ANNALI DI BOTANICA
Ann. Bot. (Roma), 2025, 15: 35–42
annalidibotanica.uniroma1.it | E-ISSN 2239-3129 | ISSN 0365-0812

ON THE TIME TREND OF AEROBIOTIC AND ANTHROPIC BIOMASS: AN APPROACH TO THE UNKNOWN

Contoli Amante L.[1†], Battisti C.[2], Fanelli G.[3]

[1]*CNR - National Research Council – Center for Evolutionary Genetics*
[2]*'Torre Flavia' LTER (Long Term Ecological Research) Station, Protected Areas – Regional Park Service, Metropolitan City of Rome Italy*
[3]*Department of Environmental Biology, Sapienza University of Rome, Italy*
[*]*Corresponding Authors Email: c.battisti@cittametropolitanaroma.it*

(Received 2025; received in revised form 2025; accepted 2025)

Abstract – Biodiversity changes in the aerobic biomass have been estimated (including the "anthrobiome"). These changes seem to be strongly affected by the anthropic impact along a long-time span (starting from 2,060 AD to 12,060 BC). The aerobic biomass excluding *Homo sapiens* shows a progressive and, perhaps, unstoppable decline, after the advent of Western industrial civilization. This preliminary work aims to highlight how biodiversity should perhaps be studied, understood and used critically by adopting innovative approaches (e.g., using biomass) and without preconceptions. Although our work is based on assumptions regarding some parameters that have been widely approximated, we believe it is necessary to proceed with this exploratory analysis considering the dramatic decline in biodiversity worldwide.

Keywords: anthrobiome, Biomass, Aerobios, simpson index

Introduction

Biodiversity—albeit in a symbolic and ante litteram form—has been admired and respected since the dawn of human history. From its veneration in Eastern spiritual traditions (e.g., Hinduism, Buddhism), to the first conceptual frameworks proposed by Aristotle, to the vivid allegories of Lucretius and the mystical interpretations of St. Francis of Assisi; from the early formal naming systems (e.g., Cesi, 1651), to Linnaeus's foundational taxonomic system (1758), and the evolutionary insights of Darwin (long before the official publication in 1859) and Wallace (1858); through the quantitative formulations influenced by thermodynamics and information theory—Gini (1912), Shannon (1948), Wiener (1948), Simpson (1949), Margalef (1957), Hill (1973), Whittaker (1972, 1977), and Patil and colleagues (Patil & Taillie, 1976; Grassle et al., 1992); to the unconventional but constructive critiques of Hurlbert (1971); the qualitative-quantitative approaches of May (1975); and finally, its establishment as a distinct scientific discipline, notably with Wilson (1992) and many others (e.g., Alatalo, 1981; Barbault et al., 1991; Colwell, 1979; Ganis, 1991; Magurran, 2004; Odum, 1973; Pielou, 1975; AA.VV., 2000).

Biodiversity has since been embraced—though often more in rhetoric than in practice, and not without risks of conceptual distortion (Battisti & Contoli, 2011)—by international political discourse (e.g., Barton, 1992).

The current crisis of biodiversity in the biosphere has long been highlighted at various levels, especially at the taxonomic level (e.g., Wilson, 1992; Gaston & Mound,

doi: 10.13133/2239-3129/18798

1993). However, given the current, ongoing uncertainty about the numerousness of taxa (in particular, species) and the respective abundance of individuals, complete knowledge of the biodiversity in the biosphere remains unknown (e.g., Mora et al., 2011; Caley et al., 2014; Hortal et al., 2015; Guedes et al., 2025). An approach to 'complex biodiversity', that is, an extended concept of biological diversity that simultaneously takes into account the various conceptual components (abundance, richness, diversity etc.), seems easier by examining biomass, large eco-environmental units and their respective dominant and characterizing taxa, as they are at the core of the functional relationships within and among ecosystems (Daly et al., 2018). This could allow a more realistic approach than the strictly taxonomic one, from an energetic and eco-functional point of view (see Barnes et al., 2018; Allen et al., 2002).

