CHARACTERIZATION OF BIODIVERSITY

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Keywords: systematics, taxonomy, codes, binomial nomenclature, species concepts, modern synthesis, diversity.

Contents

Summary

Biodiversity is characterized by classification and naming of its elements: genes, species and ecosystems. The present essay outlines the different ways to characterize biodiversity, from cultural expressions to most recent scientific endeavours such as genetic sequencing of genomes. The underlying philosophical foundations for our perception of biodiversity are often hidden, but nevertheless determine cultural and scientific attitudes, changing and conflicting until today, and reflecting the complexity of life. Classifying and naming organisms is probably as old as human language. Linnean binomial nomenclature laid the foundations of taxonomy, i.e. naming species scientifically, and evolved into Codes defining rules for scientific naming of animals, plants, bacteria and viruses. Additional frameworks and databases were established to deal with genetic variability, as observed in cultivars, animal races, genetic sequences and transgenic organisms. Only 1.75 million extant species have hitherto been named scientifically, which is at most one third of the estimated number, ranging between 5 and 80 million. Classification of biodiversity is hierarchical. Modern systematics tries to reflect the "natural" system, based on the relation and genealogy of species as "products" of evolution, based on Darwin´s theory and its extensions through the "modern synthesis". This natural system links species through genealogy, and can be visualised as a "tree of life". The exact relation between its branches is still a matter of research and discussion. Classical systematics was mainly based on morphology, while recent investigations use molecular methods, mainly analysing and comparing DNA sequences. Finally, there are different definitions of what exactly is a species. These different "species concepts" lead to distinct systematic views and taxonomies, often

complicating nomenclature, management and conservation of species by practitioners. However, these discussions stimulate research, and generally deepened our understanding about species, their origin, and their possible future.
From an ecological and functional perspective, biodiversity is often characterized at higher levels, or from a functional perspective. Species richness and diversity is measured by indices relating species numbers and their relative abundance, within and between areas, and across biogeographic realms. Biogeography and phytosociology offer a wide spectrum of methodologies, theories and classification schemes, often summarising species according to life form or ecological function (guilds).

1. Foundations of classification: from early representations to modern taxonomy

Biodiversity comprises variability between individuals of a species, among species, and among ecosystems. Therefore, biodiversity research depends mainly on three scientific disciplines: genetics, taxonomy and systematics, and ecology. All these disciplines are much older than the term biodiversity, but fundamental for the characterization of biodiversity. The present chapter cannot substitute the respective textbooks, but instead summarizes basic concepts and definitions, together with their historical and philosophical foundations.

Characterization of biodiversity is not only a scientific exercise, but a fundamental trait of humans, deeply rooted within all cultures. It might be motivated by ecological or economic dependence, religious or aesthetic empathy (Wilson 1984), or, to put it more simply, curiosity, fascination or pastime. Philosophical foundations of our perception of, and attitude towards, biodiversity are often hidden, but nevertheless determine cultural and scientific traditions. These are changing and conflicting, reflecting the complexity of life—the buzzword "biodiversity" itself being among the best examples!

Among the earliest cultural artifacts are astoundingly accurate representations of wildlife in caves (Figures 1 to 3). Though their ritual function is unclear, they are without doubt highly reliable, "proto-scientific" representations of local fauna, much more so than medieval "Bestiaria".

The very early representations are restricted to wildlife, and therefore clearly represent a hunter´s background. Cultural artefacts were made from animal products, such as bones or ivory (Figure 4). While many paintings and carvings had ritual function, and were hidden away from everyday life, other early representations are realistic pictures or stone carvings of animals occurring in the area.

Research combining archaeology and zoological analysis of cave paintings revealed that these were accurate documentations of the extant fauna and must be considered as early documents in the chain of evidence for ecological change in recent times.

Figures 1 to 3 are different examples of rock art from the French province of Périgord. The pictures are about 30,000 years old, and testify complete mastery of most of the graphic arts, such as engraving, sculpture, painting and drawing. (Source: Ministère Culture communcation France: http://www.culture.gouv.fr/culture/arcnat/lascaux/en/index.html.

