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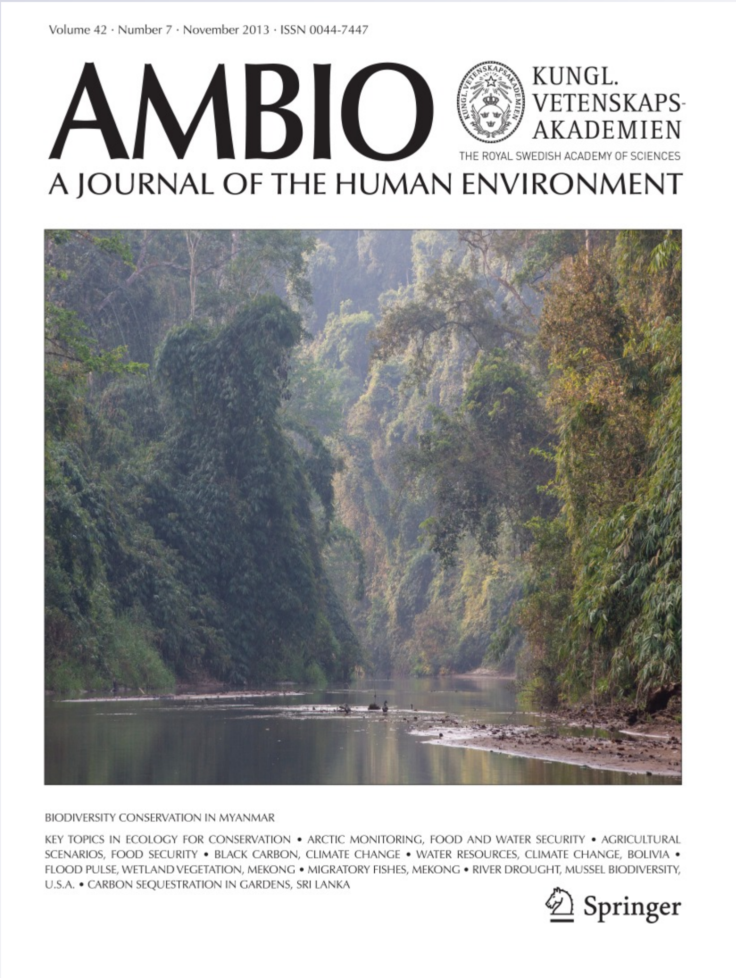

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REVIEW

Biodiversity Conservation in a Changing Climate: A Review of Threats and Implications for Conservation Planning in Myanmar

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Abstract High levels of species richness and endemism make Myanmar a regional priority for conservation. However, decades of economic and political sanctions have resulted in low conservation investment to effectively tackle threats to biodiversity. Recent sweeping political reforms have placed Myanmar on the fast track to economic development—the expectation is increased economic investments focused on the exploitation of the country's rich, and relatively intact, natural resources. Within a context of weak regulatory capacity and inadequate environmental safeguards, rapid economic development is likely to have far-reaching negative implications for already threatened biodiversity and natural-resource-dependent human communities. Climate change will further exacerbate prevailing threats given Myanmar's high exposure and vulnerability. The aim of this review is to examine the implications of increased economic growth and a changing climate within the larger context of biodiversity conservation in Myanmar. We summarize conservation challenges, assess direct climatological impacts on biodiversity and conclude with recommendations for long-term adaptation approaches for biodiversity conservation.

Keywords Myanmar · Climate change · Economic development · Protected areas · Biodiversity · Threats

INTRODUCTION

Myanmar, the second largest country in Southeast Asia (Fig. 1), has recently embarked on a path of unprecedented political and economic transition. Rich in teak, minerals, oil, and gas, half a century ago Myanmar was one of the more prosperous countries in the region (McCarthy 2000). However, decades of state socialism, oppression and sanctions reduced the state to an economically depressed and politically isolated country (Taylor 1987; Smith 1999; Steinberg 2001). Currently, there is much analysis and commentary on the nature of political and economic changes and general implications for Myanmar, its regional neighbors and the rest of the world (Steinberg 2012; Taylor 2012; Gong 2012; Orlov 2012). Overall, the country's extraordinary efforts at political and economic reform have been rewarded with increased attention by developed nations and Asian neighbors, who are now racing each other to establish diplomatic relations, lift sanctions and actively pursue economic investment. Within Myanmar, new land and investment laws are being drafted and special economic zones are being created to facilitate foreign economic investment (Schmidt 2012).

A critically important issue within the larger context of sweeping economic changes relates to Myanmar's rich biodiversity and valuable natural resources (Webb et al. 2012; Schmidt 2012). High levels of biodiversity coupled with relatively vast expanses of remaining natural forests (compared to neighboring countries) make Myanmar an urgent priority for conservation (Wildlife Conservation Society (WCS) 2012). Due to the combination and interaction of geography, topography, and climate, Myanmar has a great variety of habitats and ecosystems. The country supports 233 globally threatened species including 37 critically endangered and 65 endangered species (Wildlife Conservation Society (WCS) 2012). The country also contains large expanses of species-rich and globally threatened ecosystems such as lowland tropical forests and mangrove ecosystems that are critically threatened elsewhere in the region. Species and their habitats both within and outside protected areas in Myanmar are at risk from ongoing habitat loss and overexploitation (Platt et al.

