Introductory Research Essay

Movement ecology to the rescue: optimising the management of moving animals

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INTRODUCTORY ESSAY

MOVEMENT ECOLOGY TO THE RESCUE: OPTIMISING THE MANAGEMENT OF MOVING ANIMALS

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Introduction

Studying animal movement has long been of interest to scientists and has resulted in a diverse field of research that addresses numerous aspects of animal movement such as the mechanics of movement, understanding movement patterns, determining cues or drivers of movement and the potential consequences of movement (Dickinson et al. 2000; Rubenstein & Hobson, 2004; Bowler & Benton 2005; Patterson et al. 2008; Singh et al. 2012). Such studies have underlined how important movement is for population dynamics (Johnson et al. 1992; Morales et al. 2010) and ecosystem function (Holdo et al. 2011). Research has also shown how movements are being influenced by anthropogenic factors such as climate change (Singh & Milner-Gulland 2011) and landscape change (Fahrig 2007) and how these impacts are threatening several types of movements such as the decline of migratory behaviour (Wilcove & Wikelski 2008; Harris et al. 2009; Shuter et al. 2011) or threats to dispersal (Pearson & Dawson 2005; Schtickzelle et al. 2006; Baguette & Van Dyck 2007). Understanding animal movement is also important because of the numerous consequences it has for ecosystems, population dynamics and human interactions. Animal movement provides ecosystem services by connecting habitats in both space and time (Lundberg & Moberg 2003) through processes such as nutrient transfer, such as the transfer of nutrients from the sea to land (Ellis et al. 2006), facilitating the movement of other organisms such as invertebrates (Green & Figuerola 2005) and through seed dispersal (Myers et al. 2004). Animal movement affects population dynamics through factors such as range expansions with potential consequences for invasive species spread, such as the cane toad (Phillips et al. 2008) or species response to climate change (Hickling et al. 2006). Another important consequence of animal movement, especially with regards to management, is that it leads to human-wildlife interactions. These may be positive interactions but for management these interactions are often negative such as predation of livestock (Thirgood et al. 2005), traffic accidents (Seiler 2004) or even personal injury (Thirgood et al. 2005). These negative interactions are described as human-wildlife conflicts (HWCs) and managing them remains a constant challenge in conservation biology.

The numerous effects of animal movement have meant that the field has become an important consideration for wildlife and conservation managers, for instance how to preserve movement behaviours and to manage the consequences of movement. Traditionally, spatially explicit approaches such as protected areas (PAs), designated hunting areas and reserves have been used to manage moving animals. However even the largest PAs fail to fully protect a species (for e.g. Thirgood et al. 2004). Once animals move outside of PAs they are often exposed to exploitation (Holdo et al. 2010) or considered pests (Woodroffe & Ginsberg

1998). In addition, most PAs occur in a landscape where multiple types of natural resource extraction occur (Sanderson et al. 2002), potentially resulting in habitat degradation in surrounding areas (Ewers & Rodrigues 2008; Hansen & DeFries 2007) and isolation through fragmentation (Chape et al. 2005; Naughton-Treves et al. 2005). Consequently, alternative approaches are being developed to conserve wildlife outside of protected areas, such as temporary closures in marine and freshwater ecosystems (Hunter et al. 2006; Game et al. 2009) and wildlife corridors that improve landscape connectivity (Bennet 1998; Schmiegelow 2007). However, there has been much debate about their effectiveness (Simberloff et al. 1992; Beier & Noss 2008; Gilbert-Norton et al. 2010) and that they potentially draw attention away from some of the broader issues such as improving the amount of high quality habitats (Hodgson et al. 2009; Hodgson et al. 2011). These static management approaches of PAs and corridors fail to consider the dynamism of movement, such as the scale of movement, the varying movement strategies within the same population and whether movements are seasonal occurrences or single lifetime events. A limitation though is that until recently, scientists, researchers and managers knew very little about the movements of their focal species. Recent discoveries such as the transoceanic migrations of 11,000km in less than 100 days by Great white sharks (*Carcharodon carcharias*; Bonfil et al. 2005) and being able to identify a migratory birds' wintering grounds in the remote forests of Central Africa (Åkesson et al. 2012) underline how limited our knowledge was. Our knowledge is far from complete but tools are now becoming available to understand where an animal goes, why it goes there and how it gets there.

