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BIODIVERSITY SCIENCE: DEFINITION SCOPE AND CONSTRAINTS

Introduction

Biodiversity is the abbreviated word for **Biological Diversity**. The latter usage appears to have come into prominence around 1980, when Norse and McManus (1980) first defined it. Its abbreviation into 'biodiversity' was apparently made by Walter G. Rosen in 1985 during the first planning meeting of the 'National Forum on Biodiversity' held at Washington DC in September 1986 (UNEP 1995). The published proceedings of this meeting in a book entitled *Biodiversity* (Wilson and Peters 1988) introduced the notion of biodiversity and popularised this word among the scientific community as well as the public. Since then, not only the number of publications on biodiversity, but also of people interested in the subject for one reason or the other has steadily increased (Harper and Hawksworth 1994). The United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro (**Rio Summit** or **Earth Summit**) has also substantially elevated the status of Biodiversity.

Biodiversity—Concept and Definition

The word Biodiversity is now very widely used not only by the scientific community, but also the general public, environmental groups, conservationists, industrialists and economists. It has also gained a very high profile in the national and international political arena. In fact, the term has become very fashionable with no clear understanding of what it means. Such loose usage has given the word so many different meanings, connotations and intentions that the actual concept of biodiversity has been lost in obfuscation and confusion. Hence there is a real need to unequivocally define the concept of biodiversity, which is today a recognised separate science with its own principles and facts, and to define the scope of this new science as well.

Biodiversity is generally considered an 'umbrella term' referring to organisms found within the living world, i.e., the number, variety and variability of living organisms. It may thus be assumed to be a synonym for 'Life on Earth', 'variety of life and its processes' (Keystone Center 1991), 'condition of being different' (Gove *et al.* 1996), or what Darwin (1859) exclaimed as 'Life's endless forms'. Taken in this general sense, biodiversity is indeed 'the essence of life' (Frankel 1970). In reality, however, biodiversity is a very vast and complex concept and its ramifications extend deep into all spheres of human life and activity.

Biodiversity is normally treated in terms of genes, species and ecosystems in correspondence with the three fundamental hierarchical levels of biological organisation; these three diversities are respectively referred to as Genetic, Species and Ecosystem diversities. According to Harper and Hawksworth (1994), it was Norse *et al.* (1986) who first expanded the traditional use of the term biological diversity to the three levels of biological organisation (see also OTA 1987). Diversity within species is **Genetic Diversity**, diversity between species is **Species Diversity** (also often referred to as **Taxonomic** or **Organismal Diversity**), and diversity at the ecological or habitat level is **Ecosystem Diversity** (also known as **Ecological Diversity**). Noss (1992, 1996), Szaro and Shapiro (1990), Szaro and Salwasser (1991) and Wilson (1988 a,b), among many others, have included a fourth form of biodiversity called **Landscape Diversity**. Landscape is 'a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout' (Forman and Godron 1986); it is also defined as 'a mosaic of heterogeneous land forms, vegetation types and land uses' (Urban *et al.* 1987). Landscapes therefore have a pattern and this pattern consists of repeated habitat components. For example, a landscape may be interspersed with grasslands, meadows, ponds, streams, shrubby areas and forests. Thus, landscape diversity is **Pattern Diversity** (Scheiner 1992). The inclusion of landscape diversity as a fourth form of diversity was emphasised by Odum (1992) when he listed the following as one of his 20 great ideas in Ecology: 'An expanded approach to biodiversity should include genetic and landscape diversity, not just species diversity'. Ray (1996) is also very much in favour of including landscape diversity as the fourth category, based on his studies on coastal marine regions.

