0 50

utredning

Documentation and Measurement of Biodiversity

Ian A. Fleming
Kaare Aagaard

NORWAY/UNEP EXPERT CONFERENCE ON
B·I·O·D·I·V·E·R·S·I·T·Y
TRONDHEIM · NORWAY · 24-28 MAY 1993

NINA

NORSK INSTITUTT FOR NATURFORSKNING

Documentation and Measurement of Biodiversity

Ian A. Fleming
Kaare Aagaard

NORSK INSTITUTT FOR NATURFORSKNING

NINAs publikasjoner

NINA utgir seks ulike fem publikasjoner:

NINA Forskningsrapport
Her publiseres resultater av NINAs eget forskningsarbeid, i den hensikt å spre forskningsresultater fra institusjonen til et større publikum. Forskningsrapporter utgis som et alternativ til internasjonal publisering, der tidsaspekt, materialets art, målgruppe m.m. gjør dette nødvendig.

NINA Utredning
Serien omfatter problemoversikter, kartlegging av kunnskapsnivået innen et emne, litteraturstudier, sammenstilling av andres materiale og annet som ikke primært er et resultat av NINAs egen forskningsaktivitet.

NINA Oppdragsmelding
Dette er det minimum av rapportering som NINA gir til oppdragsgiver etter fullført forsknings- eller utredningsprosjekt. Opplaget er begrenset.

NINA Temahefter
Disse behandler spesielle tema og utarbeides etter behov for å informere om viktige problemstillinger i samfunnet. Målgruppen er "almenheten" eller særskilte grupper, f.eks. landbruket, fylkesmennenes miljøvernavdelinger, turist- og friluftlivskretser o.l. De gis derfor en mer populærfaglig form og med mer bruk av illustrasjoner enn ovennevnte publikasjoner.

NINA Fakta-ark
Hensikten med disse er å gjøre de viktigste resultatene av NINAs faglige virksomhet, og som er publisert andre steder, tilgjengelig for et større publikum (presse, ideelle organisasjoner, naturforvaltningen på ulike nivåer, politikere og interesserte enkeltpersoner).

I tillegg publiserer NINA-ansatte sine forskningsresultater i internasjonale vitenskapelige journaler, gjennom populærfaglige tidsskrifter og aviser.

Tilgjengelighet: Åpen

Prosjekt nr.: 6502

Ansvarlig sign: Kaare Aagaard

Fleming, I.A. & Aagaard, K. Documentation and measurement of biodiversity. - NINA Utredning 50: 1-23.

Trondheim mai 1993

ISSN 0802-3107
ISBN 82-426-0364-2

Forvaltningsområde:
Norsk: Bevaring av genressurser
Engelsk: Conservation of genetic resourses

Rettighetshaver ©:
NINA Norsk institutt for naturforskning

Publikasjonen kan siteres fritt med kildeangivelse

Redaksjon:
Kaare Aagaard, Odd Terje Sandlund
NINA, Trondheim

Design og layout:
Eva M. Schjetne, Kari Sivertsen
Tegnekontoret NINA

Sats: NINA

Trykk: Strindheim Trykkeri AL

Opplag: 400 (NINA omslag)
400 (UNEP omslag)

Trykt på klorfritt papir

Kontaktadresse:
NINA
Tungasletta 2
7005 Trondheim
Tel: 07 58 05 00

Oppdragsgiver:
Direktoratet for Naturforvaltning

Abstract

Fleming, I.A. & Aagaard, K. Documentation and measurement of biodiversity. - NINA Utredning 50: 1-23.

Rapid, and ever accelerating, loss of biological diversity has generated an urgent need for conservation action. The foundation of any such action depends on an understanding of the diversity of organisms and ecosystems that exist and the way they relate to each other and to humans. Biodiversity is the variety of life forms and processes of nature. It provides goods and services that are essential to human welfare, including the most persuasive of arguments for its conservation: fear of ecosystem collapse. Yet, our knowledge of biodiversity is rudimentary, as only 1.4-1.5 million of the estimated 5-50 million species thought to exist have been described. Knowledge of the diversity housed in microorganisms, insects and tropical and marine habitats is particularly poor. Interactions among individuals and species, as well as ecosystem processes, represent another major gap in our understanding of biodiversity.

Documentation of biodiversity must proceed rapidly and inventory programs must be standardized, quantitative and repeatable. A variety of trained personnel, including taxonomists, biologists and physical and social scientists are required.

Diversity can be measured at three fundamental levels in a hierarchy of biological organization: within species/genetic, species and ecosystem levels. Within species diversity is the ultimate source of biodiversity at higher levels. It can be quantified and monitored by documenting genetic diversity as: (1) single-locus variation, (2) quantitative variation, (3) chromosomal polymorphisms, (4) inbreeding, or (5) effective population size. However, demography is likely to be of greater importance to the viability of populations than genetics. Species diversity traditionally has been a focal point for inventory programs. The simplest means of quantifying such diversity is species counts, however, its accuracy depends on sampling intensity. Hence, a series of indices have been developed to estimate both species richness and abundance (e.g., species-area and species-abundance relationships, Shannon and Simpson indices). Ecosystem diversity has cascading influences on diversity at all lower levels in the biological hierarchy. The diversity of landscapes and ecosystem structure can be effectively inventoried and monitored using remote sensing and Geographical Information Systems. Community and ecosystem composition, however, requires extensive ground-level surveys and measurements. Combining knowledge of landscape diversity with that of community-ecosystem assemblages may be our most cost-effective means of monitoring environmental degradation at local and global scales.

Documentation of biodiversity is clearly a daunting task and a species-by-species approach too arduous. From both a practical and theoretical view, we have little choice but to concentrate on identifying diversity at a community-ecosystem level, recognizing the contribution of diversity at other levels. Conservation action must focus on habitats with the intention to maintain the range of ecosystem processes, numbers of species and evolutionary potential of the organisms.

Keywords: Biological diversity - Conservation - Inventory - Ecosystem processes - Biodiversity value - Genetic - Species - Ecosystem - Landscape - Diversity indices.

Ian A. Fleming & Kaare Aagaard, Norwegian Institute for Nature Research, Tungasletta 2, N-7005 Trondheim, Norway.

Referat

Fleming, I.A. & Aagaard, K. Documentation and measurement of biodiversity. - NINA Utredning 50: 1-23.

Et raskt og stadig økende tap av biologisk mangfold har ført til et presserende behov for mottiltak. Ethvert slikt tiltak må være grunnlagt på kunnskap om det mangfold av organismer og økosystemer som eksisterer og hvordan disse enkelthetene avhenger av hverandre, og deres forhold til mennesket. Biologisk mangfold er variasjonen i livsformer og prosesser i naturen. Mangfoldet gir opphav til varer og "tjenester" som er helt avgjørende for menneskets velvære. Dette kan også sies å være det mest overbevisende av alle argumenter for miljøbevaring; frykten for at det økologiske system skal bryte sammen.

Vår kunnskap om biologisk mangfold er imidlertid svært mangelfull. Til nå er bare 1,4 til 1,5 millioner av antatte 5 til 50 millioner arter beskrevet. Kunnskapen om det mangfold som skjuler seg blant mikroorganismer, insekter og i tropiske og marine habitater er særlig dårlig. Samvirke mellom individer og arter, og også prosesser i økosystemene, utgjør et annet hull i vår forståelse av biologisk mangfold.

Dokumentasjon av det biologisk mangfoldet må nå skje raskt. Undersøkelsesprogram bør standardiseres kvantitativt og være mulig å gjenta på samme måte. Det er behov for en lang rekke eksperter både innen taksonomi, økologi og samfunnsvitenskap.

Mangfold kan registres på tre fundamentale nivåer i et hierarki av biologisk organisering; på innen-arts/genetikk-nivået, på artsnivået og på økosystemnivået. Mangfoldet i arveanleggene på det første nivået er kilden til all diversitet på de høyere nivåene. Det kan bli kvantifisert og overvåket ved å dokumentere genetisk mangfold som: (1) enkellokus variasjon, (2) kvantitativ variasjon av arveanlegg, (3) kromosom-polyformi , (4) innavl eller (5) effektiv populasjonsstørrelse. Ofte vil imidlertid bestandsforholdene ha større betydning for bestandens overlevelse enn genetikken.

Artsmangfoldet har vanligvis vært mest i søkelyset ved undersøkelsesprogrammer. Den enkleste måten å tallfeste mangfoldet på er å telle opp antall arter. Dette målet er imidlertid avhengig av innsamlingsintensiteten. For å oppveie dette er det utviklet en rekke indekser som er antatt å måle både artsrikhet og artstetthet. Eksempler på dette er ulike forholdstall mellom arter og områder eller tettheter og Shannon og Simpson indeksene. Innvirkninger på mangfoldet på økosystemnivået vil påvirke mangfoldet på alle lavere nivåer i det biologiske hierarki. Mangfoldet av landskapstyper og strukturer i økosystemet kan bli overvåket effektivt ved fjernmåling og moderne GIS-opplegg. Kunnskap om sammensetningen av samfunn og økosystem forutsetter fremdeles arbeidskrevende feltundersøkelser. Ved å kombinere kunnskap om mangfold på landskapsnivå med kunnskap om økologiske samfunn eller systemer kan en muligens få noen av de mest kostnadseffektive metodene for overvåking av miljøforstyrrelser både på lokalt og globalt nivå.

Å dokumentere det biologiske mangfold er åpenbart en meget omfattende oppgave og en art-for-art tilnærming virker alt for tidkrevende. Både fra et praktisk og teoretisk synspunkt synes vi å måtte velge å kartlegge mangfoldet på økologisk samfunn- eller system-nivå samtidig med at vi erkjenner tilstedeværelsen av det biologisk mangfoldet på alle nivå. Bevaringstiltak må skje på habitatnivå med klare målsetninger om å bevare variasjonen av de økologiske prosesser, arter og utviklingsmulighetene til alt liv.

