Chapter 1
Biodiversity Healing

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With the Convention on Biological Diversity (CBD) that entered into force in 1993, the conservation of biodiversity was recognized for the first time in international law as "a common concern of humankind" and almost the entire world committed to it. Conserving biodiversity, however, is far from being an easy task, as shown by the difficulties to reach the conservation targets articulated in the strategic plans connected to the CBD. The failure of the 2010 Biodiversity Target "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level" has been explicitly recognized (Butchart et al. 2010). Moreover, there is a widespread scepticism, at present, concerning the possibility of achieving the Aichi Biodiversity Targets by 2020 (Tittensor et al. 2014), i.e., 20 time-bound targets included into the CBD strategic plan 2011–2020 (such as, for instance, making people aware of the values of biodiversity and the steps they can take to conserve it (Target 1) or identifying and eradicating invasive species (Target 9)).[1] Despite increasing communication, accelerating policy and management responses, and notwithstanding improving ecosystem assessment and endangered species knowledge, conserving biodiversity continues to be more a concern than an

[1] For the comprehensive list, see the CBD website: https://www.cbd.int/sp/targets/default.shtml

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accomplished task. Why is it so? The overexploitation of natural resources by our species is a frequently recognised factor,[2] while the short-term economic interests of governments and stakeholders typically clash with the burdens that implementing conservation actions imply. But this is not the whole story. This book develops a different perspective on the problem by exploring the conceptual and practical challenges posed by conserving biodiversity. By conceptual challenges, we mean the difficulties in defining what biodiversity is and characterising that "thing" to which the word "biodiversity" refers to. By practical challenges, we mean the reasons why assessing biodiversity and putting in place effective conservation actions is arduous. In order to situate the multi-farious conceptual and practical challenges faced when trying to outline the path **From Assessing to Conserving Biodiversity**, we think an interpretive device is useful.

An analogy is generally recognised (see, for instance, Soulé 1985; Sarkar 2002; Casetta and Marques da Silva 2015) between medicine—the discipline whose main mission is human health preservation—and conservation biology—the discipline whose main mission is biodiversity conservation. Unusually for sciences, both have a normative dimension. According to this analogy,

> Conservation biology differs from most other biological sciences in one important way: it is often a crisis discipline. Its relation to biology … is analogous to that of surgery to physiology and war to political science. In crisis disciplines, one must act before knowing all the facts. Crisis disciplines are then a mixture of science and art, and their pursuit requires intuition as well as information. (Soulé 1985: 727)

When biodiversity conservation is at issue, theoretical and practical matters go hand in hand, and practical challenges are intertwined with conceptual ones, requiring the cooperation of the natural sciences and of the humanities in a concerted effort. This book, including contributions from biologists and philosophers from different fields and traditions, reflects this necessary multidisciplinarity.

1.1 Assessing and Diagnosing the Patient. Estimating Biodiversity: Data Collection and Monitoring Challenges

Consider a first aspect of the analogy between medicine and conservation biology. The first thing medical doctors have to do when dealing with patients is to assess their general health state and the severity of the condition affecting them. Diagnosis on the basis of the collection of patients' data and their classification, as well as on the measurement and monitoring of symptoms, comes before treatment prescription and provision. In the case of biodiversity, two main kinds of diagnostic challenges

[2] In this sense, Diamond (1989) refers to the "Evil Quartet", the four horsemen of the apocalypse: habitat loss and fragmentation, overharvesting, introduced predators and competitors, and secondary extinction, while E.O. Wilson (2002) expresses similar concerns by characterizing the HIPPO (i.e., Habitat destruction, Invasive species, Pollution, (human) Population growth and Overharvesting).

have to be addressed: on the one hand, the difficulties concerning data collection and systematisation (Chaps. 2, 3 and 4); on the other hand, the choice of the appropriate measurement techniques and ways of monitoring (Chaps. 5, 6 and 7).

