Module: BIO 5202

Biological Diversity

ESSAY TITLE:

"IS CLIMATIC STABILITY A REQUIREMENT FOR HIGH LEVELS OF BIOLOGICAL DIVERSITY?"

Themis Nasopoulou
(Reg. N. 377290)

University of Plymouth

School of Science

MSc/PGDip Biological Diversity

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Module Leader: Dr Paul Ramsay

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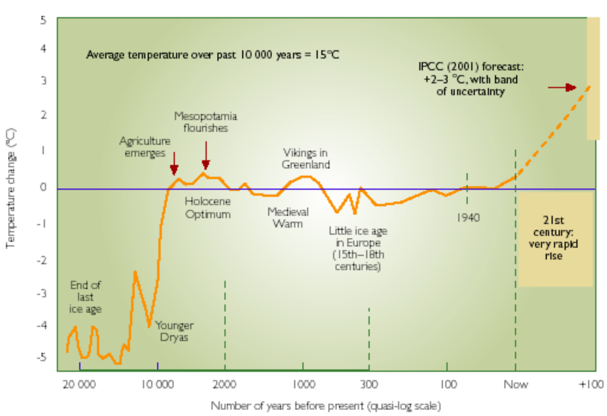
Introduction

The increased attention to biodiversity worldwide has stimulated interest in understanding biophysical factors associated with indicators of biodiversity such as species richness. Species richness is not constant through space. It is negatively related to latitude and altitude. High species richness may be caused by accumulation of species over a long time in places where environmental conditions remained stable and predictable. Biodiversity increases from a minimum at the poles to a maximum at the equator. The tropics tend to be much more diverse than other regions. In general, it is also known that tropical climate is more steady than at the poles over all time scales. What is the relationship between climate stability and biodiversity?

Global Climate Changes

Global climate is not static and is affected by many different processes. We know that natural variations can be caused by external processes, such as fluctuations in energy received from the sun and changes in the earth's orbit and internal processes involving changes in the interactions between the ocean and the atmosphere and land systems. However, whilst climate change is a natural process that occurs over a wide range of timescales, from a few years to hundreds of millions of years, observed changes in global climate, especially those in the last 100 years are now likely to be due to a combination of both natural and human factors.

Figure 1.1. Variations in Earth's average surface temperature, over the past 20,000 years



In fact, the climate of the Earth has never been stable. Recent glacial periods, for example, have been (globally) 4°–5°C cooler than now, and some interglacials have been (perhaps) 1°–2°C warmer. These prehistoric changes in climate were clearly natural in origin and occurred on a planet inhabited by primitive societies with far smaller populations than at present. Indeed, the regularity of the diurnal and seasonal rhythms of our planet has always been overlain by inter-annual, multi-decadal and millennial variations in climate, over whatever timescale climate is defined (Hulme 2003).

In their third and most recent Assessment Report, the **Intergovernmental Panel on Climate Change (IPCC),** state that "**the earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities**".

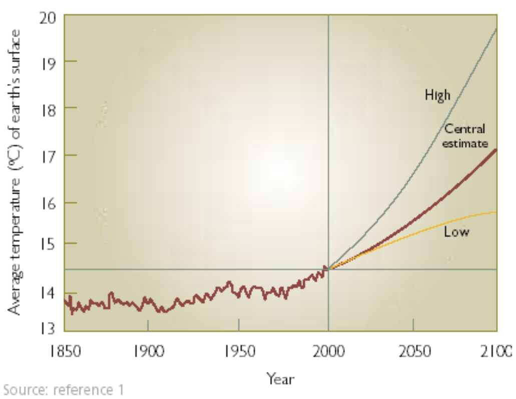
Firstly they report that the intensification of agriculture and land use and the reliance of industrial economies on carbon-intensive energy have dramatically "increased the atmospheric concentration of greenhouse gases, those that lead to a heating of the atmosphere, relative to the pre-industrial era". For example, concentrations of carbon dioxide have increased by 31%, nitrous oxide by 16% and concentrations of methane have increased by about 150% since 1750. Other pollutants from human activities, such as sulphur dioxide, which transform into aerosols and act to cool the climate however, complicate the picture (IPCC, 2001).