Emneord: Biologisk mangfold - Bevaring - Dokumentasjon - Gener - Arter - Økosystem - Landskap - Økologiske prosesser - diversitetsindekser.

Ian A. Fleming & Kaare Aagaard, Norsk institutt for naturforskning, Tungasletta 2, 7005 Trondheim..

Preface

This document was commissioned by the Directorate for Nature Management for the "Norway / UNEP Expert Conference on Biodiversity" held 24-28 May 1993 in Trondheim. Its purpose is to address the need for documentation and measurement of biodiversity.

Knowledge of the kind and variety of organisms and ecosystems that exist and the way they relate to each other and to humans will be the foundation of any effective conservation action. We examine the components that constitute biological diversity and address their importance, particularly in terms of the goods and services they provide to humans. The enormous gap in our knowledge of biodiversity is identified, as is the urgent need for its documentation and measurement. Important components that should constitute documentation procedures are outlined and various measurement techniques at three levels in a biological hierarchy reviewed. We conclude by identifying the need for documentation and measurement of biodiversity to proceed quickly and therefore to concentrate on identifying diversity at the ecosystem/habitat level, recognizing the contribution of diversity at other levels of the biological hierarchy.

We thank Peter Johan Schei for valuable discussion during the formulation of this document and Lorraine Fleming, Erik Framstad and Odd Terje Sandlund for their comments on earlier versions of it. Financial support was provided by the Norwegian Directorate for Nature Management.

Ian A. Fleming
Kaare Aagaard

Trondheim, May 1993

Contents

1 Introduction

Increasingly, human activity threatens the diversity of life on the planet, including that of *Homo sapiens*. Rough estimates suggest that we are currently undergoing not only unprecedented, but accelerating rates of species extinction largely due to the destruction of natural habitats (e.g., Lovejoy 1980, Ehrlich & Ehrlich 1981, Wilson 1988, Ehrlich & Wilson 1991). This has given rise to what has become known as the "biodiversity crisis" (McNeely 1992) and the recognition of the urgent need to conserve biodiversity.

Conservation of biodiversity is critically dependent on identifying its important components. Yet, only a small fraction of the estimated 5 to 50 million species thought to exist have been identified and catalogued (Erwin 1982, May 1988, Gaston 1991). Knowledge of the kind and variety of organisms and ecosystems that exist and the way they relate to each other and to humans must be a foundation of any conservation action.

The purpose of this document is to focus on the need for documentation and measurement of biodiversity. Our approach is to address the following questions. What is biodiversity? Is it important and if so, for what? What is our current knowledge of biodiversity and where are the major gaps in this knowledge? How should we go about documenting and measuring biodiversity and where should we focus our efforts?

1.1 What is Biodiversity?

Biodiversity has been viewed simplistically as little more than the variety of species. Yet, it is much more than the sum of its parts and thus must be viewed holistically. Biodiversity not only includes the variety and variability among living organisms, but also their interactions and the ecological processes that impinge upon, and are influenced by them. Such ecological processes, both biotic and abiotic (i.e., physical, chemical and other non-living environmental factors), are crucial to maintaining biological diversity and thus must be recognized in any definition. Biodiversity is essentially a term used to cover all of nature's variety, including its life forms and processes.

We can classify biodiversity at three fundamental levels in a biological hierarchy: (1) within species/genetic, (2) species and (3) ecosystem diversity. Within species/genetic diversity refers to the variety of genetic information contained among individuals within a species. Species diversity is the number and frequency of organisms present. Ecosystem diversity includes the variety of ecological processes (e.g., nutrient cycles), communities and habitats. The levels of this biological hierarchy are interdependent with processes and disturbances flowing across all levels.

It is also helpful to characterize biodiversity by identifying its major components at the three levels of hierarchical organization. Three primary components can be recognized: composition, structure and function (Franklin 1988, Noss 1990). Composition describes the variety of genes and species (i.e. genetic and species diversity). Structure is the physical organization or pattern of a system whether it be genes, species, communities or ecosystems. For example, effective population size is a measure of the structure of genetic diversity, and dispersion and range are measures of species structure. Function involves ecological and evolutionary process that derive from a system. Gene flow, population fluctuations, colonization, disturbance, and nutrient and hydrological cycling are all examples of biodiversity function. The compositional, structural and functional aspects of biodiversity are interdependent and link the hierarchical levels of biodiversity.

1.2 Why is Biodiversity Important?

The importance of biodiversity is beyond question. It provides goods and services that are essential to human welfare, sustaining our life-support systems on the planet. In addition, biodiversity is of fundamental social, ethical, cultural and economic value (**Table 1**) and unlike many other resources, biological resources are renewable if properly managed.

Recently, it has become necessary to identify the values of biodiversity to a country's social and economic development in order to compete for government attention. This process, however, is not without serious problems which must be recognized. Many ecosystem values, especially those of great importance (see below), cannot be translated easily into economic terms. On the other hand, the process does help focus attention on the values of biodiversity and avoid the prevalent tendency to underestimate the beneficial effects of conserving it.

Values of biological resources can be broadly categorized into two groups: direct and indirect values (**Table 1**). Direct values stem from benefits or "goods" that consumers receive directly from biological resources. Such values can easily be observed and measured, and may be used for consumptive or productive purposes (reviewed by McNeely et al. 1990; **Table 2**). When biological resources are consumed directly, without passing through a market, their value rarely appears in the national in-

***Table 1**. Values of Ecosystems. (after McNeely et al. 1990, Lubchenco et al. 1993).*

Direct Values
("goods" provided for consumptive and productive use)

- food
- firewood
- construction materials
- clothing
- medicinal plants
- dyes
- ornamental items
- fibers
- wild genes for domestic plants and animals
- pollinators and pest control organisms for crops

Indirect Values
("services" of ecosystem functions)

Non-consumptive values

- maintenance of ecosystem forces, including evolutionary processes, that influence acquisition of useful genetic traits in economic species
- storing and cycling essential nutrients
- maintenance of water cycles
- cleansing water and air
- regulation of climate (local and global)
- maintenance of gaseous composition of the atmosphere
- soil production and maintenance
- absorbing and detoxifying pollutants
- provision of recreational-aesthetic, sociocultural, scientific, educational, spiritual and historical values

Option value

- keeping options open for the future; aversion of risk
- reservoir of continually evolving genetic material

Existence value

- ethical dimension of knowing that certain species exist

come and is thus often overlooked. Harvested species, however, may make a considerable contribution to the welfare of rural communities. Furthermore, the sustainable use of local ecosystems is likely to be linked intimately with the economic development of such communities. For instance, Myers (1988) concluded that a 50,000 hectare tract of tropical rainforest could, with effective management, produce a renewable crop of wildlife with a potential value of $10 million (US), or slightly more than $200 (US) per hectare. In contrast, the return from commercial logging of the area would be only slightly over $150 (US) per hectare.

***Table 2**. Value of harvested biological production in Norway. (data from Sandlund 1992)*

Activity	Quantity	Direct Value in Norwegian Krone (US $)
Forestry	10.7 mill m^2	3748 mill ($535 mill)
Fishing	1,750,572 tonnes	5068 mill ($724 mill)
Hunting	>7100 tonnes	> 400 mill (> $57 mill)
Agriculture (grains, vegetables & fruit)	> 11,330,000 tonnes	6081 mill ($869 mill)
Farming of Domestic Animals (cattle, sheep, pigs, chickens, fish, etc.)	> 425,659 tonnes	18,510 mill ($2,644 mill)
Total		> 33,807 mill (> $4,529 mill)

Unlike consumptive use, productive use of biological resources, i.e. commercial harvest, has direct impact on national economies. Yet, estimates of productive value of biological resources are based usually on market price and rarely reflect true economic value. When costs and values of exploration, transport, processing and packaging are included, true economic value is much higher.

One aspect of the productive value of biodiversity that is sometimes overlooked is the many species of plants, animals and microorganisms that contain pharmaceutically or biochemically active substances which can be used to cure diseases.

Approximately 40% of the drugs used in western medicine today were originally based on substances from wild plants (Sandlund 1992). Although some of the active substances are now produced synthetically, the basis for all of them is found in the genetic material of specific organisms. The U.S. pharmaceutical industry alone spends about $4.1 billion on research and development annually (Farnsworth 1988).

Direct economic value of biological resources can be substantial. Prescott-Allen & Prescott-Allen (1986) estimated that 4.5% of the gross domestic product of the United States ($87 billion per year in 1976-80) was attributable to the harvest of wild resources. McNeely et al. (1990) point out that the percentage contribution of wild resources and ecosystems to the economies of developing countries is usually far greater, especially when consumptive value is included. Furthermore, from the perspective of economic development, the loss of biodiversity limits future availability of natural products for manufacturing, industry, and growth in general.

The indirect values of biodiversity and healthy ecosystems are critical to human welfare. They provide the most persuasive of utilitarian argument for preservation of biodiversity: the fear of ecosystem collapse. Humans derive enormous benefits from functioning ecosystems (**Table 1**). Yet, it is extremely difficult to evaluate these benefits economically, though attempts have been made (e.g., Oldfield 1984). The environmental "services" that ecosystems provide far outweigh direct values that the individual organisms alone could provide. Moreover, most direct values are intimately dependent on indirect values. Harvested species have coevolved within, and are dependent on, the services of the ecosystem in which they are found. Clearly, the value of biological diversity is much more than the sum of its parts.

2 What is known about Biodiversity?

The number of scientifically described species has increased enormously during the past 240 years, from the 11,000 species described by Linnaeus to 1.4 - 1.5 million today. Yet, there is an estimated a 5 to 30 or even 50 million undescribed species.

