The biodiversity crisis: A multifaceted review

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Biodiversity provides to humankind enormous direct economic benefits, an array of indirect essential services through natural ecosystems, and plays a prominent role in modulating ecosystem function and stability. Biodiversity is not uniformly distributed on the earth, and could comprise 5 to more than 50 million species. The current rates of species extinction are 1000–10,000 times higher than the background rate of 10^{-7} species/species year inferred from fossil record. Today we seem to be losing two to five species per hour from tropical forests alone. This amounts to a loss of 16 m populations per year or 1800 populations per hour. The anticipated magnitude of species loss has drawn worldwide attention, fueling attempts to rapidly assess and conserve biodiversity. Key processes of speciation, endemism, coexistence, extinction, and differential vulnerability of taxa and habitats are not adequately understood. Accuracy of estimates of the total number of resident species and current rates of extinction remains undetermined, and the impact of species deletions on ecosystem function and stability is still a subject of debate among ecologists. In its own right, the study of biodiversity is assuming the status of an interdisciplinary science with a growing body of concepts, testable hypotheses, exacting methodologies, and internalization of aspects of human sociology.

BIODIVERSITY is the very basis of human survival and economic well-being, and encompasses all life forms, ecosystems and ecological processes, acknowledging the hierarchy at genetic, taxon and ecosystem levels[1]. The current estimates[2] of the total number of species on earth vary from 5 to more than 50 million, with a more conservative figure of 13.6 million species[3]. Of these, only 1.76 million species have yet been described and awarded scientific names. Thus, our knowledge of diversity is remarkably incomplete.

Studies indicate that we have entered into a phase of mass extinctions[4,5], and have altered roughly half of the habitable surface of the earth[6], impairing and destroying several ecosystems. At least five major mass extinctions have occurred in the past at geologic-time boundaries; two most serious were those occurring at the end-Permian and end-Cretaceous[7]. But while the past extinctions occurred each time over a span of million years or less, the present mass extinction may well occur within a short period of about 200 years. Under the current scenario, about 20% of all species are expected to be lost within 30 years and 50% or more by the end of the 21st century[8]. A consideration of episodes of the past mass extinctions and the subsequent recovery periods indicates that if the present mass extinction proceeds unchecked, the biosphere shall be impoverished for a period equivalent to at least 200,000 human generations[8].

Biodiversity has attracted world attention because of the growing awareness of its importance on the one hand, and the anticipated massive depletion, on the other. This article focuses on the benefits and role, accumulation, distribution and loss, and assessment and conservation of biodiversity. It will be apparent that there are more estimates than empirical data, and more hypotheses than concrete theories. The methodologies for the assessment and conservation of biodiversity also remain inadequate.

Benefits and role

Apart from the ethical values and aesthetics, biodiversity provides to humankind enormous direct economic benefits in the form of timber, food, fibre, industrial enzymes, food flavours, fragrances, cosmetics, emulsifiers, dyes, plant growth regulators and pesticides[9,10]. Biodiversity is of incalculable value to human health (Table 1), although only 1100 of the world's 365,000 known species of plants have so far been examined for their medicinal properties[11].

Table 1. Examples of contribution of biodiversity to human health (based on ref. 11)

- One out of every 125 plant species studied at the Herb Research Foundation, Boulder, produced a major drug with a market value in the US of at least $ 200 million per year.
- Of the 118 (out of the top 150) prescription drugs in the US, 74% are based on plants, 18% on fungi, 5% on bacteria and 3% on vertebrates.
- Of the top 10 prescription drugs in the US, 9 are based on natural plant products. In 1990, sales of prescription drugs with active ingredients of plant origin amounted to about $ 1550 million.
- 80% of the world's population relies on traditional plant medicine.
- Compounds from Gingko leaves are used by 80% Europeans older than 45 years to prevent senile dementia.
- Losing one tree species a day means losing 3–4 potentially valuable drugs every year, at a total cost of $ 600 million.

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Species and their populations contain a precious genetic library, the number of genes ranging from about 1000 in bacteria, to 400,000 or more in many flowering plants and a few animals[12]. Genes of wild species have been used to confer new properties or improved yield in domesticated species, and elimination of genetic diversity through extinction of a species means a lost opportunity for transfer of potentially useful genes, in future[13]. Genetic diversity also provides the potential for subsequent evolutionary change[14].

Biodiversity is responsible for the essential ecosystem services, including regulation of the atmospheric gaseous composition, climate, disturbance and water, soil formation and maintenance of soil fertility, processing and acquisition of nutrients, waste assimilation, pollination, biological control, pollution control, recreation, etc. Costanza *et al.*[9] have estimated the current economic value of the 17 ecological services for 16 biomes, and extrapolated this for the entire biosphere in the range of US $ 16–54 trillion (10^{12}) per year.

