds due to the popularity of bird watching and the ease of conducting bird surveys relative to other species (Tulloch *et al.* 2013b; Tulloch and Szabo 2012), the resource and distribution requirements of many other harder–to–detect nomadic reptiles and mammals remain elusive. Broad–scale citizen science programs such as atlases might be the best way to start informing where to protect or manage these species (Tulloch *et al.* 2013a). When static protected areas are insufficient due to moving refugia, rather than designing local–scale actions, new regional priority threat management approaches ranking each landscape–scale action by its relative costs and benefits might begin to find effective and efficient actions for managing these species before it is too late (Carwardine *et al.* 2012; Chadès *et al.* 2015).

4. When might we fail even when we think we have a representative protected area design? Thinking about collaboration possibilities and integrated land management

It is clear that protected areas as we know them will not always succeed in preventing the declines and possible extinctions of species, particularly for nomads that are unconstrained by the anthropogenic boundaries of reserves. Even species such as migratory ungulates that appear well protected in reserves are still declining, due to loss of migratory linkages and critical, but seldom used, refugia (Harris *et al.* 2009). The impacts of threats on nomads depend not only on the extent of the threat, but also on where (and when) it occurs (Martin *et al.* 2007). In many nomadic species, site use may be scattered across the landscape and species move between ephemeral, short–used sites, making conservation via static protected areas unfeasible. Adequately protecting one or two sites might be insufficient to safeguard the population if threats in other sites lead to critical bottlenecks (Maron *et al.* 2015), or if populations sustain heavy pressure (e.g. human persecution, habitat loss, predation by invasive species) during movements between sites (Iwamura *et al.*

2013). A move away from reliance on static protected areas into large–scale integrated land management, where conservation actions and human land use are intertwined (e.g. protecting paddock trees for Painted Honeyeater) will be crucial for the majority of nomadic species.

For nomads, important resources (including refugia) are likely to occur across different environmental, political or jurisdictional boundaries. Because of this, collaboration across institutions, as well as local, state and even national boundaries is essential to manage species that spend time in different locations (Kark *et al.* 2015; Levin *et al.* 2013). The importance of cross–boundary and cross–institutional collaboration in conservation efforts is increasingly recognised in the literature, but despite this, collaboration potential and its costs have not yet been incorporated into most conservation plans and programs.

Some threats to nomads can be tackled through national or international legislative collaboration. This is becoming more common for international migrants, through the development of international agreements such as the Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention) and migratory flyway initiatives such as the East–Asian–Australian Flyway that involve internationally agreed cross–boundary management and conservation objectives, including an understanding of shared economic costs, to ensure connectivity across the entire migratory route (Murray and Fuller 2012). Trans–boundary parks spanning political boundaries are another way to achieve cross–boundary collaboration (Quinn *et al.* 2012). Multi–scale management and policy is key to conservation success, and involvement of local people can be crucial to ensure safe passage for nomads that are persecuted or have lost important habitat required for moving between sites (e.g. tree–dependent birds travelling through heavily cleared agricultural landscapes) (Kark *et al.* 2015; Linnell and Boitani 2011). New developments are constantly emerging that allow the co–existence of human resource use (e.g. cropping and grazing) and biodiversity conservation. These include alternatives to the hunting of native predators (e.g. livestock protection animals such as alpacas), private land conservation incentives that involve short–term payments to landholders providing critical resources during bottlenecks (e.g. to fence off native vegetation, or control invasive predators), or cooperation between landholders and conservation institutions to provide resources for species moving through an area (Klaassen *et al.* 2008).

Governance structures that allow rapid and dynamic implementation of cross–jurisdictional conservation actions (Martin *et al.* 2012a) will be crucial for conserving wide–ranging nomadic species, particularly in the face of a rapidly changing climate. Including the potential for different forms of collaboration into systematic conservation planning is possible, although it has not explicitly been dealt with from a nomadic species perspective (Kark *et al.* 2015; Mazor *et al.* 2013; Moilanen *et al.* 2013). Existing economic, social and political collaboration among regions or institutions can be quantified based on shared environmental policies, knowledge exchange, tourism and trade data, and can be a surrogate for the likelihood of two regions to successfully collaborate in conservation if decisions need to be made quickly (Levin *et al.* 2013). Conservation spending could be directed not only to areas where an increase in protected areas or other effective conservation actions would fill in the gaps for the greatest number of shared species, but to those areas with highest likelihood of conservation success based on human dimensions. Advances in decision–support software for conservation planning such as Marxan and Zonation (Pouzols and Moilanen 2014) could also be drawn upon to design a prioritisation that incorporates the movement capabilities of species, with the possibility of using expert elicitation where physiological limits to dispersal are unknown (Murray *et al.* 2009; Smith *et al.* 2007).

