EFFECT OF CLIMATE CHANGE ON BIRDS, HERPETOFAUNA AND BUTTERFLIES IN SIKKIM HIMALAYA: A PRELIMINARY INVESTIGATION

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ABSTRACT

Climate change is one of the greatest challenges faced by the current world. With the current rate of green house gas emission the global temperature is likely to increase by 1.5 to 4.5°C by 2100. This increase in temperature has affected the climate pattern causing cascading effect on biotic and abiotic components of the ecosystem. Warming rate, and also the consequences, is higher in the Himalayas than the rest of the world. Sikkim occupies an important biogeographic location in the entire Himalayan chain and represents high diversity of life forms. Over the years, various climate induced effects have been felt in the Sikkim Himalayas. In this chapter, we provide some evidences of climate change effect on four important faunal groups namely, birds, reptiles, amphibians and butterflies. In response to climate change, many species of these faunal groups have extended or shifted their ranges upwards along the elevation gradient in Sikkim. Late breeding or breeding failure among birds and early breeding of amphibians have been observed in recent years. Biased sex ratio towards females (higher temperature favors females) has been observed in snakes. Drying springs and erratic rainfall pattern has affected breeding activity of amphibians causing decline in amphibian population. Long dry spells has caused the near disappearance of turtles from Sikkim. Based on our observations in Sikkim, and many other studies elsewhere, we opine that there is severe effect of climate change on Sikkim fauna which might lead to serious consequences resulting in extinction of species. We recommend long term monitoring and detailed studies to understand such effects and consequences so that mitigation measures can be undertaken.

Dying streams of Sikkim - the vanishing habitat of amphibians

Rapid urbanisation along the river valley - a potential threat to sensitive faunal habitat

Climate change, its impact on biotic and abiotic components of ecosystem and implementing mitigation measures are the global challenges faced by scientists, governments and policy planners in the current world. It is reported that the earth's surface has warmed up by 0.6 °C for the past 100 years, and with the current rate of emission of green house gases the global air temperature is likely to increase by 1.5 to 4.5 °C by the end of 21st century (Walther et al. 2002; IPCC 2007). Such changes in global temperature has manifold effects ranging from glacial melt and sea level rise, unusual weather events such as flood and drought conditions, intense but short duration of rainfall, infestations of diseases, changes in agriculture pattern, and various effects on flora and fauna (Hickling et al. 2006; Pounds et al. 2006; Nogues-Bravo et al. 2007; Kannan and James 2009; Lawler et al. 2009; Xu et al. 2009).

The effect of changing climate is observed on various flora and fauna around the globe as changes in phenology, upwards shift along latitude and altitude, extinction of species and changes in community and trophic dynamics in different groups of organisms such as mammals, birds, herpetofauna, butterflies and plants (Walther et al. 2002; Hickling et al. 2006; Pounds et al. 2006; Kannan and James 2009; Sekercioğlu et al. 2012). Climatic change events have pushed most bird species into high risk of extinction (Sekercioğlu et al. 2008; Wormworth and Sekercioğlu 2011). It is predicted that 600-900 land birds will get extinct by 2100 due to warming of the surface temperature by 3.5°C with additional 100-500 extinctions with one degree rise in temperature (Sekercioğlu et al. 2012). Breeding failure and population reduction is also commonly observed in birds around the globe (Sekercioğlu et al. 2012). Being ectothermic, lower vertebrates including reptiles and amphibians are affected directly or indirectly due to climate change (Araujo et al. 2008). Upward migration and biased sex ratio are the major threat faced by reptiles (Janzen 1994). Population decline and extinction of amphibians due to climate change has been reported from different parts of the world (Pounds et al. 2006; Araujo et al. 2008; D'Amen and Bombi 2009). Similarly, various effects on butterflies have also been highlighted around the globe (Walther et al. 2002; Hickling et al. 2006; White and Kerr 2006; Forister et al. 2010).

The Himalayan region is the most sensitive zone for global climate change. The rate of increase in temperature across the Himalaya is three times the global average (Xu et al. 2009). Currently the temperature of Himalayas has been increasing by 0.06°C per year (see Shrestha et al. 2012). According to the projection made by Intergovernmental Panel on Climate Change (IPCC) average annual mean warming of the Asian land mass will be about 3°C by the 2050 and about 5° C in the 2080 (IPCC 2007) with much higher rates towards the Tibetan Plateau (Nogues-Bravo et al. 2007; Xu et al. 2009). The effect of climate change across the Himalayan region including Sikkim is manifested in the form of glacial melt, changes in sowing and harvesting season, decreased productivity of crops with new invasive species and weeds, drying up of springs, shifts in geographical range of species, changes in species composition of the communities and extinction of species (Sharma and Tse-ring, 2009; Xu et. al. 2009; Tse-ring et al. 2010; Chaudhary and Bawa 2011; Sharma and Dhakal 2011; Tambe et al. 2011, 2012; Kumar 2012). The forests, biodiversity, water sources and agricultural sectors have become highly vulnerable in the eastern Himalayan region due to climate change (Chettri et al. 2010; Tse-ring et al. 2010; Ravindranath et al. 2011).