Secondly they say that there "are an increasing body of observations that give a collective picture of a warming world and other changes in the climate system". For example, global mean temperature has risen by about 0.6°C during the 20th century and in the northern hemisphere temperature increases have been greater than during any other century in the last 1000 years. The 1990's were the warmest decade in the last 100 years and 1998 the warmest year in the instrumental record (1861-2000). Other evidence for changes in the global climate include an increase in night-time temperatures over many land areas at about twice the rate of daytime temperatures; a decrease in frost days for many land areas and an increase in precipitation (5-10%) in many northern hemisphere land areas (IPCC, 2001).

Thirdly there "is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". For example, when global mean surface temperature anomalies relative to the 1860 to 2000 mean were compared to model simulations that included natural forcing, anthropogenic forcing and both these forcings combined, the latter model was the only one to provide an adequate simulation of the global temperature series over the 140 year period. Furthermore, this model consistently found evidence for an anthropogenic signal in the climate record of the last 30 to 50 years (IPCC 2001).

Therefore, one of the major conclusions of the Third Assessment report was that "most of the warming observed over the last 50 years is likely to have been due to increasing concentrations of greenhouse gases."

Figure 1.2 Global temperature record, since instrumental recording began in 1860, and projection to 2100, according to the IPCC



Source: reference 1

World temperature has increased by around 0.4ºC since the 1970s, and now exceeds the upper limit of natural (historical) variability. Climatologists assess that most of that recent increase is due to human influence. The IPCC (2001) has estimated that the global average temperature will rise by several degrees centigrade during this century. As is shown in Figure 1.2, there is unavoidable uncertainty in this estimate, since the intricacies of the climate system are not fully understood, and humankind's developmental future cannot be foretold with certainty

How are living organisms being affected?

Many attributes of individual animal species, their size, shape and colour, and their feeding and sexual behaviours, are adapted to the climatic conditions in which they live. Changes in climate influence the size of populations, which in turn affects the distribution and abundance of species, and ultimately ecosystem structure and function. Consequently, long-term climatic trends have enormous impacts on shaping the tapestry of life in the wild.

Climate change will require plant and animal species to shift their geographical ranges or adapt to altered conditions, but habitat loss and fragmentation make this more difficult. Changes in climate may favour one species to the detriment of another and, through such a complex web of interactions, the overall impacts of such change may be buffered, or may be exacerbated, in the wider ecosystem (IPCC 2001).

Both in past and ongoing climate change events, shifts in geographical distributions of species have been observed. Particularly dramatic climate change occurred since the Last Glacial Maximum (c. 18 000 years before present), with numerous species moving tens of kilometres as climates warmed (Martinez-Mayer et al, 2004).

A paper published by Root et al. in 2003 shows that many species have altered their geographic ranges, presumably as a result of global climate change. Of those species that had altered their range, eighty percent were in the direction predicted by climate change models. The mean change of movement was about six kilometres per decade. In addition, many bird species have started laying eggs earlier in the spring. This study shows that forces of small, sustained change can be powerful over long enough time scale (Root et al, 2003).

Species show variable levels of success in shifting their ranges through fragmented landscapes in response to climate change (Hulme 2003). Changes in atmospheric CO_2 concentration, temperature or precipitation will directly affect rates of metabolism and development in many animals, and processes such as photosynthesis, respiration, growth and tissue composition in plants. A 3°C change in mean annual temperature corresponds to a shift in isotherms of approximately 300-400 km in latitude (in the temperate zone) or 500 m in altitude. Species' geographic ranges are therefore expected to move upwards in altitude or towards the poles in response to shifting climate zones, in those species capable of moving range relatively rapidly. Life cycle events triggered by environmental cues such as degree-days may be altered, and the result may break the coupling of life-cycle interactions between species. Changes in the physiology, phenology and distributions of individual species will alter their competitive relationships and other interactions with other species. This will lead to changes in the local abundance of species and to changes in the composition of communities. Inevitably, at least some species will become extinct, either as a direct result of physiological stress, or via interactions with other species (Hughes 2000).