Figure 1. Engraved bison, La Grèze (Dordogne)

Figure 2. Painted bison, Font de Gaume (Dordogne)

Figure 3. Drawing of a mammoth, Rouffignac (Dordogne)

Figure 4. A 30,000 year-old carving of a waterbird from mammoth ivory. It is probably among the oldest of human sculptures and artefacts. It was discovered in 2003 in the Hohle Fels cave in the Suavian Alp (Germany), by Conard *et al* (2003). Source: http://www.uni-tuebingen.de/uni/qvo/pm/pm2003/pm711.html

Figure 5. Flute from waterbird bone. Source: http://www.hr-online.de/website/fernsehen/sendungen/index.jsp?rubrik=2262&key=standard_document_1129268.

Scientific collecting is only a small part of taking of specimens, which for example includes harvesting or hunting (not only for food, but also for pleasure). All these non-scientific activities require characterization of biodiversity, often by extremely detailed terminology. Though these are not necessarily “scientific”, they do reflect biological diversity reflecting species’ infraspecific variation, life-cycles or pathology. For example, hunters and fishermen have their own arcane terminology, and breeders characterize thousands of races, sports or varieties. Plant breeders require exact knowledge of cultivars, including the taxonomy and genomics of their wild relatives. Hunting, fishery and logging needs data on stocks of reliably identified species. Agriculturists must identify pest species, potential invaders and their natural enemies. In summary, all these applied fields need solid, fundamental data from biodiversity research.

A hunter's bias prevailed until the nineteenth century, when natural history museums were filled with horns, bones, skins and feathers, and most collectors were also skilled hunters. Only in recent times did the "pursuit of the smallest game" begin, culminating in collection of thousands of insect specimens, collected by fogging rainforest trees (Figure 6). Particularly for insects, aesthetic and collectionist's criteria such as "rarity" are a main driving force for aficionados, many of which have turned into specialists publishing scientific species descriptions.

Figure 6. "Pursuit of the smallest game": collecting invertebrates by fogging in a central European Forest (Hainich, Germany. Courtesy: A. Floren)

2. Species concepts

Assigning a "name" to an observed specimen is fundamental for the description of biodiversity. Generally, such a name refers to a "species". A useful and practical definition of this intuitive process is given by Solbrig and Solbrig (1979):

> *We intuitively recognize a species as a group of closely similar organisms, such as humans, horses or carrots. The scientific definition has varied historically, but one that is often cited today is 'a group of morphologically similar organisms of common ancestry that under natural conditions are potentially capable of interbreeding.*

However, a closer look into species definitions reveals them to be among the most difficult problems in biology. Does the name of a species reflect a man-made concept (nominalism), or does it refer to a "real" functional unit existing in nature, waiting to be discovered and named (essentialism)? This fundamental question is still discussed vigorously, though it might not always be relevant for the practitioner.

Most species definitions fall into one of three major concepts:

- morphological species conceptbiological species conceptphylogenetic species concept.

2.1. Morphological species concept

The *morphological species concept* has been widely used, and is also adopted in everyday life and folk taxonomies: all morphologically similar organisms have the same name ('species' is derived from the Latin *speculare*: looking). It is also known as the *classical, phenetic, morphospecies* and *Linnean species concept*. An early scientific definition goes back to Regan (1926):

> "*A species is a community, or a number of related communities, whose distinctive morphological characters are...sufficiently definite to entitle it, or them, to a specific name.*"

Modern ecological studies dealing with large samples of species-rich groups such as insects or marine invertebrates, often classify samples according to *morphospecies*. But it is evident that considerable morphological differences exist within species, as, for example, between different larval stages or among sexes.

2.2. Biological species concepts

Sexual dimorphism and developmental stages clearly show that a consistent species definition cannot rely on morphology alone. The following *biological species concepts* are based on the common notion that individuals of a species mix and reproduce:

> *A species is a group of interbreeding natural populations that are unable to successfully mate or reproduce with other such groups*. (Dobshansky 1937; Mayr 1969).

This definition was extended by introduction of the ecological niche by Mayr 1982:

> *A species is a group of interbreeding natural populations unable to successfully mate or reproduce with other such groups, and which occupies a specific niche in nature.*"

The niche concept of a species "fitting" into "its" natural habitat is a concept appalling to our common sense and experience. However, niche concepts are themselves heavily disputed, and therefore do not necessarily clarify the issue. A biological species concept based on behaviour is known as the *recognition species concept* (Paterson 1985):

> "*A species is a group of organisms that recognize each other for the purpose of mating and fertilization*".