This review will outline a number of recent advances in movement ecology and show how the knowledge gained can be used to guide management planning and develop a more dynamic approach to the management of moving animals. The numerous advances in movement ecology in both technological and analytical capabilities will be introduced followed by how these advances are contributing to the management of long distance and local movements. These movements occur within a landscape of multiple uses leading to human-wildlife interactions that may result in threats and conflicts to management interventions. Important considerations regarding animal movement and stakeholder collaboration will be discussed alongside recent advances in social systems addressing stakeholder collaboration. Finally, the review will discuss the many levels that uncertainty may manifest itself and the implications this has for the management of animal movement. The numerous advances and considerations for the management of animal movement are synthesised and illustrated in a management framework developed around a species movement ecology.

Movement Ecology

Technology & Analysis

The field of movement ecology has advanced rapidly in recent decades due to a number of advances in technological and analytical capabilities. One of the major advances is global positioning systems (GPS) (Robinson et al. 2010; Tomkiewicz et al. 2010) which provide the opportunity to greatly enhance our knowledge of a species' ecology by following its fine-scale movements, even for highly cryptic species (Cagnacci et al. 2010). There have also been numerous other technological advances that enable us to track animal movement such as light-level geolocators (Stutchbury et al. 2009; Åkesson et al. 2012), acoustic animal tracking in the ocean (Costa et al. 2012) and stable isotopes (Rubenstein & Hobson 2004). The resultant movement data is being used to understand migratory movements in terms of wintering areas (for e.g.Harris et al. 2010; Campana et al. 2011), staging areas or stopover sites (Sawyer et al. 2009; Delmore et al. 2012) and migration corridors or potential barriers to migration (Schrank & Rahel 2004; Sawyer et al. 2013; Ito et al. 2013). The new technologies are also enhancing our knowledge of local movements in the landscape, such as improved estimation of home ranges that include temporal variation in space use (Börger et al. 2008; Kie et al. 2010), identifying habitats selected (Chetkiewicz et al. 2006; Godvik et al. 2009) and dispersal capability (Koenig et al. 1996; Nathan et al. 2003). Movement data may also be complemented with physiological, environmental or behavioural data obtained through biologgers that record information such as body temperature, heart rate or acceleration (Cooke et al. 2004; Rutz & Hays 2009, Signer et al. 2010). This information can be used to improve our understanding of energy expenditure for behaviours such as moving, feeding or reproduction and may indicate how species are able to adapt to their environment (for e.g. Signer et al. 2011).

These technological advances have been complimented with new ways of analysing animal movement data, which aim to incorporate the variety of information now available whilst minimising error inherent in the data (Dalziel et al. 2008; Frair et al. 2010; Hebblewhite & Haydon 2010). Methods have been developed to identify the variety and proportion of movement strategies in a population, such as sedentary, nomadic, dispersal and migratory movements (Bunnefeld et al. 2011; Börger & Fryxell 2012; Singh et al. 2012). Methods for analysing local movements such as home ranges have also advanced significantly by incorporating measures of space use such as the utilisation distribution (UD; Worton 1989). Methods for estimating UDs are advancing rapidly by initially calculating the UD based on an animal’s movement path instead of individual points (for e.g Brownian bridges; Horne et al. 2007) and more recently by incorporating movement bias between points (Benhamou 2011) and behavioural changes (Kranstauber et al. 2012). Incorporating measures of space use means that the UD can be combined with habitat selection studies (for e.g. Marzluff et al. 2004; Allen et al. *in prep*) to determine factors that influence the home range patterns of animals. Understanding how the movement paths of animals are influenced by features in the landscape may be assisted through new techniques that visualise animal movement data (Shamoun-Baranes et al. 2012). New methods of visualising data relate the movement paths of animals to features in the landscape or of individuals in relation to each other (Kavathekar et al. *in press*) which makes the results of studies more accessible and easier to understand for both scientists and managers alike. These advances are contributing significantly to our knowledge of animal movement and subsequent understanding of a species’ ecology. The next vital step is that wildlife managers/conservationists incorporate this knowledge into management strategies.