Starting with the first challenge, probably the most striking aspect of the living world is its amazing variety, so immense that it eludes even our hardest systematisation attempts. Buffon, in the First discourse of his *Histoire Naturelle* (1749) already highlighted this aspect of the natural world:

> … it takes a peculiar kind of genius and courage of spirit to be able to envisage nature in the innumerable multitude of its productions without losing one's orientation, and to believe oneself capable of understanding and comparing such productions… The first obstacle encountered in the study of natural history comes from this great multiplicity of objects. But the variety of these same objects, and the difficulty of bringing together the various productions of different climates, is another apparently insurmountable obstacle to the advancement of our understanding, an obstacle which in fact work alone is unable to surmount. It is only by dint of time, care, expenditure of money, and often by lucky accidents, that one is able to obtain well-preserved specimens of each species of animal, plant, or mineral, and thus form a well-ordered collection of all the works of nature. (Buffon, *First discourse*, quoted in Lyon 1976: 145)

Things have not become easier over time. Taxonomic knowledge, as all empirical knowledge, is hypothetical in nature, hence always susceptible to revision as new data become available and new theoretical frameworks replace old ones. In such a context, the challenge posed by taxonomic revisions is a *fil rouge* connecting the first three chapters of this part of the book. The puzzle these contributions pose is effectively a taxonomic version of Kuhn's incommensurability thesis: are the data collected and systematised according to a certain taxonomy translatable, so to speak, into another? Notice that taxonomic revisions, either caused by a change in the theoretical framework or by the availability of new data, have important consequences for biodiversity conservation. As Agapow et al. (2004) argued, for instance, a reclassification of endangered species adopting a phylogenetic species concept (which defines a species as a group of organisms that share at least one uniquely derived character) could increase the cost of recovering all species currently listed in the Endangered Species Act from \$4.6 billion to \$7.6 billion.[3] Counting species, and their members, is not only fundamental for assessing the patient's general health state, but it is also for assessing the severity of the condition affecting the patient and, hence, for determining treatments prioritisation.

Chapter 2, *The hidden biodiversity data retained in pre-Linnaean works: a case study with two important XVII century Italian entomologists* by **Francesco Andrietti**

[3] In their article, Agapow and colleagues surveyed the primary literature searching for examples of sets of organisms that had been classified by both the phylogenetic species concept and non-phylogenetic concepts (typically defined, at least for animal species, by means of the biological species concept, according to which species are groups of populations that are reproductively isolated). Reclassifying species under the phylogenetic species concept would lead, this is their conclusion, to an apparent rise in the number of endangered species for two main reasons: the detection of "new" species (for instance by the splitting of "old" ones) and the subsequent reduction in geographic range (a frequently used diagnostic indicator in establishing whether a species is threatened).

and Carlo Polidori, and **Chap. 3**, *Marine biodiversity databanks* by **Anouk Barberousse and Sophie Bary** focus respectively on pre-and post-Linnean archival data on biodiversity: what was the pre-Linnean knowledge on the extent of biodiversity? And how to systematise, today, in digital databanks, the incredible—and at the same time insufficient—amount of information on biodiversity in order to help both researchers and conservationists in their respective endeavors? While in Chap. 2 Francesco Andrietti and Carlo Polidori tackle the issue by analysing a case study, i.e., the classification of Hymenoptera in the pre- and post-Linnean taxonomic frameworks (how to make available today data "on species" collected *before* those species were given their contemporary name?), Anouk Barberousse and Sophie Bary bring to attention the taxonomic vicissitudes of earthworms, from Linnaeus' description to the *Barcoding earthworms* programme. Notice that these two case studies are particularly significant for biodiversity conservation. Several members of the Hymenoptera order (bees, wasps, ants, and parasitoids) are major pollinators, and several members of the family Lumbricidae play a fundamental role within the natural soil ecosystem, as Darwin already recognized in his 1881 book, *The formation of vegetable mould*. In **Chap. 4**, **Anne Chenuil and colleagues** discuss the *Problems and questions posed by cryptic species*: to what extent do nominal species (identified through morphological characters and referred to by Linnean binominal names) and biological species (identified instead typically through reproductive isolation) overlap? In this contribution, a rational and practical classification of cryptic species is proposed, based on the crossing of distinct levels of reproductive isolation with distinct levels of morphological differentiation. The focus is on marine biodiversity, and the conceptual challenge of establishing the possible commensurability between morphological and biological species is taken up with the help of genetic tools, such as genome sequencing and the use of genetic markers, whose impressive development (and rapidly decreasing cost) is allowing identification at an increasing rate of cryptic species, i.e., biological species "hidden" within nominal species.

