Biodiversity: Concept, Measurement, and Management

Biologia della Conservazione 25/26

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Changing paradigm

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- One of the most pervasive environmental changes of recent history is the loss of Earth's diversity of life.
- This loss is a systemic problem embedded in the normal ways the human species lives on planet earth, especially with: its ability to convert and manipulate natural habitats to system designed to maximize human benefit, its use of energy and waste production, its high rate of population growth, its ability to move themselves, and all sorts of plants and animal around, its capacity and supporting technology to harvest a large quantity of animals and plants in little time, its industrial-level production of many substances that destroy many kinds of life, its ability to influence and change the climate.

- Conservation biology origins were driven by studies and discoveries in basic sciences such as genetics and population dynamics, but soon became manifest in applied sciences like forestry, fisheries, wildlife management, and more.
- The traditional view of recent extinctions as a collection of tragic individual case histories was replaced by a conviction that the global extinction crisis was produced by the fundamental disruption of ecosystem processes.
- The extinction crisis created an urgency to develop an alternative concept and transition from loss of endangered species to loss of Biodiversity (Dyke & Lamb, 2020).

What is Biodiversity?

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- The first use of the term biodiversity in the scientific literature was in a 1980 government report by biologist Eliot Norse (Pimm, 2001).
- In origin, the word is a contraction of *biological diversity*, but today biodiversity not only has multiple definitions, but also multidimensional concepts and applications.

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- The first use of the term biodiversity in the scientific literature was in a 1980 government report by biologist Eliot Norse (Pimm, 2001).
- In origin, the word is a contraction of *biological diversity*, but today biodiversity not only has multiple definitions, but also multidimensional concepts and applications.
- To those engaged in the study of natural history biodiversity represents the biotic elements that can be described and classified. The tool for such description and classification is taxonomy.
- To environmental activists biodiversity is an intrinsic quality of natural systems that should be preserved for its own sake, expressed using the tools of environmental ethics (Dyke & Lamb, 2020).

- To conservation biologists, biodiversity is an aspect of living systems to be descriptively characterized and explained, a measurable parameter providing insight into community structure, environmental processes, and ecosystem functions determined by the tools of site-specific survey and study.

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- The structural and functional variety of life forms at genetic, population community and ecosystem levels (Sandlund, Hindar, & Brown, 1992).
- Genes and their variety of forms (alleles) are the most fundamental units at which biodiversity can be measured, and their are the basis for all other measures of diversity.

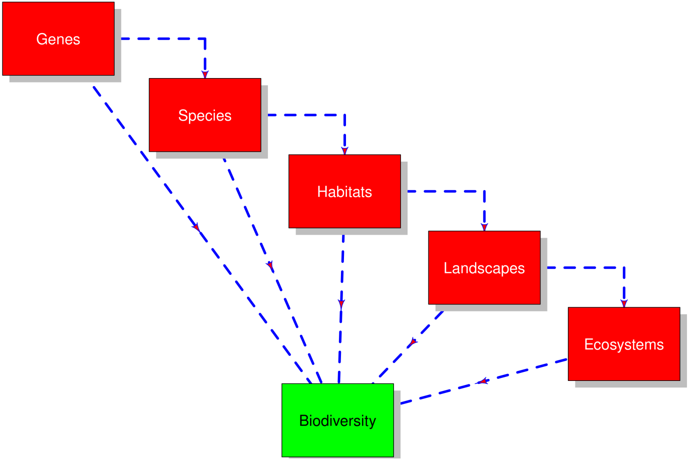


Figure 1: Main biodiversity levels.

Why should we care about Biodiversity?

- A more diverse combination of species (biological community) or, in other words, a more biodiverse system...
  - ... translates in to a more productive environment (Duffy, 2009; Hooper et al., 2005).
  - ... produces a more resistant environment (Naeem et al., 2000; Tilman et al., 1997).
  - ... produces a more resilient environment (Wilsey & Potvin, 2000).
  - ... produces more stable ecosystem processes and a more stable environment in general (Cardinale et al., 2012; Van Meerbeek, Jucker, & Svenning, 2021).

- A key concept when talking about Biodiversity is that of **emergence**. This occurs when a complex entity has properties or behaviors that its parts do not have on their own, and emerge only when they interact in a wider whole (Wikipedia contributors, 2025)

- A key concept when talking about Biodiversity is that of **emergence**. This occurs when a complex entity has properties or behaviors that its parts do not have on their own, and emerge only when they interact in a wider whole (Wikipedia contributors, 2025)
- Biodiversity is essential for food security and nutrition and offers key options for sustainable livelihoods (Convention on Biological Diversity, https://www.cbd.int)

Emergence...