Studies indicate a prominent role of the composition and quantity of biodiversity in controlling ecosystem functions and ecosystem stability[15]. Higher diversity allows greater access to available resources, and hence increased net primary production and decreased nutrient losses. A grassland field experiment indicated that the reduction of diversity occurring globally may reduce the capacity of ecosystems to capture additional C under conditions of rising atmospheric CO_2 concentrations and N deposition levels[16]. However, relating biodiversity to ecosystem function has remained an intractable problem in ecology and the subject of a hot debate among ecologists[17,18]. There are two major schools of thought on this issue. According to one school, there are clear causative relationships between diversity and ecosystem functioning[19,20], while according to the other, ecosystem properties are not necessarily driven by species diversity per se, but rather the main drivers of ecosystem properties are the key functional attributes or traits of the dominant species present and the composition of the functional types[17,21,22]. The four hypotheses that have been proposed to describe the relationship between biodiversity and the rate of ecosystem processes are summarized in Table 2 (for greater details, see ref. 23). Studies can be cited in support of each of the four hypotheses, but conclusions remain equivocal. Evidently more refined experimental designs are needed to firmly establish the nature of the relationship between diversity and ecosystem function. At the moment we can assume that losses in biodiversity are likely to impair the functioning of both species-poor and species-rich ecosystems, depending upon the order in which species are lost.

Global accumulation

Diversity of both marine and continental life increased exponentially since the end of the Precambrian reaching to 2400 families in Pliestocene and Holocene[24]. The proliferation of species and populations has been brought about by the evolutionary processes acting on the extant genetic material in a positive feedback manner (Figure 1), reflecting a gradual or a precipitous and/or stochastic accumulation of genetic differences between lineages[25]. Modes of speciation include allopatric, parapatric and sympatric divergences. Polyploidization, mutation, genetic drift, recombination, gene flow and chromosome duplication in hybrids may lead to speciation[25]. As many as 43% of 12,000 dicotyledon species and 58% of 5000 monocotyledon species appear to have evolved through polyploidy[26]. Key innovations, which are linked to the origin of higher taxa in terms of population level processes, enhance competitive ability, relax adaptive trade-offs or permit exploitation of a new productive resource base[27].

Assortative mating[28] and population differentiation in seasonal migrants[29] may also lead to speciation. Natural selection appears to play an important role in generating rainforest biodiversity, with ecotone habitats being a source of evolutionary novelty[30]. Natural selection caused by shifts in ecology (resource environment) or invasion of novel habitats can cause extremely rapid evolutionary divergence[31]. An analysis of evolutionary species–area relationship for lizards on the Caribbean islands showed that speciation was rare on islands smaller than a threshold island size, above which the rate of species proliferation increased with the area of the island[32].

The accumulation of biodiversity on earth reflects the difference between the rates of speciation and extinction. The background natural extinction rate estimated from fossil data was 10^{-7} species per species year[33], which has now increased up to 1000 to 10,000 times[25] and according

Table 2. Hypotheses regarding relationship between diversity and ecosystem function

Hypothesis	Tenets
Diversity–stability[89]	Predicts a linear relationship in which the rate of ecosystem processes increases as the number of species increases.
Rivet–Popper[90]	Predicts a positive nonlinear relationship and assumes that all species are equally important – the deletion of species gradually weakens the system, and beyond some threshold number may cause the ecosystem to collapse.
Redundancy[91]	Considers most species as superfluous, only functional groups are important; those species within the same functional group are more expendable relative to one another than species without functional analogues.
Idiosyncratic[92]	Acknowledges none or an indeterminate relationship between species diversity and ecosystem function; the identity and the order of deletion of species will affect ecosystem function.

to some, as much as 120,000 times[8]. It is now in the order of 1000 species per decade per million species[34]. Natural factors that result in species extinction are enumerated in Figure 1 (see also ref. 35). Major drivers for changes of biodiversity in future, in decreasing rank of their impact are land use change, climate change, N deposition, biotic exchange and atmospheric loading of CO_2 (ref. 36).

Distribution

Diversity is not uniformly distributed on the earth; it increases from the poles to the equator, and from high elevations to low elevations. Diversity is greater on continents than on islands, and rather low in habitats with extreme environmental conditions such as deserts, hot springs, etc. Terrestrial communities normally have greater diversity per unit area compared to marine communities. Several hypotheses have been proposed to account for the observed patterns of biodiversity distribution. Some of these are enumerated in Table 3 (for greater details see ref. 37).

The older, stable climate is expected to support high speciation rates due to more sedentary populations and hence geographical isolation, larger number of generations per year and more opportunities for selection. On the other hand, greater spatial heterogeneity would result in low extinction rates due to greater specialization of taxa, more resources, less competition and smaller size of populations.