The second challenge addressed in the first part of the book concerns the choice of the appropriate biodiversity measurements and the ways of monitoring the condition of the patient. Measuring biodiversity is a fundamental operation in biodiversity conservation, for instance because, when we need to choose and implement conservation actions, financial resources are usually limited; accordingly, ecologicals systems and/or places—i.e., specific regions on Earth's surface "filled with the particular results of [their] individual story" (Sarkar 2002)—have to be prioritised and, to do so, biodiversity must be measured. There is widespread agreement that biodiversity cannot be measured directly:

> …conservation biologists almost never measure directly the full range of phenomena that they take to constitute the biodiversity of a system. Rather, they … rely on measurable signs that vary (they believe) with biodiversity itself. Samples and signs are biodiversity surrogates. (Maclaurin and Sterelny 2008, p. 133)[4]

[4] On the "surrogacy problem", see for instance Sarkar (2002).

In a similar way as temperature can be measured by means of a substance, mercury, whose characteristics are particularly sensitive to heat fluctuations and easily measurable, a biodiversity surrogate is thought to be a sort of biological thermometer that would allow to measure biodiversity, even though indirectly. Intuitively, the surrogate *par excellence* seems to be species richness:

> Eliminate one species, and another increases in number to take its place. Eliminate a great many species, and the local ecosystem starts to decay visibly. Productivity drops as the channels of the nutrient cycles are clogged. More of the biomass is sequestered in the form of dead vegetation and slowly metabolizing, oxygen starved mud, or is simply washed away … Fewer seeds fall, fewer seedlings sprout. Herbivores decline, and their predators die away in close concert. (E.O. Wilson 1992, p. 14)

As it can be grasped from the above quote, species richness is considered to be important because it is supposed to be related with the well-functioning or the stability of an ecosystem. But it can be argued that the number of species is not the only surrogate to be taken into account when estimating biodiversity. Another important feature is so-called *evenness*: a biological community, an ecosystem, or a geographical area are said to have evenness when the *abundance* of all species present is similar. However, establishing whether and how surrogates such as species richness and evenness are correlated with one another as well as with patterns of species abundance remains an open theoretical problem that has, moreover, important practical repercussions (for instance, how to infer, from the data collected from an actually sampled area via such surrogates, a possible general estimation of its diagnostic status). **Chapter 5,** by **Luís Borda-de-Água**, *The importance of scaling in biodiversity*, is devoted to these topics, focusing on the species-area relationship (a mathematical expression relating how the number of species changes as a function of the size of the sampled area) and the scaling of species abundance distributions (i.e., the relative abundance of species). **Chapter 6**, *Measures of biological diversity: Overview and unified framework* by **Vincenzo Crupi** is dedicated to diversity indexes, more precisely to the challenge of integrating them in a unified formalism. Here, Crupi presents a unified framework, taken from generalised information theory, to measure biological diversity embedding a variety of statistical measures. While Chaps. 5 and 6 mainly rely on insights coming from information theory, mathematics and statistics to address specific problems primarily related with the choice of the appropriate biodiversity estimation techniques necessary to assess the status of the patient, **Chap. 7**, *Essential biodiversity change indicators for evaluating the effects of Anthropocene in ecosystems at a global scale* by **Cristina Branquinho and colleagues** tackles, from a conservationist point of view, the problem of monitoring the condition of the patient. Once conceded that measuring all forms of biodiversity everywhere and over time is an impossible task, this chapter proposes to broaden the outlook from species diversity to the "essential biodiversity variables" proposed by the Group on Earth Observations—Biodiversity Observation

Network.[5] These include: genetic composition, species populations, species traits, community composition, ecosystem structure and ecosystem function. Putting into practice a global monitoring network to track biodiversity change is far from being an easy endeavour, and the chapter discusses these difficulties as well as suggesting possible solutions.

