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Impact of Climate Change on Wildlife health:
A manager's perspective

All over the world today, wildlife is reeling under a constant threat of extinction through the impacts of changing climate. This extinction will probably be caused by the overwhelming impact of climate on the health and welfare of wildlife. In this paper a conceptual review of the existent situation and the strategies available to wildlife managers to conserve wildlife under these changing circumstances is offered. The Author explore the components of climate and discuss how the changes in climate are impacting the health of our wildlife. The twin strategies of climate change mitigation and adaptation, and how these can be adapted for deployment to the management of health and welfare of wildlife are analysed. These strategies are imperative to help abate the detrimental outcomes of climate change on wildlife, and require an urgent attention of managers without delay.

Key words: Climate, Climate change, Mitigation, Adaptation, Wildlife health.

The twin strategies of climate change mitigation and adaptation are imperative to help abate the detrimental outcomes of climate change on wildlife, and require an urgent attention of managers.

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Introduction

Our planet is losing species at an alarming rate, in part also due to human activities (Wilson, 1989; Turvey *et al.*, 2007; Ceballos *et al.*, 2015). Present estimates state that current rate of species extinction is between 100 and 10,000 times the prehuman, or background, extinction rates, with over a hundred species lost since 1980 (Stuart *et al.*, 2004; Chivian and Bernstein, 2008; Ceballos *et al.,* 2015; De Vos *et al.*, 2015). The losses are so high that today we talk of an "extinction crisis" (Ceballos and Ehrlich, 2002; Thomas *et al.*, 2004; Lewis, 2006) and a sixth, man-made anthropocene extinction event (Pimm and Brooks, 2000; Barnosky *et al.,* 2011; Kolbert, 2014). Thus, the task to today's wildlife manager is much more daunting than her counterparts of some decades ago. The need is to understand the crisis and to effectively respond to it.

Effective management of a crisis requires that the manager be well-versed with all five stages of crisis management: (1) signal detection, (2) preparation and prevention, (3) containment and damage control, (4) recovery and (5) learning and reflecting (James and Wooten 2005). In this regard, a sound understanding of the risks threatening the system and their management is deemed crucial. Climate change is one risk that requires an immediate attention of wildlife managers. They need to understand how it impacts the various facets of wildlife to be able to manage it. In particular, they need to understand the impact of changing climate on the health of wildlife, since climate change is known to have caused, and is predicted to cause several extinction events through the mediation of wildlife diseases (Harvell *et al.*, 2002; Pounds *et al.*, 2006; Carpenter *et al.*, 2008; Rohr *et al.*, 2011).

This paper synthesises the available information on the impacts of climate change on one crucial facet of wildlife management: the health of wildlife. We shall analyse the meaning of climate change, how climate change impacts the health of wildlife, how wildlife respond to climate change, and the management options available with the wildlife manager.

Understanding Climate and Climate change

Climate is defined as "A broad composite of the average conditions of a

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region, measured in terms of such things as temperature, amount of rainfall or snowfall, snow and ice cover, and winds (Ruddiman, 2001)." It classically averages the conditions over a span of 30 years, and so is different from weather which measures the instantaneous ephemeral and persistent conditions and their changes.

Climate is comprised of five components (hydrosphere, cryosphere, biosphere, atmosphere and lithosphere) interacting together as a system (Fig. 1a) (Houghton *et al.,* 2001; Ruddiman, 2001). These components and their interactions are modulated by conditions referred to as forcings (Fig. 1b) (Mann *et al.,* 1998; Cotton and Pielke, 2007; Philander, 2008). Forcings include changes in plate tectonics (causing volcanism and releasing copious amounts greenhouse and other gases into the atmosphere), changes in the Earth's orbit and changes in the strength of the Sun (resulting in altered amounts of energy reaching the Earth), and anthropogenic activities, such as deforestation and burning of fossil fuels (Hansen *et al.,* 1998; Bauer *et al.,* 2003).

Forcings produce effects known as responses (Hansen *et al.,* 1997; Shindell and Faluvegi, 2009). These responses cause changes in the five components of climate, resulting in climate change. Climate change is defined as: "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Baede, 2007)." Frequently, climate change is reflected by its impacts like rising or lowering temperatures, heat waves, forest fires, droughts, floods and extreme climatic phenomena (Rosenzweig *et al.,* 2001; Mirza, 2003; Luber and McGeehin, 2008) (Fig. 1c).