The uneven distribution of biodiversity is also illustrated at regional and ecosystem levels. Myers *et al.*[38] recognized 25 terrestrial biodiversity hot spots (including 9 leading and 8 hottest hot spots) around the world which contain a total of 133,149, i.e. 44% of all vascular plant species and a total of 9645, i.e. 35% of all species in four vertebrate groups (birds, mammals, reptiles and amphibians). These endemics are confined to an aggregate expanse of 2.1 million km^2 or 1.4% of the earth's land surface, which formerly occupied 17.4 million km^2 or 11.8% of the earth's land surface. Of the 25 hot spots, tropical forests appear in 15, Mediterranean-type zones in five; nine hot spots are mainly or completely islands, almost all tropical islands falling into one or another hot spot. The hottest hot spots are Madagascar, the Philippines, Sundaland, Brazil's Atlantic forest, the Caribbean, Indo-Burma, Western Ghats/Sri Lanka and Eastern arc, and coastal forests of Tanzania/Kenya. Nayar[39] has recognized 40 hot spots of Indian flora, with concentration of endemics as a major criterion.

The patchy distribution of species diversity is also illustrated at a more local scale. For example, Figure 2 illustrates the occurrence of species-rich and species-poor areas within a 3-ha plot of a dry deciduous forest in the Vindhyan highlands. Although several hypotheses have been proposed to account for locally high species richness (Table 4, see ref. 40 for more details), the ability of a large number of species which apparently compete for the same few resources to coexist in relatively homogenous sites, is still poorly understood[41].

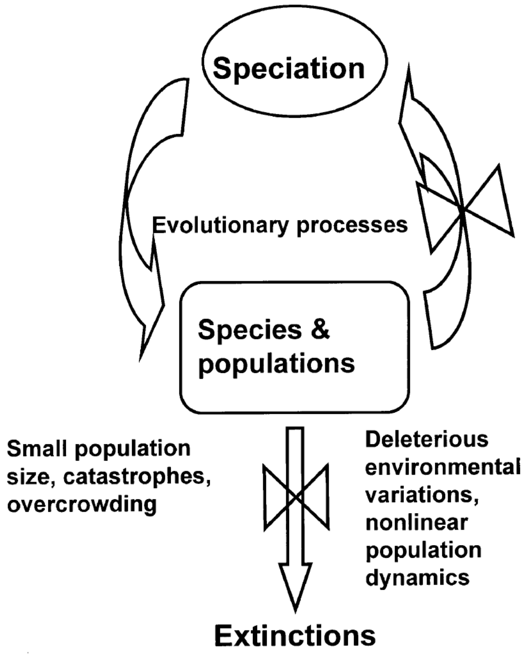

Figure 1. Accumulation of global biodiversity as a balance between rates of speciation and extinction. Evolutionary processes act in a positive feedback manner. Both evolutionary and extinction processes are driven by several factors.

Table 3. Hypotheses to account for global patterns of biodiversity distribution

Hypothesis	Tenets
Evolutionary time[93]	Older communities have high diversity compared to newly evolved ones, because more time has been available in the former for development of biota in an uninterrupted fashion.
Climate stability[94]	Uniformity of climate as well as relative constancy of resources in a stable community results in the formation of numerous niches allowing more species to occupy the unit habitat space, by evolution of finer specializations and adaptations.
Spatial heterogeneity[95]	Availability of a wide range of ecological niches in more spatially complex environment favours coexistence of more species, due to greater availability of resources and less competition between the species.
Productivity[94]	Diversity of a community is determined by the amount of energy flowing through the food web. Turner *et al.*[96] hypothesized that species richness correlates with the available solar energy as measured by temperature and sunshine hours.

The local/regional species richness represents a balance between the rates of species immigration/invasion and species extinction/disappearance (Figure 3). The major causes of local extinctions are recounted in Figure 3. Although all immigrants may not be invaders, their success at colonization imposes competitive effects on extant organisms resulting in disappearance of some of them from the site, and if the disappearing species was an endemic, this results in global extinction. Invasion, frequently has a deleterious impact on the local environment, causing a cascade of extinction events[42]. Richardson *et al.*[43] estimated that 50–80% of invaders have harmful effect. Dhar *et al.*[44] found a high percentage of non-natives in the herbaceous flora of all forest types in a protected area of the Himalaya and argued that their likely proliferation in future is a serious threat to the overall native plant diversity of the reserve.

