Biodiversity – Many Facets for Sustainable Development

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Literally defining, biodiversity is the variation of different life forms within a given ecosystem, biome, or on the entire Earth. The term is often used as a measure of the health of biological systems, the functions of which are inter-related. The biodiversity presently available on this Earth today can be considered as a real live natural wealth that has evolved on this planet millions of years before. The journey of this evolution has remained very long and so are the majority of diverse life forms of distinct biological species. Biodiversity is not distributed evenly on Earth, but is consistently richer in the tropics and in specific localized regions and lesser rich in polar regions where fewer species are known to occur.

Rapid environmental changes that are occurring since the co-evolution of the species, typically cause certain mutations leading to the evolution of a new organism or some times extinction of any species. Of all species that have existed on Earth, 99.9 percent are now extinct. Since the life started on Earth, five major mass extinctions have led to large and sudden drops in the biodiversity of species. The Phanerozoic eon (the last 540 million years) marked a rapid growth in biodiversity in the Cambrian explosion-a period during which nearly every phylum of multicellular organisms first appeared. The next 400 million years were distinguished by periodic, massive losses of biodiversity classified as mass extinction events. The most recent, the Cretaceous-Tertiary extinction event, occurred 65 million years ago, and has attracted more attention than all others because it has led to the extinction of the dinosaurs.

Terminologies

The term's contracted form ***biodiversity*** is supposed to be coined by W.G. Rosen in 1985 while planning the *National Forum on Biological Diversity* organized by the National Research Council (NRC) in 1986. The word first appeared in a publication in

Imagine the Earth without these: Diverse and fascinating life forms (coral reef) under the sea; A typical rainforest with deep afforestation; Natural attraction: nature's bank of diverse life forms, A conifer forest

1988 when Entomologist E. O. Wilson used it as the title of the proceedings of that forum. Since then, both terms and the concept have achieved widespread use among biologists, environmentalists, political leaders, and concerned citizens worldwide. The term is sometimes used to equate to a concern for the natural environment and nature conservation. This use has coincided with the expansion of concern over extinction observed in the last decades of the 20th century.

A more or less similar concept being used in the United States, besides natural diversity, is the term "natural heritage." It pre-dates both terms though it is a less scientific term and more easily comprehended in some ways by the wider audience interested in conservation. Furthermore it may be misleading if used to refer only to biodiversity, as natural heritage also includes geology and landforms (geodiversity). The term "Natural Heritage" was used when Jimmy Carter set up the Georgia Heritage Trust while he was Governor of Georgia. "Natural Heritage" was picked up by the Science Division of the US Nature Conservancy when, under Jenkins, it launched in 1974 the network of State Natural Heritage Programs.

> "Biological diversity" or "biodiversity" can have many interpretations and it is most commonly used to replace the more clearly defined and long established terms, species diversity and species richness. Biologists most often define biodiversity as the "totality of genes, species, and ecosystems of a region".

Raymond F. Dasmann apparently coined the term "Biological Diversity" and latter on Thomas E. Lovejoy introduced it to the wider conservation and science communities. An explicit definition consistent with this interpretation was first given in a paper by Bruce A. Wilcox commissioned by the International Union for the Conservation of Nature and Natural Resources (IUCN) for the 1982 World National Parks Conference in Bali. The definition Wilcox gave is "Biological diversity is the variety of life forms...at all levels of biological systems (*i.e.*, molecular, organismic, population, species and ecosystem)..." Subsequently, the 1992 United Nations Earth Summit in Rio de Janeiro defined "biological diversity" as "the variability among living organisms from all sources, including, 'inter alia', terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". This is, in fact, the closest thing to a single legally accepted definition of biodiversity, since it is the definition adopted by the United Nations Convention on Biological Diversity.

Number of species

According to the *Global Taxonomy Initiative and the European Distributed Institute of Taxonomy*, the total number of species for some phyla may be much higher as what we know currently: 10-30 million insects; (of some 0,9 we know today), 5-10 million bacteria; 1.5 million fungi; (of some 0.4 million we know today), ~1 million mites.

During the last century, decreases in biodiversity have been increasingly observed. Studies show that 30% of all natural species will be extinct by 2050. Of these, about one eighth of the known plant species are threatened with extinction. Some estimates put the loss at up to 140,000 species per year (based on Species-area theory) and subject to discussion. This figure indicates unsustainable ecological practices, because only a small number of species come into being each year. Almost all scientists acknowledge that the rate of species loss is greater now than at any time in human history, with extinctions occurring at rates hundreds of times higher than background extinction rates.