1.2 Are We Taking Care of the Right Patient? Characterising Biodiversity: Beyond the Species Approach

If measuring biodiversity poses a series of mainly practical challenges, it also opens a Pandora's box of conceptual ones, which are dealt with in the second part of the book. Consider a second aspect of the analogy between medicine and conservation biology. Diagnosis depends on the appropriate characterisation of the biological organism as a unit of medical intervention. Organisms can be decomposed in a variety of entities such as organs, tissues, cells, proteins, genes, microbiotas etc. that interact in the context of metabolic, developmental, immunological, neurological etc. processes. The intervention on the medical patient is thus dependent on the way in which the biological organism is characterised. For instance, we might characterise the organism as made of proteins, and we will be right in treating mad cow disease and Creutzfeldt–Jakob disease. However, not all illnesses are linked to protein abnormalities. Analogously, the biosphere is composed of a variety of entities classifiable in many different ways and interacting in the context of a variety of ecological and evolutionary processes. Species are just one of these entities. To conserve biodiversity by focusing merely on species loss is analogous, let us say, to maintaining the health of an organism intervening on protein deficiencies only.

In this part, two main kinds of foundational issues for diagnosis will be considered: on the one hand, the conceptual challenges in individuating the salient units of biodiversity (Chaps. 8, 9 and 10); on the other, the contrast between entity-based vs. process-based and function-based approaches to biodiversity (Chaps. 11, 12, 13 and 14).

Except for Chap. 7, the implicit underlying assumption of the contributions of the first part of the book is that assessing and measuring biodiversity ultimately amounts to counting species or, at most, taxa. This is probably the most traditional and widely used strategy: counting taxonomic groups and estimating their frequency (Maclaurin and Sterelny 2008, p. 135 ff.). This should come as no surprise. In fact, when it made its appearance in 1986, the term "biodiversity" was, implicitly or explicitly, intended to refer to species diversity. Assessing biodiversity was considered as one and the same thing as inventorying species, and conserving biodiversity consisted in maintaining the inventory. In the words of E.O. Wilson (1992, p. 38):

[5] See: https://geobon.org/ebvs/what-are-ebvs/

> … the species concept is crucial to the study of biodiversity. It is the grail of systematic biology. Not to have a natural unit such as the species would be to abandon a large part of biology into free fall, all the way from the ecosystem down to the organism.

Counting species is relatively easy in practice and theoretically well motivated. In fact, we already possess good (even though neither complete nor fully coherent, as particularly emphasised in Chaps. 2 and 3) species inventories, some fairly reliable ways to recognize them in practice as well as methodologically solid ways of counting them. Moreover, there is a widespread agreement that the concept of species refers to a fundamental unit of biological organisation (Mayr 1988) and that species, by speciating, produce new biodiversity. However, two major problems remain: on the one hand, the concept of species is severely flawed (as the persistency of the so-called "Species Problem" shows, cf. Richards 2010; Zachos 2016) and, on the other, it is questionable whether it can be applied across all branches of the tree of life, for instance to bacterial biodiversity.