Impact of Climate change on the health of wildlife

Changing climate can impact the health of wildlife in direct and indirect ways. Direct impacts occur as a result of the climate change causing a greater exposure to pathogens, vectors and non-pathogenic influences such as heat and dehydration. On the other hand, indirect impacts occur due to an increased susceptibility of the organism to diseases as a result of stress brought about by climate change.

Both these kinds of impacts can be said to emanate from Shelford's law of tolerance. This law explains the existence or non-existence of an organism based on its limits of tolerance to several environmental factors such as temperature, humidity, pathogens, nutrients, and so on. The law of tolerance is depicted graphically in Fig. 2. Panel (a) depicts the bell-shaped curve of tolerance that could be drawn for all species for many environmental

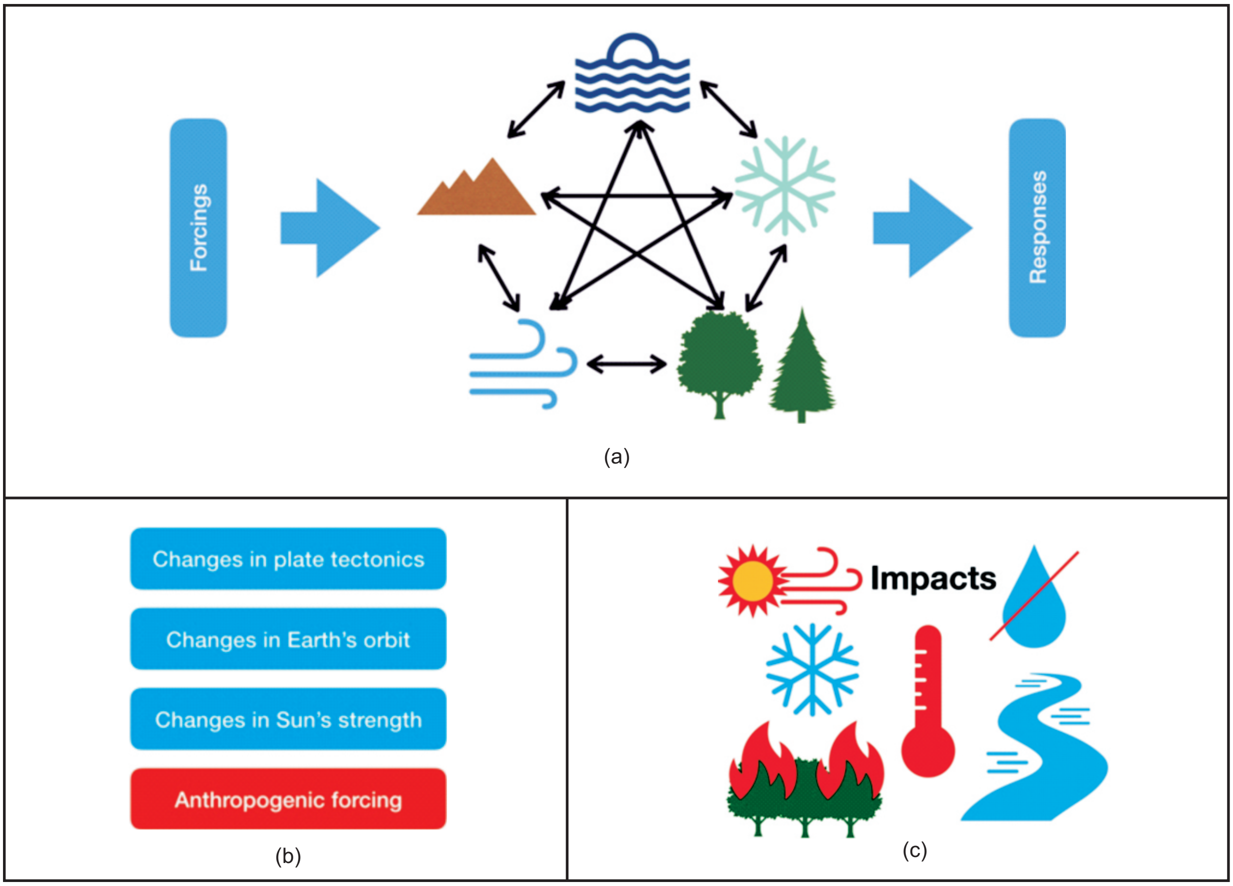


Fig. 1. (a) The components of the Earth's climate, their interactions, forcings and responses. (b) Forcing mechanisms. (c) Impacts of the changing climate: heat waves, rising or falling temperatures, droughts or floods, forest fires, etc.

variables such as temperature, oxygen concentration in air, humidity, etc. In the figure, green depicts the optimal zone, where the organism is comfortable and breeds well. Yellow depicts the zone of stress, where the organism is able to survive but under stress and reduced capacity. Red depicts the zone of intolerance, where the organism will survive for a small period of time, unless it moves out. Areas falling in the red zone typically remain uncolonised by the species.