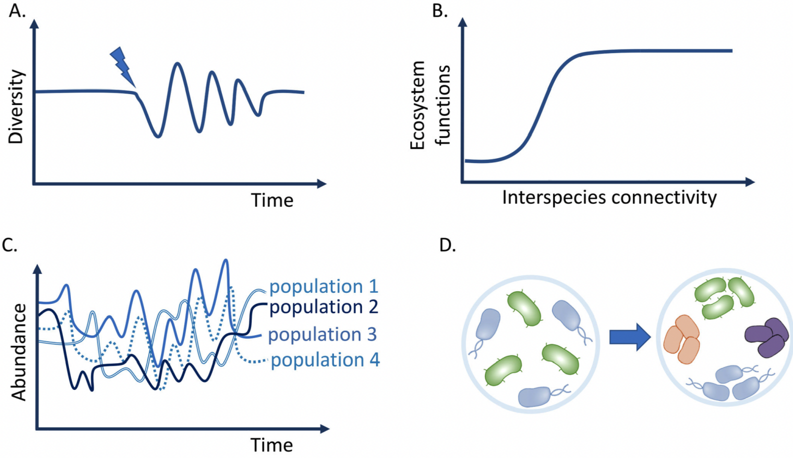


Figure 2: Examples of emergent properties arising from community complexity. After Berg et al. (2022)

Emergence...

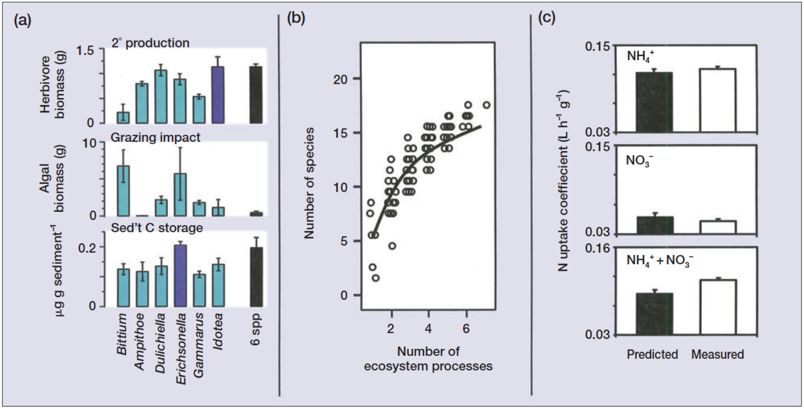


Figure 3: Multifunctional ecosystem require many species. After Duffy (2009)

Resistent environment

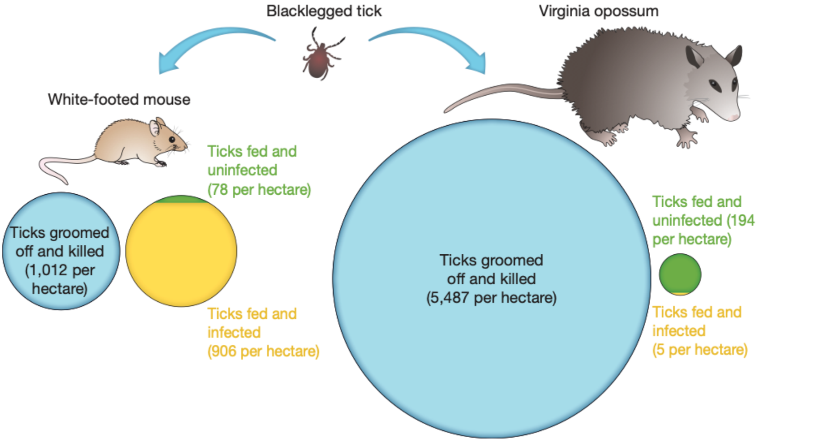


Figure 4: Roles of host species in the transmission of Lyme disease in the northeastern USA. After Keesing et al. (2010)

Higher productivity

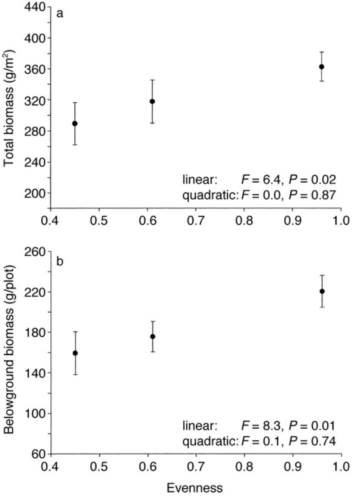
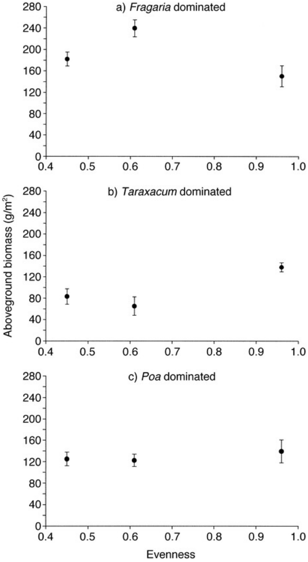


