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FORUM

Guidelines for Using Movement Science to Inform Biodiversity Policy

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Abstract Substantial advances have been made in our understanding of the movement of species, including processes such as dispersal and migration. This knowledge has the potential to improve decisions about biodiversity policy and management, but it can be difficult for decision makers to readily access and integrate the growing body of movement science. This is, in part, due to a lack of synthesis of information that is sufficiently contextualized for a policy audience. Here, we identify key species movement concepts, including mechanisms, types, and moderators of movement, and review their relevance to (1) national biodiversity policies and strategies, (2) reserve planning and management, (3) threatened species protection and recovery, (4) impact and risk assessments, and (5) the prioritization of restoration actions. Based on the review, and considering recent developments in movement ecology, we provide a new framework that draws links between aspects of movement knowledge that are likely the most relevant to each biodiversity policy category. Our framework also shows that there is substantial opportunity for collaboration between researchers and government decision makers in the use of movement science to promote positive biodiversity outcomes.

Keywords Connectivity · Conservation policy · Decision · Dispersal · Government · Impact assessment · Intervention · Management · Migration · Restoration · Risk assessment · Threatened species · Translocation

Introduction

Movement, such as migration and dispersal, is fundamental to the distribution and persistence of biodiversity (Jeltsch et al. 2013), and movement knowledge is a critical consideration in biodiversity conservation decisions (Driscoll et al. 2014). Movement ecology, to a limited extent,

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already influences biodiversity policy and management. Assisted colonization as a response to climate change (Shirey and Lamberti 2010) and restoration of fragmented landscapes (Brederveld et al. 2011; Woodcock et al. 2012) are examples where limitations to dispersal or colonization potential require information about species' movement. However, the application of movement ecology research to biodiversity conservation requires substantial improvement (Driscoll et al. 2014) to better reflect recent advances in knowledge and techniques (Nathan 2008).

Policy makers, planners, and land managers involved with biodiversity conservation are required to make decisions under time, budgetary, and political considerations. Ideally, these policy makers should be able to consider the best evidence available, and/or access relevant knowledge of species movement when making these decisions (Pullin et al. 2004). However, it can be difficult to determine what sort of movement knowledge might have the greatest relevance to a decision, and why.

In this paper, we provide a synthesis of how different aspects of movement knowledge can inform biodiversity conservation policy and management considerations. We give examples of how movement knowledge can inform different policies, including conservation programs addressing reserve selection, species protection, impact and risk assessment, restoration actions, as well as some emerging future policy opportunities. By presenting a comprehensive treatment of the broader principles of movement science, and their links to biodiversity policy, we give a heuristic approach to identifying the movement knowledge required to inform case-specific policy and management problems. Therefore, a framework presenting general guidelines could serve as a useful resource for both researchers and the needs of government and management agencies.

Movement Knowledge Relevant to Biodiversity Policy and Management

We use the term movement to mean the "change in spatial location of the whole individual in time" (Nathan et al. 2008). Under this definition, we consider three aspects of movement knowledge that are relevant to biodiversity policy and management, namely the mechanism, type, and consequence of movement (Fig. 1). We focused on these particular aspects of movement knowledge because they encompass multiple spatio-temporal scales and ecological levels of organization, ranging from individual daily movements to population-level consequences of movements. For additional overviews on types of movement knowledge consult Jeltsch et al. (2013) and Nathan et al. (2008).

The first and most fundamental aspect of movement knowledge is the mechanism of movement, including how an organism moves and its "motion capacity" (sensu Nathan et al. 2008). For example, organisms may move actively (e.g., a butterfly or bird moves by flapping its wings) or passively (e.g., winged seeds and ballooning spiders are carried out by the wind). Further, the movement of some species can be facilitated by the movement of other species, such as plant seeds eaten and moved by birds or fruit-bats, or weeds spread by livestock. Some species can be accidentally or deliberately moved by humans (Hulme 2009). The mechanism of movement will affect an organism's capacity to undertake different types of movement (see below), and this knowledge can be gained through study of the organism's fundamental biology and ecology.