Implications for long-distance movements

One of the key benefits of the recent advances made in movement ecology is that the findings can be used to develop dynamic management strategies that identify the optimal scale of management for species level conservation. The management of migratory species is one of the obvious examples of how findings in movement ecology are changing management approaches. In the past, migratory species would disappear during the winter and wildlife managers were left to hope that it would return. However, as we have learnt where species go, management approaches have moved beyond protecting summer ranges only with efforts also being focused in winter areas too. Understanding where animals go is also important for predicting future change such as habitat availability or shifting distributions (Robinson et al. 2009; Singh & Milner-Gulland 2011). As a result of discoveries in animal migration, management plans have been up-scaled to transnational and transcontinental actions that aim to maintain migratory connectivity, i.e. the movement of individuals between summer and winter ranges including stopover sites (Webster et al. 2002). This does raise issues such as the optimal allocation of resources (Martin et al. 2007; Carwardine et al. 2008) but these issues are now being considered at the scale necessary for the conservation of migratory species.

In addition to understanding where migratory species go, movement ecology is providing important insights into the drivers of why and when animals decide to migrate. A number of cues and drivers may influence an animal's decision to migrate such as precipitation, temperature and productivity (Bauer et al. 2011; Sawyer et al. 2011; Singh et al. 2012). This knowledge is important for managers because it provides information on how environmental changes influence migratory decisions and in turn, the stages of a species life history that it becomes exposed to additional threats. For example, determining the cues of migratory movements could benefit management of species such as the leatherback sea turtle (*Dermochelys coriacea*) by establishing time-area fishing regulations (Sherrill-Mix et al. 2007). Temporary PAs has been a recurring theme for the management of pelagic systems (Hyrenbach et al. 2000; Game et al. 2009) which contain many concepts that can be applied to terrestrial and coastal systems. For example, actions could be taken such as placing hunting/fishing restrictions during the migratory period which would benefit exploited animals such as ungulates, birds and fish. This could be enhanced by replacing the concept of static PAs with that of moving PAs which track the annual movements of the focal species, such a system is currently being considered for the Saiga antelope (*Saiga tatarica*) in Uzbekistan (Bull et al. 2013). The findings from movement ecology are essential to developing temporary or moving PAs, as it would only be effective if the PAs are spatially and temporally appropriate and thus relies on our knowledge of where, when and why an animal decides to move. Finally, longitudinal studies of why and when an animal decides to move will help determine how species are able to adapt to environmental change, for example, a study of migratory birds indicated that declining species had not adapted the timing of their migrations to match the earlier springs (Møller et al. 2008). Therefore management actions can be targeted to those species that are less able to adapt to environmental change. These advances in our understanding of migratory movements illustrate how movement ecology is a vital component for the management of migratory species and its necessity for identifying the optimal spatial and temporal scale of management.

Implications for local movements

It is not only the management of migratory species that is benefiting from the advances made in movement ecology. Management strategies are now able to incorporate the local movements within the landscape and the subsequent consequences of those movements. Some of the more obvious advances include improved estimation of home ranges to better understand the local movement patterns of animals. Therefore wide ranging animals will require management actions at larger scales than animals with smaller home ranges, such as the wolf (*Canis lupus*) with mean home ranges of 611km^2 compared to coyotes (*Canis latrans*) with mean home ranges of just 42km^2 (Nilsen et al. 2005). Previous research has indicated how conservation interventions have been less effective when the home ranging patterns have not been considered (e.g. Moffitt et al. 2009). The scale of movements of animals and the resultant home ranges determines the level and type of threats it may be exposed to, such as exploitation and habitat degradation. Therefore, knowledge of home range patterns is important for developing management strategies at the right scale to both manage threats and mitigate potential HWCs.

Managers are also improving their understanding of the features in the landscape that are important for the persistence of a species. This is being facilitated by uniting movement data with the habitat characteristics associated with those movements. The improvements made in GPS accuracy and the tools available to resolve imprecise locations (Frair et al. 2010) has meant that higher resolution habitat maps can be used. Satellite imagery such as Landsat with 30m resolution is commonly used however Very High Resolution (VHR) satellite imagery with resolutions less than 4m are now available (Mumby & Edwards 2002; Gottschalk et al. 2005). It is also possible to combine the satellite imagery of habitats with descriptive details such as the habitat structure using technologies such as airborne laser scanning (Melin et al. 2012). These developments provide increasing opportunities to further our understanding of the drivers of animal movements and subsequent habitat selection patterns. This knowledge can be used in several ways to enhance the management of a species within a landscape. Habitat selection models identify which habitats are important to a species and thus whether a species has enough habitat in the landscape to persist (Fahrig 2001), determine habitat suitability (Hirzel & Lay 2008) and to improve ecosystem management (McDonald & McDonald 2002). Habitat selection models also improve our knowledge of how adaptable species are and whether they are able to adapt to habitat loss and fragmentation, such as the ability to utilise resources in the matrix (Ewers & Didham 2006) or to move through the matrix between suitable habitats (Fahrig 2007).