Another ecological interaction attracting recent concern is that between **disease** and climate change. Mosquitoes and other disease vectors are often limited by cold temperatures, so a warming climate raises the possibility of these vectors expanding upslope and to higher latitudes. But pathogen-host interaction changes are not limited to vector range expansions. Other facets of climate change will give new opportunities for changed relationships between pathogens and hosts, with concomitant effects on biodiversity (Mittelmeier at al, 2004).

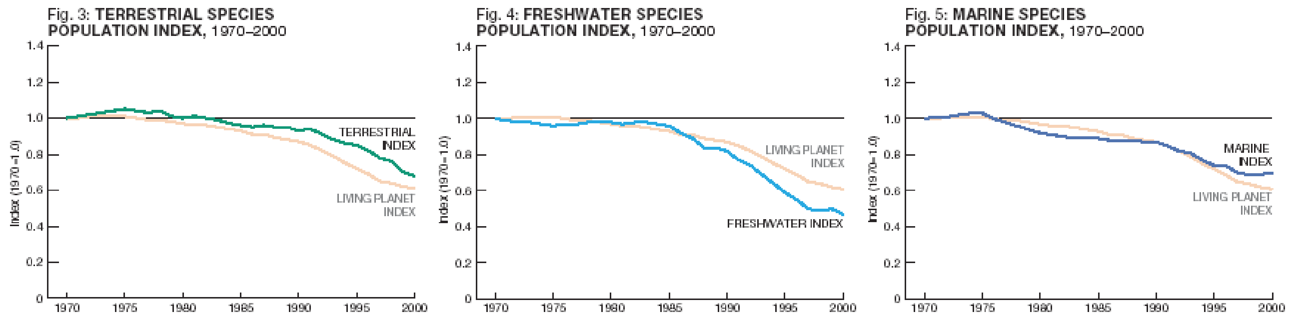
Recent analyses of long-term datasets show that some species are already responding to the anomalous atmosphere and climate of the 20th century (Hughes 2000 and 2002, Parmesan and Yohe 2003, Root et al. 2003, Walther et al, 2002). How many will adapt to the changing climate, not having emigrated northward and how many will become extinct? No one knows the answer (Wilson 2001).

Climate and Biodiversity

The projected changes in climate include increasing temperatures, changes in precipitation, sea level rise and increased frequency and intensity of some climatic events leading to climate variability. The impacts of these projected changes in climate include changes in many aspects of biodiversity and disturbance regimes (e.g. changes in the frequency and intensity of fires, pests and diseases). Systems are considered to be vulnerable if they are exposed or sensitive to change and adaptation options are limited (Watson, 2002). Although in some areas a temporary increase in biodiversity could be the result of climate change (through new species introduction), the long-term result cannot be foreseen. Current evidence suggests that overall, species loss is being increased by climate changes (Wilson 2001).

The responsiveness of species to recent and past climate change raises the possibility that anthropogenic climate change could act as a major cause of extinctions in the near future, with the Earth set to become warmer than at any period in the past 1–40 million years (Houghton et al, 2001).

Climate change over the past ~30 years has produced numerous shifts in the distributions and abundances of species (Parmesan & Yohe 2003; Root et al, 2003). In a recent study (Thomas et al, 2004), exploring three approaches in which the estimated probability of **extinction** shows a power-law relationship with geographical range size, the authors predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in the sample of regions and taxa will be 'committed to extinction'. When the average of the three methods and two dispersal scenarios was taken, minimal climate-warming scenarios produce lower projections of species committed to extinction (~18%) than mid-range (~24%) and maximum-change (~35%) scenarios. The following graphs represent the estimated gradual decrease of species since 1970.