Several methods have been used to estimate the number of undescribed species. Erwin (1982) derived an estimate based on the number of beetles found in a single tropical tree species and multiplied this by 50,000, the number of tropical tree species. He concluded that there are about 30 million species of insects alone. This estimate has been recognized as being relatively simplistic and problems with the underlying assumptions have been identified (Stork 1988, May 1988, Thomas 1990). Gaston (1991) argued for a more moderate number of undescribed species after consulting experts on the larger groups of insects. But this approach too, has been criticized for being unscientific and untestable (Erwin 1991). May (1988) used an extrapolation based on a relationship between the number of species and their body size (**figure 1**), and the knowledge that large species had received considerably more attention than small species. The number of species known in each of the larger size groups was used to estimate the number of species in smaller size groups and derive an estimate of 10 to 50 million species. May (1988) noted that

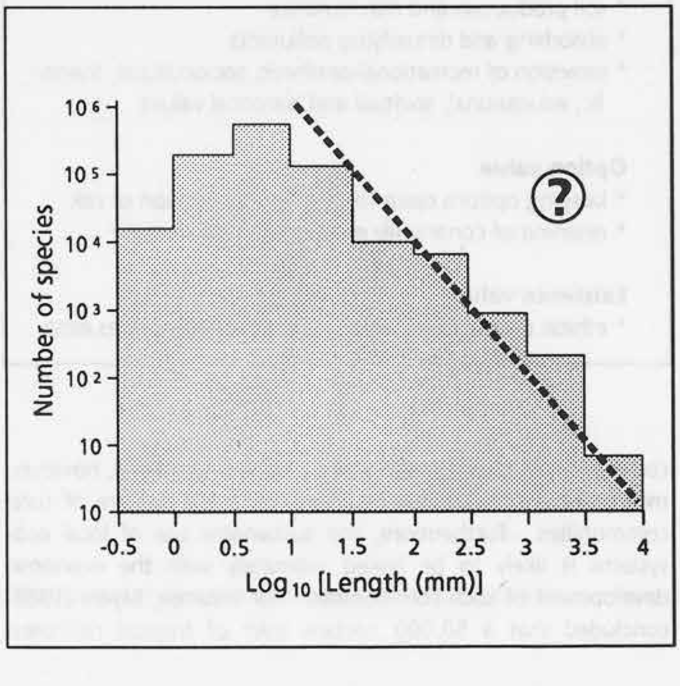

Figure 1
May's (1988) extrapolation of species number from species body size. Estimated distribution of number of species (S) of terrestrial animals categorized according to their body length (L; solid lines). Dashed line depicts extrapolation function, where $S \approx L^{-2}$. *For organisms less than 1 cm in body length, the relationship clearly breaks down. The question mark emphasizes the crudity of estimates and process. (redrawn from May 1988)*

because of our lack of understanding of the species-size relationship itself, the estimates of the number of undescribed species was necessarily crude. One thing that is clear from the preceding discussion is that there is an enormous amount still to be learnt about biodiversity.

2.1 How does Biodiversity breakdown Taxonomically?

The animal kingdom comprises more than 70% of all recorded living species. It contains the most thoroughly investigated group taxonomically, the vertebrates (i.e., mammals, birds, herptiles and fishes), of which there are less than 50 thousand species known (**Table 3**). This number, however, is unlikely to increase dramatically in the future. There is good consensus about how many new species we can expect to find. In the better known vertebrate groups, such as birds and mammals, only a few new species are described each year (on average three species of birds and one genera of mammals [May 1988]).

***Table 3**. Estimated number of described species worldwide.*

	Number of Species
Viruses	1,000[a]
Bacteria and blue-green algae	4,760[a]
Fungi	69,000[b]
Algae	26,900[a]
Bryophytes (mosses and liverworts)	16,600[a]
Gymnosperms (conifers)	750[c]
Angiosperms (flowering plants	250,000[c]
Protozoa	30,800[a]
Sponges	5,000[a]
Corals and Jellyfish	9,000[a]
Flatworms	12,200[a]
Nematodes (roundworms)	12,000[a]
Annelids (earthworms)	12,000[a]
Molluscs	50,000[a]
Starfish	6,100a
Insects	751,000[a]
Other Arthropods	123,161[a]
Fish	19,056[a]
Amphibians	4,184[a]
Reptiles	6,300[a]
Birds	9,040[a]
Mammals	4,170[d]

[a] Wilson 1988, [b] Hawksworth 1991, [c] Raven et al. 1986, [d] Honacki et al. 1982.

In contrast, in the most species rich group of all, the insects, only about 750 thousand species have been described while the number of undescribed species ranges from 30 (Erwin 1982) to 10 million or less (Gaston 1991). Of the species so far described, the four largest insect orders are the beetles (Coleoptera), the true flies (Diptera), the moths and butterflies (Lepidoptera) and the wasps (Hymenoptera). Beetles are the most species rich group known on earth, with about 350 thousand species described. Using the largest beetle families, which together contain over two-thirds of all beetles, Gaston (1991) estimated the actual number of species to be within a factor of 3 to 9 (i.e., between 1 and 3 million species). The number of described species of Diptera is 100-120 thousand and dipterologists suggest that a conservative estimate of the actual number is 150-200 thousand. Butterflies and moths are among the best known insect orders with an estimated 112-165 thousand species described of the estimated 280-500 thousand believed to exist. The Hymenoptera is the most species rich order in cold temperate regions, however, on a global scale it seems to be outnumbered both by Coleoptera and Lepidoptera. The 100-130 thousand described species of Hymenoptera is expected to grow to about 500-600 thousand species if all were described. The remaining 20 or so orders of insects and all other terrestrial invertebrates are relatively species depauperate.

Marine environments contain a large proportion of the earth's diversity, particularly in terms of invertebrates. The total number of marine species has been considered moderate. However, recent estimates suggest that the deep sea, particularly in tropical regions, may contain many more species than investigators had previously believed (Poore & Wilson 1993). Estimates of the number of marine invertebrate species varies from a conservative 0.5 million to 5 or even 10 million (May 1993), however, only a few hundred thousand have been described. While oceans may contain only 20% of all species, these are distributed across 90% or more of the existing phyla, the majority of which are exclusively marine (May 1988). For instance, all 33 living animal phyla are present in the marine environment while only 17 can be found on land and in freshwater (**Table 4**). Because phyla represent a greater range of different life forms and include greater genetic variation than their constituent species, marine systems may be the most diverse on the planet.

***Table 4**. Number of animal phyla found in various in habitats. (data from May 1988)*

	Marine	Habitat Freshwater	Terrestrial
Number of Phyla	33	14	11

How does biodiversity break down among the four remaining organismal kingdoms; plants, fungi, protists and monerans? The number of described vascular plant species is about 270 thousand. This number is expected to rise to about 400 thousand, which is a moderate estimate of the real number of plants. The fungi are much less well known. In Northwestern Europe, which is one of most extensively documented regions, the ratio of vascular plants to fungi is 1:6 (the British Isles) or 1:4 (Finland). Hawksworth (1991) used these ratios to calculate the number of fungi to be as high as 1.6 million, compared to the 69 thousand species currently recorded. The number of protists and monerans (bacterias, etc.) listed at this time is inconsiderable, ranging from a few thousand to ten thousand. The species concept in bacteria is very different, perhaps even incommensurable to that in animals. The most extreme statement is that there is only one species of bacteria with its genes distributed in a particular pattern among different populations and that this pattern is not stable through time (Carlson 1992). The opposite extreme is the assumption that every animal species has at least one specific bacteria species in its gut.

2.2 Biodiversity and Biogeography - rich south and poor north

There is enormous variation in species numbers geographically, particularly along latitudinal gradients. The great increase in species richness at tropical latitudes is well demonstrated by an example from the butterfly fauna. Papilionidae or swallowtail butterflies are a pre-eminently tropical family with the richest areas in the equatorial rain forest zones (**figure 2**). Similarly, patterns of species endemism follow latitudinal gradients. For example, Pearson & Cassola (1992) in a survey of the world distribution of the 2028 known species of tiger beetles (Cicindelidae) noted large numbers of endemic species in tropical and subtropical regions. In contrast, northern regions including Canada, the Scandinavian countries and the former USSR have only 4 endemic species, all of which are found in the former USSR.

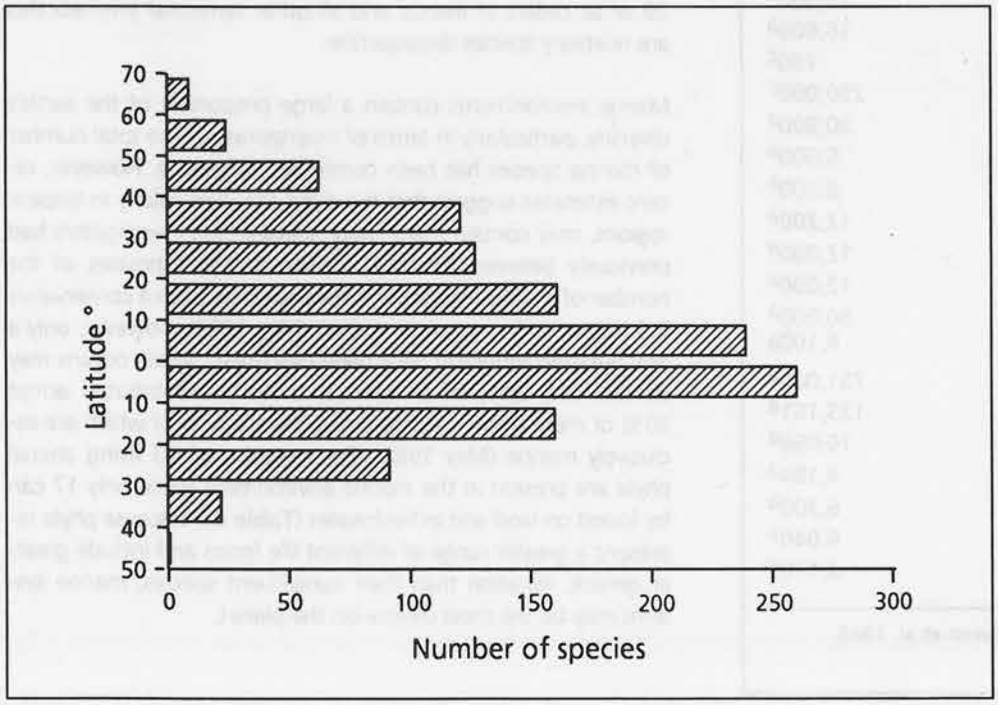

Figure 2
Latitudinal gradient in the species richness of swallowtail and birdwing butterflies (Papilionidae) of the world. (redrawn from Collins & Morris 1985)

2.3 Where are the Major Gaps in our Knowledge?

It is obvious from the preceding discussion that our knowledge of biodiversity is rudimentary. Two main factors may be responsible for this: (1) species, ecosystems and their processes are vast and diverse; and (2) research to describe this diversity has been only a fraction of what is required. This has left us with major gaps in our understanding of nature's diversity.