The relative rates of extinction and invasion determine the species richness and persistence of communities (Figure 4, based on ref. 45). Communities with high invasion rates relative to extinction rates would gain species, while those with high extinction rates relative to invasion rates would lose species. Communities that have equal but low rates of invasion and extinction would be persistent with a low rate of species replacement, while those with equal but high rates of invasion and extinction would be non-persistent, with a rapid change in species composition, although the number of species in both cases will remain the same. The differences in community persistence can also occur in different parts of the same biome. For example, the numbers of tree species occurring only as seedlings or only as adults on two sites of Vindhyan highlands are shown in Figure 5. On the Hathinala site as many as 17 species were found only as seedlings, while at the Khatabaran site, as many as 16 species occurred only as adult trees. At both the sites species composition would change in the future, perhaps more rapidly at the Hathinala site.

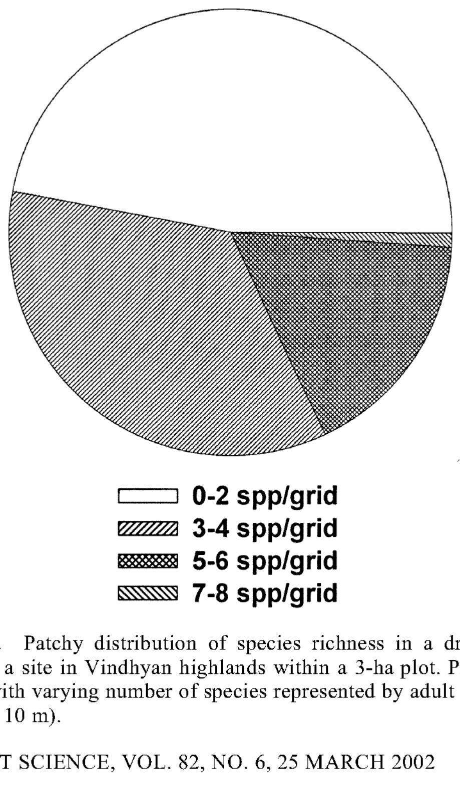

Figure 2. Patchy distribution of species richness in a dry tropical forest, on a site in Vindhyan highlands within a 3-ha plot. Proportions of grids with varying number of species represented by adult trees (grid size: 10 × 10 m).

Depletion

Expanding human population has caused increased resource exploitation and alteration of land use pattern. Biodiversity-rich areas could have particularly strong human impact. For example, Cincotta *et al.*[46] estimated that in 1995, nearly 20% of the world population was living in the 25 terrestrial biodiversity hot spots recognized by Myers *et al.*[38], and population growth rate in the hot spots (1995–2000) was 1.8% yr^{-1}, substantially higher than the mean population growth rate of the world (1.3% yr^{-1}), or that of the developing countries (1.6% yr^{-1}).

Table 4. Hypotheses to account for specially high biodiversity at local/ecosystem scales

Hypothesis	Tenets
Intermediate disturbance[97,98]	Highest diversity is maintained at intermediate levels of disturbance due to a mosaic of habitats, permitting both pioneers and late successionals to coexist.
Herbivore-driven forest diversity[99]	Establishment of young trees in the vicinity of their parents is constrained by the activity of tree-specific herbivores; however, as herbivores are specific to a tree species, other tree species may become established in the vicinity of herbivore's target, resulting in extremely high diversity.
Equilibrium model of resource competition[100]	With an increase in the availability of resources, more species are supported which tap the resources efficiently, but as resource availability increases further, competition for space and light allows only the best competitors to dominate, while others are excluded.
Neighbourhood recruitment limitation[101]	Due to poor dispersal ability, low local abundance or chance events, many species may be absent from a neighbourhood and such absentees forfeit any chance of competitive victory at the site, permitting inferior competitors to win by default. This can lead to essentially unlimited diversity[41].
Pathogen-driven forest diversity[102]	In black cherry forest of Indiana, the occurrence of the root pathogen, *Pythium*, underneath the black cherry (*Prunus serotina*) trees restricts the establishment of black cherry saplings near their parents, permitting establishment of other tree species underneath the black cherry trees, leading to an increase in species diversity.

The alteration of land use pattern has resulted in fragmentation of habitats, ecosystems and landscapes in most parts of the world. Habitat fragmentation is a leading cause of biodiversity loss. Fragmentation increases the local rate of extinction by (i) reducing population sizes or colonization from similar habitats, (ii) eliminating keystone predators or mutualists, (iii) enhancing stochastic phenomenon and genetic bottlenecks, (iv) promoting edge effects, and (v) interrupting landscape-scale processes such as wildfire[47].

Species of several trophic levels are tied to tree species. For example, approximately 300 species of insects and several bird species may depend on a single tree species. Thus tree species extinctions are conspicuously disastrous. Estimates indicate that about 80% of the world's 100,000 tree species are in the tropics, and 10% of all tree species are now threatened. As many as 77 tree species are already extinct, and 976 tree species are critically endangered, facing extinction unless urgent action is taken[48].