The complexity of the biodiversity concept is reflected in the existence of numerous definitions for this word, of which Jutro (1993) identified at least 14. Two among these 14 definitions are largely used, quoted and even officialised, since they have been approved by several countries based on worldwide negotiations, agreements and strategies. The first most-used definition is sponsored by the United Nations (UN) and was included in the Convention on Biological Diversity (CBD) (UNEP 1992). According to this definition, Biodiversity refers to: 'The variability among living, *inter alia*, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. The second most-used definition of Biodiversity is sponsored by the Global Biodiversity Strategy (WRI, IUCN, and UNEP 1992) and is as follows: 'The totality of genes, species and ecosystems in a region'.

These two definitions, according to di Castri and Younès (1996), pay very little attention to the interactions within, between and among the various levels of biodiversity recognised. According to these authors, interaction is the principal intrinsic mechanism that shapes the characteristics and functions of biodiversity. Another problem they find in the various definitions, is their ignorance of the **notion of scale**; di Castri and Younès argue that structural and functional attributes of biodiversity can only be determined by employing appropriate scales of space and time (see also Lugo 1996). Consequently, according to di Castri and Younès (1996), biodiversity should not be construed as a 'simple umbrella covering a mosaic of heterogeneous activities', but should represent a composite entity 'shaped by the continuum of all its elements and their interactions'. These interactions, according to them, are of a hierarchical nature, and by interlocking the genetic, species and ecosystem diversities one can achieve the 'classical zooming effect of hierarchical theory' (Fig. 1.1). The important outcome of such an approach is that the properties of biodiversity that do not 'occur' at a lower scale of integration (say gene levels) will 'appear' at a higher scale (say species

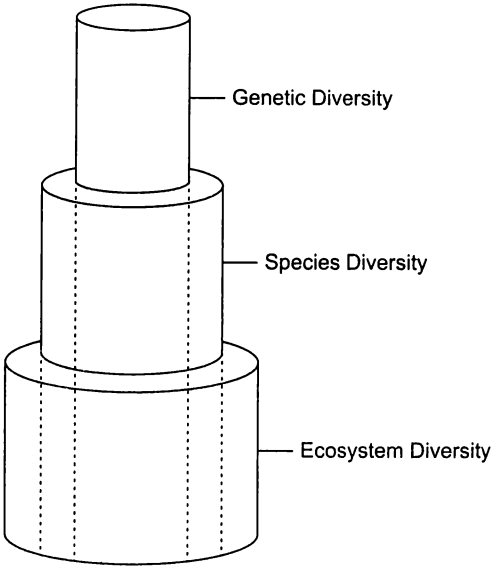
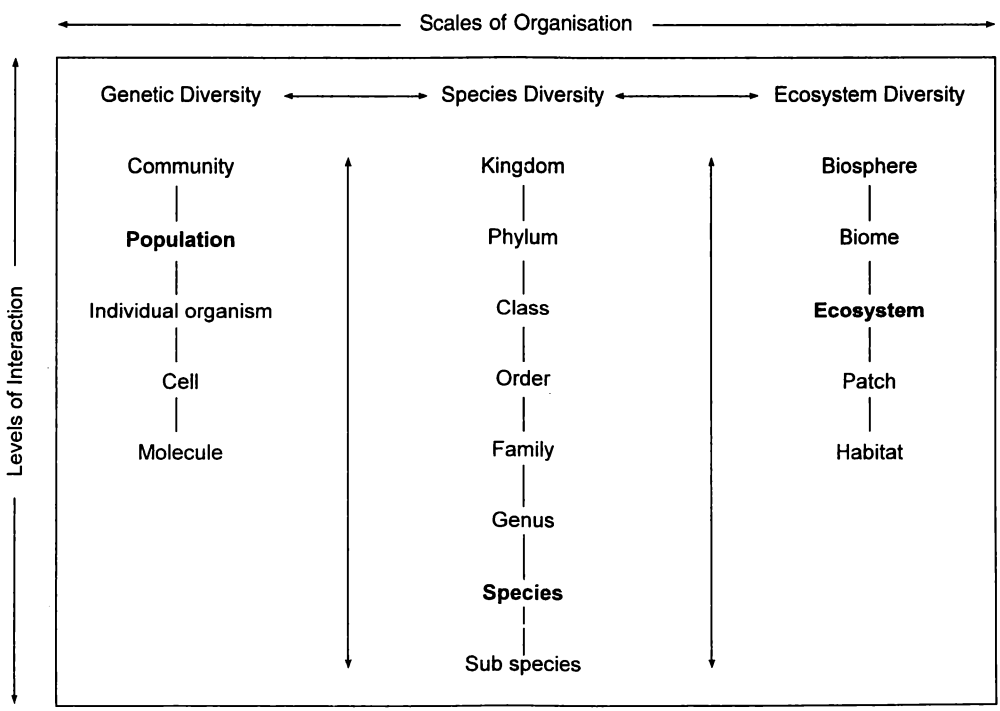