This concept adds a behavioural component—recognition of a mate—as a prerequisite for mating and gene exchange. In fact, there are many species where elaborate signals have evolved, serving as behavioural barriers for mate finding or mating. Well-known examples are birds, frogs or grasshoppers that recognize their mates through species-specific songs. Differences in song parameters of morphologically similar cricket species have revealed their reproductive incompatibility, and led to the description of a different species based on behaviour.

There are various problems related to the biological species concept including:

- it does not allow for parthenogenetic or vegetative reproduction,
- hybridization between morphologically distinct 'morphospecies' is common in some plants, and
- problems associated with different 'cytotypes' of plants.

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Bibliography

Allaby M. (1998) *Dictionary of Plant Sciences* Oxford University Press, Oxford. Hickey, M. and King, C. (2000). *The Cambridge Illustrated Glossary of Botanical Terms* Cambridge University Press, Cambridge.

Bailey R.G. and Hogg, H.C. (1989). A world ecosystems map for resource partitioning. *Environmental conservation* **13**, 195- 202.

Begon M., Harper J.L. and Townsend C.R. (1990). *Ecology – Individuals, populations and communities*. Blackwell Scientific Publications, Cambridge UK.

Braun-Blanquet, J. (1928). *Pflanzensoziologe: Grundzüge der Vegetationskunde*. Springer, Berlin.

Cannon, P.F. (1997). Strategies for rapid assessment of fungal diversity. *Biodiversity and Conservation* **6**: 669-680 [The advantages and disadvantages of preliminary diversity analyses involving different taxonomic and ecological groups, fungus/plant associations, spatial sampling, soil and litter analysis, molecular methods and indirect assessment are considered]

Chapin III FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Díaz S (2000). Consequences of changing biodiversity. *Nature* **405**, 234-242.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., & Grasso, S. (1997). The value of the world's services and natural capital. Nature 387: 253-260.

Dansereau, P. and Arros, J. (1959). Essais d'application de la dimension structurale en phytosociologie. I. Quelques exemples européens. *Vegetatio* **9**, 48-99.

Davic, R.D. (2003). Linking keystone species and functional groups: a new operational definition of the keystone species concept. *Conservation Ecology* **7**. r.11 [online response; URL: http://www.consecol.org/vol7/iss1/resp11/]

Dawkins R. (1999): The extended phenotype : the long reach of the gene. Rev. ed.. Oxford Univ. Press, Oxford UK, 313 pp.

Dobzhansky T. (1937). *Genetics and the Origin of Species*. New York: Columbia Univ. Press. [The most influential text laying the foundations of the evolutionary synthesis]

Ehrlich P.R. and R.W. Holm (1962). Patterns and populations. *Science* **137**, 652 – 657.

Ellen R.F. (1993). *The cultural relations of classification: an anlysis of Nuaulu animal categories form Central Seram*. Cambridge University Press, Cambridge UK. [An excellent example for a comprehensive ethnobiological study].

Filgueiras T.S., Nicolson D.H., Silva P.C., Skog, J.E., Trehane P., Turland N.J. & Hawksworth D.L. (eds) (2000). *International Code of Botanical Nomenclature* (Saint Louis Code) adopted by the XVI International Botanical Congress, St Louis, Missouri, July-August 1999. Regnum Vegetabile 138. Koeltz Scientific Books: Königstein, Germany.

GlobalBiodiversityOutLook (2001). Published by the Secretariat of the Convention on Biological Diversity, http://www.biodiv.org/gbo/default.shtml.

Hawksworth D.L. (1995). *Steps along the road to a harmonized bionomenclature*. Taxon 44, 447-456.

Hayden, B.P., Ray, C.G. and Dolan, R. (1984). Classification of coastal and marine environments. *Environmental Conservation* **11**, 199-207.

Hennig, W. (1966). *Phylogenetic systematics*. Transl. by D.Dwight Davis. Urbana, USA.

Herskowitz I.H. (1973). *Principles of genetics*. The Macmillan Company, New York.

Heywood V.H. (ed.) (1995). *Global biodiversity assessment* . Published for the United Nations Environment Programme, UNEP, Cambridge University Press, Cambridge, UK.

Holdridge L. (1967). *Life zone ecology.* Tropical Science Centre, San José, Costa Rica.

Huntingford,C., Cox P.M. and Lenton T.M. (2000). Contrasting response of a simple terrestrial ecosystem model to global change. *Ecological Modelling* **134**, 41-58.

IHGSC - International Human Genome Sequencing Consortium (2001). A physical map of the human genome. *Nature* **409**, 934 – 941.