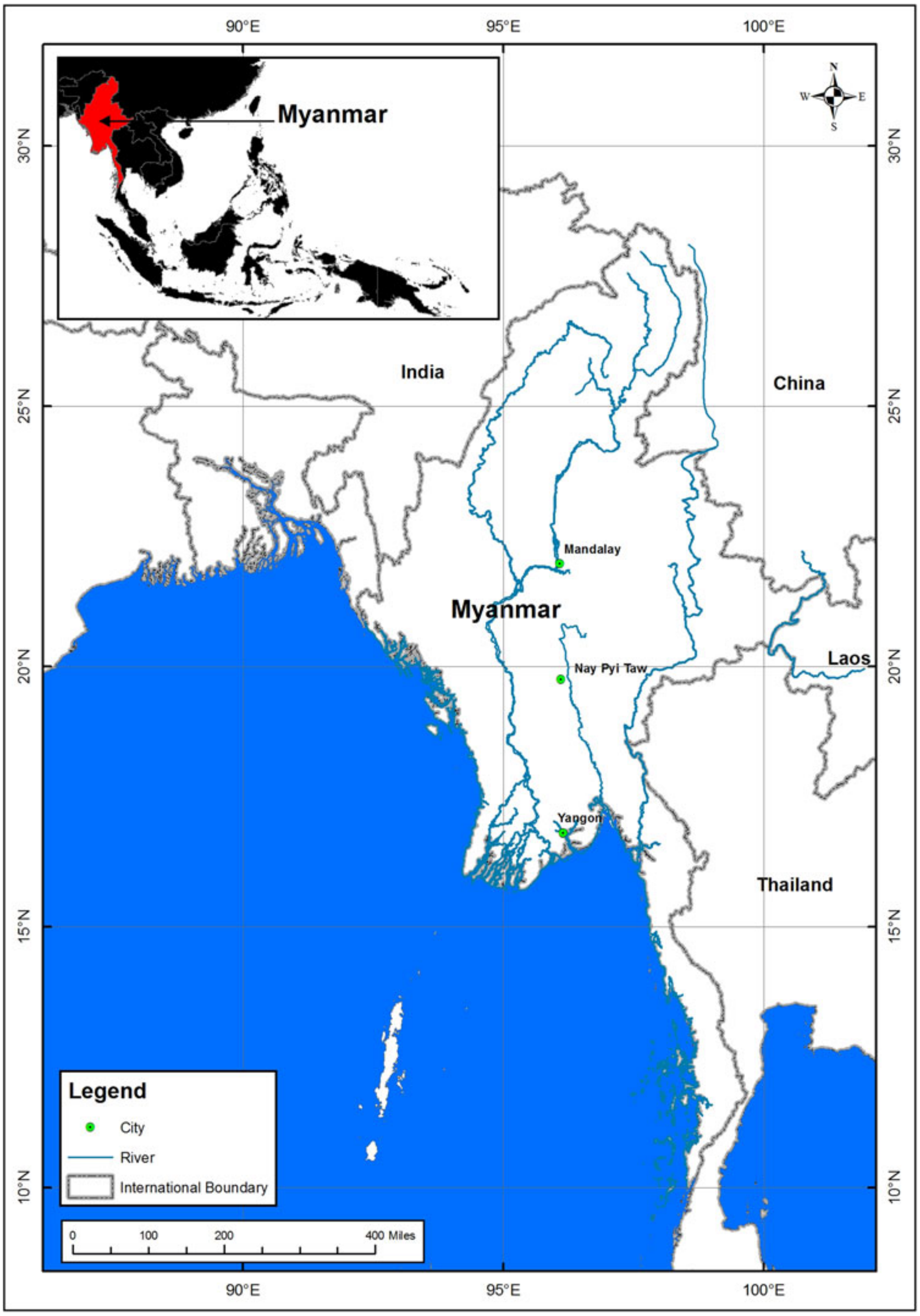

Fig. 1 Location of Myanmar (*inset*) within mainland Southeast Asia

2003a, b; Myint Aung et al. 2004; Leimgruber et al. 2005; Rao et al. 2005, 2010, 2011). Studies indicate that the protected area system needs comprehensive review and strengthening and there are urgent conservation priorities associated with threatened species and ecosystems (Rao et al. 2002; Myint Aung et al. 2004). Much conservation work remains to be done as the country's history of political isolation and associated international economic sanctions has ensured limited conservation investment focused on mitigating threats to biodiversity.

Climate change can exacerbate anthropogenic threats such as extensive deforestation on biodiversity. The IPCC 2002 Technical Report (V) explicitly recognized the importance of human influence on biodiversity loss and the additional level of threat imposed by climate change that has already begun to affect biodiversity (IPCC 2002).

Short- and long-term climate change impacts will interact with prevailing threats to species and ecosystems synergistically and in unpredictable ways to further complicate biodiversity conservation (Watson et al. 2011a, b). Climate change can be expected to aggravate existing threats to biodiversity in Myanmar through (a) direct mechanisms such as loss of suitable habitat for species or reduced resilience in ecosystems and (b) indirectly, through its impacts on humans and their dependence on the products and services produced by terrestrial, freshwater, and marine ecosystems. The response of expanding human populations to climate change will almost certainly place greater pressures on Myanmar's biodiversity. A further consideration is that degradation taking the forms of continuing loss in natural forest cover and mangrove habitats can influence processes affecting climate change through the release of carbon dioxide to the atmosphere (van der Werf et al. 2009).

Ongoing political and economic reforms are expected to attract international economic investments that will undoubtedly entail fast-paced exploitation of natural resources (Schmidt 2012). Within a context of weak regulatory capacity and inadequate environmental safeguards, rapid economic development will have far-reaching negative implications for currently imperiled species, ecosystems and natural-resource-dependent human communities (Webb et al. 2012). Comprehensive long-term conservation plans that integrate impacts of climate change will be critical to the conservation of Myanmar's imperiled biodiversity.

The aim of this review is to examine climate change implications within the larger context of biodiversity conservation issues in Myanmar. We begin with a brief review of threats to biodiversity, describe conservation challenges, and outline expected climate change impacts. We then assess direct climatological impacts on different ecosystems and conclude with recommendations for potential adaptation approaches to help overcome the impacts of climate change on ecosystems and human communities in developing long-term conservation strategies.

METHODS

We utilize both peer-reviewed and gray literature sources to review existing threats to biodiversity and the status of the protected area system in Myanmar. We summarize climate change impacts expected in Myanmar based on analyses conducted for the Myanmar Initial Communication Project (INC) for the UNFCCC as well as IPCC reports (IPCC 2007a, b, c, 2012). Following this, we assess expected climate change impacts on biodiversity based on relevant literature findings for species or habitats within Myanmar and regionally. We utilize recent development of mapping ecoregional exposure to future climate using a unique niche-based measure of future climate 'robustness' to predict the relative stability of ecoregions in Myanmar (Iwamura et al. 2010). We examine how climate change impacts can indirectly affect biodiversity through impacts on humans and their dependence on natural ecosystems and conclude with concrete management recommendations for conservation planning.

THREATS TO BIODIVERSITY CONSERVATION IN MYANMAR

The Indo Myanmar hotspot is one of the most globally threatened biodiversity hotspots and likely to lose a large proportion of plants and vertebrates through overexploitation and continuing forest loss (Tordoff et al. 2005). Although Myanmar is one of the few countries in this hotspot with relatively intact forest areas and high levels of biodiversity still remaining, there are substantial threats that need to be effectively addressed.