Fig. 1.1 The three hierarchical scales of biodiversity and their interrelationships (adapted from di Castri and Younès 1996)

or ecosystem level). The properties that are 'evident' at a higher scale 'disappear' at a lower scale. The hierarchical concept, so obtained, has been expanded and made more accurate by di Castri and Younès (1996) (Box 1.1); here the hierarchical patterns of biodiversity are shown as the interactions of the three different scales of organisation: Genetic, Species and Ecosystem. Each of these scales has different levels of organisation. For example, the Gene scale has the following levels of organisation/integration: Community, Population, Individual organism, Cell, and Molecule. Based on this, di Castri and Younès (1996) provided the following definition: Biodiversity is 'the ensemble and the hierarchical interactions of the genetic, taxonomic and ecological scales of organisation, at different levels of integration'. Indeed, populations (with their gene pools), species and ecosystems are respectively the cornerstones at

Box 1.1 The Scales of Organisation and Levels of Interaction of Biodiversity (adapted from di Castri and Younès, 1996)



the interaction points (i.e. integration points) of the three scales (Solbrig 1991).

A slightly different composition of the various scales of biodiversity (Genetic, Organismal and Ecological) was suggested by UNEP (1995) (Box 1.2). It is interesting to find Population as a common component/unit at all three scales of biodiversity. However, Heywood (1997a) stated that population is one of the most difficult to assess, whatever may be the scale. In addition, **cultural diversity** and human interactions are noticed at all these levels. Various cultures and societies place different values, exert different driving forces and influences, and practice different measures for conserving and sustaining biodiversity. All these represent Cultural Diversity, which therefore recognises the pivotal role of sociological, ethical, religious and ethnic values in human efforts concerning biodiversity.

Attention of readers has already been drawn to the fact that many biologists are inclined to add Landscape as a fourth level of biodiversity. Consequently, a revised and comprehensive approach to the biodiversity concept, incorporating the multiple levels of organisation and many different spatial and temporal scales, was successfully attempted (Noss 1990, 1994). Noss (1994) suggested that each of these scales (genetic, species, ecosystem and landscape) should be further subdivided into compositional, structural and functional components (see details in Fig. 1.2).

Scope of Biodiversity Science

In a detailed discussion on the perspectives of Biodiversity Science, di Castri and Younès (1996) have listed at least six major reasons for considering Biodiversity as a new science. These six reasons incidentally explain the scope of this branch of science.

(i) Biodiversity is the unifying driving force (*leitmotiv*), all along much needed, to provide a continuum within the broad field of Biology. The readers are quite aware of the fact that Biology is now fragmented into a large number of disciplines. Although originally done to facilitate understanding the various facets of Biology, this fragmentation has diminished, even eradicated the connections among the different disciplines as well as engendered an unhealthy competition among them, leading consequently to underestimation of each other. In most countries, Molecular Biology and Biotechnology have become the most sought-after disciplines of Biology, relegating Morphology and Taxonomy to the lowest level of preference; the latter also hold little or no career incentives. The fact has been obscured that these two groups of disciplines of Biology are equally necessary and that a close co-operation and interaction among the various disciplines are absolutely important for the welfare of human kind. Such interaction and co-operation are also needed to address all the problems of Biodiversity with greater ease and