Understanding the relationship between the movement patterns of a species and the habitat characteristics is also vital for determining landscape connectivity, i.e. “the degree to which the landscape facilitates or impedes movements among resource patches” (Taylor et al. 1993). This is particularly relevant for understanding how the landscape structure influences the dispersal behaviour of an individual, otherwise known as functional connectivity (Baguette & Van Dyck 2007). Studies into dispersal ability and propensity are being used to determine how species will be affected by climate change and habitat fragmentation (Jaeschke et al. 2013; Schtickzelle et al. 2006). Movement ecology studies of dispersal have shown how habitat fragmentation may limit dispersal (Lu et al. 2012), influence the dispersal patterns of sedentary and nomadic species (Baguette et al. 2012) or result in adaptations to better cope with fragmented habitats (Cheptou et al. 2008). Dispersal is a vital process for population viability and determines the gene flow between populations, colonisation of new habitats and the potential to rescue threatened populations. Including knowledge about the dispersal characteristics of a species is therefore vital to developing an effective management strategy.

Multiple Use of the Landscape

Unfortunately, it is impossible to develop a management strategy that only considers the ecological requirements of a species. Animals live in a landscape of multiple uses involving multiple stakeholders and it is essential to incorporate these users into conservation planning. Traditional approaches to conservation by nature protectionists has been to exclude humans through instruments such as people-free parks (Miller et al. 2011) but these approaches fail to incorporate the human dimension. In contrast, the approaches adopted by social conservationists include sustainable development or conservation through poverty alleviation (Miller et al. 2011), but these may be over-ambitious in seeking win-win scenarios (Adams et al. 2004). Both these groups have differing opinions on the value of PAs to the conservation of biodiversity. Fortunately, recent approaches to conservation have been moving away from nature protectionist or social conservationist views of PAs or not. Instead, approaches are now looking to incorporate the wider landscape, thus including PAs and the surrounding mosaic of land uses in the landscape (Wiens 2009). This is reflected in the adoption of landscape conservation approaches by major international non-governmental organisations (NGOs; Pressey & Bottrill 2009) such as the African Wildlife Foundation (AWF; Henson et al. 2009) and The Nature Conservancy (TNC; Green et al. 2009).

An important theme in these landscape approaches is the inclusion of stakeholders in the early stages of the planning process, by first identifying and then involving stakeholders (Pressey & Bottrill 2009), and thus considering the multiple uses of the landscape. It is at this step that knowledge of the movement ecology of a species is important so that stakeholders are included at the scale that animal movements result in wildlife-stakeholder interactions, such as exploitation or HWC. Over-exploitation of wildlife is a major cause of species decline (Milner-Gulland et al. 2001; Bolger et al .2008) and migratory species may have higher threats due to exploitation pressures by different stakeholder groups, such as in the winter or summer ranges and during the migratory pathway (Shuter et al. 2011). For example, migratory birds may be effectively conserved in their summer and winter ranges of Europe and Africa respectively, but populations may continue to decline due to uncontrolled exploitation pressures on the Maltese Islands, an important migratory pathway (Raine 2007; Kirby et al. 2008). Traits of many migratory species such as the predictability of routes, their timing and the higher densities may also increase the risk of exploitation (Bolger et al. 2008; Shuter et al. 2011). Therefore, for a management strategy to be effective, it is necessary to incorporate stakeholders at all scales, from the smaller scale localised movements to the larger scale of migrations.