5. Dealing with uncertainty in conservation decisions related to nomads

Regardless of which actions we choose for nomads, we will be acting under uncertainty: in the distributions of nomadic species, when they are likely to need alternative resource patches, whether their refugia are fixed or not, and the likely outcomes of alternative management strategies. When we are uncertain we have three choices: (1) invest in monitoring and learning to reduce uncertainty; (2) use available information to estimate the optimal conservation plan whilst explicitly incorporating uncertainty (Tulloch *et al.* 2013c); or (3) undertake a combination of learning while taking action, known as adaptive management (Keith *et al.* 2011). By embracing rather than avoiding uncertainty, we can better account for the risk of management failure (Tulloch *et al.* 2015a).

Currently, many nomads are excluded from systematic conservation planning studies due to uncertainty in their distributions. Increased spending on broad–scale monitoring (such as bird atlassing) to learn more about species' habitat needs before designing a conservation strategy is one solution to improving knowledge of distributions. This might be appropriate if there is a high likelihood of getting the data we need quickly and cost–efficiently (Tulloch *et al.* 2013a). For species or locations that are less readily monitored, models of habitat needs or of species surrogates and a corresponding level of confidence in that knowledge can be incorporated into decision–support tools that allow for probabilistic information (e.g. Zonation (Moilanen *et al.* 2012); Marxan with Probability (Tulloch *et al.* 2013c); Bayesian Belief Networks). Running multiple scenarios of possible distributions would allow planners to understand how

robust their current information is to uncertainty. Expert elicitation might be another way to generate information when data are scarce (Martin *et al.* 2012; Stralberg *et al.* 2011). It would be worth exploring whether accurate estimates of nomad distribution and habitat requirements can be derived from expert elicitation, and whether priority sites for conservation are consistent across both modelled and expert–elicited distributions.

The use of decision–theoretic approaches from applied mathematics and artificial intelligence can aid decision making under uncertainty for nomads, by allowing us to optimally allocate time and resources (Chadès *et al.* 2011; Martin *et al.* 2007). The application of decision science to solve nomadic species conservation problems follows the same basic principles as any well designed prioritisation process (Gregory *et al.* 2012; Runge *et al.* 2014; Tulloch *et al.* 2015b):

1. Define a clear objective (e.g. what to minimise or maximise) that considers constraints such as time and money;

2. Specify a set of conservation actions from which a subset will be chosen as priorities;

3. Build a model of system behaviour to relate the outcomes of alternative conservation actions to their contributions toward meeting the objective;

4. Consider uncertainty; and

5. Select and implement decisions in a way that promotes learning.

Many of the more advanced techniques in decision science have yet to be applied formally to nomadic species conservation problems. Once these approaches are embraced, it should be possible to design conservation action plans that are robust to different plausible patterns of connectivity, or cases where refugia or passage habitat use change as a result of threats. Through decision–theoretic value of information analyses, we can highlight what new information would reduce uncertainty and hence be most useful for improving conservation decision making in a particular situation, so that research effort can be focused on gaining new knowledge most likely to lead to a change in management (Grantham *et al.* 2009; Nicol and Chadès 2012; Runge *et al.* 2011). However, understanding of the fundamental drivers of nomadism is limited, and it remains to be seen whether any theoretical rules can be derived about this behaviour. Much uncertainty remains to be resolved. Are there spatial patterns to nomadic behaviour across a species' distribution? Is nomadism a local phenomenon or do nomadic movements occur on a continental scale, and how much seasonality is there to those movements? What habitat do species rely on during key times (breeding or

bottlenecks)? Do species use refugia and are the locations of those sites constant? How does habitat use relate to resource availability and predator dynamics? How do nomads interact with each other? Conservation of these species may not always rely on answers to all of these questions, but they remain interesting from an ecological theory perspective nonetheless.

The future for nomadic species management and protection

Despite making up a significant proportion of the biodiversity that conservationists aim to protect and manage, mobile species such as Australia's nomadic birds are still poorly accounted for in conservation planning. The success of conservation planning for nomadic species will be dependent on identifying actions that maintain viable populations across both space and time and discovering ways to integrate those actions into human land use (Bolger *et al.* 2008; Martin *et al.* 2007). For most Australian birds we have the information we need, through citizen science initiatives like eBird Australia and the BirdLife Australia Atlas, combined with analytical tools such as species distribution modelling, to be able to map or predict the key sites for conservation action to ensure their ongoing persistence. However, a key challenge for many species is identifying the drivers of decline, and the best management actions to halt and reverse those declines. Declines in nomadic species might be more difficult to detect than sedentary species, because of the difficulty in monitoring nomadic species (Figure 4). Five Australian Important Bird and Biodiversity Areas (IBAs) are in critical danger of losing the species for which they were designated (Vine and Dutson 2014) – this is despite all of them being held within the National Park estate. In these places the issues are not solved simply through protected area designation, but require better management actions, such as improved fire management and increased effort to eliminate invasive species. Notably, the species declines in these IBAs were only detected through the collaborative efforts of teams of dedicated volunteers and attentive park rangers.