Box 1.2. Composition and Scales of Biodiversity (adapted from UNEP, 1995)

Genetic diversity	**Organismal diversity**	**Ecological diversity**
Populations		
Individuals	Kingdoms	Biomes
Chromosomes	Phyla	Bioregions
Genes	Orders	Landscape
Nucleotides	Families	**Ecosystems**
	Genera	Habitats
	Species	Nichés
	Subspecies	Populations
	Populations	

Cultural diversity and human interactions at all levels.

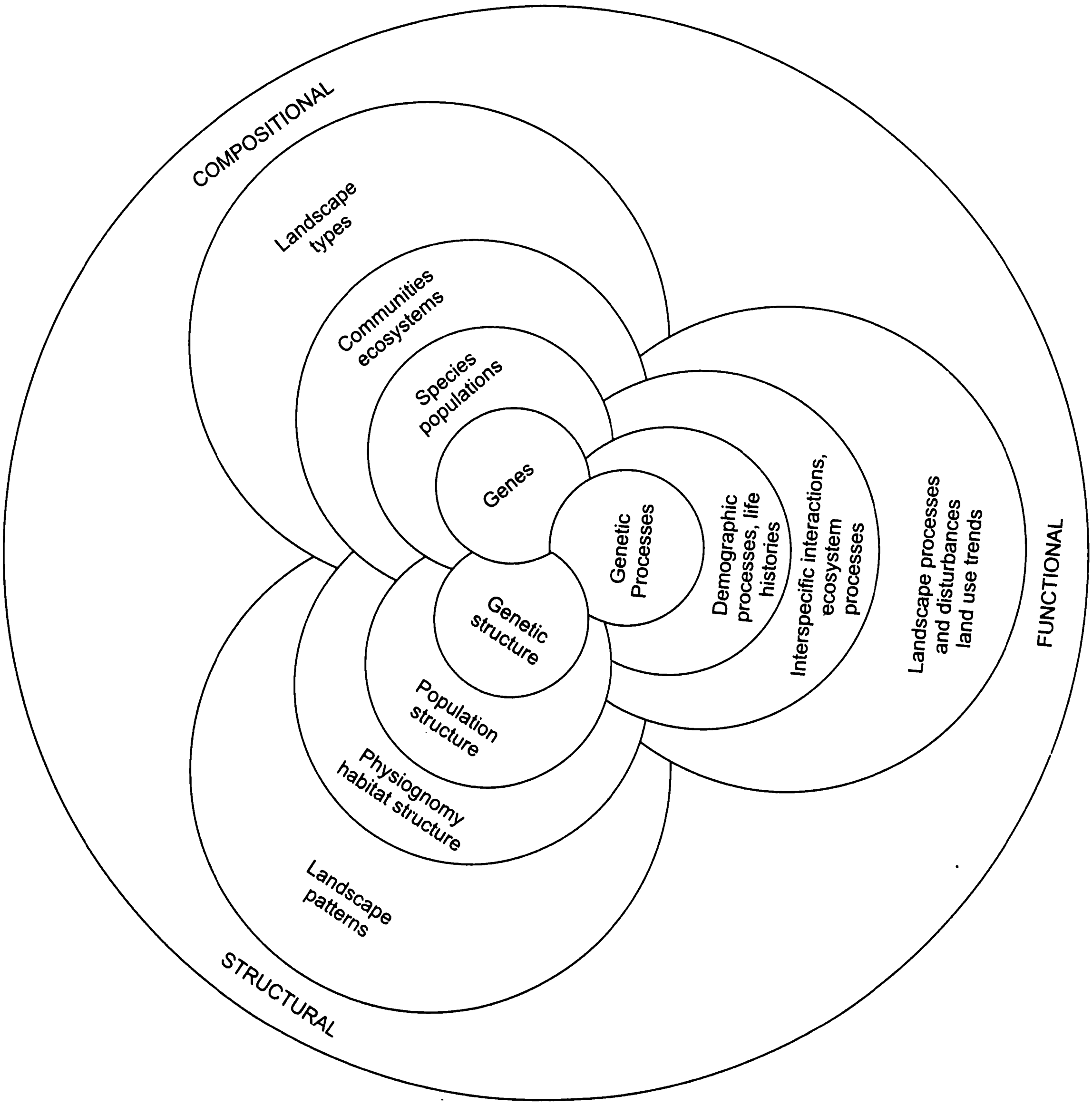


Fig. 1.2 The biodiversity concept incorporating the multiple levels of organisation and many different spatial and temporal scales, as per Noss (1990).

perfection. Thus, the science of Biodiversity has the potential to unify all fragmented disciplines of Biology and bring together the activities of all scientists professing these disciplines. This is, as a matter of fact, one of the important goals of the International Union of Biological Sciences (IUBS).

(ii) Biodiversity is the backbone for Agriculture, Aquaculture, Animal Husbandry, Forestry and a host of other applied branches of

Biology. Hence it stands at the very foundation of development, especially in a rapidly changing world. Population growth has not declined to a desired level. By the year 2005, the UN predicts that today's population of about 7 billion will likely have increased to 8 billion. We are not going to simply expand the load on the land presently available, but actually multiply the load. Evidence suggests that the Green Revolution is likely to peter out. Grain and pulse yields have stopped rising as fast as in earlier years. Supplies of fresh water are growing scarce. Human beings currently appropriate 54% of accessible freshwater run-off, but in the next 25 years, the projected increment in demand is more than 70% (Ayensu *et al* 1999). Soil quality has already started deteriorating the world over. There is very little unplanted arable land left for further agricultural exploitation. Hence, new varieties of useful plants and new breeds of domesticated animals have to be constantly evolved for increased yield/productivity, desired lifetime, disease resistance etc. For example, by 2020, world demand for rice, wheat and maize is projected to increase by ~ 40% and livestock production by more than 60%. Such an effort to increase the