We next consider four types of movement that generally operate at increasing spatial scales and typically apply to animals. Station-keeping movements are the movements that keep an animal within its home range (e.g., the daily route of a foraging mouse) (Dingle 1996). Dispersal is the movement of an individual from the site of birth to the site of potential reproduction (natal dispersal) or between sites of reproduction (breeding dispersal) (Matthysen 2012). Nomadic movements occur when animals are neither resident nor migratory, and instead move and reproduce across the landscape in routes that do not repeat across years (Mueller and Fagan 2008). Migration is a synchronized seasonal return movement of populations between areas in response to changes in resources, climatic conditions, and breeding requirements (Milner-Gulland et al. 2011). Knowledge of species' station keeping, dispersal, nomadism, and migration ecology can be acquired through a variety of methods, including telemetry, mark-recapture, occupancy analysis, diet analysis, or the development of mechanistic home range and dispersal models (Driscoll et al. 2014).

Finally, we consider the interaction of an organism with its surrounding environment and how this can be an important moderator of movement. In particular, the location and configuration of species-specific suitable and non-suitable habitats will facilitate or constrain species' movements across a landscape. Improving the connectivity of vegetation patches can allow for greater movement of some species, although the functional (or realized) connectivity of habitat will differ among species (Lindenmayer and Fischer 2006). We draw attention to functional connectivity in particular because of its importance for many conservation actions (e.g., policy and management concerned with habitat corridors and reserve systems). Knowledge of how the environment can moderate species movements can be gained through animal tracking, genetics, and occupancy analysis, as well as resistance kernel analysis that considers