Figure 5: After Wilsey & Potvin (2000)



Species richness

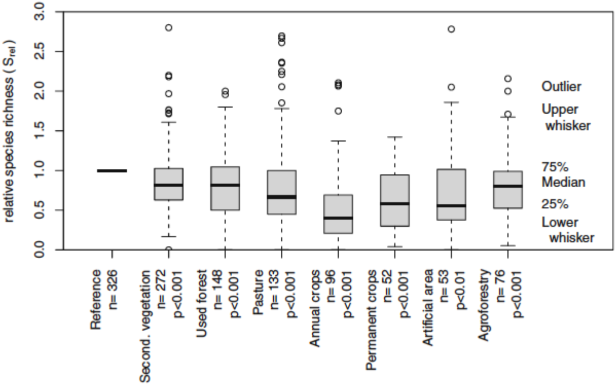


Figure 6: Relative species richness per land use type. After Baan, Alkemade, & Koellner (2013)

- The ESA (Ecological Society of America) concluded that maintaining biodiversity is a safeguard against risk resulting from changes in environmental conditions because it extends the productive use of a site's resources over time and provides an effective way to multiple goods and services (Hooper et al., 2005).

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! Question!

What are ecosystem services?

- **Provisioning services**
  - Food, Energy, Structural materials
- **Regulating services**
  - Reduce the severity of environmental events
- **Supporting services**
  - Provision of physical bodies to be used for essential services (oxygen and soil)
- **Cultural services**
  - Recreational, intellectual and spiritual activities

IUCN

IUCN

International Union for the Conservation of Nature (est. 1948)
https://www.iucn.org

- Its vision...
  ...create a just world that values and conserves nature.
- Its mission...
  ...influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature...
- Permanent staff of ca. 1000 paid employees and thousands of volunteer experts and professional dislocated and working in about 50 locations globally. Combines together government and NGOs. It has no explicit authority to make any “law”, but its authority has gained enough momentum to have the force of law as international standards for conservation practice (Stuart et al., 2017).

- The IUCN has contributed published standards and protocols that are currently in use and followed throughout the world
- Students and practitioners need to know about, appreciate, access and effectively use such resources to work in conservation at any scale
  - Guidelines for applying protected area management categories (Dudley, 2008)
  - IUCN Red List Categories and Criteria Version 3.1 Second Edition (IUCN, 2012)
  - A global standard for the identification of Key Biodiversity Areas : version 1.0 (“A global standard for the identification of key biodiversity areas ,” n.d.)
  - Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria. Version 1.1 (*Guidelines for the application of IUCN red list of ecosystems categories and criteria. Version 1.1*, 2017)

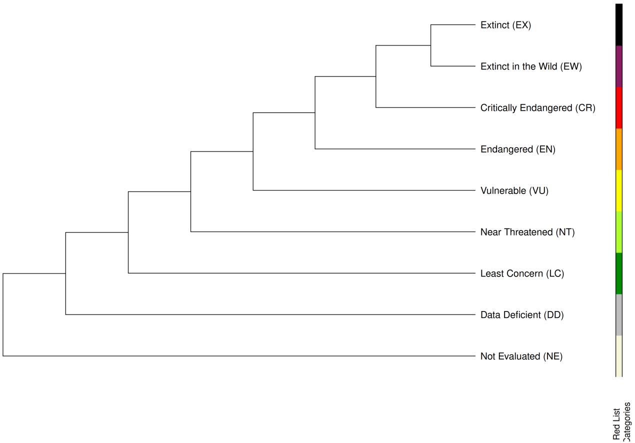

Figure 7: Red List Categories. Each one of these level is defined by very specific and stringent criteria.

Current status of biodiversity

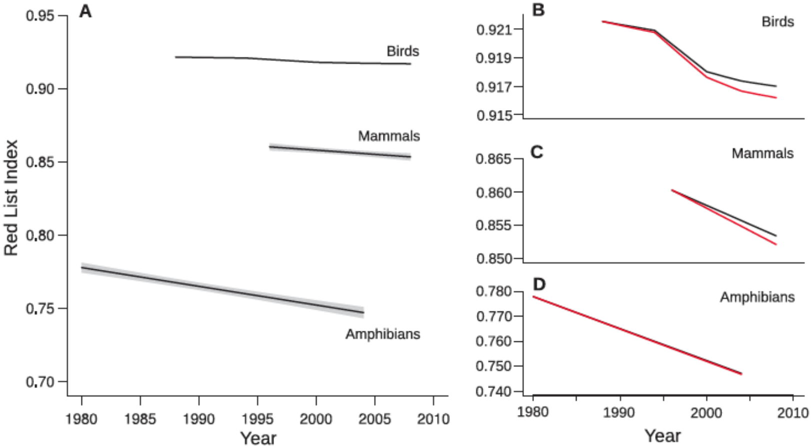

Figure 8: Current biodiversity on vertebrates according to Hoffmann et al. (2010)