quality and quantity of bioresources is possible only if we have adequate information and knowledge about their wild relatives, which form the genetic source for their further improvement through conventional or biotechnological methods. Since biodiversity deals with biological resources, it is particularly important that various ecosystems be critically assessed for their useful plant/animal germplasms, especially for the presence of wild relatives. However, for this to materialise the world should engage itself in a 'gigantic' and 'multibillion dollar scientific effort'.

(iii) It is well known to all readers that intense globalisation of trade and markets has occurred during the last decade, resulting in very rapid and dramatic changes in land-use patterns and regional developmental activities. Consequently, pronounced deforestation (at the rate of some 14 million hectares each year), alarming desertification and substantial global climatic changes have taken place. About 40 to 50% of the land on Earth has been irreversibly transformed through change in land cover or degradation by human beings. Models based on UN's intermediate population projection mentioned in the paragraph above suggest that an additional one-third of global land cover will be transformed over the next one hundred years (Ayensu *et al.* 1999). It has now become highly obligatory for mankind to not only check these alarming changes, but also to reconstruct and restore the changed ecosystems to their original state. Any new change in the existing landscape must be properly planned in order to make it environment-friendly. Such undertakings require a deep understanding of biodiversity in all its aspects.

(iv) The first half of the present century, as in the last half of the previous century, is definitely going to be dominated by Biology. Biodiversity is fast becoming the fundamental requirement on which the new industrial developments and innovations are going to be based. Biodiversity will offer in the coming years, new sources of food, medicine and other human requirements. Therefore, industrial development will become possible only by exploring the great potential of the still unknown biological resources. For this, in-depth knowledge of biodiversity is imperative.