Given this state of affairs, a question is in order: if biodiversity has to be conserved, are we describing and treating the right patient when we focus on species or, more largely, on other taxonomic groups? If we give a negative answer to this question, then the conceptual challenge consists in proposing a viable characterisation of biodiversity able at the same time to go beyond a mere species-centred approach (whose merits and limits have been mentioned above) and to account for the variety of entities other than species, and of processes other than speciation, that might be considered targets of conservation practice. But then, an entirely new set of basic challenges, both theoretical and practical, opens up: how can we individuate the salient units of biodiversity? How do such units interact among them within the same and other levels, and how can this interaction give rise to novel diversity? Is it possible to keep together, in an ideally comprehensive account, this enormously complex interplay of units belonging to different levels and describable and evaluable at different temporal and spatial scales? How to bridge epistemologies concerning biodiversity conservation? And how to link these epistemologies with the practical concern of conserving biodiversity? These and similar questions are addressed in the second part of the book.

Notice that, to go back to the medicine analogy, in discussing how the patient should be better characterised, and which of its parts, properties and functions should be emphasised, the chapters in this section do not miss to keeping an eye on the relation between diagnosis and treatment, i.e., on the issue of what it would mean, for conservation purposes, to characterise biodiversity in one way rather than another. The three initial chapters in this part couple evolutionary with conservationist considerations in order to go beyond a species-centred approach by individuating different salient units of biodiversity. In **Chap. 8, Thomas Reydon** suggests an answer to the question: *Are species good units for biodiversity studies and conservation efforts?*, embracing a radical approach: species are not good units of biodiversity; yet, a pragmatic notion of species can be used as an epistemic tool in the context of biodiversity studies. Two other contributions try to characterise biodiversity in a more encompassing way by including other entities. In **Chap. 9**, *Why a species-*

based approach to biodiversity is not enough. Lessons from multispecies biofilms, **Jorge Marques da Silva and Elena Casetta** take a look at the microbial world, where the application of the concept of species is particularly controversial. This chapter suggests that entities such as multispecies biofilms, where interaction among parts gives rise to a putative multispecies individual, might play a crucial role in the generation of biodiversity and that, as a consequence, could be adequate targets of conservation. In a similar spirit, in **Chap. 10,** *Considering intra-individual genetic heterogeneity to understand biodiversity,* **Eva Boon** aims at enlightening an unexplored dimension of biodiversity, again focusing on entities other than species, i.e., multicellular life forms characterized by intra-individual genetic heterogeneity (such as, for instance, genetically mosaic and chimeric entities). This chapter argues that studying biodiversity through the lens of intra-individual genetic heterogeneity facilitates thinking in terms of interactions between biological entities rather than in terms of organismal function, allowing a new light on the ecological and evolutionary significance of biological diversity.