In addition to exploitation pressures, another important consideration when identifying stakeholders is the potential HWCs that may arise. In multiple use landscapes, wildlife may affect the livelihoods of numerous stakeholders through HWCs such as crop-raiding, loss of livestock and property damage (Thirgood et al. 2005; Singh & Bagchi 2013). These HWCs are an important consideration for management planning because a common response to wildlife that causes damage to human livelihoods is lethal control (Woodroffe et al. 2005). Lethal control has been the primary cause of extinction for several species and may even lead to wider impacts on the ecosystem where keystone species are concerned, such as conflicts with Sea otters (*Enhydra lutris*) and elephants (Woodroffe et al. 2005). To manage and prevent these conflicts it is necessary to understand the movement patterns of these animals to a) identify the scale at which stakeholders may experience HWC and b) develop plans to mitigate the impacts of HWC. Methods for incorporating stakeholders into management planning have advanced rapidly as social systems are increasingly utilised (for e.g. Ban et al. 2013). These tools are improving the communication between stakeholders, scientists and wildlife managers, thus allowing negotiations between effected parties which clarify the necessary compromises and trade-offs (Redpath et al. 2013). If stakeholders understand and agree to the trade-offs of a management approach, previous issues regarding loss of trust or disenchantment with management strategies (McShane et al. 2011) can be overcome. Instead, alternative schemes can be developed, such as compensation for loss of livestock (Swenson & Andren 2005), thus increasing stakeholder tolerance of HWC. Understanding the scale at which these management actions are required will reduce the levels of uncontrolled HWC and improve management outcomes.

One of the challenges of managing wildlife and including relevant stakeholders is that transnational actions may be required as a result of the species' movements. In the earlier example of the conservation of migratory birds, management actions would be required in the summer ranges in Europe, the winter ranges in Africa and the countries on the migratory pathways, particularly migration bottlenecks such as Malta (Kirby et al. 2008). A failure to implement management actions across a species' entire range may mean that local management interventions are ineffective due to threats outside the scale of management. Although international management actions may be strategically, economically and logistically challenging to implement, they may provide a number of opportunities. Transboundary initiatives may resolve the conflict between nations and promote international collaboration, an initiative that has become known as peace parks, such as the establishment the Condor-Kutuke conservation corridor which alleviated many years of conflict between Peru and Ecuador (Ali 2007). Transboundary conservation areas also promote landscape level conservation by maintaining movement corridors and thus maintaining ecological links between ecosystems. The Great Limpopo Transfrontier Park was established with the aim of conserving the wider bioregion (Wolmer 2003) and research indicates that the Greater Virunga Landscape, incorporating 11 protected areas in three countries, has contributed to the recovery of the mountain gorilla (*gorilla beringei beringei*) and reduced the rate of decline for some ungulates by maintaining connectivity in the landscape (Plumptre et al. 2007). A challenge remains in maintaining stakeholder collaboration, as transboundary initiatives are frequently governed from the top down (Brosius & Russell 2003) in an effort to fulfil international commitments, thus overriding the objectives of local stakeholders (Mackelworth 2012). However, a number of international policies are available to guide international conservation efforts such as the Convention on Migratory Species (CMS) and the Ramsar Convention on Wetlands. Co-ordinating transboundary initiatives with third party facilitators, such as international NGOs, may contribute to maintaining transparency (Mackelworth 2012) and ensuring that the social objectives of stakeholders remain a consideration during the planning process.

Uncertainty

The review has indicated how advances in movement ecology have allowed management plans to incorporate the diverse nature of movement behaviours of animals, identify movement strategies in the population and adapt management plans to local movements and long distance migrations. The ways that animal movement interact with local stakeholders and their multiple use of the landscape has also been considered and how this influences the scale of management actions required. A further challenge regarding the management of moving animals is the dynamism of their movements and the uncertainty inherent in the system. Animals live in dynamic landscapes leading to different movement strategies (Mueller et al. 2011), and the proportion of strategies may vary according to the conditions animals are exposed to (Singh et al. 2012). It is also uncertain how future changes such as landscape modification, climate change and species' responses to management initiatives will lead to changes in observed movement patterns of populations. Langford et al. (2009) describe four ways in which uncertainty may manifest itself during the planning process. These include uncertainty in the inputs, uncertainty in matching the planning method to real world processes, uncertainty of future changes and uncertainty in the planning method achieving the desired outcomes. All four of these aspects of uncertainty are relevant to the management of moving animals and their implications for management will be discussed further below.

Uncertainty of the inputs occurs at several levels when considering animal movement. For example, for GPS data, there is uncertainty about the actual physical location of the animal, its behaviour during that timestamp, the external influences influencing that behaviour and the factors influencing an animal's position between two fixes (Jonsen et al. 2005; Schick et al. 2008; Hebblewhite et al. 2010). A number of modelling approaches have been developed to control for some of the uncertainty of the inputs, in both the data and the process (for e.g. Schick et al. 2008; Smouse et al. 2010; Gautestad et al. 2013). This data is being used to make a number of inferences about our understanding of animal movement, such as movement characteristics, habitat preferences and environmental cues and drivers of movement. As GPS technologies continue to improve, reducing the inaccuracy and increasing the frequency of fixes, alongside the continuing development of statistical approaches, the level of uncertainty regarding the inputs can be increasingly controlled. These advances directly benefit the second level of uncertainty regarding the planning process as a greater understanding of the real world systems reduces the risk of incorrect planning. A number of approaches have been developed to guide the planning process and thus reduce the risk of misguided planning, such as systematic conservation planning (Margules & Pressey 2000; Pressey & Bottrill 2009) and including the social considerations of real world systems through social-ecological approaches (Ban et al. 2013).