Sikkim lies in the western flank of eastern Himalaya and represents high diversity of life forms. Here, sudden climatic variation can be detrimental as Sikkim harbours the world's third highest mountain peak Mount Khangchendzonga (8598 m) along with a chain of Himalayan ranges and is located in the lap of the Tibetan plateau housing critical habitats. Hence, the effect of climate change can be more prominent and devastating in Sikkim posing serious threats to various life forms. While such changes have been noted in the Sikkim

Himalaya, systematic study and documentation are scanty, and almost lacking. Recently, Tambe et al. (2011) and TMI-India (2012) studied the impacts of climate change on spring discharge. Similarly, Kumar (2012) has observed the decline of Rhododendron population in the Sikkim Himalayas. Here, in this chapter, we highlight the effect of climate change on four important faunal groups namely, birds, reptiles, amphibians and butterflies in the Sikkim Himalaya. These are preliminary field based observations, and more quantitative and robust studies are awaited.

IMPACT OF CLIMATE CHANGE ON VARIOUS TAXA

Our field based observation revealed that climate change has significant and measurable impacts on various taxa. It has notable impacts on vegetation, butterflies, herpetofauna, birds and mammals both in temperate and tropical regions. Empirical data and computer simulations suggest that changes in temperature at higher elevations and altered rainfall pattern at lower elevations are the major causes for these effects (see Sekercioğlu et al. 2008). The most prominent impact of climate change is the alteration of the natural distribution limits of floral and faunal communities, changes in timing of biological behaviour such as flowering, fruiting and breeding, change in community composition, ecological interaction and community dynamics and ecosystem function and services. Nevertheless, several species have evolved over millions of years to adapt to specific climatic conditions as well as variation in climate. However, climate change has occurred so rapidly within a short span of time that many species fail to respond promptly and show adaptation resulting into extinction due to the fast changing climatic conditions (Pounds et al. 2006; Kannan and James 2009; Xu et al. 2009).

EFFECT ON BIRDS

Birds of the tropical mountains including Himalayas are most vulnerable to climate change (Wormworth and Sekercioğlu 2011). While there could be manifold effect of climate change on birds of Sikkim, we highlight some evidences of upward extension/shift in altitudinal ranges of species, change in breeding seasonality and the breeding failure. Here we have compared the upper and lower limit of bird species provided by Ali (1962) with our recent observations to estimate range extension/shifts. Similarly, information on breeding of birds provided by Ali (1962) and Ali and Ripley (2001) forms the basis for breeding seasonality and breeding status of some bird species in Sikkim.

Upward Extension/Shift in Altitudinal Ranges of Species

Consequent upon the increase in temperature, the snowline in the Himalayas has shifted upwards over the years (Xu et al. 2009). Such shift has created novel niches for birds in the alpine areas causing upward extension in their altitudinal ranges. Species of low to mid-elevation areas have also extended their altitudinal limit towards higher elevation displaying adaptation to climate change. Compared with the observation of Ali (1962), we found elevational range shifts in the lower as well as upper limits of some bird species in Sikkim. For example, Blood Pheasant was reported to occur as low as 1500 m and normally between 2600 m to 4500 m (see Ali 1962) but we observed this species above 3300 m displaying huge shift in lower elevational limits. Similarly, Snow Pigeon currently occurs in the sub-alpine and alpine zones far exceeding its historical lower limits of 1600 m (common at 3000 m). A very noteworthy observation is of Ibisbill, which was historically recorded as low as Rangpo and Singtam along the river Teesta but our records are mostly from 3300 m and above. Rusty-bellied Shortwing has shown shift of its habitat from temperate broad-leaved evergreen forests (upper limit 2900 m) to temperate coniferous forest (3600 m) in Sikkim. There is a clear evidence of its elevational range extension of around 700 m (Acharya and Vijayan 2007). White-winged Redstart occurs in the Tibetan Plateau above 4000 m but was recorded as low as around 1700 m by Loke-Salim Ali expedition in Sikkim in 1950s. Elevational range extension/shift has been observed in various species of birds in Sikkim among which some species with clear evidences of elevational shift are provided in Table 1. This list is not comprehensive and many other species show elevational range extension or seasonal movement along the elevational gradient.