Loss of biodiversity or species extinctions as a function of loss in area/habitat has frequently been estimated by using species–area relations of the form $S_n/S_o = (A_o/A_n)^{0.25}$. According to this relationship, as habitat is reduced from an original area A_o to A_n, A_n will hold S_n viable species in the year n from an original total of S_o. The $S_o–S_n$ doomed species will die off with a half life of 50 years (ref. 34). The current rate of tropical deforestation is 0.8% per year, and the rate of committing tropical forest species to extinction is predicted to lie between 0.1 and 0.3% per year (ref. 49). Therefore, assuming that two-thirds of the estimated 14 million species exist in tropical forests, the rate of species loss would be 14,000–40,000 species per year or 2–5 species per hour (ref. 50). Applying the species–area curve to the individual hot spots, Pimm and Raven[34] predicted that even if all the remaining habitat in hot spots is saved, some 18% of their species will be lost. However, clearing hot spots to the point where only currently protected areas are saved, would result in 40% species loss.

Clearing patches with large number of species will have a different effect than clearing areas with small

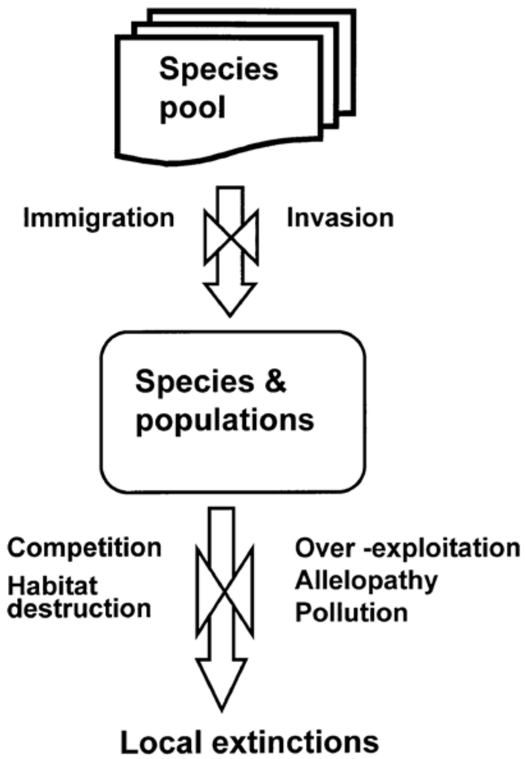

Figure 3. Regional/local biodiversity as a function of immigrations/invasions and local extinctions. Invasion is often human-aided, and there are several factors driving local extinctions.

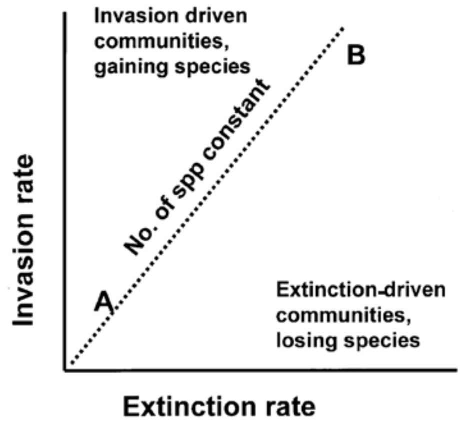

Figure 4. Relative persistence of communities as determined by the rates of invasion and local extinction. Communities on the diagonal line will have a constant number of species, but those at the bottom of this diagonal (A) will be persistent with low rates of species turnover and those at the top of the diagonal (B) will be non-persistent with high rate of species turnover. Invasion and extinction-driven communities will be non-persistent.

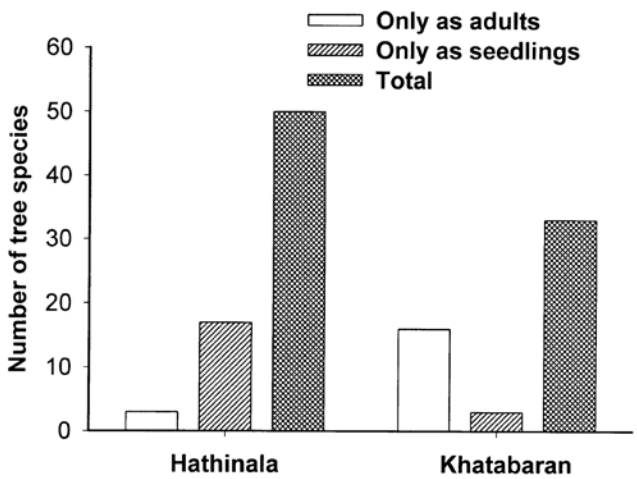

Figure 5. Number of tree species recorded only as seedlings or only as adults on two sites of a dry tropical forest in Vindhyan highlands.

number of species. Kinzig and Harte[51] derived a relationship, called endemics–area relationship (EAR), for the number of species confined to smaller patches within a larger biome. These authors used the term 'endemic' to describe species found only in a subpatch of a larger distinct biome. Estimates of species loss using EAR at low levels of habitat destruction, are significantly lower than existing estimates from species–area relationships, but extrapolation from the latter may underestimate future species extinctions under continued land clearing[51].