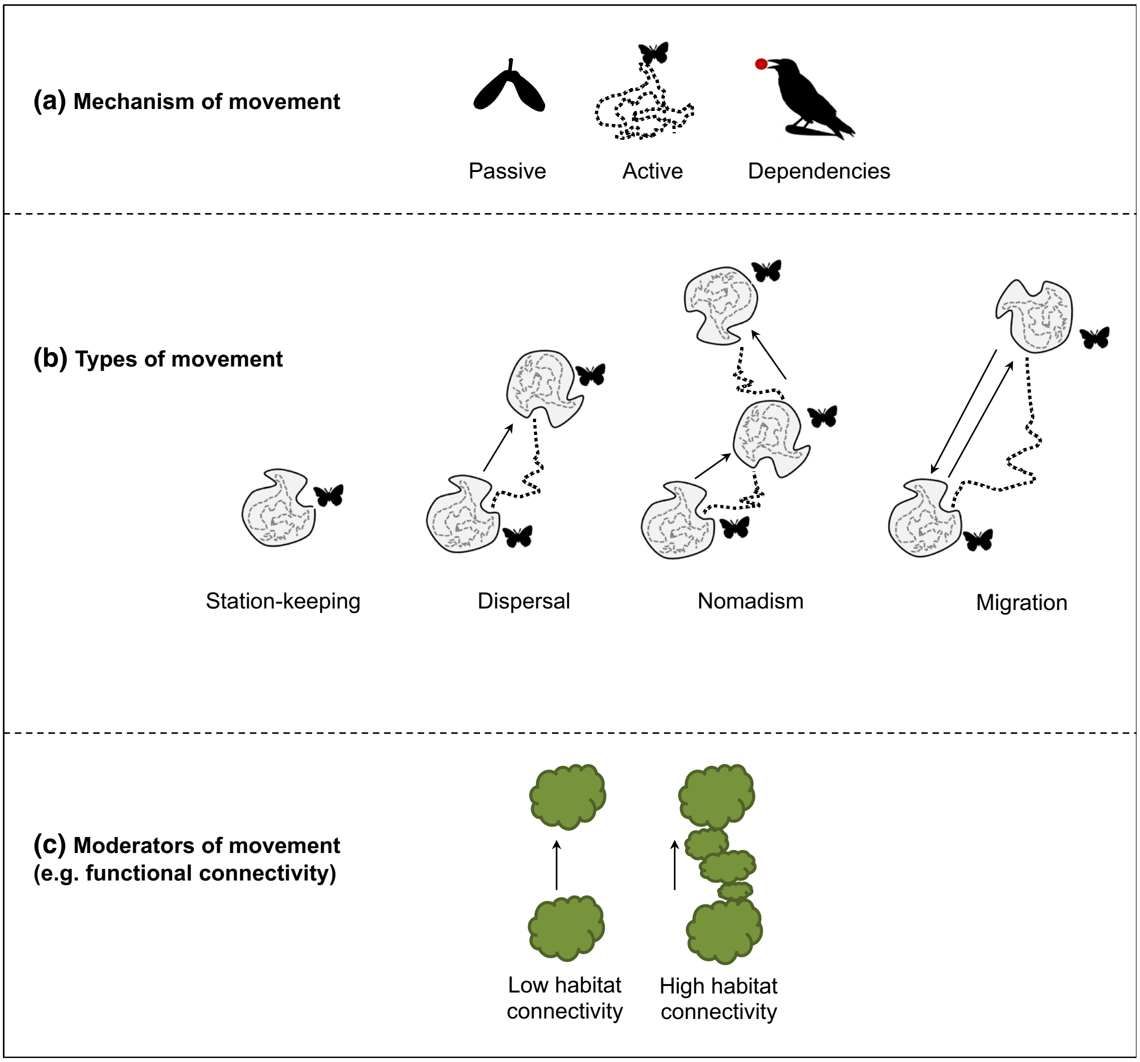

Fig. 1 Different aspects of species movement are relevant to biodiversity policy and management. The most basic is the **a** mechanism of movement, such as the active flight of a butterfly, the passive and wind-mediated movement of a winged seed, or the dependent movement of a plant fruit by a bird. Species also have different **b** types of movement, including *station-keeping* movements that involve foraging and maintenance of a home range, *dispersal* to new breeding grounds, *nomadism* to exploit shifting or unpredictable resources, and seasonal *migration* between breeding or foraging grounds. The environment is an important **c** moderator of movement, influencing how organisms move across landscapes. This will be influenced by the features of the landscape, such as the location and configuration of habitat and non-habitat (i.e., functional connectivity). We describe the movements above from the perspective of an individual, but nomadism, migration, and habitat connectivity are often considered at the population and species level

topography, vegetation, and other features of the landscape (Driscoll et al. 2014; Smith et al. 2014).

Categories of Biodiversity Policy and Management

Governments achieve their biodiversity conservation objectives using a wide variety of policy instruments and management actions (Dovers and Hussey 2013). These range from broad overarching policies to achieve aspirational conservation targets, to specific laws and regulations. Laws and regulations may include legislation to protect species and ecological communities; legislation requiring the assessment of risk to biodiversity; and governance arrangements that provide the resources and context for actions to be taken, as well as the actual physical actions performed (e.g., the planting of trees). In this paper, we use the term ‘policy’ to mean the instruments developed by governments to achieve a goal or objective (Dovers and Hussey 2013). We use the term ‘management’ to mean the decisions and actions taken ‘on the ground’ to achieve a conservation target or implement a policy.

Just as the movement of species can occur across different spatial scales, policy and management can apply to

Table 1 A heuristic framework for understanding the links between movement knowledge and areas of biodiversity policy and management