(Adopted from: Living Planet Report 2004)

Biological invasions are gaining attention as a major threat to biodiversity and important element of global change. Recent research indicates that other components of global change, such as increases in nitrogen deposition and atmospheric CO2 concentration, favour groups of species that share certain physiological or life history traits.

Table 1. Possible general impacts of global change elements on the prevalence of invasive alien species[a]

Element of global change	Prevalence of invaders[b]
Increased atmospheric CO_2 concentration	+/−
Climate change	+
Increased nitrogen deposition	+
Altered disturbance regimes	+
Increased habitat fragmentation	+

[a]Although these predictions are speculative, they are based on observations that are mentioned or cited in the text.
[b]Key: +/−, might increase prevalence of some invaders and reduce prevalence of others; +, expected to increase prevalence of invaders in many affected regions.

(Adopted from Dukes & Mooney 1999)

New evidence suggests that many invasive species share traits that will allow them to capitalize on the various elements of global change.

Integration of theoretical principles with the results of the few studies that have addressed how biological invaders respond to global change, leads to the conclusion that most of the important elements of global change are likely to increase the prevalence of biological invaders. Increases in the prevalence of some of these biological invaders would alter basic ecosystem properties (Dukes & Mooney 1999).

Although a new climate might not directly favour alien **plant species** over natives, many invasive plant species share traits that could increase their dominance in a transitioning climate. A rapid anthropogenic climate change might disadvantage species that cannot quickly extend their ranges into newly suitable regions, such as plants with long generation times. A climate-driven decline of late-successional plant species could lead to increased dominance of early successional species, or could leave ill-adapted plant communities that are susceptible to invasion by species that can thrive in the area’s new climate. In the latter scenario, species that are able to shift ranges quickly would be at an advantage. Rapid dispersal is a characteristic of many biological invaders. Within the genus *Pinus*, species that are invasive tend to have traits that facilitate rapid range shifting, such as a short juvenile period and low seed mass (which is associated with long-distance wind dispersal) (Rejmánek and Richardson,, 1996).

Coral reefs are a critical global resource, both biologically, and socio-economic terms. They are the most diverse marine habitat, with an estimated one million different species. They are also widely used by coastal communities as a source of food and as the basis for a major tourism industry, providing both a livelihood and foreign exchange earnings for many communities and developing nations. Coral reefs are also highly sensitive to climatic influences and appear to number among the most sensitive of all ecosystems temperature changes, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. (loss of colour in reef-building corals and the subsequent visibility of the underlying white skeleton). Reef-building corals are highly dependant on a symbiotic relationship with microscopic algae (a type of dinoflagellate known as zooxanthellae) which live within the coral tissues. The bleaching results from the ejection of the zooxanthellae by the coral polyps and/or by the loss of chlorophyll by the zooxanthellae themselves. This reaction of corals has been widely observed for many years: corals usually recover from bleaching but they can die in extreme cases (Montagne 2004; Spalding et al, 2004b).

Latitudinal patterns of biodiversity. Is there an explanation?

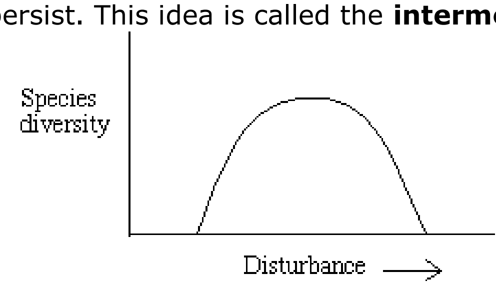
The **latitudinal gradient in species diversity** is one of the most striking patterns in the distribution of organisms on the planet. Simply put, the average number of species per unit area increases dramatically the closer the area is to the equator, almost entirely regardless of the type of organism being considered (Pianka, 1994). Researchers investigating the gradient have formulated a wide variety of hypothesis explaining the higher level of species diversity in the tropics. These include but are not limited to: a greater degree of evolution and radiation in tropical species due to the long and relatively stable geological history of the area, seasonal climatic stability and/or predictability, a higher level of productivity, an increased rate of competition and a higher predation intensity (Pianka, 1994; Wilson 2001).