Overexploitation

Throughout the Indo-Myanmar Hotspot, unregulated, unsustainable, and largely illegal exploitation has driven many endemic species such as the Tonkin snub-nosed monkey (*Rhinopithecus avunculus* (Xuan Canh et al. 2008); Chinese pangolin (*Manis pentadactyla*), Sunda pangolin (*M. javanica*), *Oriental small-clawed otter* (*Amblonyx cinereus*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*) (van Strien and Martin 2008) to the verge of extinction. In Myanmar, hunting has resulted in the depletion of several vertebrate species such as the Sumatran and Javan rhinoceros (*Dicerorhinus sumatrensis* and *Rinoceros sondaicus*) and threatens to drive a number of other species locally extinct such as the Indochinese tiger (e.g., Lynam et al. 2006) and *Geochelone platynota*, a turtle species endemic to the Dry Zone that now appears to be "ecologically extinct" in the wild (Platt et al. 2011).

Hunting is widespread and occurs both within and outside protected areas (Rao et al. 2002). Key factors driving overexploitation include hunting to meet household subsistence needs in addition to the high demand for wildlife products for food, traditional medicine and pets in domestic and international markets (Platt et al. 2000; Shepherd and Nijman 2008; Rao et al. 2010, 2011). Similarly, economically valuable plant species such as *Aquilaria malaccensis*, a source of agarwod, rattans *Calamus* spp. (Peters et al. 2007), and orchids are threatened by unsustainably high levels of harvests (Tordoff et al. 2005). The over-exploitation of fishes, chiefly for food and trade (ornamental fishes) is a major concern for many inland fisheries and dependent species such as dolphins in Myanmar (Smith et al. 2009; Allen et al. 2010). Transition from a subsistence to a market economy and use of improved fishing gear are likely to increase pressure on fish resources.

Habitat Loss and Degradation

In Myanmar, forest ecosystems support some of the most threatened elements of biodiversity including the majority of globally threatened plant and animal species. These ecosystems are threatened with degradation and loss due to commercial logging for timber (Woods and Canby 2012), agricultural expansion, conversion of forest to rubber and oil palm plantations and shifting cultivation (Leimgruber et al. 2005; NCEA 2009).

Historically, mixed deciduous forests rich in teak were targeted for commercial logging. However, with increasing land scarcity, lowland evergreen forests have become increasingly vulnerable to logging. Habitat degradation resulting from logging can reduce the suitability of forest habitats for plant and animal species, while the construction of logging roads can facilitate hunting and open up forest areas to human settlement (Tordoff et al. 2005). Loss of natural forest habitat across the country can also be attributed to agricultural expansion, shifting cultivation and conversion to commercial teak, rubber, and oil palm plantations (Leimgruber et al. 2005; NCEA 2009). Rapid economic growth is expected to increase the pressures on natural resources in Myanmar (Webb et al. 2012).

Rivers and wetlands, a key component of the hydrological cycle to maintain freshwater supplies and a vital source of water and food supply for human communities, are also being degraded (Allen et al. 2010). Wetlands in particular are essential to dependent local communities, especially in the southern Ayeyarwady delta region. Myanmar has the largest estimated population of small-scale fisheries in the world, followed by Viet Nam and China (SEAFDEC 2012). The major classes of threats to freshwater systems in Myanmar stem from alien species invasion, pollution from mining activities, river flow modification, and overexploitation of fisheries (Allen et al. 2010). Dams are another key threat to aquatic systems and species that are expected to greatly increase in number and impact. Dams result in a range of upstream and downstream impacts, not least the disruption of migratory routes and breeding patterns of freshwater fish species, changes to flow regimes, and sedimentation; dam development is also associated with indirect impacts, through the economic activity and human settlement that they encourage (Nilsson et al. 2005).

Protected Areas in Myanmar

The protected area system is affected by all the threats described above and limited in its ability to effectively conserve biodiversity due to a number of additional factors related to size, geographic representation, inadequate management capacity, weak policy, and regulatory framework (Rao et al. 2002; Tordoff et al. 2005). Except for a few large protected areas (e.g., Hukaung Valley Wildlife Sanctuary 17,373 km^2 and Hkakaborazi National Park 3,812 km^2), most protected areas are too small to effectively conserve biodiversity and many are too highly degraded to be included within the protected area system (McShea et al. 1999; Lynam et al. 2006; Myint Aung 2007).

Further, the protected area system is biogeographically incomplete and coverage of certain ecosystems such as limestone caves, inland wetlands, estuaries, mangrove, and marine habitats is extremely limited throughout the country, requiring special attention to be placed on the future conservation of these ecosystems (Tordoff et al. 2005; Myint Aung 2007). There are technical and financial capacity constraints within Government institutions with principal responsibility for conserving biodiversity within protected areas. For instance, the Nature and Wildlife Conservation Division (NWCD) of the Forest Department within the Ministry of Environmental Conservation and Forestry has insufficient financial, human, and material resources to fulfill its mandate to manage protected areas (Myint Aung 2007). The regulatory framework for environmental protection is weak in both design and implementation (Gutter 2001) and the dearth of comprehensive land use policies is a critically important deficit. Further, the lack of adequate environmental safeguards is a key concern for the country's biodiversity within a context of impending economic development trajectories that will inevitably involve large-scale extraction of natural resources within and beyond the protected area system (NCEA 2009; Webb et al. 2012).

EXPECTED CLIMATE CHANGE IMPACTS IN MYANMAR

The Special Report by the IPCC on "Managing the risks of extreme events and disasters to advance climate change adaptation" provides evidence from observations gathered since 1950 of change in certain climate extremes (IPCC 2012). Acknowledging the relevance of the quality and quantity of data, and variability of analyses across regions and for different climate extremes, the report indicates limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales. There is low confidence[1] in any observed long-term (i.e., 40 years or more) increases in the intensity, frequency, and duration of tropical cyclone activity (IPCC 2012). However, the report indicates (with high confidence) that the severity of the impacts of climate extremes depends strongly on the level of the exposure and vulnerability to these extremes. Extreme impacts on human and ecological systems can result from individual extreme weather or climate events as well as from non-extreme events where exposure and vulnerability are high.