Aspects of movement knowledge	National Scale Policies and Strategies	Reserve planning and management	Species protection and recovery	Impact and risk assessment	Prioritization of restoration action
Mechanism of movement	Provide context and scope for: Managing invasive species Determining species vulnerability to potential dispersal barriers (roads etc.) Ensuring co-dependents and/or vectors are considered Determining species' capacity for movement Evaluating changes to passive movement associated with changing climates	E.g., some plants cannot persist in reserves if the movement of their pollinators is not also considered (Brosi et al. 2008)	E.g., sessile species may need to be translocated (Thomas 2011)	E.g., weeds carried by vehicles may spread faster, and become nationally significant (Hulme 2009)	E.g., co-dependencies between some plants and animals means that colonization and recruitment of some species needs to occur in concert with others (Kaiser-Bunbury et al. 2010)
Type of movement Station keeping	Provide context and scope for: Ensuring appropriate home range area Providing for special foraging or territorial needs Assessing scale of impact, and scale required for action to be assessed	E.g., reserves intended to protect particular species need to ensure station-keeping requirements can be met for enough individuals to form a viable population (Schofield et al. 2010)	E.g., management actions need to ensure enough area can be conserved or restored to sustain a viable population (Reed et al. 1988)	E.g., even small scale impacts can have serious consequences for species which occupy narrow home ranges (Wolf et al. 2013)	E.g., restoration patches that are too small might prevent colonization by species with larger home range requirements (Lindenmayer et al. 2008)
Dispersal	Provide context and scope for: Managing invasive species Assessing scale required for action Minimizing barrier effects for dispersal-limited species Maximizing colonization potential for dispersal-limited species Predicting capacity for range shifts due to climate change Assessing role of vegetation in functional connectivity	E.g., species capable of dispersing greater distances will be able to shift ranges in response to climate change more rapidly – it may be more effective to create reserves farther from the current ranges (Travis et al. 2013)	E.g., habitat patches across a smaller region may need to be considered for protection, restoration and threat mitigation measures if species are dispersal limited (With and Crist 1995)	E.g., individuals will not be able to move away from impacted sites if suitable 'stepping stone' patches do not exist within a certain distance (Saura et al. 2014)	E.g., habitat restoration measures will be most successful if carried out at a distance within the dispersal capabilities of target species from existing occupied habitat (Moir et al. 2005)
Nomadism	Provide context and scope for: Developing climate change adaptation strategies Accommodating dynamic nature of ecosystems and species' distributions	E.g., seasonal resources may change, leading to changes in foraging ranges of species. Static or small conservation reserves may not work for some species (Frederick et al. 1996)	E.g., extreme events such as drought and fire will cause nomadic species to select refugia that continue to provide resources, such as fertile waterways (Bennetts and Kitchens 1997)	E.g., sites may not be occupied by species of interest at the time of surveys, but may still provide or have the capacity to provide important resources following certain climatic cues (Bull et al. 2013)	E.g., restored habitat may buffer against climatic shifts and or provide refuge for nomadic species (Melvin et al. 1999)

Table 1 continued

Aspects of movement knowledge	National Scale Policies and Strategies	Reserve planning and management	Species protection and recovery	Impact and risk assessment	Prioritization of restoration action
Migration	Provide context and scope for: Meeting international obligations Accommodating migration corridors Assessing impacts on tourism	E.g., protection of areas important for species such as turtles and whales will be beneficial for both conservation and local economies (McCook et al. 2010)	E.g., adequate amounts of both breeding and non-breeding habitat need to be available to migratory species if populations are to remain viable (Saunders and Heinsohn 2008)	E.g., consistently used travel routes will need to be remain free of disturbances and barriers if species are to successfully undertake movements to and from breeding grounds (Hart et al. 2002)	E.g., signatories to international treaties on species migration should consider how restoration actions could be spatially prioritized to best support migratory species (Nehlsen 1997)
Moderators of movement Habitat connectivity	Provide context and scope for: Designing large-scale corridor and revegetation strategies Assessing reserve connectivity and performance Determining importance of connectivity for reducing species' extinction risk Minimizing barrier effects	E.g., local catastrophes could jeopardize the function of reserve networks if they are not adequately connected to allow for re-colonization (Pressey et al. 2007)	E.g., maintenance of connectivity may be vital for species which exist as meta-populations, to maintain genetic diversity (Hale et al. 2013)	E.g., activities which alter vegetation may create barriers to dispersal. Mitigation actions need to restore functional connectivity (Dennis et al. 2013)	E.g., location of plantings should consider habitat connectivity, and its implications for facilitating or impeding the movement of different species (Lindenmayer et al. 2007)