The factors that threaten biodiversity have been variously categorized. Jared Diamond describes an "Evil Quartet" of habitat destruction, overkill, introduced species, and secondary extensions. Edward O. Wilson prefers the acronym HIPPO, standing for **H**abitat destruction, **I**nvasive species, **P**ollution, Human Over **P**opulation, and **O**ver-harvesting. The most authoritative classification in use today is that of IUCN's Classification of Direct Threats adopted by most major international conservation organizations such as the US Nature Conservancy, the World Wildlife Fund, Conservation International, and Birdlife International.

Threats to biodiversity : Habitat destruction

Most of the species extinctions from 1000 AD to 2000 AD are due to human activities, in particular destruction of plant and animal habitats. Raised rates of extinction are being driven by human consumption of organic resources, especially related to tropical forest destruction. While most of the species that are becoming extinct are not food species, their biomass is converted into human food when their habitat is transformed into pasture, cropland, and orchards. It is estimated that more than a third of the Earth's biomass is tied up in only the few species that represent humans, livestock and crops. Because an ecosystem decreases in stability as its species are made extinct, these studies warn that the global ecosystem is destined for collapse if it is further reduced in complexity. Factors contributing to loss of biodiversity are: overpopulation, deforestation, pollution (air pollution, water pollution, soil contamination) and global warming or climate change, driven by human activity. These factors, while all stemming from overpopulation, produce a cumulative impact upon biodiversity.

A September 14, 2007 study conducted by the National Science Foundation found that biodiversity and genetic diversity are dependent upon each other-that diversity within a species is necessary to maintain diversity among species, and vice versa. According to the lead researcher in the study, Dr. Richard Lankau, "If any one type is removed from the system, the cycle can break down, and the community becomes dominated by a single species."

At present, the most threathened ecosystems are those found in fresh water. The marking of fresh water ecosystems as the ecosystems most under threat was done by the Millennium Ecosystem Assessment 2005, and was confirmed again by the project "**Freshwater Animal Diversity Assessment**", organised by the biodiversity platform, and the French Institut de recherche pour le développement (MNHNP).

Exotic species

The rich diversity of unique species across many parts of the world exist only because they are separated by barriers, particularly large rivers, seas, oceans, mountains and deserts from other species of other land masses, particularly the highly fecund, ultra-competitive, generalist "super-species". These are barriers that couldn't have been easily crossed by natural processes, except through continental drift. However, humans have invented transportation with the ability to bring into contact species that they've never met in their evolutionary history; also, this is done on a time scale of days, unlike the centuries that historically have accompanied major animal migrations. As these species that never met before come in contact with each other, the rate at which species are extincting has increased many folds.

The widespread introduction of exotic species by humans is a potent threat to biodiversity. When exotic species are introduced to ecosystems and establish self-sustaining populations, the endemic species in that ecosystem that have not evolved to cope with the exotic species may not survive. The exotic organisms may either be predators, parasites, or simply aggressive species that deprive indigenous species of nutrients, water and light. These invasive species often have features, due to their evolutionary background and new environment that make them highly competitive; able to become well-established and spread quickly, reducing the effective habitat of endemic species.

Exotic species are introduced by human, either unwillingly or intentionally. Examples on unwilling introduction are fore example ladybugs. These were bred to help in combating pests in agriculture (for greenhouses). Other examples of unwilling introduction are species that are unknowingly brought in by vessel or automotive. These include certain bacteria, spiders, seeds of certain plants. Examples of intentional introduction are the planting of exotic plants in gardens. It is clear that with simple measures the preventing of the spread of exotic plants, yet as of present; trying to reduce the inflow of exotic species has remained low on the political agenda. Also, the intentional planting of species that are marked as "indigenous", yet are from a non-indigenous strain can be considered exotic and create problems in the ecosystem.

Genetic pollution

Purebred naturally evolved region specific wild species can be threatened with extinction through the process of genetic pollution *i.e.* uncontrolled hybridization, introgression and genetic swamping which leads to homogenization or replacement of local genotypes as a result of either a numerical and/or fitness advantage of introduced plant or animal. Nonnative species can bring about a form of extinction of native plants and animals by hybridization and introgression either through purposeful introduction by humans or through habitat modification, bringing previously isolated species into contact. These phenomena can be especially detrimental for rare species coming into contact with more abundant ones. The abundant species can interbreed with the rarer, swamping the entire gene pool and creating hybrids, thus driving the entire native stock to complete extinction. Attention has to be focused on the extent of this under appreciated problem that is not always apparent from morphological (outward appearance) observations alone.