It is important to distinguish between the concepts of ecosystem and biome. An ecosystem is linked to a territorially continuous biotope and characterized by a specific biotic composition. A biome, by contrast, is defined primarily by abiotic factors—such as macroclimate—which allows it to include ecologically similar but geographically distant and disconnected ecosystems (Clapham, 1973).

This broader view supports those (e.g., Ellis & Ramankutty, 2007) who define biomes as including human-modified areas, where a single species—*Homo sapiens*—profoundly alters biogeochemical cycles: from soil potential and food production at all trophic levels to consumption, elimination of trophic competitors, and the exploitation of local biotic and abiotic resources. This leads to the concept of the Anthrobiome (Couvet, 2019). The biomass from Anthrobiomes, together with that from natural biomes, forms an extended biomass, which can be studied in a diachronic perspective across millennia.

Furthermore, the anthropogenic impact—recognized as a major driver of ecological change—must be integrated into analyses. This impact differs qualitatively between the halobios (marine organisms), where human influence is still mainly through extraction and pollution, and the aerobios (terrestrial organisms), where humans have long replaced natural ecosystems with anthroposystems based on agriculture, livestock, and settlement (Machlis et al., 1997; Likhacheva et al., 2019). In terrestrial systems, humans have become a dominant ecological force and a major threat to biodiversity (Battisti et al., 2016).

Such an analysis can now rely on robust time-resolved data concerning human population trends since the Holocene, the characteristics of major aerobios biomes, and the distribution of biomass across biological organisms—including *Homo sapiens*—despite the need for substantial numerical approximations in these estimates (Wilkes et al., 2025). Accordingly, we propose to examine biodiversity through the lens of biomass distribution within the aerobios, using diversity indices calculated on the biomass frequency of eco-taxo-physiognomic groups within each biome, rather than on individual abundance. In this framework, eco-taxo-physiognomic groups are defined by dominant plant physiognomies (e.g., conifers, deciduous broadleaf trees, evergreen broadleaf trees, etc.).

Although this approach shows some weaknesses due to the high degree of approximation related to the coarse-grained method, we think that the general patterns may be objectively credible. We think also that this type of analyses is urgent due to the strong impact of *Homo sapiens* in the biosphere.

Methods

Data base

Biomass data, expressed in gigatonnes of carbon (Gt C), were sourced from Bar-On et al. (2018). The time span analyzed extends over the past 10,000 years—starting from the onset of a more stable macroclimate and the rise of agriculture and livestock, which triggered the ongoing expansion of *Homo sapiens*. The projection extends 55 years into the future (UN, 2019), with a forecasted global population of approximately 10 billion individuals (1010). For clarity in graphical representation, time is expressed as Log(12,060 – years), spanning from 12,060 BCE to 2,060 CE. The analysis focuses on several major biomes for which consistent and reliable data are available (Lieth, 1975; Loidi et al, 2022).

The following parameters have been considered over time: the number of individuals of *Homo sapiens*; its average individual biomass, assumed as 50 kg per capita, with approximation (Walpole et al., 2012); the current biomass of the main eco-taxo-physiognomic groups, i.e., the main plant physiognomies (Bar-On et al., 2018; Trost, 2022).

We obtained the numerical proportions of biomass between the aforementioned groups from Lieth (1975) and the human biomass or "anthrobiome" as the product of the population in a given year and the weight of a single individual of *Homo sapiens* (Groombridge, 1992). We proposed an indicative evaluation of biodiversity across different biomes, based on the biomass of eco-taxo-physiognomic groups. Given the impossibility of quantifying the biomass of every taxonomic component within each biome, we focused on identifying the dominant taxa in terms of biomass, considering only tree species. A total of 104 species was selected as a reference: specifically, 104 species for tropical rainforest, 103 for seasonal rainforest, 102 for temperate, seasonal, and evergreen sclerophyllous scrub, and 101 for Taiga. In addition, we included herbaceous plants sensu lato in the "prairie" biome (104 species), lichen symbioses in the Tundra (101 species), and various plant species that occur predominantly in isolated, scattered, and individual forms in the "semi-desert" biome (101 species), following the approach outlined in the seminal work by Cazzolla Gatti et al. (2022). Finally, we obtained the Taxonomic diversity (TAX D; Cazzolla Gatti et al. 2022).