The other chapters in this part also couple evolutionary with conservationist concerns. In order to go beyond a species-centred approach, they focus on the role of processes (other than speciation) and functions (such as, for instance, evolvability, evolutionary potential, plasticity). In **Chap. 11**, *Biodiversity, disparity and evolvability*, **Alessandro Minelli** argues that taxic diversity is not necessarily the most important aspect of biodiversity if what most matters is maintenance of ecosystem function. This chapter articulates a rationale for prioritising focus on those species providing the largest contribution to overall phylogenetic diversity, thus proceeding towards an evo-devo approach to conservation focused on evolvability, robustness and phenotypic plasticity. The potential role of the process of phenotypic plasticity in the production of new diversity is also stressed by **Davide Vecchi and Rob Mills** in **Chap. 12**, *Probing the process-based approach to biodiversity: Can plasticity lead to the emergence of novel units of biodiversity?* This contribution aims to provide a model to test the hypothesis that plastic populations of a species might be considered evolutionary significant units amenable to conservation. In addition to Chaps. 11 and 12, Chaps. 13 and 14 also propose a characterisation of biodiversity based on process and function that reveals a common ontological ground. The rationale of a process-based approach to biodiversity is that a mere focus on entities does not address the issue concerning whether evolutionary and ecological processes have the capacity to create novel, salient units of biodiversity. The suggestion is that a process-based approach should integrate an entity-based one. Process-based and function-based approaches are, as a matter of fact, strictly related to the historical roots of the concept of biodiversity. In fact, while it might be argued that the term "biodiversity" only entered the scientific and public discourse the mid-1980s—i.e., on the occasion of the National Forum on Biodiversity that took place in Washington DC in September 1986 (Takacs 1996)—the concept goes back at least to the diversity-stability debate that animated ecology in the middle of the twentieth century (McCann 2000). Yet, at least in its beginning, conservation biology displayed little interest to previous research in ecology, addressing instead the more pragmatic aspects of conservation. It seemed, in other words, that, as it often happens, two scientific disciplines working on the same subject from different perspectives were talking past each other. This stand-off started to unlock with the Harvard Forest Symposium in 1991, where it was explicitly recognised that, in order to effectively conserve biodiversity, a more precise knowledge of the functioning of ecosystems would be needed (Blandin 2014). In this perspective, it becomes clear that a characterisation merely in terms of species diversity does not seem to fully capture the multitude of dynamical interactions at different levels and scales from which biodiversity results. Again, neither do all species play the same role in a community or in an ecosystem, nor do they have the same evolutionary history and potential. However, when species are counted through indexes, they are treated as being equivalent conservation units; in fact, indexes are not easily able to mirror the possibility that a species may be more important than another for the functioning of the ecosystem. Moreover, in biodiversity conservation, it is not sufficient to preserve current biodiversity, but what is also ideally needed is to maintain diversity in the face of possible future losses; but to do so, a metric able to indicate whether diversity in a certain place is mostly constituted by rare species (that are more likely to go extinct) would be needed. Chapters 13, 14 and 15 are mainly dedicated to ecological theoretical perspectives on biodiversity and to the challenge of connecting evolutionary, ecological, and conservation considerations. Through **Chap. 13**, *Between* explanans *and* explanandum: *Biodiversity and the unity of theoretical ecology*, **Philippe Huneman** clarifies the key-role of the concept of biodiversity in ecology as both an *explanans* and an *explanandum*, while **Antoine Dussault,** in **Chap. 14**, *Functional biodiversity and the concept of ecological function*, elucidates some aspects of the concept of functional diversity. Starting from the assumption that measures of biodiversity based on species richness have epistemological limitations, this chapter explores the notion of "ecological function" and characterises it in non-selectionist terms. Finally, in **Chap. 15**, *Integrating ecology and evolutionary theory: A game changer for biodiversity conservation?*, **Silvia Di Marco** spells out the interaction between conservation science, evolutionary biology, and ecology in order to understand whether a stronger integration between evolutionary and ecological studies might help clarifying the interactions between biodiversity, ecosystem functions and ecosystem services.

1.3 Treating the Patient. Conserving Biodiversity: From Science to Policies

In the light of the ongoing complex work of characterisation of the patient articulated in the various contributions of the previous part, it is not surprising that we do not possess a final, universally agreed upon, definition of "biodiversity". The crucial question is therefore whether putting in place effective conservation actions without a satisfactory definition of "biodiversity" makes sense at all. The third part of the book deals with this issue. Consider a third aspect of the analogy between medicine and conservation biology. After diagnosis and proper characterisation of the unit of medical intervention, medical doctors prescribe treatment. The aim of dispensing treatment is always the benefit of the patient as an organism, however successful treatment is. In the case of biodiversity, there exist incompatible ways to characterise the aim of conservation policies. Part of the treatment problem, to which some contributions of this part are dedicated (Chaps. 16 and 17) is that the term "biodiversity", not being well defined, is potentially used differently by the various actors (e.g., scientists, policy-makers and conservationists) devising and implementing conservation policies. A flipside of the treatment problem can be understood if we take into consideration another facet of the definitional conundrum: the term "biodiversity" might have inherited, from the intentions of its original proponents (Takacs 1996), an intrinsic normative element that has to do with biodiversity protection and preservation. However, normativity poses a series of challenges to which the rest of the contributions of this part is dedicated: the first ones (Chaps. 18 and 19) have to do with the characterisation of normativity while the others (Chaps. 20 and 21) concern the global-local tension of conservation aims and constraints.