Myanmar has been ranked among the top three countries most affected by extreme weather events between 1992 and 2011 by the Global Climate Risk Index (2013) which measures the extent to which countries are affected by the impacts of weather-related events (Harmeling and Eckstein 2013). Exposure and vulnerability, considered key determinants of disaster risk and impacts are highly dependent on economic, institutional, governance, and environmental factors (IPCC 2012). Further, the IPCC 2012 report indicates how high exposure and vulnerability are generally the outcome of skewed development processes such as those associated with environmental degradation, failures of governance, and the scarcity of livelihood options for the poor—which are directly relevant to Myanmar.

In May 2008, a Category IV cyclone (named Nargis) struck Myanmar's Ayeyarwady delta, creating the worst natural disaster in the country's recorded history. Approximately 80 000 people died, and over 7 million people were affected as it destroyed coastal ecosystems that people relied on for food, commerce, and shelter (UN 2008). The landfall of Nargis was the first in recorded history that Myanmar experienced a cyclone of such a magnitude and severity with little warning. The high human and ecological impacts of cyclone Nargis and poor response was attributed to low quality of governance highlighted as a major vulnerability component affecting human mortality due to tropical cyclones (Peduzzi et al. 2009; Murray et al. 2012). Mangrove clearance for shrimp farms and rice paddies was a major factor in exacerbating the impacts of cyclone Nargis (Nature News 2008). In 2001, catastrophic flash floods associated with high rainfall were reported in the central Dry Zone resulting in deaths, loss of livelihoods and homes. Table 1 summarizes the vulnerability ratings (as high, medium, low) for the occurrence of extreme weather events (e.g., cyclones) and expectations for drought and sea-level rise in Myanmar based on findings reported in the Myanmar INC project (Initial National Communication Project) Report (2012). Extensive low-lying coastal areas in the south and south west appear to be highly vulnerable to impacts from floods, cyclones and associated winds and storm surges, intense rainfall and sea level rise.

Climate scenario analyses for Myanmar have been undertaken by the INC project under the United Nations Framework Convention on Climate Change using the CSIRO, GFDL, UKHadCM3, and UKHadGEM1 models applied to generate outputs for selected regions in Myanmar (Myanmar INC Report 2012). Scenarios predict both variable increases in temperature and precipitation across the country. Predictions for 2001–2020 based on scenarios generated for Myanmar show temperature increases of 0.5–0.7 °C during the year in lower parts of Myanmar, record high maximum temperatures and a 4 % increase in precipitation during March–November across the entire country. In particular, precipitation increases are expected in the wet season in central and north Myanmar. High temperatures and droughts are expected to be the norm, and are likely to be associated with more frequent forest fires in the dry zone of central Myanmar and the northern regions. Conversely, the increase in rainfall events in the wet season is predicted to cause flooding events which could affect livelihoods, transport, and homes. Prevailing and anticipated climatological changes have both direct impacts on biodiversity (see below) or exacerbate the impacts of current threats such as deforestation on biodiversity.

DIRECT CLIMATOLOGICAL IMPACTS ON BIODIVERSITY IN MYANMAR

Climate change poses major new challenges to biodiversity conservation as species will be exposed to changes at a rate and magnitude seldom previously experienced, with direct consequences for ecosystem assemblage and the services they provide to humanity (Foden et al. 2009; Watson et al. 2011a). A broad review of the literature shows that there are many possible ways climate change will impact biodiversity (Kingsford and Watson 2011). These impacts are often divided into discrete acute impacts, principally extreme weather related events (e.g., storms, droughts, fires, extreme rainfall events), and continuous chronic impacts, such as gradual increases in mean temperatures or decreases in seasonal rainfall, occurring over decades. Both these types of impacts maybe expected to interact with prevailing threats in Myanmar with largely unpredictable consequences. Early global analyses estimated that, depending on different modeling scenarios, between 1.9 and 40.5 % of endemic plant and vertebrate species in the Indo-Burma Hotspot may become extinct due to climate

[1] Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence and on the degree of agreement. Confidence is expressed qualitatively. Assigning 'low confidence' in observed changes in a specific extreme on regional or global scales neither implies nor excludes the possibility of changes in this extreme.

Table 1 Examples of some discrete impacts of a changing climate across Myanmar (*source*: based on findings from the Myanmar INC report)

Climate change drivers of vulnerability	Potential effect on species, ecosystems and ecological services	Examples
Cyclone and strong winds	High (coastal regions) Medium (region having common border with cyclone landfall region, and region with frequent strong winds history) Low (regions with strong wind-damage due to squalls)	During the last four decades, Myanmar has experienced five major cyclones. Category IV cyclone (named Nargis) struck Myanmar's Ayeyarwady delta in 2008, creating the worst natural disaster in the country's recorded history
Flood and storm surge	High (low lying regions) Medium (regions with moderate flood and flash flood history) Low (regions with flash flood history)	Floods and storm surges associated with cyclone Nargis caused massive physical destruction of mangroves, agricultural fields and infrastructure
Intense rain	High (regions with long exposure to the southwest monsoon) Medium (lower and northwestern Myanmar) Low (regions with low intense rainfall history)	Low-lying coastal areas in the Ayeyarwady delta, the southwest coast and the southern Tanintharyi region are expected to be vulnerable to intense rainfall
Extreme day temperatures	High (for regions with high annual mean temperature and relatively flat regions in central dry zone) Medium for transitional zones, Bago and Kayah regions Low for mountainous regions; regions with low annual mean temperature	Maximum day temperatures can reach up to 40 °C in the central Dry Zone during the peak hot season. Between 1951 and 2000, peak temperatures (x degrees) higher than the mean maximum were found in Kachin State, Northern Shan State, and Dry Zone during the month of May
Drought	High (dry zone regions) Medium (Bago and eastern mountain ranges) Low (remaining regions except Yangon and Taninthayi divisions	Extreme droughts have been recorded in the central dry zone region (Mandalay Division) in 2008 and 2009
Sea Level Rise	High (coastal deltaic regions) Medium (regions with narrow coastal strips) Low (regions with tide effects and coastal areas with higher ground)	Impacts of sea level rise in the low-lying Ayeyarwady delta is expected to have significant consequences for food security

change over the next century (Malcolm et al. 2006). However, the high variance in this number highlights the uncertainty on this type of modeling and species and ecosystem-specific analyses are far more useful for conservation planning (Watson et al. 2011b).