Populations supply the genetic diversity crucial for the development and improvement of pharmaceuticals and agricultural crops, and estimated rates of their extinction are even more alarming. Hughes *et al.*[50] estimate about 220 Mendelian populations per species or 1.1 to 6.6 billion populations globally. Assuming that population extinction is a linear function of habitat loss, the population extinction rates in tropical forest regions alone would be 0.8% per year. Thus, 16 million populations per year, or roughly 1800 per hour are being exterminated in tropical forests alone[50]. Such massive extinctions of living organisms are of both economic and ecological concern. Reduction of biological diversity may destabilize ecosystems important to humans, and may limit economic opportunities of future generations[52].

The current rapid decline in biodiversity has raised many questions. The two most important ones are: (i) How far would the loss of biological diversity affect an ecosystem's ability to carry out ecosystem functions? (ii) Is there a threshold of biodiversity below which the present complex ecosystems will lose their stability[15]? These questions are yet to be answered satisfactorily.

The estimates of species extinctions cited above and those reported elsewhere[8,25,34], are apparently based on well-founded assumptions. Notwithstanding the growing IUCN Red List, and increasing number of species finding place in country-level *Red Data Books*, attempts are needed to reconcile the predicted rates with the observed extinctions of known species in order to ensure greater creditability in the eyes of the general public. Major uncertainties in predicting extinctions include (i) ignorance of exact number of species, (ii) non-random nature of extinctions across habitats and taxonomic groups, (iii) some threatened species may elude extinction, while some non-threatened species may go extinct, (iv) calculations from species–area relation are based on total number of species, ignoring uneven distribution and smaller number of endemics, and (vi) non-inclusion of the effects of future drivers of biodiversity change other than land use (viz. climate change, N deposition, biotic exchange and atmospheric CO_2 concentration).

Assessment and inventory

Species diversity, which is a rough proxy for biodiversity, has been used by ecologists since several decades for characterizing and comparing communities and ecosystems. For example, species–area curve has been used by early ecologists to identify the minimum area of a plant community, its application for estimating the number of species for a given area or for estimating species loss as a function of habitat loss, has gained momentum only in recent years. Frequently used measures of species diversity are summarized in Table 5 (see refs 40 and 53 for greater details).

The growing awareness of the benefits and anticipated rapid decline of biodiversity has necessitated a speedy inventory and monitoring of biodiversity at all levels, although a complete inventory of the world's biodiversity would forever remain an elusive goal. A variety of approaches and techniques have been proposed for this purpose (Table 6, see ref. 40 for greater details). Careful inventory of selected single taxon may aid substantially in the conservation efforts. Multitaxa inventory, on the other hand, provides a relatively complete and broader understanding of site, region or global biodiversity[54]. At the temporal scale, monitoring would provide considerable insight into rhythmic versus stochastic patterns and successional events[55].

For an overall assessment of biodiversity of India, Singh *et al.*[56] suggested to stratify the country into ecoregions or biogeographical zones and to sample biodiversity patterns in those zones, with particular reference to measurable environmental gradients. Establishment of

Table 5. Frequently used diversity measures in ecological analyses

Species–area relation

The number of species encountered is proportional to a power of the area sampled, i.e. $S \alpha A^z$, where S is number of species encountered, A is area sampled and z is empirical constant. The power function model, $S = C A^z$ is an example. In such equations the regression-defined coefficients, C and z, are also diversity measures. Species individual/accumulation curves (i.e. number of stems in place of area) could provide a more accurate prediction of z, than the species–area curve in some situations.

Alpha (α) diversity

The species diversity within a community or habitat, representing a balance between the actions of local biotic and abiotic elements, and immigration from other locations, comprises two components, i.e. species richness and evenness and can be measured by a variety of indices, including a new Avalanch index which also takes account of taxonomic diversity[103].

Beta (β) diversity

The intercommunity or differentiation diversity expressing the rate of species turnover per unit change in habitat, can be assessed by a variety of indices.

Gamma (γ) diversity

The overall diversity at landscape level, including both α and β diversities, can be measured following Schluter and Ricklefs[104].