Examples are not intended to be comprehensive and may apply to more than one category. References are provided as potential resources and should be consulted for further details. National scale policies and strategies provide context and scope for action within the four other broad environmental remits of government

different geographic and jurisdictional scales. This includes conventions or legislation at international, national, or regional scales, and on-ground management actions at regional or local scales. We have identified five categories of biodiversity policy and management that span this spectrum, and that involve decisions that might be influenced by different aspects of movement knowledge (Table 1). These categories are (1) national policies and strategies, (2) reserve selection and management, (3) species protection and recovery, (4) impact and risk assessments, and (5) prioritizing restoration actions. We present a framework for linking movement knowledge to decisions about biodiversity policy (Table 1) and illustrate this framework with examples from around the world to inform future research.

National Policies and Strategies

Policy content is developed by drawing on general concepts derived from empirical movement research. The extent to which policy makers are able to access movement knowledge will influence the policy structure and content in ways that filter down to influence implementation and monitoring. For example, Australia's National Wildlife Corridors Plan (Australian Government 2012) includes a range of movement concepts, such as landscape permeability, migration, the range of different scales that species need to move, and the diverse landscape elements that can contribute to enhancing movement.

The environmental functions of national governments are guided by international conventions and high-level policies. For example, the Convention on the Conservation of Migratory Species of Wild Animals (United Nations Environment Program 1979) aims to deliver policy on the conservation and management of migratory species and their habitat within national boundaries. Similarly, the Ramsar Convention conserves wetlands used by migratory birds, based on knowledge about migratory routes and main stopover sites which are critical for this convention to be effective (Overdijk and Navedo 2012). These international agreements often provide the context and scope for national policy. Indeed, there are many regional trans-boundary agreements critical for conserving threatened and endangered species, and managing ecosystems at risk of invasion by alien species. For example, in Africa, the Nairobi Convention (United Nations Environment Program 1985) includes protocols with sections on migratory species (Article 6), alien species (Article 7), and protected areas (Article 8), all of which rely on knowledge of species' movement.

The objectives of many multilateral agreements on biodiversity conservation are implemented by the actions of national governments. These agreements help guide reserve design, threatened species management, restoration, and impact assessment, and thus, movement knowledge is required for actions to be effective (Table 1). For example, many countries have developed National Biodiversity Strategies and Action Plans (NBSAP) in response to Article 6 of the Convention on Biological Diversity (United Nations 1992). Conservation targets within these plans (https://www.cbd.int/nbsap/targets/default.shtml) often have explicit links to species movement. Target 5 of Australia's NBSAP states "By 2015, 1000 km^2 of fragmented landscapes and aquatic systems are being restored to improve ecological connectivity" (Commonwealth of Australia 2010). To achieve ecological connectivity, knowledge of species' dispersal abilities, and the arrangement and type of vegetation that provides habitat connectivity, is required (Table 1). Understanding how movement can be modified, for example, by different kinds of land use (Driscoll et al. 2013) is also critical.

The extent to which policy makers can access movement knowledge influences international and national policy structure and content, and subsequently, the programs developed to implement policies and monitor their outcomes. By referring to our framework of movement knowledge and biodiversity policy (Table 1), revisions or new policies and conventions have the potential to be more explicit about the type of movement knowledge that is needed.

Reserve Selection and Management

Protected areas form the cornerstone of global and national conservation initiatives, and their establishment is widely accepted as the most effective means of conserving biodiversity (World Resources Institute et al. 1992). Many types of movement knowledge, such as station keeping and habitat connectivity (Table 1), are relevant to reserve design and management. For example, to sustain a minimum viable population of target species, reserves have to be large enough to encompass species' home ranges, determined by their station-keeping movements, and this may not be possible for wide-roaming species (Soulé 1985). One well-known case study—of the movement of large mammals such as wolves, cougars, and grizzly bears across thousands of kilometers of the western side of North America highlighted this problem (Shafer 1995) and led to the establishment of the Yellowstone to Yukon Connectivity Conservation Initiative (Levesque 2001).