Although exact numbers and timescales are difficult to determine, it is clear that biodiversity (species and habitat richness, genetic diversity and community complexity) is declining. It is also true that species invasions have been elevated to unprecedented rates accompanying the increased globalization of our world. These high rates of extinction and invasion put ecosystems under enormous stress, making it critical that we understand how the loss, or addition, of a species influences the stability and function of the ecosystems we rely on (McCann 2000).

Pianka (1994) provided a set of hypotheses and explanations for latitudinal diversity gradients patterns:

1. **Evolutionary time.** This hypothesis suggests that diversity should increase with the age of a community.
2. **Ecological time**. It may not be evolution which is needed to re-diversify habitats at higher latitudes, but just **re-immigration of species displaced by glaciation**.
3. **Climatic stability.** A stable climate is one which changes little over time, both seasonally and from year to year. A species living in a stable climate can evolve specialized adaptations to the specific climate. One which lives in an unstable or unpredictable climate must have broad tolerance limits to deal with the variety of conditions it encounters. Pianka argues that broad tolerance limits inevitably are associated with broad niches, and thus less niche space to accommodate a diverse assemblage of species. The energetic stress of dealing with the variations in climate may also affect how many different species can be successful.
4. **Climatic predictability.** If a climate is highly predictable, the species can evolve life history adaptations which reflect climatic cycles, for example winter or drought dormancy, as long as the time of cold or dryness is predictable. A few examples suffice to make the point. Insects, Daphnia, and many mammal species have winter dormancy, though specific names of the stages or structures differ. Insects and water fleas have an egg stage which shuts down over winter (**diapause)**. Some small mammals go into a temporary metabolic slowdown, called torpor, from which they can recover quite rapidly. Other mammals, like the bears of fairy tales, become dormant. Their metabolism slows to a crawl for the entire winter. A short warming trend will not arouse them. In each case, the life history has evolved an adaptive response to predictable, seasonally harsh environmental conditions. That response is only useful and successful when the harsh season occurs predictably.
5. **Spatial heterogeneity.** The more heterogeneous the habitat, the more ways species can exploit it.

6. **Productivity.** There are a number of ways to look at the explanation for a gradient in diversity with productivity. One is simply to recognize that with more resources there are likely to be a greater number of individuals in the habitat.
7. **Stability of primary production**. Extend the arguments about climatic stability to stability in the energy supply available to food chains and webs, and it becomes apparent that more species can be supported with a finer division of resources if the amount of available resource is predictable.
8. **Competition.** If competition is intense, then selection produces populations which have differentiated niches, and remain present only in that fraction of their fundamental niches in which they are competitively superior. Specialization which results from competition leaves narrower niches and greater diversity.
9. **Disturbance.** This is essentially the antithesis of the competition hypothesis. It states that high species richness is expected in regions with intermediate levels of disturbance. Thus, the high diversity of tropical ecosystems is the result of episodes of climate extremes and the subsequent recovery of the ecosystem in a lush environment where natural selection has not yet reduced diversity on its own. Only species adapted to disturbance will survive there. The disturbances reduce the intensity and effect of competition, and reduce the diversity. In undisturbed communities competitive dominants occupy most of the space in the community. As long as new disturbances occur frequently enough, these extra species can persist. This idea is called the **intermediate disturbance hypothesis** (Connell 1978).

   Too intense or too frequent disturbances exclude all but the most resistant species, while too weak or too rare disturbances fail to impair the dominant competitors. Intermediate levels of disturbance allow pioneer species to re-establish and to coexist with dominant forms while the latter are suppressed in their abundances (Connell, 1978; Petraitis et al., 1989; Leveque & Mounolou 2004).