In his often-quoted review of definitions of "biodiversity", DeLong (1996) listed no less than 85 definitions. It is thus not surprising that the term is recognised by some authors as remarkably vague (Sarkar 2002). Other authors think that the term is clearly defined or, at least, that conservation science possesses perfectly workable operational definitions to prescribe treatments (Bunnell 1998). The role of definitions in science is controversial. On the one hand, it can be said that "definition is one of the most crucial issues in any science; an improper understanding of it can vitiate the success of the whole enterprise" (Caws 1959). On the other hand, it can be claimed that scientific enterprises can proceed quite well even without having clear, univocal and unambiguous definitions of their key terms. After all, focusing on disciplines like biology and ecology, it is widely recognized that no univocal, universally agreed upon, definitions of terms such as 'life' (Benner 2010), 'organism' (J. Wilson 2000), 'species' (Richards 2010), and 'ecosystem' (Sarkar 2002) can be provided. Still, biologists and ecologists successfully go on with their work. Why would the situation be different in the case of the term "biodiversity"? Following Bunnell's (1998) suggestion, whether a definition plays a crucial role or not in scientific endeavours probably depends on the nature of the specific enterprise at issue. For instance, when J. Wilson (2000) wrote that "Biology lacks a central organism concept that unambiguously marks the distinction between organism and non-organism because the most important questions about organisms do not depend on this concept", he was clearly not making reference to conservationist needs. But where the theoretical enterprise is strictly intertwined with pragmatic objectives, as it is the case with biodiversity studies, things are different.

In particular, two main reasons may be given for why a definition of the term "biodiversity" is needed, together with some reasons for why not having it would be a source of impediments in finding agreed-upon methods to evaluate management and conservation strategies and in the implementation of conservation actions. The first reason is that, unlike other scientific terms, "biodiversity" is supposed to play a unifying role for the plethora of discourses (Haila and Kouki 1994) produced by the different disciplines and actors involved in facing the so-called biodiversity crisis. On the one hand, the term performs a unifying function for the scientific disciplines involved in estimating biodiversity and those studying how it is generated (evolutionary biology, genetics, ecology, biogeography, systematics, and so on), for the disciplines involved in its management and conservation (from environmental economics to conservation biology) as well as for all those socio-political disciplines concerned with the interactions between our species and biodiversity exploitation and conservation (from the social sciences to political philosophy and ethics).[6] Furthermore—but not less importantly—this unifying role serves to make scientific discourses uniform for a variety of social and political actors: from the general public to stakeholders, from governments to policy makers. The term "biodiversity" is often used as a flagship, with no explicit definition provided. However, if scientist and the different social and political actors involved in facing the biodiversity crisis define biodiversity in fundamentally different ways, the agreement necessary to perform common actions could be severely impaired and the presumption that common actions are actually oriented towards the same goal could be false. Accordingly, "to create solutions for biodiversity loss, it is essential for natural and social scientists to overcome such language barriers" (Holt 2006).

Georg Toepfer embraces a different view. In **Chap. 16**, *On the impossibility and dispensability of defining "biodiversity"*, Toepfer argues that it is exactly because the term is vague that the concept of biodiversity is able to tie together many different discourses from the fields of biology and bioethics, aesthetics and economics, law and global justice. **Chapter 17**, *The vagueness of "biodiversity" and its implications in conservation practice*, by **Yves Meinard, Sylvain Coq and Bernhard Schmid,** articulates a different argument. A tension emerges here between the theoretical function of the concept and its pragmatic use: providing concrete case studies to support their argument, the authors suggest that the lack of transparency in using the word "biodiversity" can hide profound disagreements on the nature of conservation issues, impairing the coordination of conservation actions, hiding the need to improve management knowledge, and covering up incompatibilities between disciplinary assumptions.