(v) Globalisation of information and communications has markedly increased. Furthermore, a substantial human migration to various parts of the world is anticipated in the next one or two decades. There is also anticipation of substantial movement of plants and animals to different parts of the globe. All these processes will definitely lead to profound changes not only in the existing society and culture, but also in the landscape of different parts of the world. Under these circumstances, the study of biodiversity cannot be treated in isolation from the anticipated human dimension. Thus, biodiversity will become the only purposeful scientific tool with which one can bridge the social and cultural world.

(vi) Biodiversity is the resource on which all human existence depends, i.e., it is the pillar of human development. Consequently, a sustainable exploitation of bioresources should be practised. Sustainable development has been compared to a chair with four legs of similar length and strength (di Castri 1995). These four legs respectively denote the economic, environmental, social and cultural facets of biodiversity. Unless all the four dimensions of biodiversity are equally strong, sustainable development cannot result. Therefore, biodiversity is vital for sustainable development.

To these six reasons why biodiversity should be considered a science of utmost importance, the following may be added:

(vii) Biodiversity has already proved itself to be a fundamental concept for a world just entering the twenty-first century. The range of influence of Biodiversity is much more general and wider than any other field of either Biology or other scientific disciplines. Its numerous manifestations are already found in inconspicuous places, for example in the **technosphere** and in the **noosphere** (the sphere of minds uniting everyone on the planet through different types of communication networks). Biodiversity has come to include not only living species, but also the multitude of human inventions based on bioresources. In summary, Biodiversity has become the basis of a general law of dynamic stabilisation of complex systems, a law fundamental to homeostasis and applicable to the functioning of the planet as a whole (de Rosnay 1996). This is also the essence of the **Gaia Hypothesis** (Lovelock 1988 a,b), which emphasises that the physical structures and processes of this planet are regulated by Biodiversity (Myers 1985 b).

Constraints of Biodiversity Science

To meet and implement the scope and action plans mentioned in the previous section, the science of biodiversity has to remove, overcome or at least address a number of constraints (di Castri and Younès 1996):

(i) The foremost and most difficult constraint to overcome is the current status of Taxonomy. It is well known that Taxonomy is the most essential infrastructure for biodiversity development (Janzen 1993a,b) and that the recognition and characterisation of biodiversity depends critically on Taxonomy as it provides the reference system for depicting the pattern of biodiversity. Only a very limited number of all species believed to exist on this earth are known to us. Many species are yet to be discovered and described (for more details see Chapter 3). Even for the known species, the information available, especially on functional attributes, is extremely meagre. In spite of this, the number of new taxonomists the world over is very small, due primarily to lack of career incentives[1]. Further, the geographic distribution of even these few taxonomists is lop-sided. While it is estimated that in the developed countries there is one taxonomist for every 10 species occurring there, in many developing countries there is only one taxonomist for every 1000 species, even if we include taxonomists of below average competency (Manilal 1997). There is also a maldistribution of taxonomists, due to which 'the amount of taxonomic effort' made so far 'varies widely from group to group' among the Biota of the world (May 2002). This maldistribution 'reflects the vagaries of intellectual fashion, and most certainly does not

[1]Janzen and Gaméz (1997) have, however, cautioned that we should not openly admit to an insufficient number of taxonomists. They feel that such statements might generate the wrong notion that the world will immediately rush to buy more taxonomists, when *de facto* the world will interpret such statements as *prima facie* evidence that taxonomists are not needed. It is a general principle that society stops paying for what it does not need.

reflect the relative importance' of the different groups 'in maintaining the structure and functions of the ecosystems' (May 2002). Good taxonomists have indeed become a highly endangered category among biologists (Khoshoo 1995).

The status of Herbaria and Museums world over is fast deteriorating academically and financially. Their number is also slowly shrinking for want of support. Given these two conditions, it is going to be an uphill or even utopian task to recognise all the species supposedly contained in the world (for more details on this issue see Chapter 3).