The connectivity of unprotected landscape between reserves is widely acknowledged as critically important to conservation planning (Franco et al. 2009; Mokany et al. 2013). Building upon the concepts of metapopulation dynamics (Hanski 1998), reserves can be seen as reasonably stable habitat patches surrounded by less secure and potentially less suitable habitats in the matrix. If individuals can move through the matrix, even if it is providing only transient connectivity (Zeigler and Fagan 2014), then the reserve network may be able to maintain gene flow when species become locally extinct through re-colonization (Hanski 1998). However, matrix habitats are heterogeneous and tend to facilitate or impede movement in a species-specific manner (Driscoll et al. 2013), and this needs to be taken into account when making management decisions.

Sophisticated methodologies for the spatial optimization and prioritization of reserves are constantly being improved to take into account the needs of different species, or sets of species (see Box 1). Optimization includes, for example, utilizing information about emigration rates and movements of individuals (Haight and Travis 2008) to understand species' requirements, which might influence both reserve location and size. Approaches have been developed to assess the relative value of landscape elements in reserve systems, and take into account the size and quality of protected areas, the connectivity of the intervening landscape, and underlying demographic processes (e.g., Drielsma et al. 2007). Methodologies such as

Box 1 Incorporating movement knowledge into reserve design

A range of planning tools employing mathematical algorithms have been developed to help prioritize the spending of limited resources on the allocation of conservation reserves (Moilanen et al. 2009). These tools initially worked simply from geometric principles and increased the connectivity or contagion of a reserve system by applying penalties for increased boundary length of patches, thereby minimizing fragmentation (Stewart et al. 2003). It is now possible to incorporate knowledge of movement type and movement moderation (see Table 1) into reserve design. For example, the dispersal behavior of individual species can now be incorporated into two-dimensional smoothing kernels (Moilanen 2005) and by addressing the fact that the flow of organisms may be directional, as is often the case in riverine systems (Beger et al. 2010). Other approaches account for the way in which different landscape elements present varying levels of resistance to species movement (McRae et al. 2008), though in order to ensure efficient solutions, the outputs from these need to be incorporated into optimization software and adequate data about dispersal need to be collected (Driscoll et al. 2014). With the rapid development of telemetry technology (Bograd et al. 2010), it is likely that this field will evolve to account for even more dynamic and complex aspects of movements, such as seasonality and individual behavior.

these, which explicitly consider both movements of target species and the objectives of reserve establishment (such as ensuring species viability), will better cater for different species' movement requirements when implementing conservation policies.

Species Protection and Recovery

Knowledge of species-specific movement ecology such as dispersal ability and station-keeping movements (Table 1) can be used to help assess and prioritize species at risk of not being able to move as required and which might require protection under environmental legislation. Threatened species are often affected by habitat fragmentation, and this leads to elevated risks of isolation and inbreeding or local extinction due to random catastrophic events. For example, forest fire suppression in the Missouri Ozarks, USA disrupted movements of collared lizards, reducing their genetic diversity and adaptive potential (Templeton et al. 2001). Genetic studies revealed the effect of fire suppression on the movement of the lizards, leading to land management practices that re-established natural fire regimes and resulted in restoration of movement, metapopulation structure, and genetic diversity of the lizards (Templeton et al. 2011). For species that have experienced severe habitat fragmentation, other strategies that may improve or enhance movements of individuals include the establishment of habitat corridors, gamete transfer, or translocations (Trakhtenbrot et al. 2005; Tuberville et al. 2005).