Before 1975 and after 2018, the values were tentatively estimated to the dates 10,000 (approximately, the beginning of agriculture and livestock farming), 7,000, 5,000, 3,000 B. C. and 1500 (end of the Middle Ages), 1800 ("industrial revolution"), 1950 ("green revolution") B. C., as well as to 2055 (Homo sapiens with 1010 presumed individuals; UN, 2019).

Starting from the data of Bar-On et al. (2018), we calculated (i) the biomass and the relative frequencies of the various biomes and (ii) biomass of 'anthrobioma'. From these biomass values, we obtained: the total biomass for aerobios (including anthrobioma; BIOM; from Bar-On et al., 2018); the fraction of Homo sapiens biomass (on the total aerobios biomass; H BIO; calculated as the number of individual humans

Table 1. Data of biomass and diversity along the time span considered. Biomass is expressed in gigatonnes of Carbon (GT of C). Time considered, log-transformed, started from the present up to ten millennia ago. The biomes considered are from Lieth (1975). Acronyms: BIOM: total biomass for aerobios (Bar-On et al., 2018); H BIO: Fraction of *Homo sapiens* Biomass (calculated as the number of individual humans multiplied by 50 kg: Walpole et al., 2012); TAX D: Taxonomic diversity (Cazzolla Gatti et al. 2022); BIO D: Biomic diversity (Magurran, 2004). Biome acronyms: ANT: Anthrobioma; PLU: pluvial/tropical forests; PLU S: seasonal pluvial/tropical forests; TEM: temperate *sensu lato*; TEM S: seasonal temperate; SCL: sclerophilous forests; TAI: taiga; PRA: prairies; TUN: tundra; DES: semi-desertic biome.

Year	10000 B.C.	7000 B.C.	5000 B.C.	3000 B.C.	1500 A.D.	1800 A.D.	1950 A.D.	1975 A.D.	2018 A.D.	2055 A.D.
LOG Y	5.919	6.043	6.151	6.296	7.252	7.585	7.921	8.022	8.377	9.3
BIOM	589	588	587	586	585	584	577	567	541	474
H BIO	0.0006	0.0006	0.0006	0.0006	0.0006	0.0061	0.0071	0.0151	0.0043	0.022
TAX D	0.999	0.999	0.999	0.999	0.999	0.994	0.993	0.985	0.997	0.978
BIO D	0.681	0.681	0.681	0.674	0.674	0.695	0.707	0.721	0.36	0
PLU	312	312	312	312	312	288	279	267	231	163
PLU S	72	72	72	72	72	71	70	68	66	48
TEM	33	32	31	30	29	28	27	26	25	23
TEM S	37	37	37	37	37	37	37	36	35	33
SCL	5	5	5	5	5	5	5	5	5	5
TAI	43	43	43	43	43	43	43	42	41	39
PRA	101	101	101	101	101	101	100	98	95	84
TUN	5	5	5	5	5	5	5	5	5	5
DES	5	5	5	5	5	5	5	5	5	5