Compositional diversity pattern

A measure of landscape complexity can be assessed as mosaic diversity (i.e. the variation in species richness among communities and variation in commonness or rarity among species), using affinity analysis[105].

centres specialized in inventorying and quantifying biodiversity, and a greater interaction among survey organizations and such centres was envisaged. Ganeshaiah and Uma Shaanker[57] have proposed an integration of species distribution data and preparation of biodiversity atlases through a country-wide network of scientists. Such atlases together with habitat conservation maps can be combined to map the country's biodiversity. A combination of field sampling with remotely sensed information may permit successful extrapolation at progressively higher scales for whole landscapes[58]. Ramesh *et al.*[59] have described a vegetation-based approach for biodiversity gap analysis, and in an innovative approach, Roy and Tomar[60] have combined data from field sampling (including α diversity), satellite images and geographic information system to identify and map areas of particularly high biological richness on a regional scale.

Biodiversity conservation

The fact that species are disappearing before we have even named them or determined their possible uses and role, suggests that it is wise to take a precautionary approach, and make serious attempts to conserve them. There are four basic, often complementary strategies for biodiversity conservation (Table 7).

The *in situ* strategy emphasizes the protection of ecosystems for the conservation of overall diversity of genes, populations, species, communities and the ecological processes which are crucial for ecosystem services. Establishment of networks of Protected Areas (PAs) selected for high conservation interest is a basic tenet of the *in situ* conservation strategy. World Conservation Monitoring Centre recorded 37,000 protected area sites as of 1994 (ref. 61). Although the success of PAs to protect the biological resources within their borders has been questioned in view of growing human pressures and development needs[62], a study of 93 PAs in 22 tropical countries indicated that both creating new PAs and addressing the tractable problem of making existing PAs perform better will make a significant contribution to long-term biodiversity conservation[63]. Nevertheless, maintaining current reserves in the face of intense and growing population pressure is an important challenge. In order to avoid the loss of resident species, the PAs need exacting management practices in tune with the evolutionary history of the *in situ* biotic complex[64].

Areas to be protected, however, need to be chosen carefully so as to maximize the conservation interest and minimize the cost of protection; those rich in species, rare species or threatened species or some combination of these attributes can be delineated to help set priorities for conservation[65]. Myers *et al.*'s[38] terrestrial biodiversity 'hot spots' concept is an example. However, species-rich areas frequently do not coincide for different taxa, many rare species do not occur on the most species-rich sites[66], and the hot spots of threatened biodiversity for different species groups rarely overlap[67]. Smaller networks of reserves with a design based on how well different sites complement one another biologically, rather than on species richness, are a viable option[68]. However, the complementary concept and assumptions of surrogacy do not find universal support[69,70]. Perrings[71] has cautioned

Table 6. Approaches for biodiversity assessment and inventory

Level/scale	Purpose	Sampling
Genetic	Genetic variation among individuals, within populations and among species.	Molecular techniques
Population	Size of populations for rarity and threat status.	Point sampling
Species	Identity, number, new taxa, geographical distribution, endemism, possible uses.	Point and broad-scale sampling
Single species inventories	• High impact species (e.g. keystone, exotic invasive). • Indicator species (pollution, disturbance, age indicators, etc.) • Conservation-focus species (umbrella species, flagship species, threatened species, etc.). • Species of value to humans. • Typical or representative species.	Point and broad-scale sampling
Multiple taxa inventories	• All taxa biodiversity inventory (ATBI): site-specific, all species • All biota taxonomic inventory (ABTI): all species of selected taxa – global perspective. • Rapid biodiversity assessment (RBA): focus on certain taxa to provide estimate of biological richness of a site/region.	Point sampling Taxonomic survey Visual encounter survey (VES); point sampling, broad-scale sampling
Ecosystem and landscape	Type, geographical extent, land cover, unique habitat, threatened ecosystem, etc.	Broad-scale sampling; remote sensing
Spatial scale		
Local	Checklists of species, comprehensive inventories.	Point sampling
Regional	Checklists of species, can be assembled from local inventories.	Synthesis of point sampling data
Global	Extrapolation for global coverage.	Point sampling coupled with broad-scale sampling; remote sensing

against the designation of PAs exclusively in mega-diversity zones, as species deletions may impose much higher costs in species-poor systems than in species-rich systems. Evidently, there is still no concensus on the basis for selecting areas for protection.

India has a rich tradition of biodiversity conservation. Traditional human relationships like beliefs, faith, taboos, customs and preferences played an important role in conservation of habitats and individual species[72]. The ‘sacred groves’, and ‘sacred lakes’ established by local communities in several parts of India predate the modern concept of PAs. The cultural ethos of the Indian people is amply demonstrated by such conservation efforts[73]. In a majority of Indian villages, trees have been planted and dedicated to different Gods/Goddesses or have been declared as abode of spirits, making them sacred. Frequently, species selected by the local people for social significance turn out to be also of ecological significance[74]. This predates the very concept of *ex situ* conservation. A large number of forest preservation plots, several being more than ninety years old, established by the forest department in representative forest types of India and covering 85,000 ha, could play a major role in biodiversity conservation and detection of change[75–77]. India now has 448 Wildlife Sanctuaries, 85 National Parks and 10 Biosphere Reserves, covering about 4.2% of the total geographical area[77].