Our knowledge of tropical and marine habitats is particularly poor. Far less than 5% of the species in the tropics have been described, yet rough estimates suggest that more than 10,000 species are going extinct per year in the tropics (Ehrlich & Ehrlich 1981, Wilson 1988). Furthermore, the greatest threat of species loss is in the tropical forests, which are thought to contain at least half of the world's species on just 7% of the world's land surface (Wilson 1988). As a result, tropical biodiversity has drawn considerable attention. The same, however, cannot be said for the world's marine environments (Grubb & May 1991, Upton 1992). We tend to overlook marine systems because humans are a terrestrial species. Our general perception is that marine environments are vast and limitless with respect to their resources and ability to dilute pollution. Only now are we beginning to recognize the diversity of the oceans and their importance in ecosystem processes. The marine environment contains the majority of phyla on the earth and is thus likely the most diverse biologically. Furthermore, the oceans regularly yield new discoveries including new phyla (Baker et al. 1986) and habitats (Grassle 1985). Oceans also play vital roles in global processes such as climate regulation and CO_2 balance.

Documentation of biodiversity has been highly biased taxonomically. Vertebrates, which comprise less than 2% of the world's species, have received the vast majority of attention. For instance, the 5-30 million insect species have received the same yearly scientific attention, measured by publications, as the 13,500 species of birds and mammals (May 1988). The situation is even worse for microorganisms (i.e., algae, bacteria, fungi, protozoa, viroids and viruses), where it is estimated that less than 5% of the species have been described (Hawksworth & Colwell 1992). Yet, invertebrates and microorganisms are vital to the function and maintenance of ecosystems and the biosphere, being basal components of food chains and playing crucial roles in biogeochemical cycles.

Interactions among individuals and species, as well as ecosystem processes, represent other major gaps in our understanding of biodiversity (Lubchenco et al. 1991). We need to understand how organisms respond to competitors, predators, mates, resources and their physical environment, including environmental stresses. To what extent do patterns of biological diversity determine the behaviour of ecological systems, including their responses to climate change and pollutants? Which species are essential for the continued functioning of a given ecosystem? How do ecological processes interact with physical and chemical factors to control or determine biological diversity?

3 Documentation of Biodiversity

Documentation of biodiversity is a foundation of any conservation action. Programs to document and inventory biological diversity must not only catalogue and map species distributions and associations, but also link these with habitat distributions and with the natural and anthropogenic (i.e., human induced) processes influencing them (Soulé & Kohm 1989; Table 4). Because time and resources (e.g., money and skilled labor) available for conservation are invariably in short supply relative to the work required, there is a need to set priorities. A full inventory of biodiversity is considered impossible. Moreover, the current, rapid rate of loss of biodiversity (Myers 1979, Ehrlich & Ehrlich 1981, Wilson 1988, Ehrlich & Wilson 1991) has meant inventory methods and programs must allow rapid assessment of biological diversity so preservation and management of ecosystems can begin. This means sampling, both systematically and geographically, to represent the taxonomic range of organisms and the extent of ecosystems. It is clear that this is bound to lead to errors that result in loss of some biodiversity, but it is generally agreed that circumstances dictate that this must now be accepted.

To undertake the large-scale inventory programs required, rigorous application of standardized, quantitative and repeatable documentation protocols are necessary (Table 5). Datasets need to be comparable not only between studies at different times to meet the needs of long-term monitoring, but also comparable among sites at regional and global scales to allow an examination of biodiversity patterns. They require documentation of the accuracy and methods used in data collection, identifying the levels of information and technology. Standard methods of presentation should be applied to ease interpretation of the information for users. Information available and its location should be identified. Extensive bibliographic servicing would be helpful to this end.

Ideally, the database should be linked to a network of local, national and international levels that make information accessible. Such a network should use standard transfer formats allowing data exchange. Finally, an information source should be available that summarizes the data in a form useful and accessible to planners and decision-makers. The World Conservation Monitoring Centre (WCMC), a joint venture of the International Union for Conservation and Natural Resources (IUCN), World Wildlife Fund (WWF) and United Nations Environmental Program (UNEP), is an example of such a repository for information on global biodiversity (see McNeely et al. 1990, Pellew 1991).

Planners and decision-makers must also devise a decision framework for establishing priorities for conserving biological diversity. While no single scheme for establishing priorities will satisfy all interest groups because of differing perspectives, values and goals, a decision framework allows for the evaluation of the tradeoffs. McNeely et al. (1990) identified three elements useful in the formation of such a decision framework: (i) distinctiveness, (ii) threat and (iii) utility. **Distinctiveness** would give priority to characteristic and unique elements of biodiversity. The objective being to maintain the variety of the world's biodiversity, such as its life forms and processes. For instance, ecosystems with many endemic species, habitats which are rare and biogeographic units having no or few protected areas should be given priority. **Threat** would consider the danger of loss of a particular element of biodiversity due to anthropogenic causes. Because of considerable variation in the magnitude of human threats to biodiversity, areas at greater risk should receive higher priority. However, as McNeely et al. (1990) point out, there is an important weakness. The imminence of threat is dependent on our knowledge of the system, and thus, the adequacy of this ap-

Table 5. Considerations for documentation and inventory programs.

Catalogue and Map (requires setting priorities and sampling)
* species distributions
* genetic diversity
* species associations
* ecological communities
* habitats
* natural processes
* ecosystems
* anthropogenic disturbances and processes

Inventory procedures
* standardized
* quantitative
* repeatable

Documentation (Databases)
* standard method of presentation
* accuracy and methods of data collection identified
* information available and its sources
* bibliographic servicing
* a network for information exchange
* standard transfer formats

proach declines the less we know about the system. **Utility** is generally an anthropogenic perspective identifying the current or future utility of particular unit of biodiversity. It is, however, easier to justify the conservation of areas containing several threatened species or species likely to be of direct economic importance, or ecosystems that provide direct services to surrounding areas than areas without these qualities. There is, of course, the danger that many important ecosystem values, especially those that do not translate easily into economic terms will be overlooked. Measures of utility must also carefully consider both local and global value.

Finally, documentation of biodiversity requires a variety of trained personnel. Taxonomists and parataxonomists (i.e., workers trained in the technical skills and basic taxonomy needed for collection and preparation of biological samples; *sensu* Janzen 1992) are needed to identify and catalogue species diversity. The Committee on Research Priorities in Tropical Biology (NAS 1980) has recommended that at least a five-fold increase in the number of systematists is needed to begin to deal with the task. Since research will be the foundation on which informed environmental decisions must rely, biologists and physical scientists are needed to understand the ecological, evolutionary and physical processes that shape and determine biodiversity. Social scientists, including economists, human geographers and sociologists should be involved to address anthropogenic influences on patterns of biodiversity (e.g., Meyer & Turner 1992).

4 Measures of Biodiversity

In this section we examine measures of biodiversity at each of the three levels of biological organization: within species/genetic, species and ecosystem. As with most categorizations, there will be overlap among measuring techniques at the various levels of biodiversity.

4.1 Within Species/Genetic Diversity

The importance of within species/genetic diversity is often overlooked. Yet, diversity within species is the ultimate source of biodiversity at higher levels. Genetic and life-history variation, and population structure and dynamics shape the way species respond to their environment. The potential for subsequent evolutionary change is determined, in large part, by the genetic variation. Furthermore, genetic and ecological diversity among populations buffer species against extinction. Thus, such diversity will be a important determinant of how successfully species respond to anthropogenic disturbance.

Anthropocentrically, the ability of species to provide many of the goods and services needed by humans are also intimately linked to within species diversity. Domestic crops and animals, for example, are derived from and modified using genetic diversity from within wild species.

The composition of genetic diversity within species can be quantified and monitored as: (i) single-locus variation, (ii) quantitative variation, (iii) chromosomal polymorphisms, and (iv) inbreeding. We briefly discuss each of these below; Lande & Barrowclough (1987) provide more detailed descriptions.