Panel (b) depicts the role of climate change in changing the colonisation range of a species. With warming, many species will move up the mountains and latitudes into areas that were hitherto extremely cold for them (Overpeck *et al.,* 1990; Pounds *et al.,* 1999; Iverson and Prasad, 2001; Walther *et al.,* 2002; Perry *et al.,* 2005; Hamann and Wang, 2006). This is already evident by shifts in tree lines on mountains (Payette *et al.,* 1989; Grace *et al.,* 2002) and the spread of mosquitoes to hitherto uncolonised locations (Epstein *et al.,* 1998; Hughes 2000; Hales *et al.,* 2002). It may convert a resident species into an invasive species, or may even result in the proliferation of alien invasive species to the detriment of indigenous species (Sutherst, 2000; Stachowicz *et al.,* 2002; Hellmann *et al.,* 2008; Rahel and Olden, 2008). This increases the chances of exposure of wildlife to species, pathogens and vectors that they were not exposed to before. If it causes changes in the timings of life cycles of species (Dixon, 2003; Visser and Both, 2005; Inouye, 2008; Singer and Parmesan, 2010), this asynchrony could produce conditions where plants and trees will not have pollinators when they flower, while fauna will not have ample food. This may result in disease conditions such as malnutrition, growth retardation and developmental delays. Such conditions may even decimate several plant and animal species. Those species that have a longer season for flowering may