A review of published literature shows that there is still much to learn before we can assess accurately the impacts of climate change on species diversity in Myanmar. Very few field studies on the potential impacts of climate change on species have been conducted in the Indo-Burma Hotspot. One exception is an analysis of the elevational distributions of Southeast Asian birds over a 28-year period which provides evidence for a potential upward shift for 94 common resident species regardless of habitat specificity (Peh 2007). The White-browed Nuthatch *Sitta victoriae*, Myanmar's most limited by distribution endemic bird is confined to oak woodland on the peak of Nama Taung (Mount Victoria) and nearby peaks in the Chin Hills (Thet Zaw Naing 2003). Although this habitat is under limited threat, forest fire is a regularly occurring threat as it expands from nearby shifting cultivation plots and such a localized species likely has a very limited ability to adapt to climate change.

Similarly, climate warming has been shown to impact reproduction of the critically endangered Chinese Alligator (*Alligator sinensis*) (Zhang et al. 2009). Indeed, all reptiles exhibiting temperature-dependent sex determination are potentially at risk from global climate change (Janzen 1994). Furthermore, Skelly et al. (2007) have suggested that lengthy generation times of long-lived reptiles such as turtles will not favor rapid evolution of thermal tolerance. Although growth rates of ectotherms can increase in response to warmer temperatures, this could prove detrimental if insufficient food is available to meet increased metabolic demands (Dalrymple 1996). In seasonal habitats, shorter wet seasons and decreased hydroperiods might also reduce the time available for growth among aquatic ectotherms, and consequently neonates of some species may be unable to reach a body size necessary for survival during their first aestivation (Mitchell et al. 2012).

Increased anthropogenic burning in response to drier conditions is likely to negatively impact many populations of reptiles and amphibians (Russell et al. 1999), especially in habitats that currently experience infrequent fires. In particular, anthropogenic fires will undoubtedly increase mortality rates among terrestrial chelonian populations (Platt et al. 2010) already depressed by chronic over-harvesting (Platt et al. 2003a, b). Climatically driven hunting pressure can likewise be expected to further impact chelonian populations in Myanmar where most species are already subject to an intense harvest (Platt et al. 2000). Because chelonian populations are extremely sensitive to even minor perturbations among adult size classes (Congdon et al. 1993), these stressors acting in synergy are likely to depress many populations beyond the point of recovery.

Broader, region-wide analyses provide a view into the long-term prospects for Myanmar's biodiversity.

The recent development of mapping ecoregional exposure to future climate using a unique niche-based measure of future climate 'robustness' (defined as a measure of how similar the future climate of an ecoregion is to the current climate (Iwamura et al. 2010) offers a way of assessing how different the climates of each ecoregion within Myanmar will look like under different emissions analysis. In their model, Iwamura et al. (2010) used a downscaled spatial dataset for climate variables at the resolution of 2.5 arc min (approx. 4.6 km at the equator). Observed spatial databases of bioclimatic variables for current climate were obtained from the WorldClim database (Hijmans and Graham 2006), which provided 8.48 million data points across all the ecoregions. From the 19 bioclimatic variables, Iwamura et al. (2010) selected six climate predictors (annual mean temperature, mean diurnal temperature range, mean annual temperature range, annual precipitation, precipitation seasonality, and precipitation of the driest quarter) to represent general climate patterns, seasonality, and limiting factors of climatic patterns based on global scale research. Estimated spatial databases of the same climate variables for 2050s were downloaded from the International Centre of Tropical Agriculture (CIAT) Downscaling dataset (Ramirez and Jarvis 2008). This dataset provides high resolution maps for seven major global circulation models (GCMs) from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) (IPCC 2007a), A1b greenhouse gas emission scenario. This scenario represents technology-focussed rapid economic growth with mixed (fossil and non-fossil) fuel sources, and reflects current economic and developmental activity.

Using the findings of Iwamura et al. (2010), we can predict the relative stability of ecoregions in Myanmar based on these emission scenarios (Fig. 2). The Irrawaddy Dry Forests in central Myanmar stand out as being extremely unstable and it is clear that the ecoregion will face very important changes as a consequence of changing rainfall and temperature regimes. Highly variable and reduced rainfall patterns are expected to worsen an already water-stressed environment. In the north, the Mizoram–Manipur–Kachin Rain Forests are expected to be climatically less stable than the Irrawaddy Moist Deciduous Forests and the Northern Triangle Sub-Tropical Forests. The ecoregions to the south of the country appear to be more climatically stable than those the north, but none are robust and will certainly experience some changes. Temperature and rainfall changes in the Tenasserim Semi-Evergreen Tropical Forests in the extreme south of the country can be expected to alter the bioclimatic envelope for many tropical species. Freshwater swamp forest, a lowland forest type occurs in permanently or seasonally inundated lowlands such as the Ayeyarwady Delta and the floodplains of the Chindwin and other rivers. These forest types have been extensively cleared throughout mainland South-East Asia and Myanmar supports some of the largest remaining examples of this highly threatened habitat in the region (Tordoff et al. 2005). These forests are expected to be climatically more unstable than Myanmar coastal rainforests (further inland). Ecoregions in Myanmar will be variably affected by climatic impacts and sound interpretation of analyses such as those developed by Iwamura et al. (2010) will be critically important for effective adaptation planning for both species and human communities.