Hybridization and genetics

In agriculture and animal husbandry, the green revolution popularized the use of conventional hybridization to increase yield by creating "high-yielding varieties". Often the handful of hybridized breeds originated in developed countries and was further hybridized with local varieties in the rest of the developing world to create high yield strains resistant to local climate and diseases. Local governments and industry have been pushing hybridization which has resulted in several of the indigenous breeds becoming extinct or threatened. Disuse because of un-profitability and uncontrolled intentional and unintentional cross-pollination and crossbreeding (genetic pollution), formerly huge gene pools of various wild and indigenous breeds has collapsed causing widespread genetic erosion and genetic pollution. This has resulted in loss of genetic diversity and biodiversity as a whole.

A genetically modified organism (GMO) is an organism whose genetic material has been altered using the genetic engineering techniques generally known as recombinant DNA technology. Genetically Modified (GM) crops today have become a common source for genetic pollution, not only of wild varieties but also of other domesticated varieties derived from relatively natural hybridization.

Genetic erosion coupled with genetic pollution may be destroying unique genotypes, thereby creating a hidden crisis which could result in a severe threat to our food security. Diverse genetic material could cease to exist which would impact our ability to further hybridize food crops and livestock against more resistant diseases and climatic changes.

Linking types of biodiversity

A complex relationship exists among the different types of biodiversity. Identifying one type of diversity in a group of organisms does not necessarily indicate its relationship with other types of diversity until and unless functional aspects and interactions within the system are well defined. All types of diversity can be broadly linked and numerical study investigating the link between tetrapod taxonomic and ecological diversity of tetrapods (terrestrial vertebrates) shows a very close correlation between the two.

Measuring biodiversity

A number of objective measures have been created in order to empirically measure biodiversity. Each measure of biodiversity relates to a particular use of the data. For practical conservationists, measurements should include a quantification of values that are commonly-shared among locally affected organisms, including humans. For others, a more economically defensible definition should allow the ensuring of continued possibilities for both adaptation and future use by humans, assuring environmental sustainability. Ecosystem diversity is one meaning a range of ecosystems within a larger landscape. Species diversity is another meaning variety of species throughout the world or community. And last of all genetic diversity referring to the number of genetic characters in an organism or community.

Distribution

Biodiversity is not distributed evenly on Earth. It is consistently richer in the tropics and in other localized regions. Polar regions are usually lacking high degree of biodiversity because of the presence of fewer species. A vast diversity of organisms are occupying marine and other aquatic ecosystems. Diversity of flora and fauna depends on climate, altitude, soils and the presence of other species. In the year 2006 large numbers of the Earth's species were formally classified as rare or endangered or threatened species; moreover, many scientists have estimated that there are millions of species that were actually endangered and which could not have yet been formally recognized. About 40 percent of the 40,177 species assessed using the IUCN Red List criteria, are now listed as threatened species with extinction - a total of 16,119 species. Even though biodiversity declines from the equator to the poles in terrestrial eco-regions, whether this is the same in an aquatic ecosystems is still a hypothesis to be tested, especially in marine ecosystems where causes of this phenomenon are unclear. In addition, particularly in marine ecosystems, there are several well stated cases where diversity in higher latitudes actually increases. Therefore, the lack of information on biodiversity of Tropics and Polar Regions prevents scientific conclusions on the distribution of the world's aquatic biodiversity.

Brazil’s Atlantic Forest is considered a hotspot of biodiversity and contains roughly 20,000 plant species, 1350 vertebrates, and millions of insects, about half of which occur nowhere else in the world. The island of Madagascar including the unique Madagascar dry deciduous forests and lowland rainforests possess a very high ratio of species endemism and biodiversity, since the island separated from mainland Africa 65 million years ago, most of the species and ecosystems have evolved independently producing unique species different from those in other parts of Africa. In India, many diverse ecoregions with variable environmental conditions like high cold regions, lakes of high salinity (Chilika and Sambher lakes), mangrove ecosystems (Goa), thermal springs (Manikaran etc.), environment of high desiccation and drought (Rajasthan and Gujrat) constitute such hot spots. Many regions of high biodiversity (as well as high endemism) arise from very specialized habitats which require unusual adaptation mechanisms.