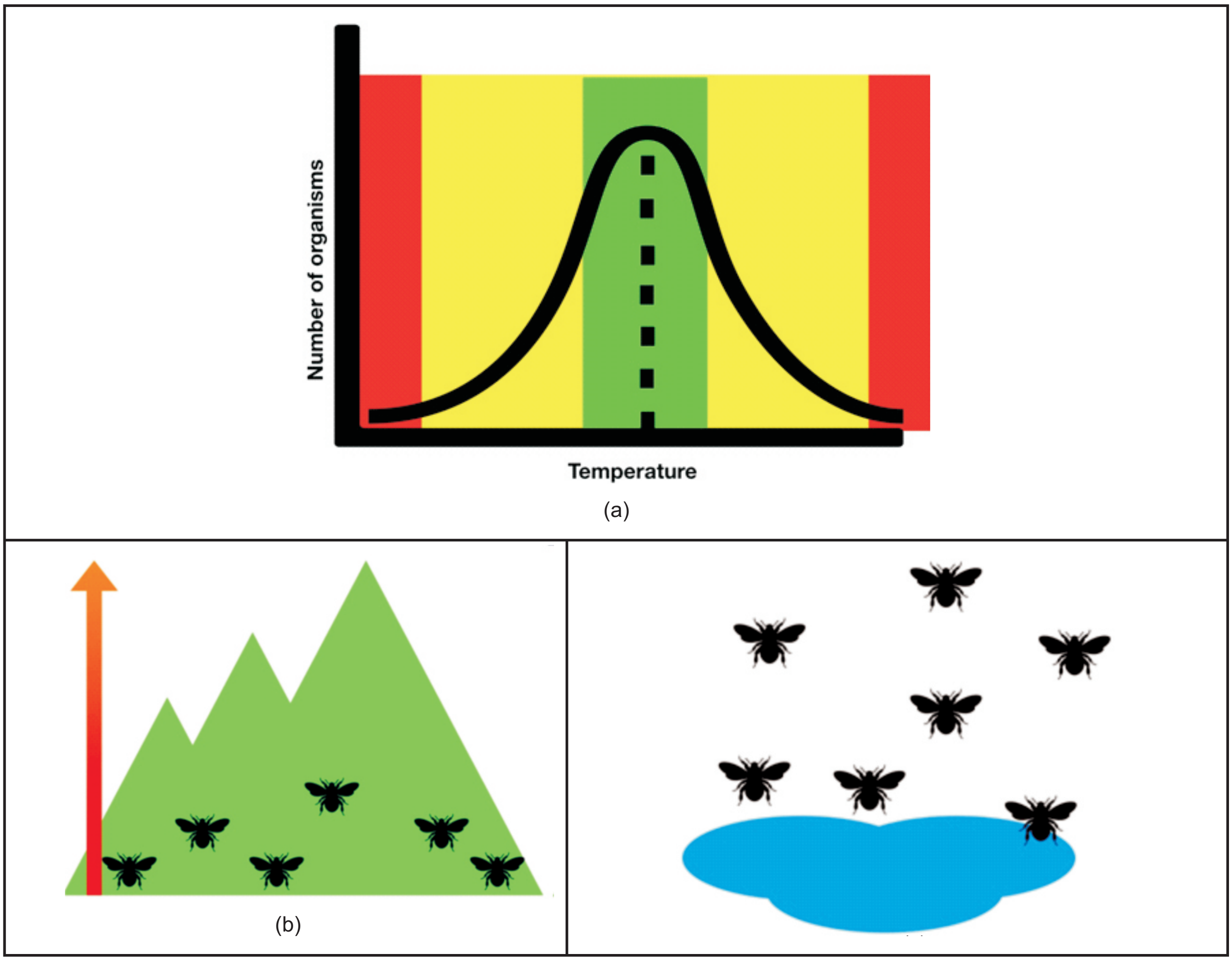


Fig. 2: Shelford's law of tolerance. (a) For most environmental variables such as temperature, we can draw a bell-shaped curve for the tolerance of a species to that variable. In this figure, green depicts the optimal zone, where the organism is comfortable and breeds well. Yellow depicts the zone of stress, where the organism is able to survive but under stress and reduced capacity. Red depicts the zone of intolerance, where the organism will survive for a small period of time. Areas falling in the red zone are not colonised by the species. (b) As climate change shifts the variables, the regions colonised by a species will change. For instance with warming, many species will move up the mountains into areas that were hitherto extremely cold for them. (c) Many organisms, including vectors will utilise the flood pools for breeding and increase their numbers.

result in increased incidence of pollen grain allergies (Emberlin *et al.,* 2002; D'amato *et al.,* 2007; Shea *et al.,* 2008). Dust and pollution-based allergies may also increase.

Panel (c) depicts another role of climate change, as a force multiplier for diseases. With rising sea levels and floods, many organisms, including vectors will utilise the flood pools for breeding and increasing their numbers. This might engender higher vectorial capacities (Patz *et al.,* 1998; Martens *et al.,* 1999; Githeko *et al.,* 2000; Watts *et al.,* 2017) and spread of diseases like encephalitis, insect-carried worms and Lyme disease. Similarly, flooding and hot and humid conditions will result in a greater proliferation of pathogens such as bacteria, causing an increased incidence of illnesses due infections such as gastrointestinal diseases (Bunyavanich *et al.,* 2003; Hunter, 2003; McMichael *et al.,* 2006). Allergens and mycotoxins are also implicated in several cancers and birth defects (Bunyavanich *et al.,* 2003).

Climate change is also believed to result in several short-term and long-term impacts on forests that are the home of wildlife (Dale *et al.,* 2001; Van der Meer *et al.,* 2002; Bergh *et al.,* 2003, Millar *et al.,* 2007; Xu *et al.,* 2009; Lindner *et al.,* 2010) ultimately impacting wildlife health. It will precipitate massive changes in the ecologies in terrestrial, freshwater, coastal zones and marine ecosystems (Walther *et al.,* 2002; Harley *et al.,* 2006; Bellard *et al.,* 2012), disrupting the food security of several species of wildlife, and resulting in malnutrition. With changed ecosystems, we might also witness the emergence and spread of new diseases (Patz *et al.,* 1996; Epstein, 2001).

By causing extreme climates (Rosenzweig *et al.,* 2001; Mirza, 2003; Luber and McGeehin, 2008) such as droughts, floods, winds, heat waves and increased forest fires (Dale *et al.,* 2001; Flannigan *et al.,* 2009; Wotton *et al.,* 2010), climate change may result in diseases and conditions like heat stroke, dehydration, trauma and drowning (Bunyavanich *et al.,* 2003; Watts *et al.,* 2017).

Besides, climate change will also have an indirect impact on health. With hot areas becoming hotter, cold areas colder, dry regions drier and wet regions wetter, the extreme conditions will produce stress in plant and animal species (Ahuja *et al.,* 2010), hindering their successful reproduction. Stresses may also cause reduction in immunity to pests and diseases (Keller *et al.,* 1981; Keller *et al.,* 1983; Brey, 1994), causing outbreaks both inside and outside forests (Sturrock *et al.,* 2011).

Responses of wildlife towards the changing climate

Different species of wildlife will show different responses towards changing climate and diseases depending on their genetic diversity and adaptability. Some species have revealed great adaptability due to already existing variability in the population. One such success story is that of the tawny owl (Fig. 3) (Karell *et al.,* 2011). This species exists in two colour varieties: grey and brown. In the mountainous areas with snow-covered trees, the grey variety is better camouflaged providing an advantage in hunting. However, with the temperatures rising and the trees getting devoid of snow, the camouflage gets lost. The tawny owl, however, has been able to fight malnutrition by selecting the melanistic variety over the lighter variety, so that the population, overall, has been able to maintain a cloak of camouflage even under changed conditions.