Range extension in some species seems to be quite high or over estimated. These data provides an average value based on historical records and point the way forward for an extensive field study to understand various effects related to climatic change on birds and their adaptation strategy.

In Sikkim most bird species have shown upward shift from lower elevation limits resulting in reduced range sizes. Many studies have found that species shift their elevational ranges in order to adapt to the changing

Table 1. Historical Elevational Range (HER) based on Ali (1962) and average range extension/shift (RES) (both upper and lower elevational limits) in some bird species in Sikkim

Species	**HER (m)**	**RES (m)**
Blood Pheasant *Ithaginis cruentus*	2600-4500	700
Snow Pigeon *Columba leconota*	3000-4880	250
Speckled Wood Pigeon *Columba hodgsonii*	1500-3960	300
Ashy Wood Pigeon *Columba pulchricollis*	1200-3000	550
Barred Cuckoo Dove *Macropygia unchall*	450-2700	250
Great Barbet *Megalaima virens*	450-2100	350
Hodgson's Hawk Cuckoo *Hierococcyx fugax*	600-1800	600
Ibisbill *Ibidorhyncha struthersii*	2600-4250	700
Peregrine Falcon *Falco peregrinus*	1500-2750	650
Golden-fronted Leafbird *Chloropsis aurifrons*	300-750	200
Large-billed Crow *Corvus macrorhynchos*	1800-4250	700
Scarlet Minivet *Pericrocotus flammeus*	300-1800	300
Yellow-bellied Fantail *Rhipidura hypoxantha*	300-3650	400
Ashy Drongo *Dicrurus leucophaeus*	300-2750	250
Plain-backed Thrush *Zoothera mollissima*	1200-3650	500
Rusty-bellied Shortwing *Brachypteryx hyperythra*	Upto 2900	700
Rufous-bellied Niltava *Niltava sundara*	300-2100	250
White-throated Redstart *Phoenicurus schisticeps*	3000-4550	500
Grandala *Grandala coelicolor*	2800-5200	600
Coal Tit *Parus ater*	2750-3800	250
Black-throated Tit *Aegithalos concinnus*	1200-2450	300
Striated Laughingthrush *Garrulax striatus*	750-2300	600
Black-chinned Yuhina *Yuhina nigrimenta*	350-900	300
Fire-tailed Sunbird *Aethopyga ignicauda*	1400-4000	600
Scarlet Finch *Haematospiza sipahi*	600-2000	600

Grandala *Grandala coelicolor: A* high altitude species with probable effect of climate change on its lower elevation limit.
Photo courtesy: Karma Zimpa

Ashy Drongo *Dicrurus leucophaeus:* A common species but its population might be under threat due to climate change.
Photo courtesy: Ganesh Mani Pradhan

climatic conditions; warming at lower elevation prompts them to shift to higher elevation. Some species, especially migratory birds, will be able to adapt or shift ranges along horizontal gradient (Sekercioğlu et al. 2008). Elevational gradients provide complex situations displaying various climatic, ecological and physiological effects that impose limitations on species range extensions. Hence, range extension is limited or almost unaccomplished in most bird species due to their physiological and ecological constraints resulting into high extinction risks or mass extinctions (Sekercioğlu et al. 2008; Sekercioğlu et al. 2012). Uphill shift of species due to warming temperatures reduce their ranges, sometimes entirely, pushing them to mountain tops. In montane species, range size can be best used to predict the threat of extinction as most of the species have very small range size (Harris and Pimm 2008). Consequently, high elevation species are facing higher risk of extinction compared to low elevation species particularly where there is no land or habitat available at higher elevations (Benning et al. 2002). The most vulnerable to extinction risks are endemics and restricted range species with little or no space for upward movement or their inability to shift upwards due to intolerance to physiological limits imposed by geographical gradients (Lawler et al. 2009).

In many cases the effect of climate change on birds is indirect. Unusual weather events and warming temperature has multifarious effect on forests and bird habitats (Walther et al. 2002; Xu et al. 2009). Alteration in habitats prompts birds to shift their ranges vertically and horizontally (Sekercioğlu et al. 2012).