Knowledge of variations in home ranges can be fundamental to developing strategies and actions for the management of threatened species because it can be linked to social and mating interactions, habitat quality, population densities, seasonal and annual variation in climate, and the availability of food resources (McGlynn et al. 2003; Schofield et al. 2010). For example, koalas in eastern Australia alter their station-keeping behavior during extremely hot days and move into taller trees that provide more shelter (Crowther et al. 2013). It is likely that many species alter their foraging behavior during drought conditions, resulting in temporary changes to the home ranges of many species across the affected regions. Knowledge of these fluctuations in movement behavior suggests that identifying and protecting refugia is an important consideration for the protection and recovery of some threatened species.

Impact and Risk Assessment

Knowledge of species nomadism and associated habitat connectivity (Table 1) can inform impact mitigation strategies. In many countries, Environmental Impact Assessments (EIAs) are carried out in response to proposals for agricultural, industrial, and urban developments, and consider the likelihood and the consequences of negative environmental impacts (Burgman 2005). Despite the time and effort dedicated to EIAs, some species of interest may go undetected (Wintle et al. 2005). This is especially problematic if species occupy broad home ranges, or if the sites to be developed contain resources only following particular environmental phenomena such as rainfall or fire. Mongolian gazelles, for example, have very large ranges of over 10,000 km^2 (Olson et al. 2010), but the nomadic movement of individuals between potential feeding areas can be restricted by livestock fencing and roads. The migratory swift parrot (*Lathamus discolor*) occupies a broad overwintering range on the Australian mainland, with specific foraging locations varying year to year depending on environmental conditions (Saunders and Heinsohn 2008). The difficulty in predicting these movements, and uncertainty about the significance of sites, is a clear example of how policy and management problems can inform research directions.

Development can also threaten connectivity between fragmented populations of species. For example, the growling grass frog (*Litoria raniformis*) in Melbourne, Australia, occurs as a metapopulation, and sub-populations directly overlap with the urban growth boundaries for the city (Heard et al. 2010). The species is at risk of localized extinction and populations becoming genetically isolated when dispersal pathways are blocked by urbanization (Hale et al. 2013). Conservation strategies developed through an environmental impact assessment and approval for this species that risks of reduced connectivity are addressed through the retention of habitat corridors and habitat offsets (DPIE 2013). Habitat corridors or offsets are often prescribed to compensate for the loss of habitat caused by developments.

Prioritizing Restoration Actions

Restoration of habitat to increase the amount and diversity, or configuration and connectivity of native vegetation cover, can reduce or reverse threats to diversity caused by fragmentation and loss of connectivity between natural areas. Decisions regarding habitat restoration might involve which projects to fund if several options are available. These decisions should consider which options satisfy the movement ecology of different species, and especially mechanisms of movement, dispersal ability, and habitat connectivity (Table 1), so as to provide the best biodiversity outcome.

For revegetation projects, knowledge of species' dispersal to and from existing habitat patches might inform decisions about the spatial location, size, composition, and configuration of new plantings, particularly because dispersal influences the ability of species to colonize revegetated areas. For example, the size of a revegetated area can affect population densities of birds (Kavanagh et al. 2007), with larger patches supporting larger populations, thus potentially altering dispersal dynamics. Alternatively, the proximity of plantings to remnant vegetation can also affect the number and type of species able to colonize plantings (Lindenmayer et al. 2010); however, this could also lead to rapid genetic homogenization of native populations following massive planting efforts (Steinitz et al. 2012), highlighting the need to consider the consequences of species' movement before taking restoration action.

When considering alternative restoration actions, and expectations for progress, decision makers should consider mechanistic movement knowledge, such as the capacity or mode of dispersal. Differences in dispersal capacity will result in a different temporal pattern of species arrival at new habitat created by a planting. For example, highly mobile and flight-capable insects, bats, and birds have far greater potential to quickly colonize and establish populations in restored sites, while slow moving or dispersal-limited species will take longer to arrive (Golet et al. 2011). Arrival is also affected by other moderating factors which can interact with movement capacity. Although wind-dispersed plants might seem to have high capacity for colonization, fragmentation of their habitat can impair this capacity (Soons and Heil 2002). Yet, understanding movement, as illustrated by applying advanced mechanistic wind dispersal models to explore plant population, and community dynamics in experimentally fragmented landscapes can assist by informing actions to enhance or maintain connectivity (Damschen et al. 2014). Co-dependencies between many species, such as those between some plants and their animal dispersers (Robinson and Handel 1993), might also affect the arrival and colonization of areas by particular species. Among these many factors that need to be considered, an understanding of movement knowledge has significant potential to inform action priorities, as well as the expectations for how effective restoration actions might be in the short and long term.