PEOPLE, BIODIVERSITY AND CLIMATE CHANGE

The short- and long-term impacts of climate change will aggravate existing threats to biodiversity in Myanmar through direct mechanisms (Table 2) and indirectly, through impacts on humans and their dependence on the products and services produced by terrestrial, freshwater, and marine ecosystems. Climate change is anticipated to impact human populations through the loss of agricultural lands (e.g., Johnston et al. 2010a, b), fisheries and aquaculture impacts (e.g., Kam et al. 2010), shortages of food and fresh water, damage to property, disease/health issues, and the need for resettlement away from lands affected by sea-level rise or floods (e.g., Wassmann et al. 2004; Hoanh et al. 2010). Impacts of sea level rise and storm surges on the low-lying Ayeyarwady delta of Myanmar have major implications for food security and the national economy through direct consequences for rice production. For example, higher water levels caused by underlying salt-water intrusion attributed to sea-level rise could detrimentally affect the wet season crop (namely, during

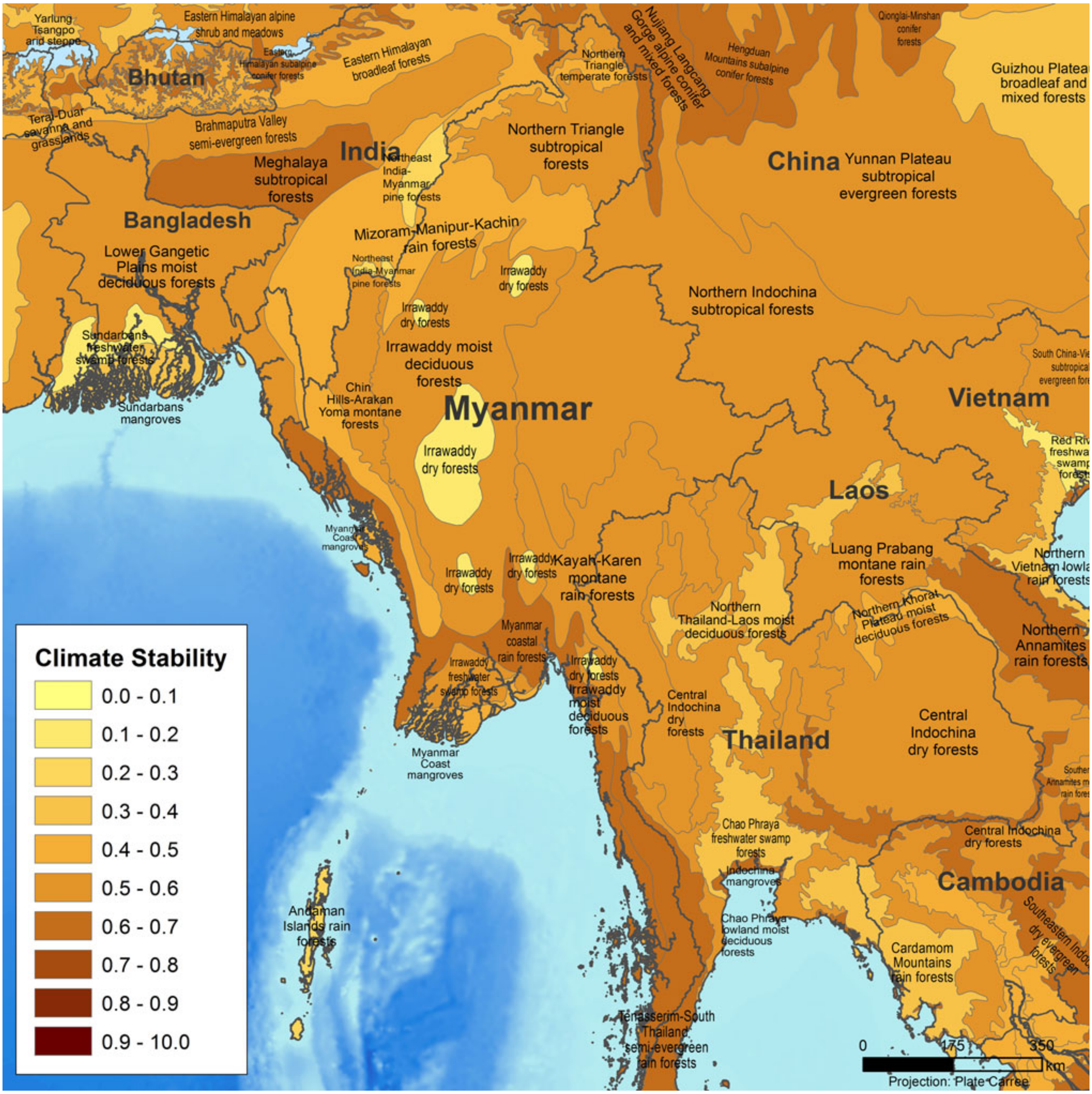

Fig. 2 The distribution of ecoregional *climate stability* across Myanmar. *Climate stability* was calculated based on six bioclimatic variables (annual mean temperature, mean diurnal temperature range, mean annual temperature range, annual precipitation, precipitation seasonality, and precipitation of the driest quarter) of current and future climates. The *darker colors* represent more stable climates (i.e., regions more suitable for existing ecosystems). The climate similarity shown here is the average over seven general circulation models, and compares today's climate with 2050 (*Source*: Iwamura et al. 2010)

seeding and vegetative stages) which accounts for 85 % of the national rice production (Wassmann et al. 2010). Further, observations, experiments, and simulation models show that climate change would result in changes in primary productivity, shifts in distribution and changes in the potential yield of exploited marine species, resulting in impacts on food security and the economics of fisheries (Sumaila et al. 2011).

Poor human populations are among the most vulnerable to climate change, due to their reliance on natural resources and limited resources for adaptation. Declines in fish productivity due to climate change and hydropower development could result in food shortages for many (e.g., Baran et al. 2008). Myanmar's freshwater ecosystems form an integral part of agricultural production systems which will be impacted by climate change. Climate change impacts on

Table 2 Climate change impacts that are expected to interact with current threats to ecosystems in Myanmar (the relevant ecoregion in Fig. 2 is indicated in italics within brackets)