Climate induced effects differ among species based on their body physiology. While some species might not get affected, the rate of effect differs among others so that all species in a community do not synchronize their shifting behavior. Asynchronous shift results in changed species assembly and community structure along the elevation gradients. As the area and also the resources decrease at higher elevations, interspecific competition also increases posing fatal effects to high elevation residents (Jankowski et al. 2010). In some cases migrant species can completely dominate their upland congeners pushing them further upwards or leading them to extinction (Jankowski et al. 2010).

Plain-backed Thrush *Zoothera mollissima:* Responded to climate change showing elevation range shift. Photo courtesy: Karma Zimpa

Blue-fronted Redstart (female) *Phoenicurus frontalis:* Alpine species shifting its range further up, threat of reduced range sizes. Photo courtesy: Ganesh Mani Pradhan

Change in Breeding Seasonality

Warmer temperature, alteration in habitats and changed climatic pattern may alter bird's reproductive strategies. Many tropical bird species might shift their breeding periods in response to changes in temperature and rainfall regimes. Birds start breeding earlier than their usual breeding season or produce lesser offsprings due to reduced reproductive rate resulting in population decline (Both and Visser 2001; Wormworth and Sekercioğlu 2011). Change in temperature and humidity indirectly affects the activity and behavior of birds. Abandonment of habitat due to unfavorable climate hinders important activities such as feeding and breeding displays. Erratic heavy rainfall leading to lower temperatures during breeding season in the mountains can even postpone their breeding activity (Sekercioğlu et al. 2012).

Generally, in response to climate change, birds start breeding earlier than their usual breeding period. In contrast we have observed that some bird species are breeding in the later half of their breeding season in Sikkim. Breeding activities such as habitat selection, nest building and even laying of eggs and emergence of hatchlings is supposedly delayed in birds such as Ashy Drongo *Dicrurus leucophaeus*, Black Bulbul *Hypsipetes leucocephalus*, Chestnut-crowned Laughingthrush *Garrulax erythrocephalus*, Grey-backed Shrike *Lanius tephronotus*, White-capped Water Redstart *Chaimarrornis leucocephalus* and White-collared Blackbird *Turdus albocinctus*. This is attributed to unexpected weather events such as longer dry spells, altered plant phenology and insect emergence or may be heavy rainfall at the onset of breeding season. Nevertheless, there is an evidence of advancement of breeding activity in some species due to cue provided by warming temperature.

Breeding season in Common Tailorbird *Orthotomus sutorius* in Sikkim lasted only for two to three months which otherwise reported to breed almost round the year (Ali and Ripley 2001; Acharya 2008; Acharya and Vijayan 2009). This is an indication of climatic effect on breeding habitats and food availability of this species. We also observed reduction in clutch size in some species such as Chestnut-crowned Laughingthrush, Grey-backed Shrike and White-rumped Munia *Lonchura striata* most probably due to effect of climate change. Among the set of nesting characteristics, environmental variables are potential factors for nest-site selection in birds of Sikkim (Acharya and Vijayan 2009).

Change in breeding seasonality impacts breeding success of birds. The mis-match between breeding season and food availability jeopardizes the bird's life history strategies (Visser et al. 1998). The food available to breeding individuals or the hatchlings might not be enough to support their physiological and metabolic demand

Grey-winged Blackbird *Turdus boulboul* (female): A species of the forest edges.
Photo courtesy: Ghanashyam Sharma

A very rare shot: Common Green Magpie *Cissa chinensis* on the air carrying its prey Khukri Snake (*Oligodon* sp.).
Photo courtesy: Ghanashyam Sharma

leading to breeding failure. In addition, early breeders have to compete with the space and other resources with birds breeding in their own timing or migrant species have to compete for nest site and food with the resident species (Both and Visser 2001). Temporal partitioning of the breeding period due to climate induced changes can lead to interspecific competition with severe consequences (Ahola et al. 2007).

Breeding Failure

Ali (1962) reported breeding records of 229 species of birds in Sikkim but the number of breeding species decreased in the recent years (Acharya 2008). It shows that breeding period is either shortened in most species or they fail to make nests and reproduce due to climate induced changes in plant phenology, food availability and habitat alteration. Long spell of dry season fails to induce fruiting and flowering of plants (Markham 1998) and emergence of insects (Kai and Corlett 2002) resulting in low food availability. As many birds coincide their breeding with increased resource abundance (mostly during wet season), longer and unpredictable dry seasons as a result of climate change can affect reproductive performance leading to population decline or complete breeding failure in birds (Williams and Middleton 2008). Most birds in Himalayas start breeding immediately after the first summer rainfall. Unexpected heavy rainfall and high humidity at the onset of breeding season equally disrupts the breeding activity and nesting characteristics of birds.