Some other species might try to adapt to climate change through migration (Walther *et al.,* 2002). However, many other wildlife species might not be able to adapt quickly enough, and may perish due to factors including the crossing of physiological tolerances of temperature leading to heat strokes (Deutsch *et al.,* 2008; Somero, 2010) and water leading to dehydration (Foden *et al.,* 2007; Team *et al.,* 2007), increased fires resulting in burns (Keith *et al.,* 2008), rising sea levels resulting in drowning (Team *et al.,* 2007), changing habitats (Jones, 2012), negative impacts on useful species like prey, hosts and pollinators often causing malnutrition and starvation (Munday, 2004; Memmott *et al.,* 2007; Durance and Ormerod, 2010; Schweiger *et al.,* 2012), positive impacts on harmful species like predators, competitors and pathogens causing predation, malnutrition and diseases (Benning *et al.,* 2002; Wethey, 2002; Suttle *et al.,* 2007; Ytrehus *et al.,* 2008; Goddard *et al.,* 2011; Harley, 2011) and temporal mismatch between interacting species (Visser and Holleman, 2001; Visser and Both, 2005; Cahill *et al.,* 2012). It is estimated that the changing climate will be directly and indirectly responsible for the extinction of upto 54% of the species present on the planet (Thomas *et al.,* 2004; Malcolm *et al.,* 2006; Foden *et al.,* 2013; Warren *et al.,* 2013; Urban, 2015). This makes active management extremely crucial and vital for the management of wildlife and their health.

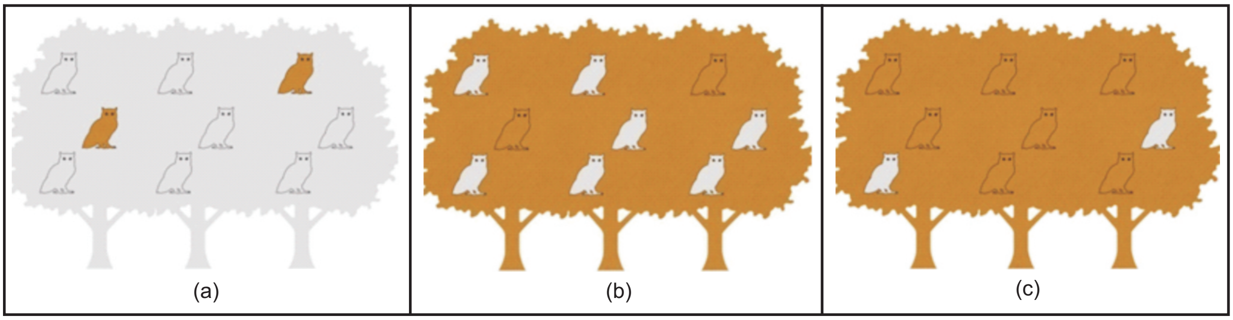


Fig. 3: The success story of the tawny owl. (a) The tawny owl exists in grey and brown colours, with grey colours providing greater camouflage in snow-covered trees. (b) With rising temperatures and lesser snow covered trees, the grey owls lose their camouflage, whereas the brown owls become better at camouflaging. (c) This has resulted in a selection pressure favouring the brown variety.

Management options: Mitigation versus adaptation

Wildlife managers have two options to tackle climate change: mitigation and adaptation (Schipper, 2006). Mitigation is defined as"A human intervention to reduce the sources or enhance the sinks of greenhouse gases (Baede, 2007)." On the other hand, adaptation is defined as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (UNFCCC, 2014)."

While historically these two approaches were often considered dichotomous and even incompatible (Cohen *et al.,* 1998; Huq and Grubb, 2003; Schipper, 2006), and we have had focussed our attention to the mitigation approaches only, of late we have started considering both these approaches to be complimentary and not exclusive or antagonistic (McCarthy *et al.,* 2001). One such integrated algorithm is depicted in Fig. 4.