   Although the IDH became one of the central paradigms in community ecology, experimental evidence for the validity of the concept is scarce (Mackey and Currie, 2001). Lenz et al (2004) tested the validity of predictions derived from the intermediate disturbance hypothesis (IDH) was tested in situ by manipulating mussel dominated Western Baltic fouling communities. The authors concluded that their study partially confirmed the validity of the mechanisms proposed by the IDH, but also showed that their forcing can be masked by fluctuations in environmental parameters, such as climatic conditions. Diversity increased again under severe disturbance conditions, due to a disturbance-induced change in community structure, namely the shift from mussel to algal dominance.
10. **Predation.** Predation frequently reduces the population size of dominant species.

'Rapoport's rule'

One of the hypotheses proposed to explain regional species richness patterns was **'Rapoport's rule'**, proposed by Stevens (1989) after observations made by Eduardo Rapoport (1982, cited in Kerr 1999). It stated that the latitudinal gradient in species richness can be explained indirectly as a function of narrower geographic ranges for species at low latitudes. Annual climatic variability, or deviation from mean climatic conditions, has been hypothesized to moderate this phenomenon.

According to Stevens' hypothesis, the latitudinal extent of species' ranges declines toward the tropics, coincident with progressively smaller annual climatic variation. Organisms that exist at higher latitudes must be able to withstand a broad range of environmental conditions. As climatic **generalists**, such species are hypothesized to have relatively large ranges. Tropical species, faced with relatively little deviation from mean climatic conditions, are likely to become climate **specialists**, adapted for highly specific temperatures and precipitation levels. Stevens argues that the latitudinal trend toward high diversity exists because **climatic stability promotes specialization**, so more species may coexist toward the equator. The incidental result of this climatic specialization is 'Rapoport's rule'. Taxa that are dormant for much of the year or which migrate, should not be influenced by climatic variability, and should exhibit reduced latitudinal species richness gradients. The obvious empirical prediction, if Stevens' claim is correct, is that climatic stability should provide the best overall prediction of regional species richness levels. Furthermore, taxa that avoid much of this seasonality, such as temperate zone insects that enter diapause or species that migrate, were predicted to show reduced latitudinal gradients in richness (Kerr 1999). Evidence in support of this hypothesis seems to be weak (Willing et al, 2003).

Indeed, it is possible that 'Rapoport's rule' may be at least partially correct (Rohde 1996), but that it provides no insight into the issue of the latitudinal gradient of species richness. Exceptions to 'Rapoport's rule' include New World bird species whose ranges are smallest at about 17° N (Blackburn & Gaston 1996), rather than at the equator, as predicted. The ranges of Pacific marine molluscs exhibit no clear relationship with latitude (Kaustuv et al, 1994), although the effects of climatic variability on marine organisms should be substantially reduced relative to nearby terrestrial taxa.

Tropical Ecosystems: High levels of biodiversity associated with climate stability

Many **tropical ecosystems** have evolved over millions of years, and some refugia have survived through the ice ages, evolving into complex and highly diverse communities. Many are finely balanced ecosystems with high species diversity, and some species have very tightly defined ecological requirements. Such species, and the ecosystems in which they live, could thus be highly sensitive, even to the lower rates of change predicted for the tropics. The examples of cloud forests and coral reefs provide the first warnings of such sensitivity. (Montagne 2004; Spalding et al,2004).

Kleidon and Mooney (2000), based on the observation that tropical climates are related to higher levels of diversity compared to temperate ones, investigated the connection between plant species diversity and climate, using a process-based generic plant model. They concluded that 'the less the number of days favorable for growth (parameter used as an expression of climate constraints), the greater the level of constraints and the less the species diversity'. Thus, **the climate can explain much of the globally observed plant species diversity**. Their results and conclusion are summarized in the following graph, relating climatic stability to locally observed plant species diversity in different ecosystems.