Climate change has severely affected the breeding activity of birds especially in the higher elevation areas of Sikkim leading to reproductive failure. There are breeding records of species such as Ruddy Shelduck *Tadorna ferruginea*, Ibisbill *Ibidorhyncha struthersiii,* Common Redshank *Tringa totanus* and Black-necked Crane *Grus nigricolis* in Sikkim (Ali 1962, Ganguli-Lachungpa 1990, 1998; Ganguli-Lachungpa et al. 2007). However no breeding observations have been made on these species in the recent years. Increase or decrease in water temperature during breeding season in high altitude fresh water bodies in Sikkim (Gurudongmar Lake, Changu Lake, Thangu Chu, Yumthang Chu etc.) has affected the breeding performance of these birds. Change in surface temperatures of water bodies can reduce prey availability for aquatic birds. Many bird species have a critical water surface temperature threshold, above which the lack of prey leads to chick mortality (Wormworth and Sekercioğlu 2011). As birds require optimum temperature for egg laying and incubation, extended cold spells and snow fall events either postpone breeding activity or leads to breeding failure in both terrestrial and aquatic birds. Well designed intensive study is urgently required to understand the breeding status of birds in Sikkim (especially in high elevation areas) and probable impact of climate change in their reproductive behavior.

Breeding habitat of birds at lower elevation. Note holes in the tree for hole-nesters such as woodpeckers
Photo courtesy: Ghanashyam Sharma

EFFECT ON HERPETOFAUNA

Herpetofauna form an important component of our ecosystem by linking terrestrial with aquatic ecosystem and the higher vertebrates with the lower vertebrates (Bickford et al. 2010). Although herpetofauna are ecologically diverse and occupy an important position in trophic dynamics, they are generally not adequately considered in ecosystem planning and management. Due to their ectothermic nature, they are more susceptible to climate change than other vertebrates. Here we discuss potential effect of climate change on amphibians and reptiles of Sikkim, and link them with evidences from other regions.

EFFECT ON REPTILES

Upward Species Migration

In Sikkim, reptiles are represented by lizards and snakes. Many previous studies (Smith 1943; Waltner 1973) report the occurrence of turtles and tortoises in Sikkim but recent studies did not support their occurrence in Sikkim. Due to their preference for warmer climate and scaly body, reptiles are less likely to be affected by climate change compared to amphibians (Henle et al. 2008). While warmer temperature seems to be beneficial on a short term basis, its long term impact is detrimental. As observed in other organisms, one of the significant impacts of climate change on reptiles is the shift in altitudinal and latitudinal limits of species (Bickford et al. 2010). With the increase of temperature, the animals tend to seek refuge towards higher elevation leading to upward migration. There are some examples of such movements in the Sikkim Himalayas. Monocled Cobra *Naja kaouthia* is a tropical species and occurs mostly below 1000 m but we have observed this species at 1700 m showing clear evidence of its upward movement. Upward movement of King Cobra *Ophiophagus hannah* has been reported from western Sikkim (Bashir et al. 2010). King cobra generally considered to be a tropical species, does its recent occurrence in the temperate forests of west Sikkim indicate the impact of climate change? Similarly, Smith (1943) reported the occurrence of Himalayan Mountain Keelback *Amphiesma platyceps* between 1500-1800 m and Worm Snake *Trachischium guentheri* between 900-2100 m, but our study reported the maximum occurrence at 2600 m and 2700 m respectively in North Sikkim. We never observed *Trachischium guentheri* below 1700 m but was common above 2100 m. While there are many instances of

Snakes of Sikkim – *Naja kaouthia*, a species of lower elevation but observed at middle elevation in South Sikkim-a case of uphill migration. *Trachischium guentheri,* a high elevation species which shows biased sex ratio uphill migration of species due to increased temperature, there are also reports of downhill migration from high to mid-elevation due to various reasons (Bickford et al. 2010). Species sandwiched at mid-elevation from low and high elevation may increase the species richness initially but in long term due to competition, altered community dynamics may result in loss of biodiversity. More extensive research should be carried to assess the altitudinal migration of species and its consequences of climate change on reptiles.