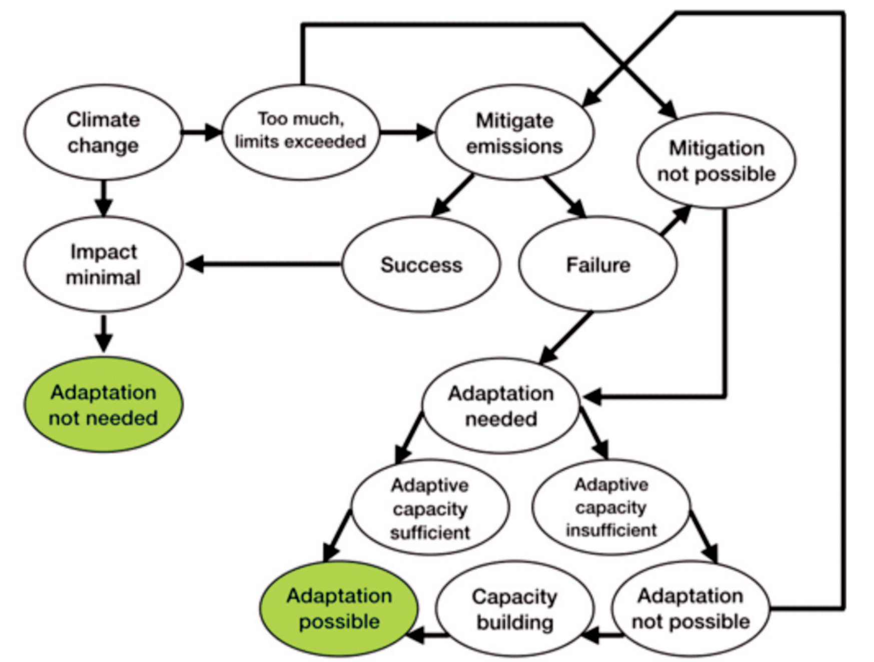
Mitigation

Mitigation options have included the options to reduce emissions, including changes in laws to make polluting more expensive both legally and economically (Budzianowski and Budzianowska, 2012), shift from conventional fossil fuels to greener sources of energy (Hoffert *et al.,,* 2002, Edenhofer *et al.,* 2011; Edenhofer *et al.,* 2011; Mathiesen *et al.,* 2011) such as solar, wind and hydel, increasing efficiency (Worrell *et al.,* 2009; Stern 2010) and trying to reduce emissions from deforestation and forest degradation (REDD) (Parker *et al*., 2008; Agrawal *et al*., 2011). They have also included attempts to construct sinks for carbon dioxide and other greenhouse gases, including synthetic trees (Lackner, 2009), carbon sequestration in geological sites (Bachu, 2000; White *et al.,* 2003), afforestation and conservation (Trabucco *et al.,* 2008; Zomer *et al.,* 2008), sustainable management of forests and enhancement of forest carbon stocks (termed as REDD+) (Angelsen, 2009; Parker *et al.,* 2009).

While wildlife managers would not be directly involved in these mitigation options, they could use the charisma of wildlife to lobby for mitigation. Forests which are the home to wildlife form part of both the options. When managed for multiple uses, they not only reduce carbon emissions by substituting carbon and energy-intensive materials such as concrete and steel by forest products such as wood and plywood ((Brown *et al.,* 1996; Gustavsson *et al.,* 2006; Malmsheimer *et al.,* 2008), conserving them also reduces carbon emissions from deforestation and forest degradation (DeFries *et al.,* 2002; Van der Werf *et al.,* 2009; Baccini *et al.,* 2012; Harris *et al.,* 2012). Forests also are prominent sinks for the carbon dioxide already present in the atmosphere. Through the natural process of photosynthesis, trees fix atmospheric carbon dioxide into biomass. Thus, afforestation and conservation, and sustainable management of forests, so essential for the management of wildlife, are also consequential mechanisms for the mitigation of climate change. Conserving wildlife habitats automatically protects wildlife, and even protects us!

Adaptation

Adaptation is the process of facilitating adjustments in natural or human systems to adjust to actual or expected changes in climate. It has a lot to do with computing and enhancing the adaptive capacity of the system in question. Adaptive capacity is defined as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages,



Adapted from Schipper, E. L. F. (2006). "Conceptual history of adaptation in the UNFCCC process." Review of European, Comparative & International Environmental Law **15**(1): 82-92.

Fig. 4: The relationship between the mitigation and adaptation options for tackling climate change.

to take advantage of opportunities, or to cope with the consequences (McCarthy *et al.,* 2001)."

The adaptation responses can be divided into several dichotomous groups (McCarthy *et al.,* 2001). The responses could be anticipatory (proactive), in which case the responses are made before the detrimental impacts of climate change actually happen. Or they could be reactive, acting after and in response to the detrimental impacts of climate change. We could have mechanisms that act autonomously (spontaneously), without the need for constant adjustments as climate change clicks in. Or they could be planned, requiring constant human interventions. The responses could also be divided into private responses, undertaken by individuals for themselves. Or they could be public responses, done by the society at large.