Causes of rapid decline in amphibians

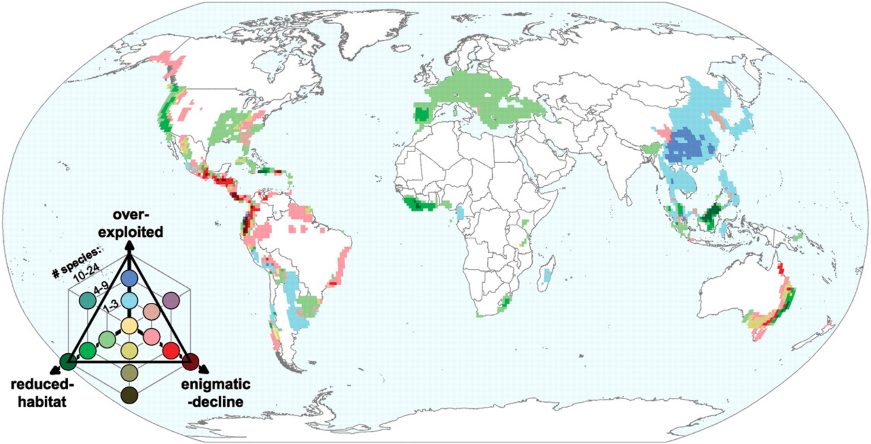

Figure 9: After Stuart et al. (2004)

Main causes of biodiversity loss

1. Habitat modification (Baan et al., 2013)
   - Transformational effects
   - Occupational effects
   - Permanent effects
2. Climate change (we will talk about this in a separate class)

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Transformational effects

Change in the way the land is used. For example, a prairie changed to become a soybean field. The land is still there, and the productivity in term of biomass may even be higher, but the system structure's is simplified and the chance to have a diverse group of species is lost

Occupational effects

Colonization of areas that were previously human free. The human presence directly and indirectly affect the newly colonized system by removing resources, producing wastes, altering the landscape

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Permanent effects

Areas can be disturbed in a more or less permanent way. Lumbering of a forest section in a specific area can be, with time and proper management, reversed and the forest could be reestablished. A prairie covered in asphalt to build a mall and a parking lot is probably lost for good

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Although as an applied concept we can measure it at multiple levels, the most widely used currency to measure and compare biodiversity across sites is SPECIES!

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Species concept	Description	Reference
Typological Species Concept (TySP)	Defines species as distinct and fixed morphological types	Based on Plato’s, Aristotele’s, and, later, Christian philosophies

		(continued)
Evolutionary Species Concept (ESC)	A species is a lineage of ancestral descent which maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate	(Wiley, 1978)
Biological Species Concept (BSC)	Groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups	(Mayr, 1942)

		(continued)
Phylogenetic Species Concept (PSC)	A species is the smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent	(Cracraft, 1983)
Differential Fitness Species Concept (DFSC)	Groups of individuals with features that would have negative fitness effects in other groups and cannot regularly be exchanged between groups upon contact	(Hausdorf, 2011)

- Important to conservation is the identification of operational units to be preserved (individuals, populations, species, etc. etc. etc.)
- Conservationists, thus, not only work to preserve organisms, but also their ability to adapt and respond to environmental changes (i.e., the capability of individuals to give rise to new species in the future)
- From this perspective, the PSC has become widely used by conservationists as it incorporates well defined tools (both scientific and normative) to define species (Agapow et al., 2004)
- The concept of Evolutionary Significant Units (ESU) aims at preserving both evolutionary potential and organisms. ESUs are based on criteria that are associated to genetic variation between and within populations (Moritz, 1994)