Horizons and Emerging Policy Opportunities

Technological improvements (e.g., reduced size and greater efficiency of tracking devices, faster sampling, analysis of genetics, and nanotechnology) are pushing back the limitations in investigating the movement of organisms (Tesson and Edelaar 2013). Trait databases, such as the plant seed dispersal database 'D3' (Hintze et al. 2013), continue to be developed and will present new opportunities for meta-analyses that reveal movement knowledge of different species (Travis et al. 2013). Recently developed tools can now link environmental data to movement paths (Dodge et al. 2013), facilitating the detection of movement-environment interactions which are relevant to biodiversity policy and management. Such environmental effects could be counter-intuitive, for example, the finding that fire can substantially increase wind-mediated gene flow in a pine population (Shohami and Nathan 2014). Existing knowledge of movement patterns is focused on a few well-studied species (Hodgson et al. 2011), and generalizing from models of these taxa is therefore a challenge for researchers. Future research will benefit from emerging analytical techniques that accommodate the multi-scaled processes involved in movement, such as hierarchical models (Schick et al. 2008) and from interdisciplinary collaboration (Damschen et al. 2014; Holyoak et al. 2008).

Another developing issue relevant to movement knowledge is the accelerating trend toward protected area downgrading (reduction in legal protection), downsizing (decrease in size), and degazettement (loss of legal protection) (PADDD; Mascia and Pailler 2011). The continuation of this pattern may further fragment habitats and, as such, will have important implications for the movement of species among patches and across landscapes. There is a pressing need for improved knowledge of species' connectivity requirements within existing protected areas to provide evidence that PADDD decisions will not further threaten biodiversity.

Under projected climate change scenarios, large shifts in the distribution of biomes are expected to alter the distribution of biodiversity and ecosystems (Butchart et al. 2010), driving the shift of many species to higher altitudes, latitudes, and deeper oceanic depths (Pereira et al. 2010). In addition to direct changes to temperature and rainfall patterns, changes to the biophysical environment and evolutionary changes to organisms could directly and indirectly affect dispersal and migration routes (Travis et al. 2013). Furthermore, complex interactions with other anthropogenic threats (e.g., habitat fragmentation, altered disturbance regimes) may exist (Driscoll et al. 2013). The prioritization of habitat connectivity to facilitate species' movement in light of climate change has been vigorously debated (Hodgson et al. 2011), and policy decisions about adequate habitat area, species movement pathways, and changes in movement behavior will benefit greatly from movement knowledge.

Conclusion

Here, we have demonstrated how central movement knowledge is to multiple levels of biodiversity policy, and have provided a new framework for linking multiple levels of movement knowledge and biodiversity policy. The growing appreciation of the importance of movement ecology in biodiversity research (Jeltsch et al. 2013) suggests that movement research will increasingly support biodiversity conservation decisions. Biodiversity conservation presents many opportunities for engagement between researchers and decision makers to make advances in the practical application of movement ecology. Initiatives such as the Australian Government National Environmental Research Program (NERP) provide ideal models for the integration of science with policy (van Kerkoff 2005). This review was a direct outcome of NERP activities and provides an example of the types of science/policy integration that can be developed if these programs continue. We identified important links between movement science and biodiversity policy but integrating, synthesizing, and preparing movement knowledge for specific decisions remains a challenge in applied biodiversity conservation. Greater collaboration, the use of high-quality movement knowledge, and an understanding of risk and uncertainty in its absence will strengthen the legitimacy of decisions and promote positive movement-related biodiversity outcomes.

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