International Commission on Zoological Nomenclature (ICZN) (2000). *International Code of Zoological Nomenclature*. Fourth Edition. The International Trust for Zoological Nomenclature 1999 c/o The Natural History Museum - Cromwell Road – London, UK. [available at: http://www.iczn.org/iczn/index.jsp]

IUCN (2000). 2000 IUCN Red List of Threatened Species. Compiled by C. Hilton-Taylor. IUCN, The World Conservation Union. Gland, Switzerland. http://www.redlist.org

Linnaeus C. (1735) *Systema naturae, sive regna tria naturae systematice proposita per classes, ordines, genera et species. 12 pp.* Lugduni Batavorum.

Linnaeus C. (1758) *Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis*. Edition decima, reformata. 1. Laurentii Salvii, Holmiae. 824 pp.

Lovelock J (2003). The living Earth, Nature 426, 769-770.

Mayr E. (1969). *Principles of systematic zoology*. McGraw-Hill, New York.

Margalef R. (1995). *Ecología*. Ediciones Omega S.A., Barcelona.

Mayr E. (1982) *The growth of biological thought: diversity, evolution and inheritance.* Harvard University Press, Cambridge, Mass.

Nixon K.C., and Wheeler, Q.D. (1990). An amplification of the phylogenetic species concept. *Cladistics* **6**, 211-223.

Nowak R.M. (1999). *Walker's Mammals of the World*. 6th Ed. The Johns Hopkins Univ. Press, Baltimore.

Paterson H.E.H. (1985). The recognition concept of species. Pp. 21-29 *in* E. S. Vrba, ed. *Species and Speciation*. Transvaal Museum, Pretoria. (Transvaal Museum Monograph; 4)

Raunkaier,C. (1934). *The life forms of plants and statistical plant geography*. Clarendon Pr., Oxford.

Regan C.T. (1926). *Organic Evolution*. In (Ed.), *Report British Association for Advancement of Science, 1925* . (pp. 75-86).

van Regenmortel M.H.V., C.M. Fauquet D.H.L. Bishop E.B. Carstens M.K., Estes S.M. Lemon J., Maniloff M.A. Mayo D.J. McGeoch C.R. Pringle R.B. Wickner (2000). *The Classification and Nomenclature of Viruses. The Seventh Report of the International Committee on Taxonomy of Viruses*. Virus Taxonomy, VIIth report of the ICTV. Academic Press, SanDiego, 1167pp. [Online publication of rules: http://www.ncbi.nlm.nih.gov/ICTV/rules.html]

Riede, K. (2001). *Global Register of Migratory Species - Database, GIS Maps and Threat Analysis. Weltregister wandernder Tierarten*. 404 + CD. Münster, Germany: Landwirtschaftsverlag.

Riede K. (2003). Biodiversity Informatics in Germany: ongoing projects and their possible contribution to the Global Taxonomy Initiative (GTI). In: Junko Shimura (ed): *Global Taxonomy Initiative in Asia*. National Institute for Environmental Studies, Japan, pp. 294-300.

Solbrig, O.T. and Solbrig. D.J. (1979). *An Introduction to Population Biology and Evolution.* Addison Wesley, Reading, MA.

Takhtajan A. (1969). Flowering plants, origin and dispersal. Olover and Boyd, Edinburgh.

Watson J.D. and Crick F.H.C. (1953). Molecular structure of nucleic acids. A structure for deoyribose nucleic acid. *Nature* **171**, 738-740

Udvardy M.D.F. (1975). *A classification of the biogeographical provinces of the world*. IUCN Occasional pa Paper No. 18. IUCN, Morges, Switzerland.

Whittaker R.H. (1978). *Classification of plant communities*. Junk, The Hague. 408 pp.

Wilson E.O. (1984)..*Biophilia: the human bond with other species*. 2. ed., Cambridge, Mass.: Harvard Univ. Press.

Biographical Sketch

Klaus Riede studied zoology and biocybernetics in Frankfurt and Tuebingen, Germany. After his dissertation in Zoology, at the Max-Planck-Institute for behavioural physiology, he studied the species-rich grasshopper fauna of South America. He continued field studies in Malaysia, combining them with neuroethological laboratory experiments about hearing physiology in Orthoptera. Since 1997, he designed and managed two major biodiversity informatics projects at Museum Koenig, Bonn: the "Global Register of Migratory Species" (www.groms.de) and the “Digital Orthoptera Access” project (www.dorsa.de).