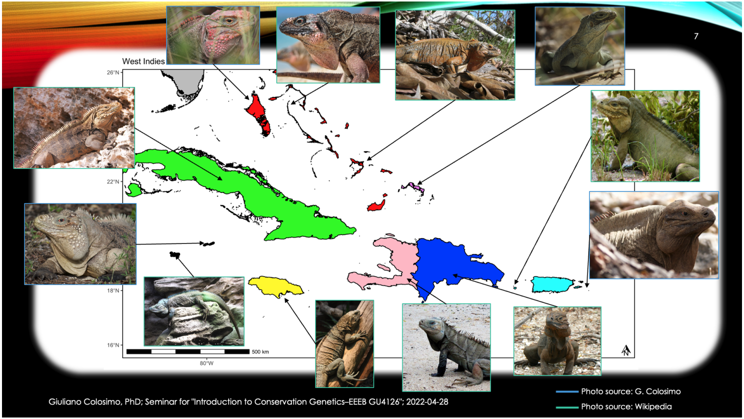


Figure 10: *Cyclura* diversity in the West Indies

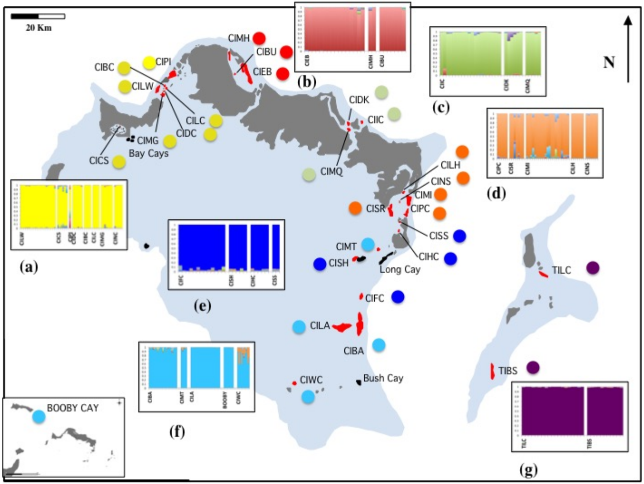


Figure 11: Cyclura carinata population structure, After Welch et al. (2017)

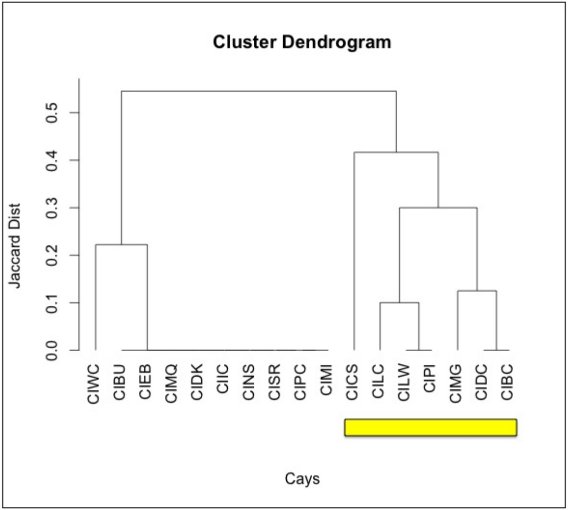


Figure 12: Cyclura carinata ESU identification, After Welch et al. (2017)

Measuring biodiversity

Measuring biodiversity

Index	Formula and Terms
Alpha diversity: The diversity of species within an ecological community. The number of different species (species richness) and their evenness (the species' relative abundance)	$H = -\sum_{i}^{s} p_i \, ln(p_i), \ (i = 1, 2, 3, ..., s), \ \ (0 \leq H^{'} \leq \infty)$ (Dyke & Lamb, 2020); p_i = proportion of the total community abundance of the species i
Beta diversity: Measure of diversity among communities. A measure of the gradient of species composition across a landscape	$S/\alpha - 1$ (Whittaker, 1975); S = number of species in the area; α = average number of species per site

Index	Formula and Terms
Gamma diversity: Biodiversity of species across larger landscape levels	$dS/dD[(g+l)/2]$ (Cody, 1986); D = distance; g = rate of species gain; l = rate of species loss

Calculating biodiversity: Excercise 1

Site	Sp_1	Sp_2	Sp_3	Sp_4	Sp_5
1	22	2	18	17	2
2	21	0	27	12	2
3	14	3	28	11	2
4	23	3	35	16	5
5	17	5	15	31	5
6	19	0	31	19	3
7	20	5	27	8	0
8	20	0	36	19	2
9	18	1	65	16	4
10	20	1	46	17	4

Figure 13: Excercise dataset.

- What is the most diverse site based on Shannon index? $H = -\sum_i^s p_i \, ln(p_i)$

Calculating biodiversity: Excercise 1 in R

```
library(vegan)
data(BCI)
plantDivExcercise <- BCI[1:10,
                         c(144, 186, 208, 216, 223)]
species_names <- rep(NA, ncol(plantDivExcercise))
for (i in 1:ncol(plantDivExcercise)){
  species_names[i] <- paste("Sp_", i, sep = "")
}
names(plantDivExcercise) <- species_names
Site <-  1:10
plantDivExcercise <- cbind(Site, plantDivExcercise)
diversity(plantDivExcercise)[diversity(plantDivExcercise)
    [] == max(diversity(plantDivExcercise))]
```

```
       5
1.544138
```

Calculating biodiversity: Exercise 1 explanation

- In $H = -\sum_i^s p_i \, ln(p_i)$, p_i is the proportion of the total community abundance of the species i
- We can workout the value for site 5:

$$17 + 5 + 15 + 31 + 5 = 73$$

$$p_{species1} = 17/73 = 0.233$$

$$ln(p_{species1}) = ln(0.233) = -1.457$$

$$0.233 * -1.457 = -0.339$$

Calculating biodiversity: Exercise 2

Site	Sp_1	Sp_2	Sp_3	Sp_4	Sp_5
1	22	2	18	17	2
2	21	0	27	12	2
3	14	3	28	11	2
4	23	3	35	16	5

Figure 14: Excercise 2 dataset A.