Conserving biodiversity

Conservation biology has gained importance and matured in the mid-20th century as ecologists, naturalists, and other scientists began to collectively research and address issues pertaining to global declines in biodiversity. The conservation ethic differs from the preservationist ethic, historically lead by John Muir, who advocate for protected areas devoid of human exploitation or interference for profit. The conservation ethic advocates for wise stewardship and management of natural resource production for the purpose of protecting and sustaining biodiversity in species, ecosystems, the evolutionary process, and human culture and society. Conservation biologists are concerned with the trends in biodiversity being reported in this era, which has been labeled by science as the Holocene extinction period, also known as the sixth mass extinction. Rates of decline in biodiversity in this sixth mass extinction match or exceed rates of loss in the five previous mass extinction events recorded in the fossil record. Loss of biodiversity results in the loss of natural capital that supplies ecosystem goods and services. The economic value of 17 ecosystem services for the entire biosphere (calculated in 1997) has an estimated average value of US$ 33 trillion (10^{12}) per year.

In response to the extinction crisis, the research of conservation biologists is being organized into strategic plans that include principles, guidelines, and tools for the purpose of protecting biodiversity. Conservation biology is a crisis orientated discipline and it is multi-disciplinary, including ecological, social, education, and other scientific disciplines outside of biology. Conservation biologists work in both the field and office, in government, universities, non-profit organizations and in industry. The conservation of biological diversity is a global priority in strategic conservation plans that are designed to engage public policy and concerns affecting local, regional and global scales of communities, ecosystems, and cultures. Conserving biodiversity and action plans identify ways of sustaining human well-being and global economics, including natural capital, market capital, and ecosystem services.

Strategic means

One of the strategies involves placing a monetary value on biodiversity through biodiversity banking, of which one example is the Australian Native Vegetation Management Framework. Other approaches are the creation of gene banks, that have the intention of growing the indigenous species for reintroduction to the ecosystem (*e.g.* via tree nurseries). The eradication of exotic species is also an important method to preserve the local biodiversity. Exotic species that have become a pest can be identified using taxonomy (*e.g.* with DAISY, barcode of life) and can then be eradicated. This method however can only be used against a large group of a certain exotic organism due to the economic cost. Other measures contributing to the preservation of biodiversity include- the reduction of pesticide use and/or a switching to organic pesticides. These measures however, are of less importance than the preserving of rural lands, reintroduction of indigenous species and the removal of exotic species. Finally, if the continued preservation of native organisms in an area can be guaranteed, efforts can be made in trying to reintroduce eliminated native species back into the environment. This can be done by first determining which species were indigenous to the area, and then reintroducing them. This determination can be done using databases as the *Encyclopedia of life, Global Biodiversity Information Facility*. Extermination is usually done with either (ecological) pesticides, or natural predators.

Biodiversity is not as rich everywhere on the planet. Regions such as the tropics and subtropics are considerably much richer in biodiversity than regions in temperate climates. In addition, in temperate climates, a lot of countries are located which are already vastly urbanized, and require -in addition- great amounts of space for the growing of crops. As rehabilitating the biodiversity within these countries would again require the clearing and redeveloping of spaces, it has been proposed of some that efforts are best instead directed unto the tropics. Arguments include economics, it would be far less costly and more efficient to preserve the biodiversity in the tropics, especially as many countries in these areas are only now beginning to urbanize.

However, only directing the efforts into these areas would not be enough, as many species still need to migrate at certain times of the year, requiring a connection to other regions/countries. In the more urbanized countries in temperate climates, this would mean that wildlife corridors need to be made. However, making wildlife corridors would still be considerably cheaper and easier than clearing/preserving entirely new areas.

Evolutionary trends

Biodiversity found on Earth today is the result of 3.5 billion years of evolution. The origin of life has not been definitely established by science, however some evidence suggests that life may already have been well-established a few hundred million years after the formation of the Earth. Until approximately 600 million years ago, all life consisted of archaea, bacteria, protozoans and similar single-celled organisms.

The history of biodiversity during the Phanerozoic (the last 540 million years), starts with rapid growth during the Cambrian explosion-a period during which nearly every phylum of multicellular organisms first appeared. Over the next 400 million years or so, global diversity showed little overall trend, but was marked by periodic, massive losses of diversity classified as mass extinction events.

The apparent biodiversity shown in the fossil record suggests that the last few million years include the period of greatest biodiversity in the Earth's history. However, not all scientists support this view, since there is considerable uncertainty as to how strongly the fossil record is biased by the greater availability and preservation of recent geologic sections. Some argue that, corrected for sampling artifacts, modern biodiversity is not much different from biodiversity 300 million years ago. Estimates of the present global macroscopic species diversity vary from 2 million to 100 million species, with a best estimate of somewhere near 13-14 million, the vast majority of them arthropods.