(ii) Measuring biodiversity is the second major constraint (Hawksworth 1994), closely related to the first. There is considerable disagreement over how to measure biodiversity (Hurlbert 1971; Norton 1986). The currently practised measures select very different components of the ecosystem for emphasis. Potential indicators include the total number of species or 'richness' (Magurran 1988; Scott *et al.* 1987), abundance and distribution of populations (Krebs 1972; Westman 1990), number of endangered species, centres of species-richness with high endemism (Myers 1988a), and degree of genetic variability (Allen 1963; Ruffie 1982). Other approaches treat ecosystem functions (Ray 1988), interactions (Janzen 1988), natural communities (TNC 1975; Western *et al.* 1989), successional stages (Franklin 1988) or ecological redundancy (Walker 1992) as key measures of diversity.

Genetic diversity is almost fully known only for a few taxa such as *Arabidopsis*, maize and *E coli*. The problems involved in measuring species diversity are alluded to above. Ecosystem diversity is measured to some extent by direct field surveys, remote-sensing techniques or by fractal analysis. But it is really difficult to link these three diversities.

Related to the above is the assessment of biodiversity loss. There are many problems in measuring loss of biodiversity, which is an important requirement in Conservation Biology. There is widespread agreement that global biodiversity is reducing at an accelerated rate (Myers 1980a; Wilson 1988b). But there is less agreement about the actual quantum of such loss (Harwood 1982; Lovejoy 1986), compounded by the wide range of operational measures, variation between biomes, and lack of baseline knowledge about the number of species already available (Freedman 1989). Even when a common measure is employed (i.e., species richness), differences in estimated rates of loss as computed by different people are large. Lugo (1988a,b), for example, compared the several estimates of species loss in the tropics and found they ranged from 15% to 50% for all species by the year 2000.

(iii) A dichotomy exists between biodiversity agenda and priorities of developed and developing countries. It is very difficult to resolve this dichotomy at present, in spite of the Rio Summit and other efforts. Khoshoo (1996) has critically summarised this dichotomy between two sets of countries, commonly referred to as North and South, its reasons and effects, as well as strengths and weaknesses (Table 1.1). Biodiversity is an important biological resource and strength in the developing countries, while the developed countries are technically developed but wanting in biodiversity. As di Castri and Younès (1996) have emphasised, 'a reconciliation of national prerogatives with a global interest, based on principles of overall equity' is immediately needed. Immediacy of achievement is a very tall order, however.

(iv) The lack of adequate knowledge about biodiversity among the people is another important constraint. As already indicated, the concept and definition of biodiversity have largely been misunderstood or poorly understood by many people, including some biologists. It is our primary duty to educate people and clear all myths that pervade the biodiversity concept. It is also important to negate the assumption that biodiversity science

Table 1.1 Comparison of biodiversity and its potential between developing and developed countries (adapted from Khoshoo, 1996)

Developing Countries	*Developed countries*
• Biodiversity rich	• Relatively poor Biodiversity
• Vavilovian Centres of Diversity	• Nil to almost nil
• Backed by indigenous people, local technical knowledge and indigenous systems	• Largely non-existent
• Biodiversity supported by cultural diversity	• Largely non-existent
• Genetics, breeding and biotechnology base poor	• Rich base in Technology
• Largely *in situ* conservation	• Largely *ex situ*, but *in situ* for their own non-agricultural biodiversity
• Conservation indigenous-science-based	• Largely modern science-based
• Largely subsistence or intensive agriculture	• Largely modern science-based
• Sustainable utilisation of biodiversity: not possible without capacity building	• Capacity exists
• Research and development, education and training, and demonstration and extension need enhancement	• Rich base
• Poverty	• Rich base
• Largely bioindustrial development	• Largely industrial development

is 'intrinsically opposite to economy and development' (di Castri and Younès 1996). To attain this task, not only should children be taught about biodiversity at an early age, but also adults sufficiently educated through media and other programmes.