There are a number of areas of uncertainty with regards to future changes and animal movement. Movement strategies are adapted to the stability and predictability of resources in the landscape, which occurs along a spectrum with migratory animals on one end in variable but highly predictable landscapes, sedentary animals in stable landscapes with low variation and nomads in unpredictable environments (Mueller & Fagan 2008; Mueller et al 2011). How will animals adapt their movement strategies in response to changes in the climate and subsequent changes in the stability and predictability of the landscape? Adaptations to climate change have already been observed in bird migrations with some species adapting the timing and distance of migrations and some populations becoming only partially migratory (Crème et al. 1997; Jenni & Kéry 2003; Visser et al. 2009). A further uncertainty is how these adaptations will interact with anthropogenic influences on the landscape. These interactions may occur at several levels, for example red deer (*Cervus elaphus*) reduce their predation risk by altering their migration strategy and remaining close to human habitation which is avoided by their predators (Hebblewhite & Merrill 2009). Supplemental feeding of birds in winter increases their winter survival and may subsequently increase their reproductive fitness (Robb et al. 2008), potentially influencing the natural selection of resident or migratory strategies in a partially migrant population. The way that humans alter the landscape also creates uncertainty about how animal movement will change in the future, such as the implications of anthropogenic barriers (Sawyer et al. 2013), dispersal ability in fragmented landscapes (Baguette et al. 2012) and resource availability (Allen et al. *in prep.*). A field of science important for managing and understanding these future uncertainties is predictive science. Predictive science uses existing knowledge of ecological systems to develop realistic models that can be projected into the future whilst incorporating environmental change (Evans 2012). For example, species distribution modelling predicts the future distribution of species in response to climate change by incorporating, *inter alia*, the dispersal characteristics of a species, the structure of the landscape and suitable climate envelopes (Stanton et al. 2012; Travis & Dytham 2012). Subsequently, the continuing advances being made in movement ecology can be combined with new methods in predictive ecology, such as process-based ecological modelling (Evans et al. 2012) and pattern-orientated modelling (Grimm & Railsback 2012), to improve our understanding of species response to future change. These methods allow management plans to prepare for the future, and including uncertainties such as climate change provides an opportunity for scientists to assess our existing knowledge by comparing predicted species responses to reality.

The final element of uncertainty is whether the planning method will achieve the desired outcomes. An important aspect of managing this uncertainty is evaluating the effectiveness of management interventions and this has become an important field of research in the last decade (for e.g. Stem et al. 2005; Ferraro & Pattanayak 2006; Kapos et al. 2008). Due to the dynamic nature of animal movement, the multiple stakeholders in the system and differing levels of uncertainty, a management intervention will need constant evaluation so that methods and approaches can be modified and refined. The requirement of managing animal movement and its consequences falls well with the adaptive management framework. Williams (2011) describes the general features to which adaptive management is applied which include dynamic systems changing through time in response to environmental conditions, where the variation is only partially predictable, systems that are subject to management intervention and where effective management is limited by uncertainty. All of these features are relevant to the management of moving animals, and future uncertainties such as climate change provides to the opportunity to experimentally test our predictions of species response and existing knowledge. Therefore, an adaptive management framework for moving animals would use our existing knowledge of the movements of the focal species in a systematic process to identify management issues such as the scale of management required or the stakeholder collaboration. This information is used to generate and implement a management plan that requires constant evaluation to determine how management actions are performing. The outcomes of research and the knowledge gained from the evaluation process are used to update the management plan and thus become adaptive to changes resulting from management and from future uncertainty.