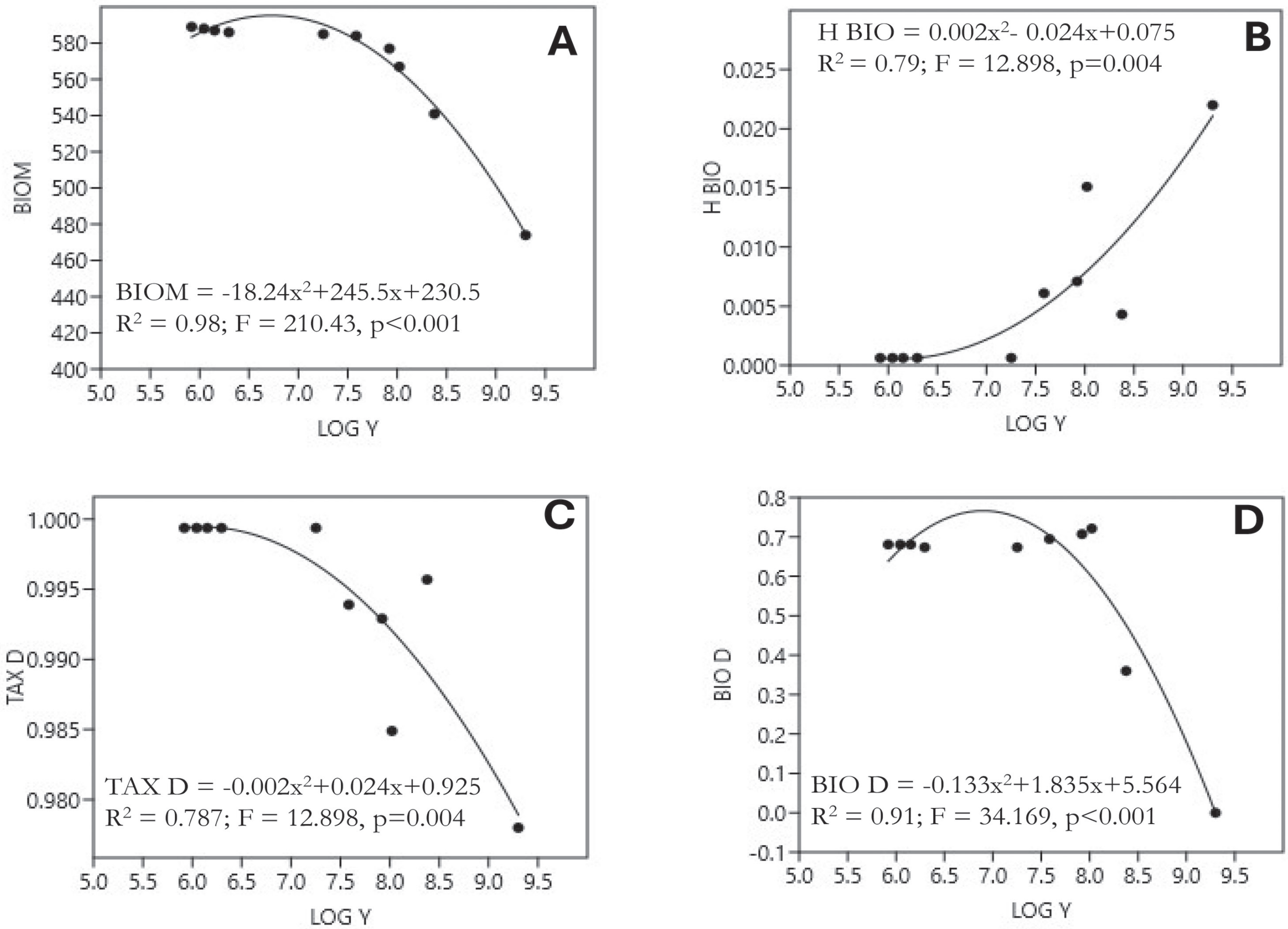

Figure 1. Trends along the time range studied (log y=log years after 12.060 B.C.; see Methods for details) with equations of polynomial regression, order 2. A: total biomass for aerobios (including anthrobioma; BIOM); B: Fraction of *Homo sapiens* Biomass (on the total aerobios Biomass; H BIO); C: Taxonomic diversity (TAX D); D: Biomic diversity (BIO D).

multiplied by 50 kg: Walpole et al., 2012). Moreover, from the biomass values for each biome (including anthrobiome), we obtained the relative frequency (fr) of biomass for each biome. After, we calculated the Simpson diversity index as $D=1-\Sigma fr^2$ (Magurran, 2004; see also Patil & Taillie, 1976; Ganis, 1991; Contoli Amante & Luiselli, 2015). The Simpson index has also been calculated on the biomass of the biomes (included the anthrobiome) divided by the number of species, obtaining an estimate of the average biomass per species of the arboreal layer (or more in general of the dominant species; Bar-On et al, 2018; biomic diversity: BIO D; Magurran, 2004). The trend over time of the overall aerobic biomass and of diversity index was therefore verified.