Site	Sp_1	Sp_2	Sp_3	Sp_4	Sp_5
6	19	0	31	19	3
7	20	5	27	8	0
8	20	0	36	19	2
9	18	1	65	16	4

Figure 15: Excercise 2 dataset B.

- Question: What is the most diverse area based on β diversity index as postulated by Whittaker (1975)? $S/\alpha - 1$

Calculating biodiversity: Exercise 2 in R

```
data(BCI)
plantDivExcercise <- BCI[1:10, c(144,186,208,216,223)]
species_names <- rep(NA, ncol(plantDivExcercise))
for (i in 1:ncol(plantDivExcercise)){
  species_names[i] <- paste("Sp_", i, sep = "")
}
names(plantDivExcercise) <- species_names
Site <-  1:10
plantDivExcercise <- cbind(Site, plantDivExcercise)
ncol(plantDivExcercise[1:4, 2:6])/
  mean(specnumber(plantDivExcercise[1:4, 2:6])) - 1
```

```
[1] 0.05263158
```

Calculating biodiversity: Exercise 2 explanation

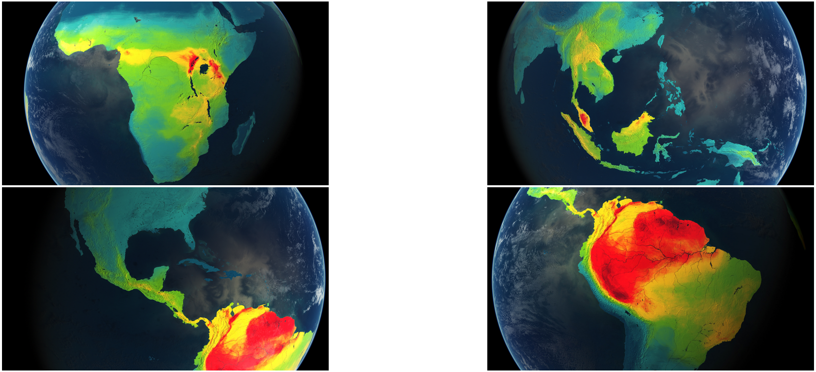
Site	Sp_1	Sp_2	Sp_3	Sp_4	Sp_5
1	22	2	18	17	2
2	21	0	27	12	2
3	14	3	28	11	2
4	23	3	35	16	5

Figure 16: Excercise 2 dataset A.

- The Whittaker (1975) formula: $\beta = (S/\alpha) - 1$, where S is the total number of species in the area, and α is the average number of species in the area. β diversity gives us an index of species turnover along a geographic gradient.

$$\beta = \frac{5}{(5+4+5+5)/4} - 1 = 0.052$$

Biodiversity distribution



Mammal richness. Data downloaded from https://biodiversitymapping.org.

Global prioritization strategies

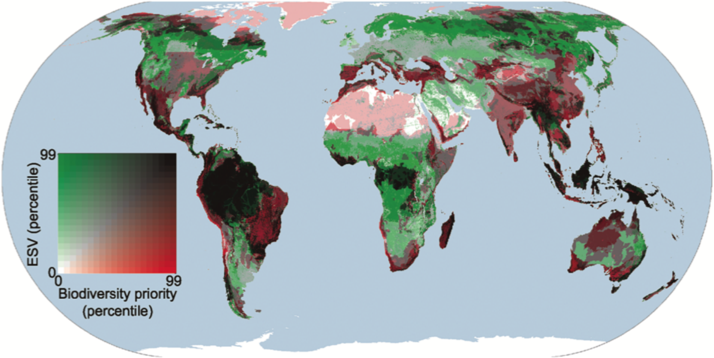


Figure 17: Spatial concordance of global biodiversity priorities and ecosystem service value (ESV). Increasing intensities of green and red represent, respectively, increasing rank ESV and increasing rank consensus biodiversity priority. White corresponds to low values for both variables, black to high values for both, and shades of gray to covarying values for both. After Turner et al. (2007)