Ecosystem	Current threats to ecosystems in Myanmar	Expected climate change impacts
Terrestrial		
Lowland tropical forest ecosystems		
Wet evergreen forests (extensive in the Taninthayi Division of south Myanmar). High species diversity (*Tenasserim south Thailand semi-evergreen forests*)	Commercial logging and conversion to oil palm plantations leading to habitat loss and fragmentation throughout Southeast Asia with similar pressures in Myanmar. Severely threatened	Species unable to adapt to warmer conditions due to physiological limitations will be extirpated (Feeley and Silman 2010; Corlett 2011); movements of species will be impeded by fragmented, degraded and cultivated landscapes
Freshwater swamp forests in permanently or seasonally inundated lowlands (Ayeyarwady Delta and the floodplains of the Chindwin and other rivers) (*Ayeyarwady freshwater swamp forests*)	Extensive clearing throughout mainland Southeast Asia with the largest remaining areas in Myanmar	Sea level rise, cyclones and associated storm surges can be expected to negatively impact these ecosystems
Mixed deciduous forests (Central Dry Zone) (*Ayeyarwady Dry Forests*)	Subject to intensive commercial logging and represent a highly water stressed environment	Meteorological observations and climate change scenarios indicate highly variable and reduced rainfall patterns in this region causing further water stress
Eastern and Greater Himalayas		
Alpine/sub-alpine ecosystems (lying between the tree line at 4000 m and the snow line at 5500 m) (*Eastern Himalayan Alpine Shrub and Meadow*) Montane evergreen hill forests (Chin hills) and the Northern mountains forest complex (includes gradients over 5000 m). Large contiguous areas, high floristic diversity and endemism (*Northern Triangle Sub-tropical forests*)	Few existing threats to the ecosystem beyond hunting Shifting cultivation, hunting and timber extraction	In general, alpine plant communities will likely increase in height and cover and decrease in species diversity and evenness in a nonlinear response to global warming (Luo et al. 2004). A 1 °C increase in mean annual temperature will result in a shift in isotherms about 160 m in elevation or 150 km in latitude. Upland species that have narrow altitudinal ranges may suffer from range-shift gaps where they are unable to keep up with advancing climates up mountainsides (Colwell et al. 2008)
Freshwater		
Rivers (Ayeyarwady, Chindwin), lakes (Inle), floodplains, flooded grasslands, and wetland ecosystems	Eutrophication, organic pollution, sediment release, acidification, impoundment, urbanization, hydropower development, flood-risk management and invasion by exotic species. Freshwater biodiversity is very poorly documented (Allen et al. 2010)	Climate change is anticipated to alter seasonal flow regimes and the timing, extent and duration of flooding[a] (TKK and SEA START 2009). Hotter and drier conditions, especially toward the end of the dry season, could result in the drying out of small floodplain water bodies and the contraction of shallow-water zones in lakes such as Inle lake. In seasonally flooded grasslands (Hukawng Valley) a critically endangered habitat, hotter dry seasons and rising CO_2 concentrations could facilitate fire and the invasion of woody plants

Table 2 continued

Ecosystem	Current threats to ecosystems in Myanmar	Expected climate change impacts
Marine		
Coastal ecosystems: mangroves, coral reefs (*Myanmar coastal mangroves*) Coral reefs, Myeik Archipelago of the Tanintharyi Region	Pollution, harvesting and coastal development. Coral reefs are not fully surveyed, protected or monitored	In the nearer term, sea level rise, increased water temperatures will accelerate beach and coastal erosion and cause degradation of estuarine communities, mangroves and coral reefs with ultimate impacts on water supply and fisheries productivity (Grantham et al. 2011). Sea level rise is expected to impact globally threatened species of migratory shorebirds through the loss of intertidal mud flats (Buckton and Safford 2004; Tordoff et al. 2005). Breeding colonies of seabirds and turtles may be particularly vulnerable to sea level rise (Duffy 2011)
		Ocean acidification leads to a reduction in coral calcification and affects coral reefs which provide habitat for about a quarter of all marine species and are the most diverse among marine ecosystems (Roberts et al. 2002)

[a] Predictions are confounded by modeling limitations and natural hydrological variability, and the potential impacts of hydropower dams

the flows of the Ayeyarwady and its tributaries are expected to have important repercussions for economically critical rice-growing regions (Wassmann et al. 2010). Similarly, climate change impacts on coastal ecosystems will have implications for human populations as they provide many functions, services and goods in terms of coastal protection and sediment retention, nurseries and habitats for aquatic organisms and feeding grounds for economically important species of fish.

The response of human populations to climate change will almost certainly place greater pressures on Myanmar's biodiversity. Upland crop production, practiced close to the margins of viable production, can be highly sensitive to climatic variability. The nature of that sensitivity varies according to the region, crop, and agricultural system of interest (Beniston 2003). Furthermore, scenarios of climate change in mountain regions are highly uncertain; they are poorly resolved even in the highest-resolution general circulation models (GCMs).

In coastal areas, sea-level rise would force communities to clear and occupy new lands. In the lowlands generally, declining fish catches would force communities to seek alternative protein sources, and hunting of wildlife would probably increase. An important impact of climate change for wild populations as well as human communities is the increased risk of disease. Anthropogenic global climate change is likely to cause major changes to the geographic range and incidence of arthropod-borne infectious diseases such as malaria and dengue with implications for both wild species and human communities (Daszak et al. 2000; Harvell et al. 2002).

In all regions, increased conflict with protected areas is virtually certain, as displaced communities seek new lands to settle in. In coastal regions, the need to shift some infrastructure inland (such as coastal roads) to avoid sea-level rise may require the clearance, or further fragmentation, of remnant habitats. The scale of these impacts is potentially huge, involving millions of people, and human biogeography will thus be critical to conservation planning under climate change (Woodruff 2010). For biodiversity conservation within a changing climate, adaptation planning will be key to ensuring minimum impacts on species and ecosystem services.

CONSERVATION PLANNING IN A CHANGING POLITICAL AND ENVIRONMENTAL CONTEXT

Strengthening the Protected Area System

Following years of political and economic isolation and relatively low conservation expenditures, there is much that remains to be understood about the status of biodiversity within many of Myanmar's ecosystems. The protected area system has been developed in an ad hoc fashion over time and to date, no systematic review of the distribution of Myanmar's biodiversity ecosystems has been conducted for the purpose of identifying gaps in the protected area network. For example, there are acknowledged gaps in knowledge for freshwater and marine ecosystems with consequent underrepresentation of these systems in the protected area system. There is an urgent need to expand the protected area network to include areas of global conservation importance and for increased investment to effectively protect these areas. Carefully designed biodiversity surveys could provide up to date information on priority species as well as poorly known taxonomic groups (WCS 2012). Specifically, stronger law enforcement and greater engagement of local communities in protected area management are essential requirements. Appropriately designed conservation laws and land use policies are crucial to clarify how local communities can legally manage and benefit from natural resources including timber and other minor forest products.