We correlated BIOM, H BIO, TAX D, and BIO D to the range studied (log y=log years after 12.060 B.C, performing equations of polynomial regression, order 2 and using the PAST 4.01 software (Hammer et al. 2001). Alpha was set to 0.05 level.

RESULTS AND DISCUSSION

Trend in all the values of biomass (including anthropic biomass or 'anthrobiome') and of the Simpson diversity index have been reported in Table 1 and Fig. 1.

We observed a progressive decline of the total biomass (Fig. 1A) largely due to the decline in biomass of the aerobios, while anthropic biomass increased progressively (Fig 1B).

The taxonomic biodiversity (i.e., the numerousness of species, Fig. 1C) has always been very high in the temporal range considered (approximately 107 species). However, over time, the biodiversity shows, after an initial stability, a progressive decline, due to the growing role of the biome dominated by a single species (Homo sapiens) towards the others.

The biomic biodiversity (Fig 1D) after a very slight initial decline, shows an increase, as expected, given the growing weight of the anthrobiome, initially quantitatively negligible and today tendentially hegemonic over the others. The future forecast (2055) is that of a rapid collapse, if the current trends were to be confirmed. Our data support evidence yet provided by other authors (Pereira et al., 2010, Segan et al., 2016) with implication for cascade effects also on our species (Undheim & Ahmad, 2024).

Our preliminary data indicate a decline in total biomass, which appears to contrast with the progressive increase in anthropic biomass. This reflects a clear anthropogenic pressure on the aerobios—and thus on the biosphere as a whole. The onset of this decline seems to coincide with the historical phase spanning from the discovery of the Americas to the beginning of the Euro-Western Industrial Revolution

This preliminary work aims to emphasize the need to study, interpret, and apply the concept of biodiversity critically and without preconceptions—as an essential tool for understanding biological reality. While our analysis is based on certain assumptions and approximate parameters subject to a degree of uncertainty (see Ladle, 2009), we consider this exploratory approach necessary given the alarming global decline in biodiversity.

Acknowledgments

An anonymous reviewer and the Editor provided useful comments and suggestions both to the first and second drafts of the manuscript.

Foreword

This work was born from an idea of Longino Contoli, who recently passed away (2024). To him, friend and Magister, we dedicate our effort to make it public. The language and style of the work may seem outdated, but we wanted to keep it because it is characteristic of this researcher trained in the 70s when the way of writing articles was different from today. We wanted to interpret the original content as closely as possible.

References

AA. VV. (2000). Biodiversity. *Nature 405*, 207-253.

Allen, A. P., Brown, J. H., & Gillooly, J. F. (2002). Global biodiversity, biochemical kinetics, and the energetic-equivalence rule. *Science, 297(*5586), 1545-1548.

Barbault, R., Colwell, R. K., Dias, B., Hawksworth, D. L., Huston, M., Laserre, P., ... & Younes, T. (1991). Conceptual framework and research issues for species diversity at the community level. *From genes to ecosystems: a research agenda for biodiversity. IUBS, Cambridge, Mass*, 37-71.

Barnes, A. D., Jochum, M., Lefcheck, J. S., Eisenhauer, N., Scherber, C., O'Connor, M. I., ... & Brose, U. (2018). Energy flux: the link between multitrophic biodiversity and ecosystem functioning. *Trends in ecology & evolution*, *33*(3), 186-197.

Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences*, *115*(25), 6506-6511.