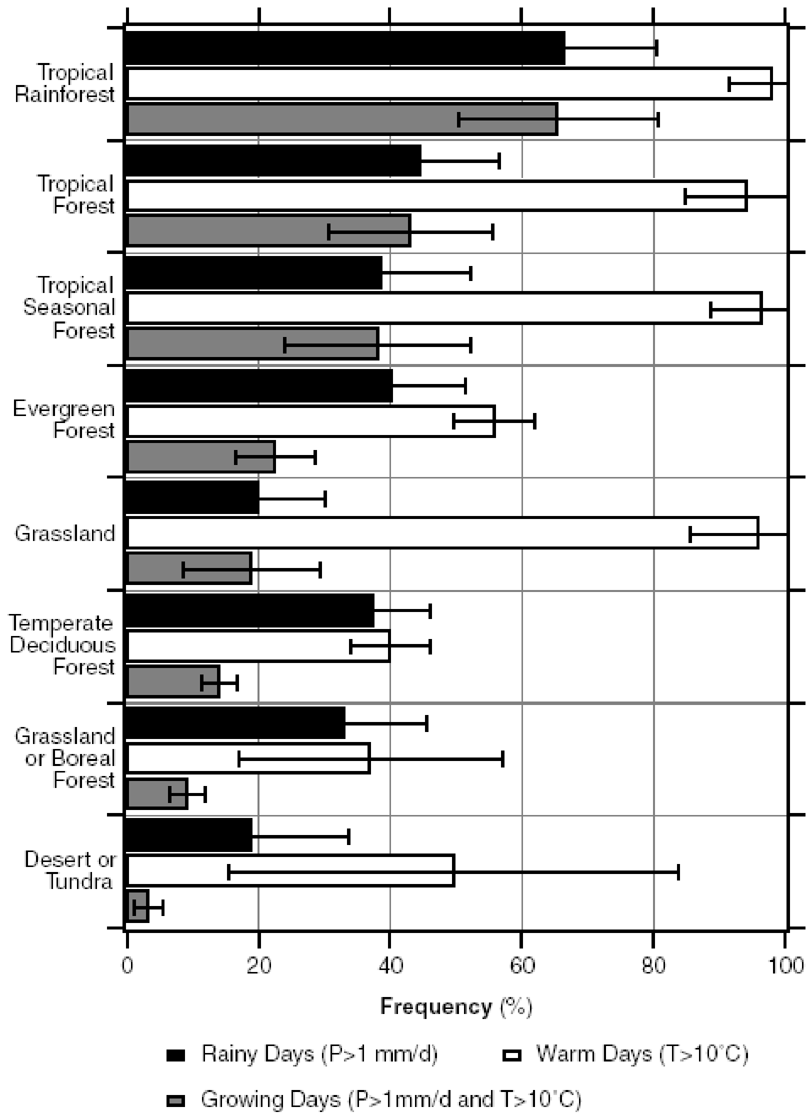


Fig. 4 Mean climatic conditions within each 'biome', expressed in terms of days with favourable growing conditions (precipitation and temperature). The 'biomes' are sorted in an increasing order of climatic constraints, thus decreasing in terms of diversity. The mean diversity of the 'biomes' are (top to bottom): 75%, 48%, 30%, 29%, 12%, 12%, 5% and 1%, respectively of the maximum achieved value. Error bars denote 1SD.

In another recently published study (Oindo 2002) the advanced very high resolution radiometer (AVHRR)–normalized difference vegetation index (NDVI) has been established to be a good approximation for studying inter-annual climate variability as well as regional drought condition. In this study, the relationship between large herbivore species richness and AVHRR–NDVI were examined, derived climatic-variability indices, inter-annual average NDVI and coefficient of variation of NDVI at a regional spatial scale in Kenya. Regions with a relatively low coefficient of variation of NDVI and high inter-annual average NDVI characterize current ecoclimatic stability. By contrast, a high coefficient of variation of NDVI and relatively low inter-annual average NDVI characterize ecoclimatic instability (drought risk). Statistical analyses revealed that a high inter-annual average NDVI increases species richness, whereas a high coefficient of variation of NDVI lowers species richness. This indicates that maximum numbers of species are found in regions with current ecoclimatic stability. Statistical analyses revealed that a high inter-annual average NDVI increases species richness, whereas a high coefficient of variation of NDVI lowers species richness. This indicated that **maximum numbers of species are found in regions with current ecoclimatic stability** (Oindo 2002).