Biased Sex Ratio

Reproduction and development in reptiles has direct link with temperature. Temperature determines the sexes in most reptilian species (Adolph and Porter 1993; Janzen 1994; Bull 2008). In a study on painted turtle in North America, 4°C rise in temperature favored all female offspring resulting in profound gender imbalance eventually leading to population crash as no males were available for fertilization (Janzen 1994). Our study in Sikkim supports this finding. *Trachischium guentheri*, a high altitude snake in Sikkim, showed skewed sex ratio (M:F=1:1.6; Chettri et al. 2009). More in-depth studies are needed to understand the impact of climate change on sex determination of Himalayan reptile species. According to Fisher (1930), natural selection has always favoured equilibrium in sex ratio (1:1) if the expenditure of producing both sexes is equivalent. While the effect of slight increase in ambient temperature can be minimised by selecting cooler places for nesting by female but behavioural shift alone may not be sufficient to compensate the recent climate change (Bickford et al. 2010). Hence deviation of sex ratio from the normal due to global warming can disrupt population dynamics of reptilian community.

Influx of Exotic Species

Climate change has lead to the influx of exotic species. Influx might lead to disproportion in prey-predator relationship thereby disturbing the entire food chain (Pianka 2000). As the hilly terrain of Sikkim forms natural continuum with the plains of North Bengal, species influx could be more than expected (Chettri and Bhupathy 2007). Due to favorable temperature in the hills, movement of species from lowland to highland occurs thereby threatening the local diversity and endemicity (Raxworthy et al. 2008). For example, in Sikkim, we find Indo-Chinese elements of rat snake *Ptyas korros*, whereas in plain area of West Bengal an Oriental species *Ptyas mucosus* occurs. Due to climate change there is a possibility of *Ptyas mucosus* to penetrate into the hills affecting niche dimension of the native *Ptyas korros*.

Disappearance of Turtles from Sikkim

Turtles and tortoises are not found in Sikkim although historical records of their occurrence at lower elevations are available (Smith 1943; Waltner 1973). While the occurrence of turtles in Sikkim cannot be completely ruled out (sporadic sightings of turtles was reported in the local media in recent past), they have not been observed within the geographical boundary of Sikkim in the recent years. Hence, turtle disappearance is attributed to drying of springs and streams in the lower elevation in Sikkim. Dryness could have pushed the habitat of turtles further down necessitating an area for further research and confirmation.

EFFECT ON AMPHIBIANS

Amphibians are potentially good bio-indicators due to their highly permeable skin and dual mode of life (Beebee and Griffiths 2005). Climate change affects three major physiological functions of amphibians viz., water balance, thermo-regulation and hormonal regulation of reproduction (Donnelly and Crump 1998). The permeable nature of the amphibian skin results in high rate of water loss through evaporation thereby disturbing the normal water balance of the body. Moisture availability also influences amphibian behavior. As amphibians are poikilothermic vertebrates, thermo-regulation has manifold effect on amphibian body physiology such as digestion, oxygen uptake, vocalization, emergence from hibernation, development, metamorphosis and growth (Donnelly and Crump 1998). Most of these processes are complex and they have cascading effect on various other body functions. In addition, most amphibians are able to carry out their activities at suboptimal temperature and unable to survive at near critical maximal temperature (Donnelly and Crump 1998; Bickfor

Amphibians of Sikkim - *Nanorana blanfordi,* species of torrential streams of Eastern Himalaya (A); *Scutiger sikimmensis* and its clusters of eggs in a stagnant puddle of water adjacent to running streams (B) et al. 2010). Similarly, climate change can impact the hormonal regulation of reproduction on amphibians. Reproductive cycles in amphibians are controlled by Gonadotropin releasing hormone released from the hypothalamus which influences the activity of gonads (Beebee 1995). While reproduction in amphibians is affected by many factors, rainfall seems to be the most significant especially for tropical species (Bickford et al. 2010). Onset of rainfall provides environmental cue to the hypothalamus which then prepares for breeding. Some examples of climate change effect on amphibians of Sikkim are provided below.

Advance Breeding

As highlighted above, amphibians prepare for breeding after the onset of rainfall. Due to unusual rainfall event or early summer rain, some amphibians in Sikkim started breeding earlier than their actual breeding time. For example, Bush Frog *Philautus* sp. normally breeds during May-September but their breeding period have been advanced in recent years (breeding sets late March or early April now). As *Philautus* sp. have direct development, they experience more mortality due to drier and warmer condition (Bickford et al. 2010). During many occasions we observed well developed tadpoles of *Duttaphrynus* spp. and *Amolops* spp. at low and middle elevation during early April. Similarly, *Paa liebigii* is reported to lay eggs during July-August but its breeding has been advanced by almost three months now (breeding starts first week of April; Barkha Subba *pers. comm.*). The short and heavy episode of early rain followed by dry spells leads to drying of many streams before amphibians complete their metamorphosis. Such irregular rainfall pattern poses serious threat to both eggs and larva; either they face the risk of being washed away by heavy rains or face desiccation before the completion of metamorphosis leading to mass mortality. Advancement in breeding season in amphibians has been reported from many other regions (Donnelly and Crump 1998; Bickford et al. 2010). Breeding of amphibians in temperate zone has also been advanced due to climate change (Beebee 1995).