The existence of a global carrying capacity has been debated, that is to say that there is a limit to the number of species that can live on this planet. While records of life in the sea show a logistic pattern of growth, life on land (insects, plants and tetrapods) shows an exponential rise in diversity. As one author states, "Tetrapods have not yet invaded 64 per cent of potentially habitable modes, and it could be that without human influence the ecological and taxonomic diversity of tetrapods would continue to increase in an exponential fashion until most or all of the available ecospace is filled."

On the other hand, it has been demonstrated that changes in biodiversity through the Phanerozoic correlate much better with hyperbolic model (widely used in demography and macrosociology) than with exponential and logistic models (traditionally used in population biology and extensively applied to fossil biodiversity as well). The latter models imply that changes in diversity are guided by a first-order positive feedback (more ancestors, more descendants) and/or a negative feedback arising from resource limitation. Hyperbolic model implies a second-order positive feedback. The hyperbolic pattern of the world population growth arises from a second-order positive feedback between the population size and the rate of technological growth. The hyperbolic character of biodiversity growth can be similarly accounted for by a feedback between the diversity and community structure complexity.

Most biologists agree however that the period since the emergence of humans is part of a new mass extinction, the Holocene extinction event, caused primarily by the impact humans are having on the environment. It has been argued that the present rate of extinction is sufficient to eliminate most species on the planet Earth within 100 years. New species are regularly discovered (on average between 5-10,000 new species each year, most of them insects) and many, though discovered, are not yet classified (estimates are that nearly 90% of all arthropods are not yet classified). Most of the terrestrial diversity is found in tropical forests.

Linking biodiversity with Human benefits

Biodiversity also supports a number of natural ecosystem processes and services. Some ecosystem services that benefit society are : air quality, climate (both global CO_2 sequestration and local), water purification, pollination, and prevention of erosion. Since the stone era, species loss has been accelerated above the geological rate by human activity. The rate of species extinction is difficult to estimate, but it has

Diversity of flowers *(Centaurea cyanus and Papaver rhoeas)*; wildlife, habitats and vegetation : All means of human happiness been estimated that species are now being lost at a rate approximately 100 times as fast as is typical in the geological record, or perhaps as high as 10000 times as fast. To feed such a large population, more land is being transformed from wilderness with wildlife into agricultural, mining, lumbering, and urban areas for humans. Non-material benefits that are obtained from ecosystems include spiritual and aesthetic values, knowledge systems and the value of education.

Biodiversity provides food for humans. Although about 80 percent of our food supply comes from just 20 kinds of plants, humans use at least 40,000 species of plants and animals a day. Many people around the world depend on these species for their food, shelter, and clothing. There is untapped potential for increasing the range of food products suitable for human consumption, provided that the high present extinction rate can be stopped.

The relevance of biodiversity to human health is becoming a major international political issue, as scientific evidence builds on the global health implications of biodiversity loss. This issue is closely linked with the issue of climate change, as many of the anticipated health risks of climate change are associated with changes in biodiversity (*e.g.* changes in populations and distribution of disease vectors, scarcity of fresh water, impacts on agricultural biodiversity and food resources etc.). Some of the health issues influenced by biodiversity include dietary health and nutrition security, infectious diseases, medical science and medicinal resources, social and psychological health, and spiritual well-being. Biodiversity is also known to have an important role in reducing disaster risk, and in post-disaster relief and recovery efforts.

One of the key health issues associated with biodiversity is that of drug discovery and the availability of medicinal resources. A significant proportion of drugs are derived, directly or indirectly, from biological sources; It is reported that at least 50% of the pharmaceutical compounds on the market in the US are derived from natural compounds found in plants, animals, and microorganisms, while about 80% of the world population depends on medicines from nature (used in either modern or traditional medical practice) for primary healthcare. Moreover, only a tiny proportion of the total diversity of wild species has been investigated for potential sources of new drugs. Through the field of bionics, considerable technological advancement has occurred which would not have without a rich biodiversity. It has been argued, based on evidence from market analysis and biodiversity science, that the decline in output from the pharmaceutical sector since the mid-1980s can be attributed to a move away from natural product exploration ("bioprospecting") in favour of R&D programmes based on genomics and synthetic chemistry, neither of which have yielded the expected product outputs; meanwhile, there is evidence that natural product chemistry can provide the basis for innovation which can yield significant economic and health benefits. Marine ecosystems are of particular interest in this regard however unregulated and inappropriate bioprospecting can be considered a form of over-exploitation which has the potential to degrade ecosystems and increase biodiversity loss, as well as impacting on the rights of the communities and states from which the resources are taken.