Tropical montane cloud forests occur where moisture-laden tradewinds blow onto a mountain range, leading to the formation of cloud and mist at high elevations. The deposition of this moisture onto the vegetation and soil plays a key role in the hydrological cycle. Montane cloud forests, characterised by persistent high humidity, hold the highest levels of animal endemism to be found on the continents and consequently they rank high when areas are prioritised for the conservation of biodiversity. Their richness in species has come about partly because they often form archipelagos of habitat islands, isolated from each other by lowland habitats that are unsuitable for the specialised inhabitants of the cloud forest. This has frequently led to the evolution of species unique to each cloud forest patch. However, another important factor is the extremely long periods for which the distinctive physical and climatic conditions of cloud forests have persisted in the same region and the influence of the glacial cycles on the extent and interconnectedness of cloud forest fragments. (Foster 2001;Montagne 2004; Spalding 2004a).

Prospects for the future of tropical montane cloud forests and their biota are not good. Global climate models have been used to predict the elevation at which conditions suitable for cloud forests will occur in future climates as carbon dioxide continues to accumulate in the atmosphere. The same models have been used to study past climate change. They indicate that cloud forest conditions at the last glacial maximum occurred at much lower elevations than they do today. This finding is in accord with analyses of the pollen paleorecord, which shows that cloud forest plant species occurred lower on mountain slopes during glacial times. In the climates likely to prevail at the end of the present century, conditions suitable for cloud forests are expected to occur several hundred metres higher in elevation than they do today. Thus, many cloud forests, may undergo a severe reduction in area and could disappear altogether as the zone of cloud formation shifts to elevations above the highest peaks. These forests are sensitive indicators of climate change and are among the areas where the greatest losses of biodiversity may occur (Foster 2001; Pounds 2004).

Discussion

The basis for regional variation in species richness is the subject of a long-standing debate. Climate is the major factor controlling the global patterns of vegetation structure, productivity and plant and animal species composition. Many plants can successfully reproduce and grow only within a specific range of temperatures and respond to specific amounts and seasonal patterns of precipitation. Thus, they may be displaced from competition by other plants or may fail to survive if climate changes. Animals also have distinct temperature and/or precipitation ranges and are also dependent on the ongoing persistence of their food sources Watson 2002). Tropical climates stability is related to the high levels of biodiversity observed in those areas and represents a live example of climate stability contributing to biodiversity (Wilson 2001).

Biodiversity is dependent on an intricate web of factors that can be upset by rapid climatic change. Projections of human-induced climate changes and evidence of past rapid climate shifts indicate that patterns of biodiversity may change over time scales as short as decades. Climate change is much more than just temperature change, so biodiversity will also be confronted with challenging rainfall patterns, declining water balances, increased extreme climate events and changes in oscillations such as El Nino (Hannah et al, 2002).

Additionally, changes in the frequency and extent of disturbances affect the rate at which plant and animal assemblages change. Disturbances increase the rate of species loss and create new opportunities for the establishment of new species. Rapidly changing climates and habitats will likely increase opportunities for invasive species to spread because of their adaptability to disturbance (Wilson 2001).

Climatic variability, or deviation from mean climatic conditions, is hypothesized to promote specialization, so in relatively stable environments more species may coexist. Species with limited climatic ranges, restricted habitat requirements and small populations are typically more vulnerable to extinction (Wilson 2001).

Conclusion

The observed variability among living organisms is the result of complex interactions. The different proposed hypotheses focus on individual factors contributing to the extent of biodiversity. It seems that no single theory offers an adequate explanation on the several aspects of biodiversity on earth. Climatic stability is definitely an essential requirement for high levels of biodiversity. The documented decline of biodiversity in recent years, strongly associated with the rapidly changing climate, offers an argument favouring the positive impact of climatic stability on biodiversity.

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