In numerous areas around the world, landscapes represent a matrix of modified ecosystems within which small remnants (fragments) of natural ecosystems remain and these lose species sooner or later. Fragments can, however, act as last refuges for plant and animal species and may provide an opportunity for conservationists to launch last-chance attempts to rescue species from extinction[78]. For conservation of fragmented landscape, linkages or corridors between remnant areas could be a solution.

Overuse of natural populations poses remarkably increasing threat to taxa important to humans. For example, Dhar *et al.*[79] found that about 70% of identified

Table 7. Major strategies of biodiversity conservation

Strategy	Work element
In situ	Establish protected area network, with appropriate management practices, corridors to link fragments; restore degraded habitats within and outside PAs.
Ex situ	Establish botanical and zoological gardens, conservation stands; banks of germplasm, pollen, seed, seedlings, tissue culture, gene and DNA, etc.
Reduction of biotic pressure	Reduce anthropogenic pressure on natural populations by cultivating them elsewhere.
Rehabilitation	Identify and rehabilitate threatened species; launch augmentation, reintroduction or introduction programmes.

medicinal plants of Indian Himalaya are exposed to destructive harvesting, which has adversely affected the resource base. A reduction in the anthropogenic pressure on natural populations by cultivating them elsewhere, would substantially contribute to their conservation in nature.

Ecological restoration, that is returning biological communities to their original state with human help, within as well as outside of the PAs, is a viable strategy for conservation[6,80]. Restoration or rehabilitation of endangered species is an extremely difficult and expensive process. The species restoration plans should include diagnosis of factors responsible for the decline of species, habitat conservation, captive breeding and restriction of harvesting, etc. and could follow the strategies of augmentation, reintroduction or introduction[61]. However, massive introduction of predatory carnivores in islands may not be good for long-term ecological success because of the fragility of island populations[81], and prior to a reintroduction, the void created by the loss of species must be thoroughly assessed, including the effect that it would have on the ecosystem[82].

Any biodiversity conservation programme, however, cannot succeed without the involvement of local people. For example, in the sub-Saharan Africa, areas of outstanding conservation importance coincided with dense human settlement, and modifying priority-setting to take account of human density showed that conflicts between conservation and development are not easily avoided[83]. The greatest challenge, therefore is to preserve biodiversity in heavily populated areas. Policies that concentrate on mechanisms which ensure that local communities appropriate a large share of total gains from their conservation of biodiversity, are needed[84]. Two recent studies in Sikkim, one on the sacred Khecheopalri lake[85] and the other on the Khangchendzonga National Park[86], have demonstrated the potential of ecotourism in promoting conservation and at the same time enhancing the living standards of the local inhabitants. Societal forces need to be motivated to promote ecologically prudent behaviour with focus on protected elements at all scales, from individual trees and small sacred groves to the larger nature reserves, as well as areas subject to different levels of human uses outside the nature reserve system[87]. The Ministry of Environment and Forests has recently launched a multidisciplinary and multi-institutional process to prepare a National Biodiversity Strategy and Action Plan (NBSAP) with technical execution being coordinated by the NGO Kalpvriksh, and administration is being handled by the firm Biotech Consortium India Limited[88]. Besides a broad-scale assessment of biodiversity at various levels, the programme emphasizes a widespread participatory approach, gender-sensitive decentralized planning, integration of biodiversity into various sectors of planning, and ensuring ecological security as also peoples’ livelihood security (for details, see the website http://sdnp.delhi.nic.in/nbsap). Evidently, considerable research and thinking need to be devoted on evolving policies and mechanisms to integrate people's livelihoods with conservation efforts.

Conclusions

Biodiversity is essential for human survival and economic well-being and for the ecosystem function and stability. Biodiversity at the global scale is a balance between the rates of speciation and extinction and at the ecosystem level, it is a balance between the rates of invasion and local extinction. It is unevenly distributed on the earth, with broad global and regional patterns. The current rates of extinction are 1000–10,000 times higher than the background rate inferred from fossil record. The growing awareness of importance and high rates of loss make it imperative to rapidly assess and conserve biodiversity, both at regional and global levels. Notwithstanding the growing volume of literature, there is a paucity of concrete data, theories and methodologies for all aspects of biodiversity. Successful strategies for people's participation in preserving biodiversity are lacking. India has a rich tradition of conservation, and with growing inputs from the Government, scientists and NGOs, should provide leadership in developing appropriate methodologies and strategies for biodiversity assessment and conservation.

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