(I) **Single-locus genetic variation** (i.e., variation at single chromosome location) is most easily measured at the protein level, but may also be examined at other levels including DNA. Electrophoresis is a relatively inexpensive and widely used technique for surveying protein polymorphisms (see Hartl & Clark [1989] for description). The proportion of heterozygotes (i.e., individuals carrying different alleles, or different forms of the gene, at a locus) is the measure of genetic variation derived from such surveys. It can be computed directly from the observed frequencies of actual heterozygotes at each locus or can be estimated from allele frequencies. Estimation of heterozygosity (*h*) at a single locus is derived as follows:

$$h = 2n(1 - \sum_{i} x_i^2)/(2n - 1)$$

where x_i is the frequency of the allele i summed across all alleles segregating at the locus and n is the number of individuals examined. Overall heterozygosity (H) is the sum of heterozygosity across all loci $j = 1$ to L, where L is the total number of loci sampled.

$$H = (1/L) \sum h_j$$

A problem with heterozygosity as a measure of genetic variation is that there is no objective standard to compare calculated values to, as they vary naturally among species (**Table 5**). Furthermore, an estimate of heterozygosity for a representative survey of about 20 enzymes is unlikely to be closely correlated with overall genomic heterozygosity (Chakraborty 1981, Hedrick et al. 1986). When measured over time in a population, however, it provides a good method for monitoring genetic variability.

(ii) **Quantitative variation** is the variation in continuous traits (e.g., body size) that are controlled by several interacting genes. It can be measured and monitored with heritability studies. Heritability measures the portion of the total or phenotypic variability in a trait that is genetically based. Narrow-sense heritability (h^2), the ratio of additive genetic variance to the total phenotypic variance, is the form commonly used to monitor changes in quantitative genetic variation. It can be estimated, for example, as the slope from a parent-offspring regression, where the trait value in offspring is regressed against the mean trait value of the two par-

***Table 6.** Genetic variation at the protein level in animals and plants detected by electrophoresis. (data from Nevo et al. 1984)*

	Number of species examined	Average number of loci/species	Average proportion of loci	
			Polymorphic /population	Heterozygous /individual
Plants				
Flowering Plants (monocotyledons)	5	26.2	0.303	0.062
Flowering Plants (dicotyledons)	39	19.4	0.311	0.059
Conifers	4	20.8	0.914	0.152
Coelenterates	5	17.6	0.567	0.147
Nematodes	4	24.0	0.076	0.014
Molluscs				
Slugs	5	18.2	0.0	0.0
Others	37	22.5	0.624	0.313
Chelicerata	6	20.8	0.311	0.093
Crustacea	116	23.2	0.642	0.091
Insects				
Drosophila	33	26.8	0.419	0.115
Others	116	20.5	0.316	0.077
Echinoderms	15	20.4	0.479	0.109
Fish	168	24.5	0.222	0.050
Amphibians	60	21.1	0.309	0.082
Reptiles	69	22.1	0.240	0.052
Birds	41	22.8	0.233	0.050
Mammals				
Man	1	107	0.470	0.125
Others	164	24.4	0.222	0.050

ents (see Falconer [1981] for further discussion). Calculations require that the individuals used for the regressions be from roughly the same location, otherwise genetic-environmental interactions may artificially inflate h^2 values. For monitoring purposes, quantitative traits with moderate to high heritability should be used. Typically, h^2 for many traits is in the order of 0.35 to 0.65, but for traits closely related to fitness (e.g., viability, clutch size) it is often considerably less (see Falconer 1981). Because the majority of adaptive evolution in eukaryotic organisms is based on quantitative characters, maintenance of genetic variation in these traits is crucial to the long-term adaptation of populations.

(iii) **Chromosomal polymorphisms** or variation in the arrangement of chromosomes provide another means of examining genetic variation within species. Some species are known to contain more than one chromosomal sequence. Karyotypic analyses (i.e., analyses of the structural characteristics of the chromosomes) may be used to look for such polymorphisms. However, chromosomal polymorphisms are not common in all organisms. Furthermore, different types of chromosomal variation require differing interpretations (Lande & Barrowclough 1987) and lack of variability may be unimportant. Karyotypic analysis is thus of limited use for quantifying genetic diversity.

(iv) **Inbreeding** can have deleterious effects on the viability of populations and species. It involves the mating of individuals that are more closely related to each other, than are individuals drawn by chance from the population. Inbreeding depression, the decline of population fitness due to inbreeding, is a nearly universal phenomenon. However, quantifying exact levels of inbreeding in a population is difficult, if not impossible (see Lande & Barrowclough 1987). It requires some knowledge of the pedigree of the individuals of interest, which is difficult to obtain for natural populations. Alternatively, it is possible to monitor inbreeding indirectly by examining indicators of genetic stress, such as variation in morphology (e.g., Leary & Allendorf 1987), but such variation is confounded by phenotypic effects.

In summary, while there are several methods available for quantifying and monitoring the composition of genetic variation (**Table 7**), their use will be constrained. Monitoring quantitative genetic variation will provide the most important information to understand the long-term adaptability of populations, but it is difficult and expensive to undertake. Electrophoretic analysis of single-locus variation is the most cost-effective method, but even so its use will usually be restricted to captive populations, commercially important species (e.g., trees, salmon, moose), or species of scientific interest.

In terms of structure of within species variability, the effective population size is a crucial parameter. It determines the amount of genetic variability that can be maintained in a population. The effective size of a population, N_e, is the number of individuals needed to maintain the genetic properties of the population given its demographic pattern. Franklin (1980) suggested that in general an effective population size of 500 individuals is necessary to maintain the genetic variation found in natural populations. It has become evident, however, that this value may be very species specific, requiring different calculations for each species (Soulé et al. 1986, Lande & Barrowclough 1987, Hedrick & Miller 1992). In a panmictic population (i.e., randomly interbreeding), when generations are discrete and non-overlapping, the calculation of N_e is relatively straightforward. It is a function of the numbers of males and females (i.e., sex ratio), variance in number of progeny individuals within each sex produce, and fluctuations in population size (see Lande & Barrowclough 1987). However, when the

***Table 7**. Methods for quantifying and monitoring genetic variation within species. (after Lande & Barrowclough 1987)*

Form of genetic variation	Index Used	Technique
Single-locus	Overall heterozygosity	Electrophoresis of 30-40 loci
Quantitative	Narrow-sense heritability	Offspring-parent regression or sib analysis
Chromosomal	Heterozygosity	Karyology; G-, C-banding
Inbreeding	Inbreeding depression	Correlation of fitness-related traits with inbreeding coefficients computed from pedigrees

simultaneous operation of several complicating factors are included, such as overlapping generations and subdivided population structure, calculations of N_e become difficult and only provide approximate values. In the short-term, estimates of effective population size will be useful in predicting the impact of management practices on the loss of genetic variability due to the effects of random drift, but may prove inaccurate for long-term use.

Genetic variation is not important if the population becomes extinct. Demography is usually going to be of more immediate importance to the viability of populations (Lande 1988). Anthropogenic fragmentation of natural areas has made it increasingly important to understand the ecological and evolutionary dynamics of small populations to effectively manage and preserve them. Yet, the details of species' ecology and population structure are often overlooked, resulting in conservation plans for some species being developed primarily on population genetic principles.

The primary demographic factors affecting population dynamics include social structure, life history variation caused by environmental fluctuation, dispersal in spatially heterogeneous environments, and local extinction and colonization (reviewed by Lande 1988). For instance, viability and reproduction may decline in populations of many species for nongenetic reasons when population size is low (e.g., reduced group defense and competition, density-dependent mating success). There may be a threshold density or number of individuals below which a population cannot recover. Conservation plans for individual species thus need to not only incorporate population genetics, but more importantly demography to be effective in managing and preserving the species.

4.2 Species Diversity

Diversity at the species level will continue to be a focal point of inventory programs for two basic reasons (Noss 1990). Species, unlike genes and ecosystems, are easily tangible and thus draw considerable attention. Second, current conservation laws often mandate attention to species but not to other levels of organization (e.g., Norwegian Wildlife Act, U.S. Endangered Species Act).

The simplest and most obvious measure of species diversity is the number of species. This is referred to as species richness and involves the counting of species in an area that is well delimited in space and time.

Invariably, however, we have to work with samples rather than a total inventory of species in an area. This creates problems in determining the number of species because counts depend on sampling intensity. Species-area or species-abundance relationships can be used to get around this and derive measures of diversity. In the former case, species density is studied and in the latter case, species richness.

Species-area relationships have been thoroughly investigated by plant and island ecologists. The relationships between the size of an area and the number of species is often given as:

$$S = cA^z$$

where S is the number of species, A the area and c and z constants. The constant c represents the number of species in an unit area, while z measures the slope of the line relating S and A which will vary with the taxonomic groups and regions examined. If the area is occupied by a set of lognormally distributed individuals, z will have a theoretical value of 0.262 (Preston 1962). Typically, species-area curves, relating the number of species to area size, increase rapidly near the origin and then flatten asymptotically towards an upper limit. This flattening reflects a decrease in the number of new species found as the size of the area examined increases. Species-area relationships are most useful for examining the biota of real or "ecological" isles (Kikkawa 1986).

Species-abundance relationships rely on knowledge of the frequency distribution of individuals (N) among species (S) to derive estimates of diversity. Comparing different data sets of number and relative abundance of species, we very soon find a characteristic pattern. In most samples, a few species will be very common, some will be of medium abundance and many species will be rare and represented by only a few individuals. This pattern led to the development of an array of different species abundance models, which were eagerly discussed in the literature twenty years ago. The most common models were named the geometric series, the log series, the log normal and the broken stick model (**figure 3**).

One of the more applied uses of these models was suggested by Gray & Mirza (1979) who demonstrated an aberration from the log-normal curve in samples from polluted areas. If such aberrations could also be detected for faunas in the richer tropical regions, this would provide an opportunity to monitor pollution through species diversity.