Synthesis

The review has outlined how advances made in the study of animal movements have made it possible to include this important aspect of ecology in wildlife management. This can be achieved through an adaptive management framework. The first step of an adaptive movement ecology framework (Figure 1) is to understand the type and scale of movements occurring within the targeted population. The scale of management may be based on the home range patterns of a sedentary species or the movements of a migratory species that incorporates a species entire range or the summer and winter ranges and stopover sites individually. A strategy can then be developed that identifies a minimum PA size required or whether it is necessary to establish a network of PAs that protects each site separately. The scale of animal movement will guide other management considerations, such as the scale of human-wildlife interactions in the landscape. Identifying all stakeholders ensures that threats and conflicts can be managed and also determines whether some management approaches are feasible. For example, PAs may not be suitable in some systems due to its impacts on stakeholder livelihoods. In such a system, knowledge of animal movement can be used to generate flexible management strategies, such as temporary or moving PAs based on drivers and cues of animal movement. Finally the management actions required for the focal species can be adapted based on its habitat requirements and the functional connectivity of the landscape. This process is nested within an evaluation framework that aims to understand how management interventions are influencing the focal species, the landscape and the stakeholders. A management framework that incorporates the movement ecology of a species has the potential to contribute significantly to understanding and improving the scale and dynamism of wildlife management necessary.

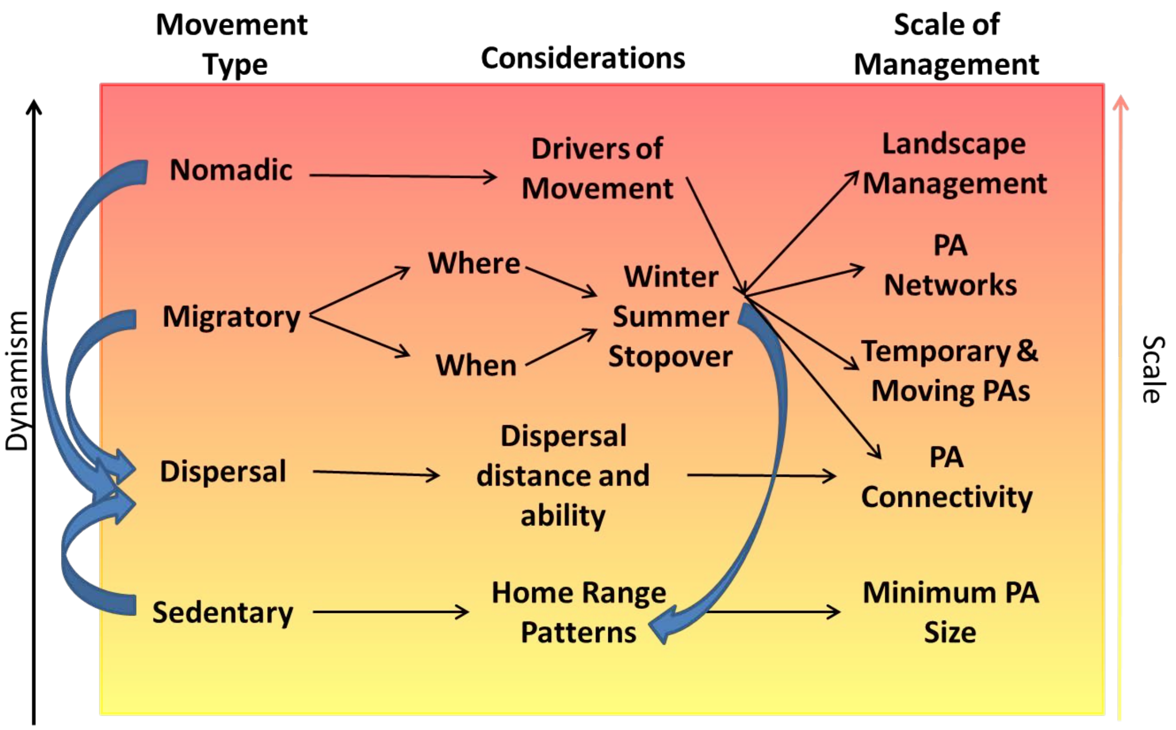

Figure 1 – Management framework that identifies the optimal scale of management based on the movement patterns of the study population. The scale of management moves from smaller scale programmes of sedentary movements using PAs to larger scale programmes for migratory or nomadic movements where larger landscape perspectives are required. Dynamic PA networks for migratory species can be established based on ranging patterns during winter/summer movements or the migratory/movement phase. All scales of management need to consider the dispersal patterns of the species and thus the functional connectivity of the landscape and its influence on population dynamics.

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