Upward Migration of Species along the Elevation Gradient

With the emerging global warming and climate change patterns, many amphibians across the globe have shifted their range towards higher elevation (Pounds et al. 1997). As the animals of lower elevation moves upward, there is no space for species of higher elevation to move up indicating serious ecological consequences leading to extinctions (D'Amen and Bombi 2009). In Sikkim, we have observed many species much above their recorded elevational limits. *Scutiger sikkimensis* commonly known as snow toad was observed at an altitude of 4600 m, exceeding by 1100 m from its commonly recorded elevation (Schleich and Kastle 2002). Similarly, Common Toad *Duttaphrynus himalayana* was observed upto 3300 m, whereas historical records shows its highest elevation as 2700 m. Due to absence of baseline data for Sikkim and Darjeeling, comparison was made mostly with Nepal (Schleich and Kastle 2002). These authors highlighted that species in the eastern Himalaya are supposed to be restricted to lower range than the similar species of central or western Himalaya.

Generalist species can easily adapt to climate change by extending their range upwards. However, specialist in terms of diet, micro-habitat and temperature are unable to adapt to climate change. Raxworthy et al. (2008) found an average of 19-51 m uphill movement of 30 species of herpetofauna in Madagascar over a period of one decade due to climate change. Due to dearth of long term data, robust analysis to prove the upward movement of species along elevation gradient in Sikkim is awaited. Nevertheless, almost 50% of the respondents have perceived the upward range shift of many species in the Khangchendzonga Himalayan Landscape (Chaudhary et al. 2011).

Elevational Range Limit

Our recent study shows that amphibians of Sikkim have narrow elevational width; around 45% species have less than 500 m elevational width (Chettri 2010). The narrow elevational range of most amphibian species reflects their sensitivity towards various environmental factors which changes at a faster rate along the elevation gradient. Extreme temperature usually occurs near the boundary of the species distributional limit and hence jeopardizes their range expansion (Donnelly and Crump 1998). Hence, endemic and restricted range species are the major victims of climate change (Araújo et al. 2008). Disappearance of golden toad from Costa Rica is an example of vulnerability based on narrow distribution limit (10 sq. km.) (Pounds et al. 2006). However, species with broad elevation range can expand their ranges and hence becomes better colonizers.

Impact of Disease on Amphibians

Another significant impact of climate change on amphibians is the rapid spread of fungal diseases which makes them more vulnerable than birds and mammals (Stuart et al. 2004). The most charismatic brightly coloured frog of Central America (*Atelopus* sp.) were the first terrestrial vertebrate to witness the impact of evolving climate change. In Costa Rica alone, 67 out of 110 endemic species became extinct within a short span of two decades (Pounds et al. 2006). The high altitude golden toad of Monteverde, Costa Rica has extirpated because of Chytrid fungus which extensively proliferated due to increasing temperature because of climate change (see Pounds et al. 2006). The major impact of this fungal disease is experienced in mid-elevation rather than low and high elevations as the temperature is optimum there for fungal proliferation. In Sikkim the maximum diversity of amphibians occurs at mid-elevation (Chettri 2010). Hence, disease proliferation in amphibians due to climate change can affect species inhabiting most diverse mid-elevation regions.

Drying of Spring Affects Amphibian Population

Short episodes of high intensity rainfall followed by dry winter has resulted in drying up of streams and springs in Sikkim (Tambe et al. 2011; TMI India 2012). Apart from services to humans, these water bodies are home to most amphibians. With current dry spells and spring drying rate as reported by the above mentioned studies, breeding of most amphibians gets affected leading to breeding failure and population decline. More importantly, drying up of fast flowing streams is detrimental to many Himalayan endemic species such as *Paa* sp., *Amolops* spp., *Megophrys* spp. (locally termed as 'Paa') which are adapted to torrent streams. Due to their specific adaptation to fast flowing waters, they are restricted to rapid streams. Drying of these streams might gradually lead to extinction of these species.

Being ectothermic, both amphibian and reptile distribution and ecology are closely governed by rainfall and temperature patterns, and hence climate change will have significant impacts on their diversity (Araújo et al. 2008; Bickford et al. 2010). Most ectotherms do not perform optimally at upper end of their thermal tolerance but perform better at lower temperature referred as thermal optimum (Feder and Burggren 1992). Climate change could act in synergy with biotic and abiotic agents like disease and infection, intense UV radiation, predator and competition leading to global decline of species (Araujo et al. 2006; Sathaye et al. 2006).