Agriculture and biodiversity

The economic value of the reservoir of genetic traits present in wild varieties and traditionally grown landraces is extremely important in improving crop performance. Important crops, such as the potato and coffee, are often derived from only a few genetic strains. Improvements in crop plants over the last 250 years have been largely due to harnessing the genetic diversity present in wild and domestic crop plants. Interbreeding crops strains with different beneficial traits has resulted in more than doubling crop production in the last 50 years as a result of the Green Revolution.

Crop diversity is also necessary to help the system recover when the dominant crop type is attacked by a disease:

- The Irish potato blight of 1846, which was a major factor in the deaths of a million people and migration of another million, was the result of planting only two potato varieties, both of which were vulnerable.

- When rice grassy stunt virus struck rice fields from Indonesia to India in the 1970s, 6273 varieties were tested for resistance. One was found to be resistant, an Indian variety, known to science only since 1966. This variety formed a hybrid with other varieties and is now widely grown.
- Coffee rust attacked coffee plantations in Sri Lanka, Brazil, and Central America in 1970. A resistant variety was found in Ethiopia. Although the diseases are themselves a form of biodiversity.

Monoculture, the lack of biodiversity, was a contributing factor to several agricultural disasters in history, the European wine industry collapse in the late 1800s, and the US Southern Corn Leaf Blight epidemic of 1970. Higher biodiversity also controls the spread of certain diseases as pathogens will need to adapt to infect different species.

Biodiversity and business

A wide range of industrial materials are derived directly from biological resources. These include building materials, fibers, dyes, resin rubber and oil. There is enormous potential for further research into sustainable utilizing materials from a wider diversity of organisms. In addition, biodiversity and the ecosystem goods and services it provides are considered to be fundamental to healthy economic systems. The degree to which biodiversity supports business varies between regions and between economic sectors, however the importance of biodiversity to issues of resource security (water quantity and quality, timber, paper and fiber, food and medicinal resources etc.) are increasingly recognized as universal. As a result, the loss of biodiversity is increasingly recognized as a significant risk factor in business development and a threat to long term economic sustainability. A number of case studies recently compiled by the World Resources Institute demonstrate some of these risks as identified by specific industries.

Other ecological services

The diversity of species and genes in ecological communities affects the functioning of these communities. These ecological effects of biodiversity in turn affect both climate change through enhanced greenhouse gases, aerosols and loss of land cover, and biological diversity, causing a rapid loss of ecosystems and extinctions of species and local populations. The current rate of extinction is sometimes considered a mass extinction, with current species extinction rates on the order of 100 to 1000 times as high as in the past.

The two main areas where the effect of bio-diversity on ecosystem function has been studied are the relationship between diversity and productivity, and the relationship between diversity and community stability. More biologically diverse communities appear to be more productive (in terms of biomass production) than are less diverse communities, and they appear to be more stable in the face of perturbations. Also animals that inhabit an area may alter the surviving conditions by factors assimilated by climate.

Definitions of diversity, productivity and stability

In order to understand the effects that changes in biodiversity will have on ecosystem functioning, it is important to define some terms. Biodiversity is not easily defined, but may be thought of as the number and/or evenness of genes, species, and ecosystems in a region. This definition includes genetic diversity, or the diversity of genes within a species, species diversity, or the diversity of species within a habitat or region, and ecosystem diversity, or the diversity of habitats within a region. Two things commonly measured in relation to changes in diversity are productivity and stability. Productivity is a measure of ecosystem function. It is generally measured by taking the total aboveground biomass of all plants in an area. Many assume that it can be used as a general indicator of ecosystem function and that total resource use and other indicators of ecosystem function are correlated with productivity.

Stability is much more difficult to define, but can be generally thought of in two ways. General stability of a population is a measure that assumes stability is higher if there is less of a chance of extinction. This kind of stability is generally measured by measuring the variability of aggregate community properties, like total biomass accumulation over the time. The other definition of stability is a measure of resilience and resistance, where an ecosystem that returns quickly to an equilibrium after a perturbation or resists invasion is thought of as more stable than one that doesn't.

Productivity and stability as indicators of ecosystem health

The importance of stability in community ecology is clear. An unstable ecosystem will be more likely to lose species. Thus, if there is indeed a link between diversity and stability, it is likely that losses of diversity could feedback on themselves, causing even more losses of species. Productivity, on the other hand, has a less clear importance in community ecology. In managed areas like cropland, and in areas where animals are grown or caught, increasing productivity increases the economic success of the area and implies that the area has become more efficient, leading to possible long term resource sustainability. It is more difficult to find the importance of productivity in natural ecosystems.