The abundance models are also useful in indicating how complete the actual sampling program has been. In very large samples or those large enough to include most of the species in the

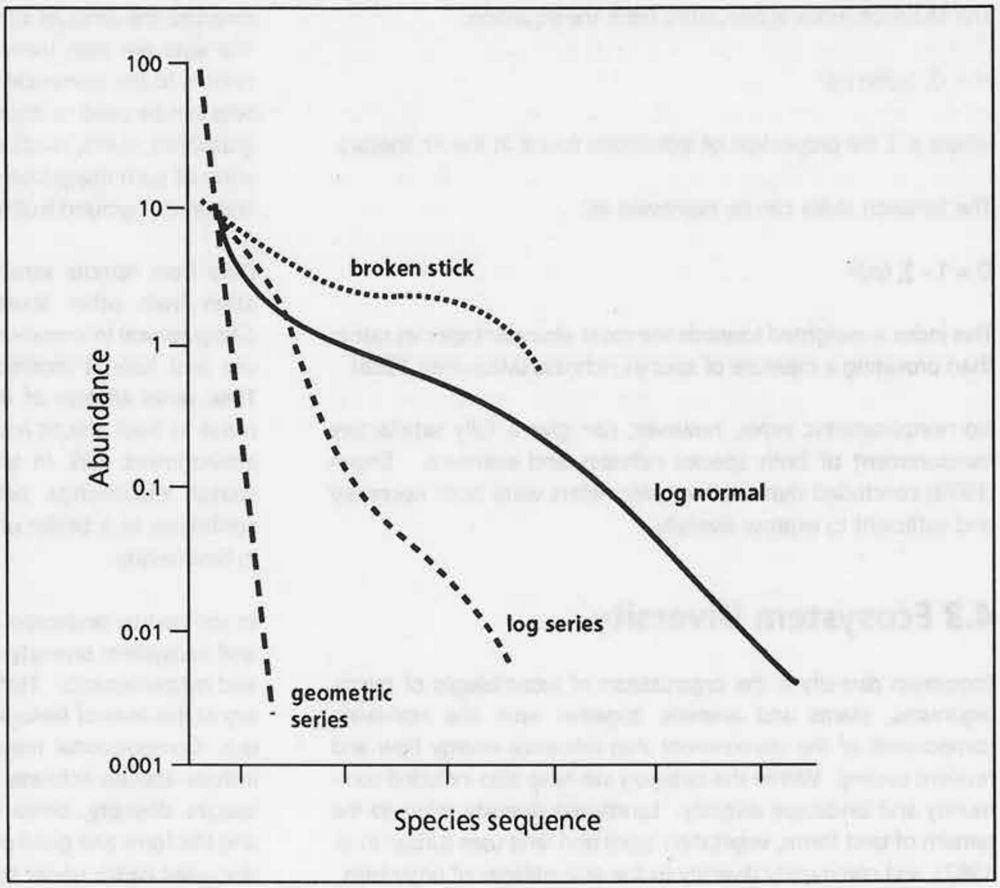

Figure 3
Rank abundance plots illustrating the typical shape of four species abundance models: geometric series, log series, log normal and broken stick. The abundance of each species is plotted on logarithmic scale against the species' rank, in order from the most abundant to least abundant species. (redrawn from Magurran 1988)

area, species abundance will shift from the usual hollow curve to a bell shaped curve (**figure 4**). This is much like the drawing back of a veil to reveal the true underlying pattern. Species abundance will have a lognormal distribution, where species represented by only a single individual are no longer the most frequent.

Simpler measures of diversity are obtained using "non-parametric" indices, which are both distribution and sample size free. These indices take both evenness (i.e., relative abundance of the various species) and species richness into account. The two most recognized indices in this group are the Shannon index and the Simpson index.

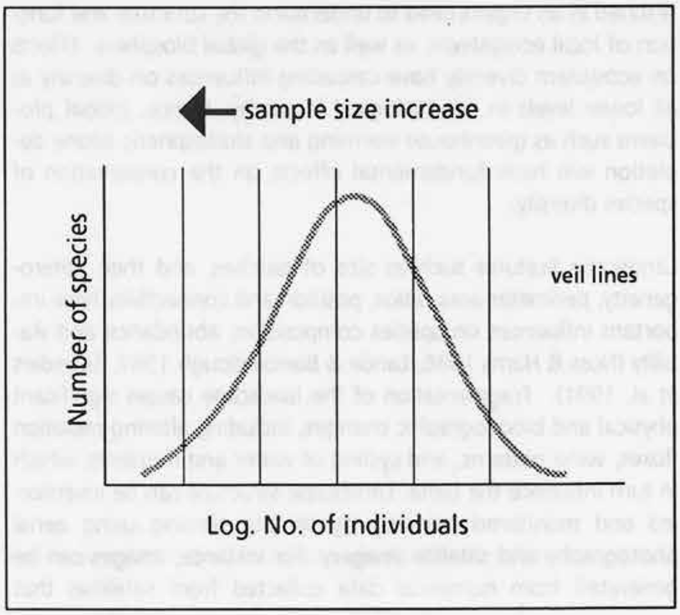

Figure 4
The veil line. In small samples only the portion of the distribution to the right of the mode is apparent. As the sampling intensity increases the veil lines moves to the left, revealing first the mode and eventually the entire log normal distribution. (redrawn from Magurran 1988 after Taylor 1978)

The Shannon index is calculated from the equation:

$H = -\Sigma (p_i)(\ln p_i)$

where p is the proportion of individuals found in the ith species.

The Simpson index can be expressed as:

$D = 1 - \Sigma (p_i)^2$

This index is weighted towards the most abundant species rather than providing a measure of species richness (Magurran 1988).

No nonparametric index, however, can give a fully satisfactory measurement of both species richness and evenness. Engen (1978) concluded that the two parameters were both necessary and sufficient to express diversity.

4.3 Ecosystem Diversity

Ecosystem diversity is the organization of assemblages of micro-organisms, plants and animals, together with the non-living components of the environment that influence energy flow and nutrient cycling. Within this category we have also included community and landscape diversity. Landscape diversity refers to the pattern of land forms, vegetation types and land uses (Urban et al. 1987), and community diversity to the assemblages of organisms.

Rapid human-induced alterations of the earth's environment has resulted in an urgent need to understand the structure and function of local ecosystems, as well as the global biosphere. Effects on ecosystem diversity have cascading influences on diversity at all lower levels in the biological hierarchy. Hence, global problems such as greenhouse warming and stratospheric ozone depletion will have fundamental effects on the conservation of species diversity.

Landscape features such as size of patches, and their heterogeneity, perimeter-area ratios, position and connectivity have important influences on species composition, abundance and viability (Noss & Harris 1986, Lande & Barrowclough 1987, Saunders et al. 1991). Fragmentation of the landscape causes significant physical and biogeographic changes, including altering radiation fluxes, wind patterns, and cycling of water and nutrients, which in turn influence the biota. Landscape structure can be inventoried and monitored primarily by remote sensing using aerial photography and satellite imagery. For instance, images can be generated from numerical data collected from satellites that measure the amount of reflected energy from land-cover types. The data are then translated into an image by assigning visible colours to the numerical values. Images generated from this process can be used to distinguish habitats, such as tundra, forests, grasslands, rivers, roads and cities. It is important that interpretation of such images be verified by on-the-ground observations, known as "ground truthing."

Data from remote sensing can also be combined with information from other sources, organized and displayed with a Geographical Information System (GIS) to allow analysis of land-use and habitat modification (see **figure 5** for an example). Time series analysis of this data is a powerful monitoring technique to track abiotic and biotic changes and disturbances in the environment. GIS, in some cases, may also allow analysis of spatial relationships between different landscapes and thus contribute to a better understanding of causes behind changes in biodiversity.

In contrast to landscape diversity, an examination of community and ecosystem diversity requires extensive ground-level surveys and measurements. Techniques to inventory and monitor diversity at this level of biological organization are diverse and numerous. Compositional measures of communities and ecosystems include species richness, species redundancy, species evenness, species diversity, similarity indices, dominance-diversity curves and life-form and guild proportions. Many of these indices were discussed earlier under species diversity and details of their calculation can be found in standard ecology texts (e.g., Krebs 1985, Begon et al. 1990, Ricklefs 1990, Smith 1990). Structural components of communities and ecosystems consist primarily of habitat variables such as: foliage density and layering; canopy openness and gap proportions; water and resource availability; and the abundance, density and distribution of important physical features and structural elements (Noss 1990). Here, various remote sensing techniques may help improve sampling efficiency. Functional indicators include: biomass and resource productivity; herbivory, parasitism, and predation rates; patch dynamics; and disturbance and nutrient cycling rates (Noss 1990).

Combining investigations of landscape patterns with community-ecosystem structure and function will be particularly profitable. Landscape variables when combined with knowledge of species assemblages and processes can be used to provide inventories of community and ecosystem diversity. Scott et al. (1990), for example, used such a process to develop a method of identifying centres of species richness and endemism to locate gaps in the distribution of protected areas.