Whatever the adaptive response, we can describe the process in the form of a cycle of elements (Fig. 5a). The response begins with the observation of climatic and non-climatic variables to understand the system, set baselines and measure changes. This is followed by an assessment of the impacts of climate and climatic changes, and the vulnerability of the natural or human system whose adaptive capacity needs to be enhanced. Once these elements have been completed, we shift to the management 'Deming cycle' (Johnson, 2002), comprising the four components abbreviated as 'PDCA'. The first component is called planning, in which adaptive strategies are formulated. This is followed by 'doing' component, in which the formulated strategies are implemented on the ground. The outcomes of this implementation are evaluated in the 'checking' component of the cycle, followed by 'adjusting' of the strategies to optimise the enhancement of adaptive capacity. Simultaneously, the elements of observation and assessment are undertaken for contemporary and future courses of action.

In the case of forest and wildlife sector, we can divide the adaptation approaches into three categories (Fig. 5b) (Millar *et al.,* 2007). These are as follows:

1. Creating resistance to change: The approaches in this category support forests and wildlife in such a manner that they are able to resist the alterations brought about by climate change. For instance, since climate change is believed to increase the frequency and intensity of forest fires (Clark, 1988; Bonan, 2008), approaches could include attempts to reduce the impacts of these forest fires. Similarly, since the movement of species would expose trees and animals to newer insects, pests and pathogens (Sutherst, 2000; Stachowicz *et al.,* 2002; Hellmann *et al.,* 2008; Rahel and Olden, 2008), attempts could be made to reduce the impacts of these. This could be done through better protection strategies, and also thorough mechanical, chemical or biological removal of invasive species. Similarly, resistance breeding could be attempted to make species more resistant to changes of climate. Provisioning of water and shade for coping can also be included in this category.

2. Promote resilience to change: Resilience is defined as "The capacity of an ecosystem to return to the pre-condition state following a perturbation, including maintaining its essential characteristics, taxonomic composition, structures, ecosystem functions, and process rates (Thompson *et al.,* 2009)." Thus, resilience approaches target the times after a perturbation has been brought about by climate change. The aim is to bring the forests and ecosystems to the same state they were in before the impacts of climate change clicked in. These approaches include surplus seed banking, in which seed banks are established to provide a source to bank upon when impacts of climate change have abated. These also include intensive management of species during establishment phase, including assisted natural regeneration techniques, and promotion of biodiversity-rich ecosystems where the number and variety of species aid in promoting resilience to climate change. Creation of wildlife corridors can also be included in this category.

3. Enable forests to respond to change: These approaches aid the ecosystems to accommodate changes being brought about by climate change in place of resisting them. In this manner, the ecosystems are exposed to changes gradually in place of sudden dramatic changes that could be catastrophic. Thus, we could assist natural adaptations and transitions that would happen in the face of climate changes, or even facilitate assisted migration of species to newer areas that would become their abode under the altered circumstances. The approaches also aim to increase redundancy and manage for asynchrony between the life cycles of dependent species. Approaches also include establishment of neo-native forests considering their past spread and promotion of connected landscapes to counter habitat fragmentation and ease migrations.

For the case of wildlife management, Mawdsley and others (Mawdsley *et al.,* 2009) have given 16 general adaptation strategies. These are: 1. increasing the extent of protected areas 2. improving representation and replication within protected area networks 3. improving management and restoration of existing protected areas to facilitate resilience 4. designing new natural areas and restoration sites to maximise resilience 5. protecting movement corridors, stepping stones and refugia 6. managing and restoring ecosystem function rather than focussing on specific components (such as species or assemblages) 7. improving the matrix by increasing landscape permeability to species movement 8. focussing conservation resources on species that might become extinct 9. translocating species at a risk of extinction 10. establishing captive populations of species that would otherwise go extinct 11. reducing pressure on species from sources other than climate change 12. evaluating and enhancing monitoring programmes for wildlife and ecosystems 13. incorporating predicted climate-change impacts into species and land management plans, programs and activities 14. developing dynamic landscape conservation plans 15. ensuring wildlife and biodiversity needs are considered as part of the broader societal adaptation process 16. reviewing and modifying existing laws, regulations, and policies regarding wildlife and natural resource management.