Barton, J. H. (1992). Biodiversity at Rio. *BioScience*, *42*(10), 773-776.

Battisti, C., & Contoli, L. (2011). Diversity indices as 'magic'tools in landscape planning: a cautionary note on their uncritical use. *Landscape Research*, *36*(1), 111-117.

Battisti, C., Poeta, G., & Fanelli, G. (2016). An introduction to disturbance ecology. *Cham: Springer*, 13-29.

Caley, M. J., Fisher, R., & Mengersen, K. (2014). Global species richness estimates have not converged. *Trends in Ecology & Evolution*, *29*(4), 187-188.

Cazzolla Gatti, R., Reich, P. B., Gamarra, J. G., Crowther, T., Hui, C., Morera, A., ... & Liang, J. (2022). The number of tree species on Earth. *Proceedings of the National Academy of Sciences*, *119*(6), e2115329119.

Cesi, F. (1651). Plantarum inter se diversitas. Tabulae phytosophicae, XVIIII. In : 'Thesaurus Mexicanus'.

Clapham Jr. W.B. (1973). Natural ecosystems. MacMillan, New York.

Colwell, R. K. (1979). Toward a unified approach to the study of species diversity. *Ecological diversity in theory and practice. International Cooperative Publishing House, Fairland, Maryland, USA*, 75-91.

Contoli Amante, L., & Luiselli, L. (2015). Contributions to Biodiversity Theory: the importance of Formal Rigor. *Web Ecology*, *15*(1), 33-37.

Couvet, D. (2019). Citizen and Landscape Governance. In *Current Trends in Landscape Research* (pp. 287-302). Cham: Springer International Publishing.

Daly, A. J., Baetens, J. M., & De Baets, B. (2018). Ecological diversity: measuring the unmeasurable. *Mathematics*, *6*(7), 119.

Darwin C. (1859). On the origin of species by means of natural selection (Vol. 167). John Murray, London.

Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, *6*(8), 439-447.

Ganis, P. (1991). La diversità specifica nelle comunità ecologiche: concetti, metodi e programmi di calcolo. *Quaderni del Gruppo Elaborazione Automatica Dati Ecologia Quantitativa, Dipartimento di Biologia, Università di Trieste, CETA (International Center of Theoretical and Applied Ecology), GEAD-EQ*, (10), 97.

Gaston, K. J., & Mound, L. A. (1993). Taxonomy, hypothesis testing and the biodiversity crisis. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *251*(1331), 139-142.

Gini, C. (1912). *Variabilità e mutabilità: contributo allo studio delle distribuzioni e delle relazioni statistiche.[Fasc. I.]*. Tipogr. di P. Cuppini.

Grassle, J.F., Patil, G. P., Smith, W., Taillie, C. (Eds) (1992). Ecological Diversity in Theory and Practice. *International Cooperative Publishing House*, Fairland, MD.

Groombridge, B. (1992). Status of the Earth's living resources. *Global Biodiversity*.

Guedes, J. J., Moura, M. R., Jardim, L., & Diniz-Filho, J. A. F. (2025). Global patterns of taxonomic uncertainty and its impacts on biodiversity research. *Systematic Biology*, syaf010.

Hammer, Ø., & Harper, D. A. T. (2001). Past: Paleontological Statistics Software Package for Educaton and Data Anlysis. *Palaeontologia Electronica*, *4*(1), 1-9.

Hill, M. O. (1973). Diversity and evenness: a unifying notation and its consequences. *Ecology*, *54*(2), 427-432.

Hortal, J., De Bello, F., Diniz-Filho, J. A. F., Lewinsohn, T. M., Lobo, J. M., & Ladle, R. J. (2015). Seven shortfalls that beset large-scale knowledge of biodiversity. *Annual review of ecology, evolution, and systematics*, *46*(1), 523-549.

Hurlbert, S. H. (1971). The Nonconcept Of Species Diversity: A Critique and Alternative Parameters. *Ecology*, *52*(4), 577-586.