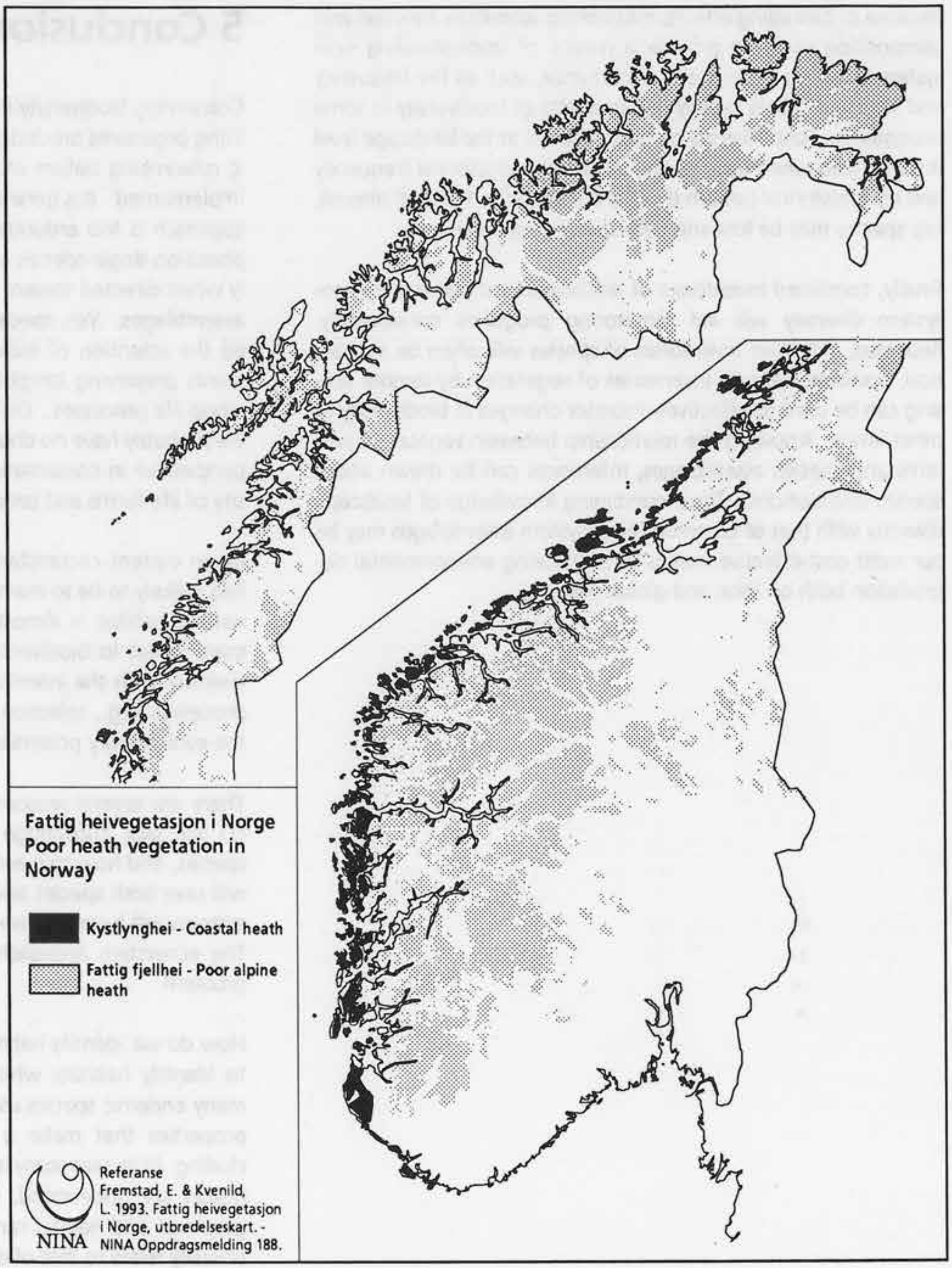

Figure 5

An example of a map constructed by means of a GIS system (ARC/info) illustrating the distribution of poor heath vegetation in Norway. The map was derived by combining information on vegetation and bedrock geology. (redrawn from Fremstad & Kvenild 1993)

Because of cascading effects, monitoring landscape function and composition can also provide a means of understanding ecosystem structure. Landscape disturbance, such as fire frequency and seasonality may be key determinants of biodiversity in some ecosystems. Total diversity of native species at the landscape level is maximized when disturbance occurs at its historical frequency and in its historical pattern (Hobbs & Huenneke 1992). If altered, key species may be lost and new spaces may invade.

Finally, combined inventories of landscape and community-ecosystem diversity will aid monitoring programs considerably. Repeated, extensive inventories of species will often be impractical, however, periodic inventories of vegetation by remote sensing can be used to effectively monitor changes in biodiversity at other levels. Knowing the relationship between vegetation patterns and species assemblages, inferences can be drawn about species distributions. Thus, combining knowledge of landscape diversity with that of community-ecosystem assemblages may be our most cost-effective means of monitoring environmental degradation both on local and global scales.

5 Conclusions

Conserving biodiversity is a daunting task. The sheer number of living organisms precludes complete enumeration and geographic referencing before crucial conservation decisions have to be implemented. It is generally recognized that a species-by-species approach is too arduous. It must also be recognized that emphasis on single-species conservation can be dangerous, especially when directed toward the rarest organisms instead of species assemblages. Yet, species richness and endemism have attracted the attention of biologists likely due, in part, to a bias towards preserving tangible life forms rather than poorly understood life processes. On both practical and theoretical grounds, we probably have no choice but to use an ecosystem-community perspective in conservation, which incorporates both the diversity of life forms and processes.

Given current circumstances, the best way to minimize species loss is likely to be to maintain the integrity of ecosystems. Loss of natural habitat is almost universally acknowledged as the primary threat to biodiversity. There is need to focus on habitat diversity with the intention to maintain the range of ecosystem processes (e.g., selection pressures), the number of species and the evolutionary potential of the organisms.

There are several reasons for focusing on habitat conservation. (1) We lack knowledge about ecosystems and the needs of species, and how to meet these needs. (2) Ecosystem protection will save both species and ecosystems. (3) Conservation of ecosystems will have positive effects on the species within them. (4) The ecosystem approach focuses attention on the long-range problem.

How do we identify habitats for conservation? One approach is to identify habitats which are taxonomically rich and contain many endemic species using indicator species. There are several properties that make a species group a useful indicator including: (i) its taxonomy is well established; (2) its biology and life history are understood; (3) it is distributed over a broad geographical and habitat range; (4) its patterns of distribution and diversity relate to that of other taxa; (5) it is easy and cost-effective to inventory in the field; and (6) the species within the taxon are relatively specialized within different habitats and thus sensitive to habitat degradation and ecological stress (Noss 1990, Pearson & Cassola 1992). Vascular plants, large butterflies, tiger beetles, dung beetles and birds have all been suggested as potential indicator taxa (e.g., di Castri et al. 1992, Ehrlich 1992, Pearson & Cassola 1992).

Vane-Wright et al. (1991) have suggested that the taxonomic distinctiveness of species be given consideration when choosing areas to conserve. Taxonomically distinctive species should be given added weight during decisions to ensure that maximum biodiversity is included. The use of indicator or taxonomically distinctive species, however, may provide little insight into the diversity and response of higher levels of biological organization (reviewed by Landres et al. 1988). Using these approaches alone to identify habitats for conservation ignores the functional aspects of diversity.

Thus,there is need to incorporate functional diversity in conservation plans to preserve ecosystems. Attention must be given to the aspects of biodiversity that are critical for maintaining ecosystem function and resilience (i.e., capacity of the ecosystem to maintain its characteristic patterns and rates of processes in response to variability inherent in its climatic regime). Walker (1992) has suggested a functional group approach focusing attention on species and species assemblages of major concern in managing or identifying appropriate boundaries, a particular area or region to minimize the loss of biodiversity and ecosystem processes. Consideration must also be given to the biological consequences of ecosystem fragmentation when choosing habitats for conservation. How will the size, shape and isolation of the ecosystem fragments effect their continued functioning? Furthermore, since most impacts on remnant areas will come from the surrounding landscape it is necessary to look beyond the reserve boundaries and incorporate an integrated landscape management plan. Preserving biodiversity will also require explicit consideration of the disturbance processes that shape it. Identifying the structural and functional aspects of biodiversity will be key to successfully conserving it.

The rapid and ever increasing loss of biodiversity has forced our hand. Documentation and measurement of biodiversity must proceed quickly and thus focus on the need to conserve particular habitats, recognizing their contribution to biodiversity at multiple levels of biological organization.

6 Literature cited

Baker, H.G., Rowe, F.W.E. & Clark, H.E.S. 1986. A new class of Echinodermata from New Zealand. - Nature 321:862-864.

Begon, M., Harper, J.L. & Townsend, C.R. 1990. Ecology: individuals, populations and communities. - Blackwell, Cambridge, MA, USA.

Carlson, K. 1992. Det finns bare en bakterie. - Forskning och Framsteg 92(2):42-49.

Chakraborty, R. 1981. The distribution of the number of heterozygous loci in an individual in natural populations. - Genetics 98:461-466.

Collins, N.M. & Morris, M.G. 1985. Threatened swallowtail butterflies of the world: the IUCN red data book. -International Union for Conservation of Nature and Natural Resources, Cambridge and Gland, Switzerland.

di Castri, F., Robertson Vernhes, J. & Younès, T. 1992. Inventorying and monitoring biodiversity. - Biol. Internat. 27:1-28.

Ehrlich, P.R. 1992. Population biology of checkerspot butterflies and the preservation of global biodiversity. - Oikos 63: 6-12.

Ehrlich, P.R. & Ehrlich, A.H. 1981. Extinction, the causes of the disappearance of species. - Random House, New York, NY, USA.

Ehrlich, P.R. & Wilson, E.O. 1991. Biodiversity studies: science and policy. - Science 253:758-762.

Engen, S. 1978. Stochastic abundance models with emphasis on biological communities and species diversity. - Chapman and Hall, London, UK.

Erwin, T.L. 1982. Tropical forests: their richness in Coleoptera and other arthropod species. - Coleopterists' Bull. 36:74-75.

Erwin, T.L. 1991. How many species are there?: revisited. - Conserv. Biol. 5:330-333.

Falconer, D.S. 1981. Introduction to quantitative genetics. - Longman, London, UK.

Farnsworth, N.R. 1988. Screening plants for new medicines. - In E.O. Wilson and F.M. Peter, eds. Biodiversity. National Academy Press, Washington, D.C., USA. pp. 83-97.

Franklin, I.R. 1980. Evolutionary change in small populations. - In M.E. Soulé & B.A. Wilcox, eds. Conservation biology: an evolutionary-ecological perspective. Sinauer, Sunderland, MA, USA. pp. 135-150.