Mainstreaming Biodiversity Conservation into National Development Planning

At this stage in Myanmar's economic development, large-scale infrastructure projects such as hydropower plants, deep sea ports, gas pipelines, and enhanced transportation networks are being developed across the country. It is important to review and modify relevant environmental policies and in parallel develop strict regulatory frameworks to ensure that environmental and social impacts are minimized and mitigated (Webb et al. 2012; WCS 2012). Concomitantly, the results of the protected area gap analysis should be integrated with national land use plans to limit conflicting land uses and maximize connectivity across conservation corridors. With the economic opportunities presented by the increasing number of development projects in the country there is a need to include valuation of environmental services and biodiversity in development planning. Following the examples from neighboring countries the use of a Payment for Ecosystem Services (PES) approach could be strategically used to increase funding for environmental protection (WCS 2012).

Conservation Planning in the Context of Climate Change

There are clear challenges associated with uncertainty of forecasts, variability of climate impacts, and limited understanding of climate change impacts on biodiversity that influence our ability to develop strategies to increase resilience of species and ecosystems to climate change in Myanmar. In addition to the problems of assessing key, direct threats that climate change poses to biodiversity (e.g., sea-level rise, the impacts of severe droughts), there are less obvious impacts that affect ecosystems that are hard to predict (Watson et al. 2011a, 2012). Key abiotic characteristics, the basic building blocks of a species' fundamental niche (e.g., temperature, rainfall, evapotranspiration) will change and affect distribution and abundance of many species in unknown ways. Consequently, given both the uncertainty in projections of future climates and the uncertainty inherent in most relevant ecological forecasting approaches, conservation managers within Myanmar must become comfortable undertaking conservation actions within realms of uncertainty.

Within the context of the challenges associated with climate change outlined above, there are two distinct categories of actions in adaptation planning that are relevant to Myanmar. The first set of actions involves 'no regret' actions in the absence of good biodiversity baseline and forecast data. A strategy for conserving regional biodiversity in a dynamic climate is to conserve the full spectrum of geophysical settings. If geophysical diversity helps to maintain species diversity, then conserving representative examples of geophysical settings could potentially protect biodiversity under both current and future climates (Beier and Brost 2010). Importantly, reducing or removing the effects of non-climate-related threats such as habitat loss and degradation and overexploitation will increase the ability of species and ecosystems to respond to climate change. Improving management and restoration of existing protected areas and ensuring adequate representation and replication within the protected area network will facilitate resilience. Increasing functional landscape connectivity is the most commonly cited climate change adaptation strategy for biodiversity management (Heller and Zavaleta 2009) and refers to management actions that facilitate dispersal of species among natural areas, for example, through the establishment of landscape corridors or stepping-stone reserves or through actions that increase matrix permeability. For climate change, a particular challenge is determining the pattern and nature of connectivity needed to allow species or communities to track changing habitat conditions through space and time. This is difficult given that we cannot necessarily anticipate where new habitat is going to exist in the future, how long it will persist as climate continues to change, or even whether a species' connectivity pattern will remain similar in an altered climate. A widely applicable example of pre-emptive conservation planning to increase connectivity would be preserving (or restoring) forest continuity along altitudinal gradients, maximizing the opportunity for low-altitude species populations to retreat to cooler refuges in response to warming (Hughes et al. 2010; Corlett 2011).

Based on the above, a series of best practice principles have been actively promoted for adaptation planning that are relevant in Myanmar: (1) Substantially expand the current protected area system to maintain viable populations of priority species and maximize adaptive capacity; (2) Expand the current protected area system so as to capture refugia; (3) Assign priority to protecting large, intact landscapes; (4) Ensure functional connectivity is maintained beyond protected areas; (5) Develop and implement strong environmental safeguards to protect biodiversity within a context of rapidly evolving economic development in the form of large-scale infrastructure projects.

The second category of actions involves undertaking vulnerability analyses for threatened species and ecosystem services, modeling future ecological states (accepting uncertainties) and integrating into a holistic planning framework that includes human responses to climate change impacts (Seimon et al. 2011; Cross et al. 2012). A first step is to build critically important knowledge and capacity to make climate change adaptation of conservation management effective in the absence of data. More advanced climate modeling studies are critical to understanding climate change at relevant spatial and temporal scales in Myanmar. Subsequently, scenario building exercises with scientists and stakeholders may be used to consider how outcomes may vary and what actions would be appropriate for different combinations of factors driving environmental responses to climate change. It is critical to recognize that this second category is climate adaptation (as defined by the IPCC), as relying solely on no-regrets actions (first category above) is unlikely to overcome all the short- and long-term threats climate change presents. Further, it would also be useful to undertake assessments of how climate change is likely to affect current threatening processes to biodiversity and ecosystem services in Myanmar.

THE ROLE OF ECOSYSTEM-BASED ADAPTATION (EBA)

Strong linkages between the impacts and responses of people and biodiversity to climate change indicate the need to develop coherent strategies that seek to conserve biodiversity while maintaining ecosystem services that human communities depend upon. In recent years, EBA has been developed by members of the conservation community as a key approach that uses ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change (Andrade et al. 2011). EBA differs from a single species or single sector approach to management by considering complex interactions between humans and the living and non-living environment over multiples scales in space and time (Clarke and Jupiter 2010). The goal of EBA is to sustainably manage both target and non-target species by preserving or restoring habitat quality to maintain ecosystem services (Rosenberg and McLeod 2005). In particular, it emphasizes the protection and restoration of ecosystem structure, function and key processes, and integrates biological, socioeconomic, and governance perspectives. We believe that EBA will play an important role in climate change adaptation in Myanmar especially given strong human dependence on natural resources such as mangroves and for both inland and marine fisheries. It is important to note that EBA is focused on management of human activities within ecosystems and not the ecosystems themselves, and hence biodiversity conservation is not the primary goal of ecosystem-based management (McLeod and Leslie 2009). As such, there will be a need for specific biodiversity oriented adaptation strategies to be put in place in conjunction with EBA (Ingram et al. 2012).

CONCLUSION

Myanmar offers a unique opportunity to conserve biodiversity that is increasingly under threat in the region. While pressures on natural ecosystems are not inconsequential and are likely to be exacerbated in the coming decade, integrating the impacts of climate change on vulnerable species and ecosystems into immediate conservation planning measures will undoubtedly characterize a prudent approach in the long-term. A key challenge will be to effectively address knowledge gaps both in terms of biodiversity status as well as climate change impacts in comprehensive conservation planning within a context of rapid environmental changes driven by brisk economic growth and noteworthy socio-political transformations.

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