Leisure, cultural and aesthetic value

Many people derive value from biodiversity through leisure activities such as hiking, birdwatching or natural history study. Biodiversity has inspired musicians, painters, sculptors, writers and other artists. Many cultural groups view themselves as an integral part of the natural world and show respect for other living organisms. Popular activities such as gardening, caring for aquariums and collecting butterflies are all strongly dependent on biodiversity. The number of species involved in such pursuits is in the tens of thousands, though the great majority does not enter mainstream commercialism.

The relationships between the original natural areas of these often 'exotic' animals and plants and commercial collectors, suppliers, breeders, propagators and those who promote their understanding and enjoyment are complex and poorly understood. It seems clear, however, that the general public responds well to exposure to rare and unusual organisms-they recognize their inherent value at some level. A family outing to the botanical garden or zoo is as much an aesthetic or cultural experience as it is an educational one.

Philosophically it could be argued that bio-diversity has intrinsic aesthetic and spiritual value to mankind *in and of itself*. This idea can be used as a counterweight to the notion that tropical forests and other ecological realms are only worthy of conservation because they may contain medicines or useful products. An interesting point is that evolved DNA embodies knowledge, and therefore destroying a species resembles burning a book, with the caveat that the book is of uncertain depth and importance and may in fact be best used as fuel.

Effects of diversity on community productivity

How species diversity influence productivity?

- **Complementarity-** Plant species coexistence is thought to be the result of niche partitioning, or differences in resource requirements among species. By complementarity, a more diverse plant community should be able to use resources more completely, and thus be more productive. Also called niche differentiation, this mechanism is a central principle in the functional group approach, which breaks species diversity down into functional components.
- Facilitation- Facilitation is a mechanism whereby certain species help or allow other species to grow by modifying the environment in a way that is favorable to a co-occurring species. Plants can interact through an intermediary like nitrogen, water, temperature, space, or interactions with weeds or herbivores among others. Some examples of facilitation include large desert perennials acting as nurse plants, aiding the

establishment of young neighbors of other species by alleviating water and temperature stress, and nutrient enrichment by nitrogen-fixers such as legumes.

- The Sampling Effect The sampling effect of diversity can be thought of as having a greater chance of including a species of greatest inherent productivity in a plot that is more diverse. This provides for a composition effect on productivity, rather than diversity being a direct cause. However, the sampling effect may in fact be a compilation of different effects. The sampling effect can be separated into the greater likelihood of selecting a species that is 1) adapted well to particular site conditions, or 2) of a greater inherent productivity. Additionally, one can add to the sampling effect a greater likelihood of including 3) a pair of species that highly complement each other, or 4) a certain species with a large facilitative effect on other members of the community.

Implications for ecological well-being

In order to correctly identify the consequences of diversity on productivity and other ecosystem processes, many things must happen. First, it is imperative that scientists stop looking for a single relationship. It is obvious now from the models, the data, and the theory that there is no one overarching effect of diversity on productivity. Scientists must try to quantify the differences between composition effect and diversity effects, as many experiments never quantify the final realized species diversity (instead only counting numbers of species of seeds planted) and confound a sampling effect for facilitators (a compositional factor) with diversity effects.

Relative amounts of over yielding (or how much more a species grows when grown with other species than it does in monoculture) should be used rather than absolute amounts as relative over yielding can give clues as to the mechanism by which diversity is influencing productivity, however if experimental protocols are incomplete, one may be able to indicate the existence of a complementary or facilitative effect in the experiment, but not be able to recognize its cause. Experimenters should know what the goal of their experiment is, that is, whether it is meant to inform natural or managed ecosystems, as the sampling effect may only be a real effect of diversity in natural ecosystems (managed ecosystems are composed to maximize complementarily and facilitation regardless of species number). By knowing this, they should be able to choose spatial and temporal scales that are appropriate for their experiment. Lastly, to resolve the diversity-function debate, it is advisable that experiments be done with large amounts of spatial and resource heterogeneity and environmental fluctuation over time, as these types of experiments should be able to demonstrate the diversity-function relationship more easily.

How species diversity influence community stability?

- **Averaging Effect:** If all species have differential responses to changes in the ecosystem over time, then the averaging of these responses will cause a more temporally stable ecosystem if more species are in the ecosystem.. This effect is a statistical effect due to summing random variables.

- **Negative Covariance Effect:** If some species do better when other species are not doing well, then when there are more species in the ecosystem, their overall variance will be lower than if there were fewer species in the system. This lower variance indicates higher stability. This effect is a consequence of competition.