Integrated conservation strategies

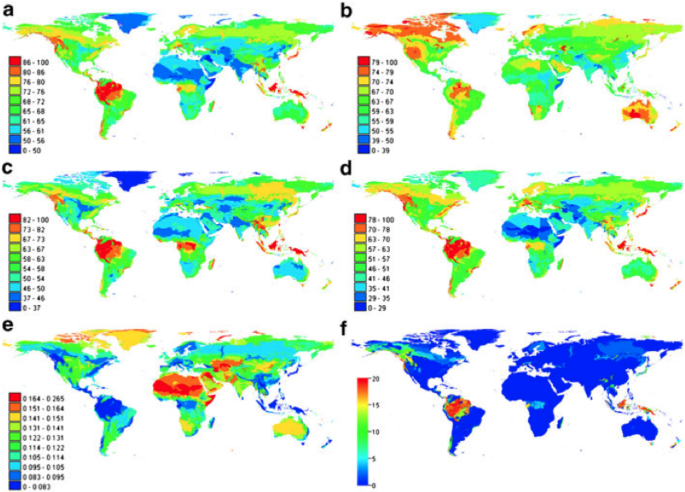


Figure 18: Conservation priority-setting indices combining EcoWise, SocioWise and ClimateWise priorities. After Freudenberger et al. (2013)

How to support biodiversity in human modified landscapes?

1. Prefer diversity in crops (polyculture) and land use (land-use mosaic).
2. Encourage traditional agricultural practices over large-scale mechanized solutions.
3. Monitor and maintain keystone structure or species from the environment.
4. Maintain as much natural vegetation as possible.
5. Expand protected areas to encompass species of significant value (keystone-species).
6. Favor use of native species in gardens and cultivation.
7. Maintain urban green areas.
8. Discourage urban sprawl.
9. Encourage appreciation and understanding of conservation goals among land users.

After Trimble & Aarde (2014)

Synthesis

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- Biodiversity is a core concept of conservation biology. Its usefulness is only valid if we are able to thoroughly measure it and define it mathematically.
- Only with a clear understanding and measurement of biodiversity and its value we could use it in conservation studies, conservation laws and conservation policy.
- Effective future research on biodiversity will not only keep on refining and finding new ways on how to measure it, but also understand the evolutionary and ecological processes that can contribute to its creation and maintainment.
- The hope is to increasingly see biodiversity as a core concept of future local and international strategies for the conservation of nature.

References

References I

A global standard for the identification of key biodiversity areas : Version 1.0. (n.d.). IUCN, International Union for Conservation of Nature.

Agapow, P.-M., Bininda-Emonds, O. R. P., Crandall, K. A., Gittleman, J. L., Mace, G. M., Marshall, J. C., & Purvis, A. (2004). The impact of species concept on biodiversity studies. *The Quarterly Review of Biology*, *79*(2), 161–179. University of Chicago Press. Retrieved from https://doi.org/10.1086%2F383542

Baan, L. de, Alkemade, R., & Koellner, T. (2013). Land use impacts on biodiversity in LCA: A global approach. *The International Journal of Life Cycle Assessment*, *18*(6), 1216–1230. Retrieved from https://link.springer.com/content/pdf/10.1007/s11367-012-0412-0.pdf

References II

Berg, N. I. van den, Machado, D., Santos, S., Rocha, I., Chacón, J., Harcombe, W., Mitri, S., et al. (2022). Ecological modelling approaches for predicting emergent properties in microbial communities. *Nature Ecology & Evolution*, *6*(7), 855–865. Springer Science; Business Media LLC.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., et al. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59–67. Springer Science; Business Media LLC. Retrieved from https://doi.org/10.1038%2Fnature11148

Cody, M. L. (1986). Conservation biology: The science of scarcity and diversity. In M. E. Soulé (Ed.),. Sinauer Associates.

References III

Cracraft, J. (1983). Species concepts and speciation analysis. In R. F. Johnston (Ed.), *Current ornithology* (pp. 159–187). New York, NY: Springer US. Retrieved from https://doi.org/10.1007/978-1-4615-6781-3_6

Dudley, N. (2008). *Guidelines for applying protected area management categories*. IUCN.

Duffy, J. E. (2009). Why biodiversity is important to the functioning of real-world ecosystems. *Frontiers in Ecology and the Environment*, *7*(8), 437–444. Retrieved from https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/070195

Dyke, F. V., & Lamb, R. L. (2020). *Conservation biology*. Springer International Publishing. Retrieved from https://doi.org/10.1007%2F978-3-030-39534-6

References IV

Freudenberger, L., Hobson, P., Schluck, M., Kreft, S., Vohland, K., Sommer, H., Reichle, S., et al. (2013). Nature conservation: Priority-setting needs a global change. *Biodiversity and Conservation*, *22*(5), 1255–1281. Retrieved from https://link.springer.com/content/pdf/10.1007/s10531-012-0428-6.pdf

Guidelines for the application of IUCN red list of ecosystems categories and criteria. Version 1.1. (2017). IUCN International Union for Conservation of Nature.