These 16 strategies aim to increase the resistance, resilience and responsiveness of wildlife management

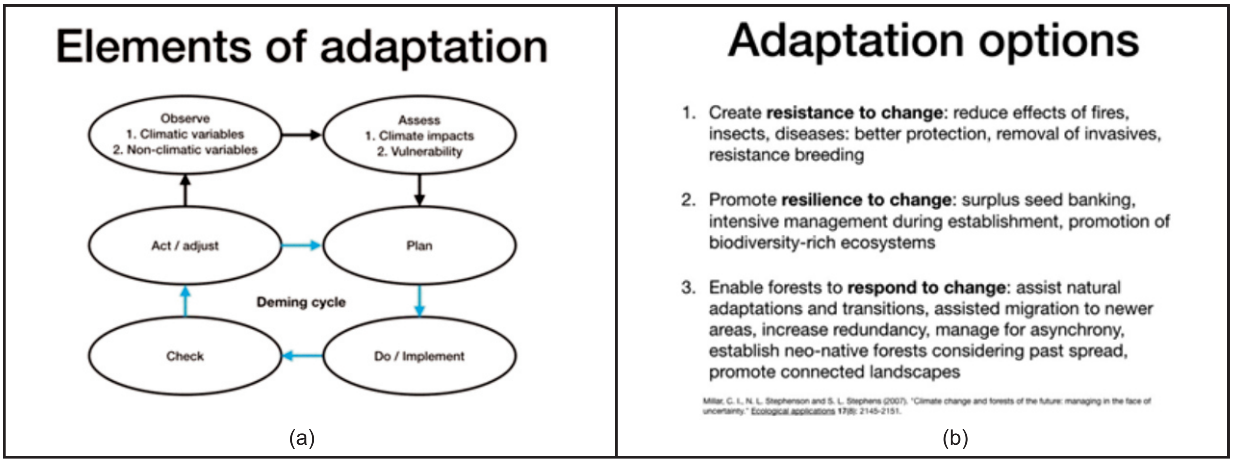


Fig. 5: (a) The elements of adaptation response (b) and the adaptation options.

towards climate change, and need to be incorporated in wildlife management plans for efficient and effective management of wildlife and their diseases. Even small steps like the provisioning of perennial water sources and shade, and *in-situ* and *ex-situ* conservation strategies will go a long way.

Conclusion

In this review, we explored the components of climate and climate change, and scrutinised the impacts of climate change on the health of wildlife. We observed that while certain species might be able to survive the changing climate through natural adaptation mechanisms and migration, several other species might face the risk of extinction. The routes to extinction could be through health issues, impacting the animals directly through processes like heat stroke, dehydration, malnutrition, predation, allergies, increased exposure to vectors and pathogens, newer diseases, etc., or indirectly by reducing their fitness and immune response through stress. Thus, management of the impacts of climate change on the health of wildlife is of crucial importance to wildlife managers. Two mechanisms exist to combat these challenges: mitigation and adaptation, and both will need to be harmoniously deployed on the ground to permit effective management of this threat.

वन्यजीव स्वास्थ्य पर जलवायु परिवर्तन का प्रभाव: एक प्रबंधक का संदर्श

अंकुर अवधिया

सारांश

आज विश्वभर में वन्यजीव परिवर्तनशील जलवायु के प्रभावों के जरिए विलोपन के संकट से गुजर रहे हैं। संभवत: यह विलोपन वन्यजीव के स्वास्थ्य एवं कल्याण पर जलवायु के अत्यधिक प्रभाव से उत्पन्न हुआ होगा। इस शोधपत्र में इन परिवर्तनशील पारिस्थितियों के तहत वन्यजीव के संरक्षण के लिए वर्तमान स्थिति का एक सैद्धान्तिक पुनरीक्षण और वन्यजीव प्रबंधकों हेतु उपलब्ध रणनीतियां दी गई हैं। लेखकों ने जलवायु के घटकों का पता लगाने तथा इस पर विचार-विमर्श किया है कि कैसे जलवायु में परिवर्तन हमारे वन्यजीव के स्वास्थ्य को प्रभावित करते रहे हैं। जलवायु परिवर्तन न्यूनीकरण एवं अनुकूलन की दोहरी रणनीतियों का यह विश्लेषण किया गया है कि कैसे इन्हें वन्यजीव के स्वास्थ्य एवं कल्याण के प्रबंधन हेतु नियोजन के लिए अनुकूल बनाया जा सकता है। ये रणनीतियां वन्यजीव पर जलवायु परिवर्तन के हानिकर परिणामों को कम करने में सहायता हेतु अनिवार्य हैं तथा देरी किए बिना प्रबंधकों द्वारा इस ओर तत्काल ध्यान देने की आवश्यकता बताती हैं।

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