- **Insurance Effect:** If an ecosystem contains more species then it will have a greater likelihood of having redundant stabilizing species, and it will have a greater number of species that respond differently to perturbations. This will enhance an ecosystem's ability to buffer perturbations.

- **Resistance to Invasion:** Diverse communities may use resources more completely than simple communities because of a diversity effect for complementarity. Thus invaders may have reduced success in diverse ecosystems, or there may be a reduced likelihood that an invading species will introduce a new property or process to a diverse ecosystem.

- **Resistance to Disease:** A decreased number of competing plant species may allow the abundances of other species to increase, facilitating the spread of diseases of those species.

Review of temporal stability data

Models have predicted that empirical relationships between temporal variation of community productivity and species diversity are indeed real, and that they almost have to be. Some temporal stability data can be almost completely explained by the averaging effect by constructing null models to test the data against. Competition, which causes negative covariance and only serves to strengthen these relationships.

Review of resistance/resilience stability data

This area is more contentious than the area of temporal stability, mostly because some have tried generalizing the findings of the temporal stability models and theory to stability in general. While the relationship between temporal variations in productivity and diversity has a mathematical cause, which will allow the relationship to be seen much more often than not, it is not the case with resistance/resilience stability. Some experimenters have seen a correlation between diversity and reduced invasion, though many have also seen the opposite. The correlation between diversity and disease is also tenuous, though theory and data do seem to support it.

Implications for ecology

In order to more fully understand the effects of diversity on the temporal stability of ecosystems it is necessary to recognize that they are bound to occur. By constructing null models to test the data against, it becomes possible to find situations and ecological contexts where ecosystems become more or less stable than they should be. Finding these contexts would allow for mechanistic studies into why these ecosystems are more stable, which may allow for applications in conservation management.

More importantly more complete experiments into whether diverse ecosystems actually resist invasion and disease better than their less diverse equivalents as invasion and disease are two important factors that lead to species extinctions in the present day.

Modeling future impacts

Accurate predictions of the future impacts of climate change on plant diversity are critical to the development of conservation strategies. These predictions have come largely from bioinformatics strategies, involving modeling individual species, groups of species such as 'functional types', communities, ecosystems or biomes. They can also involve modeling species observed environmental niches, or observed physiological processes.

Although useful, modeling has many limitations. Firstly, there is uncertainty about the future levels of greenhouse gas emissions driving climate change and considerable uncertainty in modeling how this will affect other aspects of climate such as local rainfall or temperatures. For most species the importance of specific climatic variables in defining distribution (e.g. minimum rainfall or maximum temperature) is unknown. It is also difficult to know which aspects of a particular climatic variable are most biologically relevant, such as average vs. maximum or minimum temperatures. Ecological processes such as interactions between species and dispersal rates and distances are also inherently complex, further complicating predictions.

Improvement of models is an active area of research, with new models attempting to take factors such as life-history traits of species or processes such as migration into account when predicting distribution changes; though possible trade-offs between regional accuracy and generality are recognized. Climate change is also predicted to interact with other drivers of biodiversity change such as habitat destruction and fragmentation, or the introduction of foreign species. These threats may possibly act in synergy to increase extinction risk from that seen in periods of rapid climate change in the past.

The recent phenomenon of global warming is also considered to be a major threat to global biodiversity. For example coral reefs -which are biodiversity hotspots-will be lost in 20 to 40 years if global warming continues at the current trend. All species are likely to be not only directly impacted by the changes in environmental conditions discussed above, but also indirectly through their interactions with other species. While direct impacts may be easier to predict and conceptualize, it is likely that indirect impacts are equally important in determining the response of plants to climate change.

A species whose distribution changes as a direct result of climate change may 'invade' the range of another species for example, introducing a new competitive relationship. The range of symbiotic fungi associated with plant roots may directly change as a result of altered climate, resulting in a change in the plants distribution. A new grass may spread into a region, altering the fire regime and greatly changing the species composition. A pathogen or parasite may change its interactions with a plant, such as a pathogenic fungus becoming more common in an area where rainfall increases.

Conclusions

It is imperative that the phenomenon of biodiversity is very vast, complex and interdependent and there is no single over-arching effect of diversity on either productivity or stability. The realized effects will depend heavily on environmental context and the time scale over which the effects are studied. However, it has become obvious that biodiversity is indeed important for both managed and natural ecosystems, though the relative contributions of diversity and composition remain unclear. It is therefore necessary for legislators to understand the basic science in order to maintain diversity at its current levels. If current human growth and resource management patterns do not change, it is likely that we will lose many important species, and the ecosystems of the world may never recover.

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