Hausdorf, B. (2011). Progress toward a general species concept. *Evolution*, *65*(4), 923–931. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1558-5646.2011.01231.x

References V

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., Carpenter, K. E., et al. (2010). The impact of conservation on the status of the world's vertebrates. *Science*, *330*(6010), 1503–1509. Retrieved from https://www.science.org/doi/abs/10.1126/science.1194442

Hooper, D. U., Chapin III, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., et al. (2005). EFFECTS OF BIODIVERSITY ON ECOSYSTEM FUNCTIONING: A CONSENSUS OF CURRENT KNOWLEDGE. *Ecological Monographs*, *75*(1), 3–35. Retrieved from https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/04-0922

IUCN. (2012). *IUCN Red List Categories and Criteria Version 3.1 Second Edition* (pp. 1–32).

References VI

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., Hudson, P., et al. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, *468*(7324), 647–652. Springer Science; Business Media LLC. Retrieved from https://doi.org/10.1038%2Fnature09575

Mayr, E. (1942). *Systematics and the origin of species*. New York, NY: Columbia University Press.

Moritz, C. (1994). Defining "Evolutionarily Significant Units" for conservation. *Trends in Ecology & Evolution*, *9*(10), 373–375. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/0169534794900574

References VII

Naeem, S., Knops, J. M. H., Tilman, D., Howe, K. M., Kennedy, T., & Gale, S. (2000). Plant diversity increases resistance to invasion in the absence of covarying extrinsic factors. *Oikos*, *91*(1), 97–108. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1034/j.1600-0706.2000.910108.x

Pimm, S. L. (2001). The world according to pimm: A scientist audits the earth, *39*(06), 39-3373-39-3373. American Library Association.

Sandlund, O. T., Hindar, K., & Brown, A. H. D. (1992). *Conservation of biodiversity for sustainable development*. A scandinavian university press publication. Scandinavian University Press. Retrieved from https://books.google.de/books?id=rmPrPEXFja4C

Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., & Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*(5702), 1783–1786. American Association for the Advancement of Science (AAAS).

Stuart, S. N., Dhaheri, S. A., Bennett, E. L., Biggs, D., Bignell, A., Byers, O., Cooney, R., et al. (2017). IUCN's encounter with 007: Safeguarding consensus for conservation. *Oryx*, *53*(4), 741–747. Cambridge University Press (CUP). Retrieved from https://doi.org/10.1017%2Fs0030605317001557

References IX

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., & Siemann, E. (1997). The influence of functional diversity and composition on ecosystem processes. *Science*, *277*(5330), 1300–1302. Retrieved from https://www.science.org/doi/abs/10.1126/science.277.5330.1300

Trimble, M. J., & Aarde, R. J. van. (2014). Supporting conservation with biodiversity research in sub-saharan africa's human-modified landscapes. *Biodiversity and Conservation*, *23*(9), 2345–2369. Retrieved from https://link.springer.com/content/pdf/10.1007/s10531-014-0716-4.pdf

Turner, W. R., Brandon, K., Brooks, T. M., Costanza, R., Fonseca, G. A. B. da, & Portela, R. (2007). Global Conservation of Biodiversity and Ecosystem Services. *BioScience*, *57*(10), 868–873. Retrieved from https://doi.org/10.1641/B571009

References X

Van Meerbeek, K., Jucker, T., & Svenning, J. (2021). Unifying the concepts of stability and resilience in ecology. *Journal of Ecology*, *109*(9), 3114–3132. Wiley.

Welch, M. E., Colosimo, G., Pasachnik, S. A., Malone, C. L., Hilton, J., Long, J., Getz, A. H., et al. (2017). Molecular variation and population structure in critically endangered Turks and Caicos Rock Iguanas: identifying intraspecific conservation units and revising subspecific taxonomy. *Conservation Genetics*, *18*(2), 479–493. Retrieved from http://link.springer.com/10.1007/s10592-016-0922-6

Whittaker, R. H. (1975). *Communities and ecosystems* (Second.). Macmillan Publishers Limited.

References XI

Wikipedia contributors. (2025). Emergence — Wikipedia, the free encyclopedia. Retrieved from https://en.wikipedia.org/w/index.php?title=Emergence&oldid=1310041482

Wiley, E. O. (1978). The evolutionary species concept reconsidered. *Systematic Zoology*, *27*(1), 17–26. Oxford University Press, Society of Systematic Biologists, Taylor & Francis, Ltd. Retrieved from http://www.jstor.org/stable/2412809

Wilsey, B. J., & Potvin, C. (2000). Biodiversity and ecosystem functioning: Importance of species evenness in an old field. *Ecology*, *81*(4), 887–892. Wiley. Retrieved from https://doi.org/10.1890%2F0012-9658%282000%29081%5B0887%3Abaefio%5D2.0.co%3B2