The sheer extent of area used by nomadic species across years and seasons, and the continually shifting nature of their distributions, mean that cumulative management costs will soon limit the feasibility of a conservation approach based solely on protected areas, despite the relatively low agricultural value of much of the region in Australia across which they occur. It is increasingly clear that survival of these birds into perpetuity will require management of key threats across communities, landholders and government agencies. While dynamic implementation of management actions in only the places and times when birds are present might seem ideal, the current static structures of governance and land ownership in inland Australia, and the time lag

involved in implementing on–ground management hinder the implementation of dynamic solutions (Smith and McAllister 2008). Key management actions for nomadic species will coincide with actions for maintaining biodiversity across the board. For instance:

• Ground–dwelling or granivorous birds such as Flock Bronzewing *Phaps histrionica*, Stubble Quail *Coturnix pectoralis*, and Budgerigar *Melopsittacus undulatus* should benefit from market–based incentives to limit high intensity grazing during drought conditions, control of feral predators particularly during breeding events, and management of grass species for cover and food availability. Notably many nomadic species coexist quite happily with low to medium levels of grazing intensity, and for some species grazing is essential for maintaining habitat (e.g. Plains Wanderer *Pedionomus torquatus*). Grazing can also increase cover of unpalatable shrub species such as *Eremophila*, which, while unwanted by graziers and reducing habitat for grassland species, provide nectar–rich food sources for nomadic honeyeaters such as Black Honeyeater *Sugomel niger* (James *et al.* 1999).

• Woodland birds such as the Painted Honeyeater *Grantiella picta* will rely on strong and enforced land–clearing laws, including the maintenance of regrowth, to protect key habitat from ongoing clearing.

• Restriction of cattle access to fragile ephemeral wetland areas will play a role in protecting water refugia for arid zone birds and minimising trampling damage (Frank *et al.* 2012; Ward 2005).

• Closure of artificial water sources to reinstate water remoteness will limit grazing intensity and could reduce the spread of feral predators (e.g. cats) currently threatening nomadic birds (Fensham and Fairfax 2008).

Landholders, including graziers and indigenous landholders will play a key role in safeguarding nomadic species into the future. Future conservation efforts focus on these stakeholders, whether through community engagement, market–based incentives (such as biodiversity farming or payments for artificial water source and ephemeral wetland management), cross–boundary and cross–agency collaboration policies, and new legislative instruments (Pannell 2008; Pannell 2011).

One of the main issues facing conservation of nomadic species is the current perception of arid ecosystems that many nomads inhabit – the 'frontier mentality'. Much of the work presented here shows that far from being homogenous, featureless landscapes, arid ecosytems shift between habitat type and species composition across short distances. Conservation of nomadic species requires recognition that these birds depend on very specific sets of environmental conditions. Terrestrial conservation effort is currently strongly focussed on forests (Fazey *et al.* 2005), most likely due to the historical misconception that sparsely vegetated gibber plains, sand dune country, and grasslands offer little of conservation value. In fact, grasslands are arguably one of the least protected and most vulnerable ecosystems in the country and in fact in the world (Fuhlendorf and Engle 2001), despite (or perhaps because of) extensive human modification. Far from being wide, empty plains, these ecosystems contain unique sets of species with incredible adaptations to conditions that humans, as a water–dependent species, see as harsh and unforgiving. Conservation of nomadic species will depend on recognition that arid ecosystems are worthy of protection in their own right and their habitats are as distinct and valuable as a rainforest or a eucalypt woodland.

Acknowledging uncertainty and misconceptions in the value of dynamic ecosystems for conservation is the first step towards learning about how and where to conserve nomads. The future of nomadic species conservation lies in better knowledge of how best to monitor them to directly inform management, and the use of a strong decision science approach to management that explicitly accounts for uncertainty, whether this is in selecting where and how to locate protected areas, or choosing between alternative threat management actions, or deciding which species to start recovery actions for. Accounting for the movements of nomadic species and incorporating the likelihood of successful management will help design conservation solutions that are effective, cost–efficient, and robust to uncertainty in this rapidly changing world.

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APPENDIX 1

Letter–winged Kite (Photo credit: Jeremy Ringma)

Letter–winged Kite (Photo credit: Jeremy Ringma)

APPENDIX I

Flock Bronzewing (Photo credit: Jeremy Ringma)

Flock Bronzewing (Photo credit: Jeremy Ringma)

APPENDIX 1

Budgerigars (Photo credit: Rob Clemens)

Male Orange Chat (Photo credit: Rob Clemens)