Ladle, R. J. (2009). Forecasting extinctions: uncertainties and limitations. *Diversity*, *1*(2), 133-150.

Lieth, H. (1975). Primary productivity in ecosystems: comparative analysis of global patterns. In: *Unifying Concepts in Ecology: Report of the plenary sessions of the First international congress of ecology, The Hague, the Netherlands, September 8–14, 1974* (pp. 67-88). Dordrecht: Springer Netherlands.

Likhacheva, E. A., Nekrasova, L. A., & Kladovschikova, M. E. (2019). Geomorphic assessment of terrestrial resources. *Geography, Environment, Sustainability*, *12*(2), 78-86.

Loidi, J., Navarro-Sánchez, G., & Vynokurov, D. (2022). Climatic definitions of the world's terrestrial biomes. *Vegetation Classification and Survey*, *3*, 231-271.

Machlis, G. E., Force, J. E., & Burch Jr, W. R. (1997). The human ecosystem part I: the human ecosystem as an organizing concept in ecosystem management. *Society & Natural Resources*, *10*(4), 347-367.

Magurran A., 2004. Measuring biological diversity. Blackwell Publishing Malden, MA.

May, R. M. (1975, May). Stability in ecosystems: some comments. In *Unifying Concepts in Ecology: Report of the plenary sessions of the First international congress of ecology, The Hague, the Netherlands, September 8–14, 1974* (pp. 161-168). Dordrecht: Springer Netherlands.

Minerbi, S., & Cescatti, A. (2015). Tree volume and biomass equations for Picea abies and Larix decidua in South Tyrol. *For. Obs.*, *7*, 5-34.

Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G., & Worm, B. (2011). How many species are there on Earth and in the ocean? *PLoS biology*, *9*(8), e1001127.

Patil, G. P., & Taillie, C. (1976, August). Ecological diversity: concepts, indices and applications. In *Proceedings of the 9th Int. biometric conference, The Biometric Society* (Vol. 2, pp. 383-411).

Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P., Fernandez-Manjarrés, J. F., ... & Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. *Science*, *330*(6010), 1496-1501.

Segan, D. B., Murray, K. A., & Watson, J. E. (2016). A global assessment of current and future biodiversity vulnerability to habitat loss–climate change interactions. *Global Ecology and Conservation*, *5*, 12-21.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell system technical journal*, *27*(3), 379-423.

Simpson, E. H. (1949). Measurement of diversity. *Nature*, *163*(4148), 688-688.

Trost P., (2022). Quanto è attendibile l'ipotesi di 1000 miliardi di alberi? *Natura e Società 3,* 11-13.

Undheim, T. A., & Ahmad, T. (2024). Quantitative scenarios for cascading risks in AI, climate, synthetic bio, and financial markets by 2075. *Frontiers in Complex Systems*, *2*, 1323321.

United Nations (2019). World Population Prospects 2019, Online Edition. *Department of Economic and Social Affairs, Population Division*, New York.

Wallace, A. (1858). On the tendency of varieties to depart indefinitely from the original type. *J. Linn. Soc. Lond. Zool.*, *3*, 53-62.

Walpole, S. C., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G., & Roberts, I. (2012). The weight of nations: an estimation of adult human biomass. *BMC public health*, *12*(1), 439.

Whittaker, R. H. (1972). Evolution and measurement of species diversity. *Taxon*, *21*(2-3), 213-251.

Whittaker R.H. (1977). Evolution of species Diversity in land communities. *Evolutionary Biology, 10,* 1-67.

Wiener, N. (1948) Cybernetics: Control and Communication in the Animal and the Machine. *John Wiley & Sons*, New York, 194.

Wilkes, M. A., Mckenzie, M., Johnson, A., Hassall, C., Kelly, M., Willby, N., & Brown, L. E. (2025). Revealing hidden sources of uncertainty in biodiversity trend assessments. *Ecography*, *2025*(5), e07441.

Wilson E. O. (1992). The diversity of life. Harvard University press, Cambridge, Massachusetts.