Franklin, J.F. 1988. Structural and functional diversity in temperate forests. - In E.O. Wilson and F.M. Peter, eds. Biodiversity. National Academy Press, Washington, D.C., USA. pp. 166-175.

Fremstad, E. & Kvenild, L. 1993. Fattig heivegetasjon i Norge: utbredelseskart. - NINA Oppdragsmelding 188:1-17.

Gaston, K.J. 1991. The magnitude of global insect species richness. Conserv. Biol. 5:283-296.

Grassle, J.F. 1985. Hydrothermal vent animals: distribution and biology. - Science 229:713-717.

Gray, J.S. & Mirza, F.B. 1979. A possible method for the detection of pollution.induced disturbance on marine benthic communities. - Marine Pollution 10:142-146.

Grubb, P.J. & May, R.M. 1991. Comments on the sustainable biosphere initiative. - Conserv. Biol. 5:548-549.

Hartl, D.L. & Clark, A.G. 1989. Principles of population genetics. - Sinauer, Sunderland, MA, USA.

Hawksworth, D.L. 1991. The fungal dimension of biodiversity: magnitude, significance, and conservation. - Mycol.Res. 95:641-655

Hawksworth, D.L. & Colwell, R.R. 1992. Biodiversity amongst microorganisms and its relevance. - Biol. Internat. 24:11-15.

Hedrick, P.W., Brussard, P.F., Allendorf, F.W., Beardmore, J.A. & Orzack, S. 1986. Protein variation, fitness and captive propagation. Zoo Biol. 5:91-99.

Hedrick, P.W. & Miller, P. 1992. Conservation genetics: theory and management of captive populations. - In O.T. Sandlund, K. Hindar & A.H.D. Brown, eds. Conservation of biodiversity for sustainable development. Scandinavian University Press, Oslo, Norway. pp. 70-87.

Hobbs, R.J. & Huenneke, L.F. 1992. Disturbance, diversity, and invasion: implications for conservation. - Conserv. Biol. 6:324-337.

Honacki, J.H., Kinman, K.E. & Koeppi, J.W. (eds.) 1982. Mammal species of the world: a taxonomic and geographic reference, Allan Press and The Association of Systematics Collections, Lawrence, KS, USA.

Janzen, D.H. 1992. A south-north perspective on science in the management, use, and economic development of biodiversity. - In O.T. Sandlund, K. Hindar & A.H.D. Brown, eds. Conservation of biodiversity for sustainable development. Scandinavian University Press, Oslo, Norway. pp. 27-52.

Kikkawa, J. 1986. Complexity,diversity and stability. In Kikkawa, J. & Anderson, D.J., eds. Community ecology:pattern and process. - Blackwell, Carlton, Australia. pp. 41-62.

Krebs, C.J. 1985. Ecology: The experimental analysis of distribution and abundance. - Harper & Row, New York, NY, USA.

Lande, R. 1988. Genetics and demography in biological conservation. - Science 241:1455-1460.

Lande, R. & Barrowclough, G.F. 1987. Effective population size, genetic variation, and their use in population management. - In M.E. Soulé, ed. Viable populations for conservation. Cambridge University Press, Cambridge, UK. pp. 87-123.

Landres, P.B., Verner, J. & Thomas, J.W. 1988. Ecological uses of vertebrate indicator species: a critique. - Conserv. Biol. 2:316-328.

Leary, R.F. & Allendorf, F.W. 1989. Fluctuating asymmetry as an indicator of stress: implications for conservation biology. Trends Ecol. Evol. 4:214-217.

Lovejoy, T.E. 1980. A projection of species extinctions. - In G.O. Barney, ed. The global 2000 report to the President. Council on Environmental Quality, U.S. Government Printing Office, Washington, D.C., USA. pp. 328-331.

Lubchenco, J., Olson, A.M., Brubaker, L.B., Carpenter, S.R., Holland, M.M., Hubbell, S.P., Levin, S.A., MacMahon, J.A., Matson, P.A., Melillo, J.M., Mooney, H.A., Peterson, C.H., Pulliam, H.R., Real, L.A., Regal, P.J. & Risser, P.G. 1991. The sustainable biosphere initiative: an ecological research agenda. - Ecology 72:371-412.

Lubchenco, J., Risser, P.G., Janetos, A.C., Gosz, J.R., Gold, B.D. & Holland, M.M. 1993. Priorities for an environmental science agenda in the Clinton-Gore administration: recommendations for transition planning. - Bull. Ecol. Soc. Am. 74:4-8.

Magurran, A. 1988. Ecological diversity and its measurements - Croom Helm, London 179 pp.

May, R.M. 1988. How many species are there on earth? - Science 241:1441-1449.

May, R.M. 1993. Marine species richness: May replies. - Nature 361:598.

McNeely, J.A. 1992. The sinking ark: pollution and the worldwide loss of biodiversity. - Biodiv. Conserv. 1:2-18.

McNeely, J.A., Miller, K.R., Reid, W.V., Mittermeier, R.A. & Werner, T.B. 1990. Conserving the world's biological diversity. - IUCN, World Resources Institute, World Bank, WWF-US and Conservation International, Washington, D.C., USA.

Meyer, W.B. & Turner, B.L. 1992. Human population growth and global land-use/cover change. - Ann. Rev. Ecol. Syst. 23:39-61.

Myers, N. 1979. The sinking ark: a new look at the problem of disappearing species. - Pergamon Press, Oxford, UK.

Myers, N. 1988. Tropical forests: much more than stocks of wood. - J. Trop. Ecol. 4:209-221.

NAS (National Academy of Sciences). 1980. Research priorities in tropical biology. - Committee on Research Priorities in Tropical Biology, National Academy of Sciences, Washington, D.C., USA.

Nevo, E., Beiles, A. & Ben-Schlomo, R. 1984. The evolutionary significance of genetic diversity: ecological, demographic and life history correlates. - In G.S. Mani, ed. Evolutionary dynamics of genetic diversity. Springer, Berlin, GR.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. - Conserv. Biol. 4:355-364.

Noss, R.F. & Harris, D. 1986. Nodes, networks, and MUMs: preserving diversity at all scales. - Env. Manag. 10:299-309.

Oldfield, M. 1984. The value of conserving genetic resources. - U.S. Department of Interior, National Park Service, Washington, D.C., USA.

Pearson, D.L. & Cassola, F. 1992. World-wide species richness patterns of tiger beetles (Coleoptera: Cicindelidae): indicator taxon for biodiversity and conservation studies. - Conserv. Biol. 6:376-391.

Pellew, R.A. 1991. Data management for conservation. - In I.F. Spellerberg, F.B. Goldsmith & M.G. Morris, eds. The scientific management of temperate communities for conservation. The 31st symposium of the British Ecological Society. Blackwell, Oxford, UK. pp. 505-521.

Poore, G.C.B. & Wilson, G.D.F. 1993. Marine species richness. Nature 361:597-598.

Prescott-Allen, C. & Prescott-Allen, R. 1986. The first resource: wild species in the North American economy. -Yale University Press, New Haven, CT, USA.

Preston, F.W. 1962. The canonical distribution of commonness and rarity. Ecology 43:185-215; 410-432.

Raven, P.H., Evert, R.F. & Eichhorn, S.E. 1986. Biology of plants. - Worth, New York, NY, USA.

Ricklefs, R.E. 1990. Ecology. - Freeman, New York, NY, USA.

Sandlund, O.T. (ed.) 1992. Biological diversity in Norway. DN-rapport 1992-5b, Directorate for Nature Management, Trondheim, Norway.

Saunders, D.A., Hobbs, R.J. & Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: a review. - Conserv. Biol. 5:18-32.

Scott, J.M., Csuti, B., Smith, K., Estes, J.E. & Caicco, S. 1990. Gap analysis of species richness and vegetation cover: an integrated conservation strategy for the preservation of biological diversity. - In K. Kohm, ed. Balancing on the brink: a retrospective on the Endangered Species Act. Island Press, Washington, D.C., USA.

Smith, R.L. 1990. Ecology and field biology. - Harper & Row, New York, NY, USA.

Soulé, M.E., Gilpin, M., Conway, N. & Foose, T. 1986. The Millenium ark: how long a voyage, how many staterooms, how many passengers? - Zoo Biol. 5:101-114.

Soulé, M.E. & Kohm, K.A. (eds.) 1989. Research priorities for conservation biology. - Island Press, Washington, D.C., USA.

Stork, N.E. 1988. Insect diversity: facts, fiction and speculation. - Biol. J. Linn. Soc. 35:321-337.

Taylor, L.R. 1978. Bates, Williams, Hutchinson - a variety of diversities. - In L.A. Mound & N. Warloff, ed. Diversity of insect faunas. The 9th symposium of the Royal Entomological Society. Blackwell, Oxford, UK. pp. 1-18.

Thomas, C.D. 1990. Fewer species. - Nature 347:237.

Urban, D.L., O'Neill, R.V. & Shugart, H.H. 1987. Landscape ecology. - BioScience 37:119-127.

Upton, H.F. 1992. Biodiversity and conservation of the marine environment. - Fisheries 17:20-25.

Vane-Wright, R.I., Humphreys, C.J. & Williams, P.H. 1991. What to protect—systematics and the agony of choice. - Biol. Conserv. 55:235-254.

Walker, B.H. 1992. Biodiversity and ecological redundancy. - Conserv. Biol. 6:18-23.

Wilson, E.O. 1988. The current state of biological diversity. -In E.O. Wilson and F.M. Peter, eds. Biodiversity. National Academy Press, Washington, D.C., USA. pp. 3-18.

0 50

nina
utredning

ISSN 0802-3107
ISBN 82-426-0364-2

Norsk institutt for
naturforskning
Tungasletta 2
7005 Trondheim
Tel. 07 58 05 00