EFFECT ON BUTTERFLIES

Butterflies are considered as indicators of ecosystem change and are used to predict various environmental alterations (Chettri 2010a; Rákosy and Schmit 2011). Due to their specificity in ecological requirements such as temperature, humidity, food plants and egg laying habitats, they are most likely to get affected by global climate change (Forister and Shapiro 2003; González-Megías et al. 2008). Studies have found early migration, northward shift in latitudinal ranges, upward shift in elevational ranges, population decline and species extinction as climate induced effect among butterflies (Parmesan et al. 1999; Walther et al. 2002; Hickling et al. 2006; Forister et al. 2010). Since butterflies are the important pollinator component of ecosystem, any affect on them would lead to disruption in pollinator relationships. Less nectar availability affected by dry spells and drought on plant phenology have negative consequences on butterflies.

Clockwise from top- Yellow Swallowtail *Papilio machao*n, Knight *Lebadea Martha*, Lemon Pansy *Precis lemonias* and Red Lacewing (female) *Cethosia biblis*: Victims of climate induced changes

In Sikkim Himalaya, there are already signs of climate change on butterflies. Many species have extended their distribution in response to the changing climate. Most butterflies have very narrow elevation ranges. Hence, upward extension has further contracted their ranges making them more vulnerable. Upward range shift and contraction of elevational and latitudinal range of butterflies have been observed in different parts of the world (Parmesan et al. 1999; White and Kerr 2006; Wilson et al. 2007; Forister et al. 2010).

Some of the species in Sikkim Himalayas showing elevational range shift due to climate change are Common Birdwing *Troides helena*, Yellow Swallowtail *Papilio machaon*, Red Helen *Princeps helenus*, Yellow Helen *Princeps nephelus*, Yellow Orangetip *Ixias pyrene*, Redspot Jezbel *Delias descombesi*, The Small Grass Yellow *Eurema brigitta*, Forest Pierrot *Taraka Hamada*, Angled Sunbeam *Curetis dentate*, Golden Sapphire *Heliophorus brahma*, Metallic Cerulean *Jamides alecto*, Dark Judy *Abisara fylla*, Common Evening Brown *Melantis leda*, Common Red Forester *Lethe mekara*, Nigger *Orsotrioena medus*, Circe *Hestina nama*, Large Yeoman *Phalanta alcippe*, Large Silverstripe *Childrena childreni*, Common Map *Cyrestis thyodamas*, Green Commodore *Limentis daraxa*, Common Earl *Tanaecia julii*, and Red Lacewing *Cethosia biblis*. The impact on various species of blues, whites and skippers, and many rare and scarce butterflies are not known.

It is apparent that climate change has relatively more effect on biodiversity of low to mid-elevation compared to higher elevation (Pounds et al. 2006; Colwell et al. 2008). Butterflies peak their diversity in the lower elevation band in Sikkim (Haribal 1992; Acharya and Vijayan 2011) where climatic effect and habitat alteration is maximum. Unusual weather events have affected their potential habitat at lower elevations posing serious threats to butterflies. Haribal (1992) also noted decline in population of butterflies of Sikkim mostly due to anthropogenic activities.

Climate change has some positive effect on butterflies as the warmer temperature is favorable for various behavioural activities such as flight, feeding, mud-puddling, migration etc. (Haribal 1992). Early flowering of food plants or advance leafing of egg laying plants is beneficial for early emergence of butterflies. But these short term benefits might turn detrimental for survival of butterflies or their offspring in the long run.

Most of the climate change studies are focused on vertebrates. Despite comprising vast majority of global species richness, effects of climate change on insects remains poorly understood. Studies on impact of climate change on butterflies are very scanty around the globe and lacking in the Himalayan region mostly due to lack of appropriate methodology. With the development of standard methodology, the number of studies in this aspect might increase the contribution to our knowledge on understanding the effect of climate change on these insect groups.

CONCLUSION

Climate change has been felt worldwide and its impact is clear on different organisms and ecosystems. Although some species have shown adaptation to this global phenomenon, many others have been pushed into extinction or near extinction. Such impacts are reported to be more serious in the Himalayan region. Sikkim displays various signs of climate change impact on water sources, agriculture, forests, flora and fauna. While we have ample examples to prove that many species of plants and animals have responded to climate change but precise responses are not known. To understand and address the climatic effect on flora and fauna in the Himalayas we recommend widespread and long term monitoring across the entire Himalayan region.

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