Sarkar (2002) highlighted a second reason for why a definition of "biodiversity" is needed. It concerns the "sociologically synergistic interaction between the use of "biodiversity" and the growth of conservation biology [that] led to the reconfiguration of environmental studies that we see today". In other words, the term would convey the necessity of conserving something we are losing and we care about. In this respect, the vagueness of the term "biodiversity" implies a lack of clarity as to what has to be conserved. At this juncture, a particularly thorny issue is whether a good definition should reflect the normativity that—according to several

[6] Many concepts may play a similar unifying role in biology and science at large. For instance, the concept of gene is definable in multifarious ways and has undergone a series of profound conceptual transformations. Nonetheless, it has continued to play an important theoretical and heuristic role in classical and molecular genetics as well as in genomics, constraining and directing both the thoughts and actions of biologists (Kay 2000).

philosophers (Callicott et al. 1999; Norton 2008)—is embedded into the concept of biodiversity. Such normativity was presumed in the early literature on biodiversity, like Soulé's (1985) *manifesto* of conservation biology, which included explicit normative postulates besides scientific ones. In **Chap. 18, Sahotra Sarkar** asks: *What should "biodiversity" be?*, and distinguishes between "scientistic", "normativist", and "eliminativist" approaches to biodiversity. In direct dialogue with **Chap. 19**, *Natural diversity: how taking the bio- out of biodiversity aligns with conservation priorities*, in which **Carlos Santana** embraces a strongly eliminativist approach according to which the concept of biodiversity should just be dismissed and replaced by the more encompassing concept of natural diversity, Sarkar instead advocates a strongly normativist position: biodiversity should be understood as a normative concept, although constrained by a set of adequacy conditions that reflect scientific analyses of biological diversity. The main problem with normativism is, of course, as the chapter underlines, that values are usually culture-dependent: global values ranging across cultures are probably a myth, and local norms (supposedly revealed by the local commitments of people living in their habitats) can be in conflict with each other as well as with alleged global values (Vermeulen and Koziell 2002). The last two chapters of the book are devoted to this tension between local and global values. **Andrea Borghini** in **Chap. 20**, *Ordinary biodiversity. The case of food,* focuses on an often-neglected aspect of biodiversity, which might be called "the edible environment". This chapter poses a series of questions concerning the nature of the criteria for inclusion in conservation effort. The way this contribution tries to answer this question is by asking whether these criteria are global or local, whether they are applicable equally to all living entities, for instance to wild and domesticated species alike. Finally, **Markku Oksanen and Timo Vuorisalo,** in **Chap. 21**, *Conservation sovereignty and biodiversity*, look at the "owners" of wild and domesticated biodiversity: on the one hand, states are self-determining actors and the principal possessors of biological resources in their territories but, on the other hand, the actual fragmentation of conservation labour is not always efficient from the conservation perspective. This contribution tries to address this stand-off.

1.4 The Way Ahead: Interdisciplinary Solutions to Biodiversity Healing

Aiming to cover the entire conceptual and practical pathway that leads from assessing to conserving biodiversity, this book highlights some critical issues that must be addressed to foster effective biodiversity conservation. These include both conceptual and philosophical issues as well as scientific and technological challenges. In Part I, concerned with the assessment of biodiversity, it becomes clear that technical and practical advances are needed. From its origins, the study of living beings was mainly concerned with their phenotypes. The main systematic classification efforts, from Buffon to Linnaeus, were built under a phenotypic paradigm. The concept of gene, formally introduced by the Danish botanist W. L. Johannsen in 1909, started its slow way into biology with Mendel's work in the nineteenth century, received a significant boost in the middle of the twentieth century with the unravelling of DNA structure, ultimately becoming dominant in the 1980s, with the development of the polymerase chain reaction and other molecular techniques. This prevalent role of genes in the conceptual corpus of biology was accompanied by the rapid development of gene sequencing technologies. This had a positive effect on the pursuit of biodiversity inventories—think of the use of DNA barcoding—but at the expense of a decrease on the original focus on the description and characterisation of phenotypes. In fact, the number of "classical" (i.e., non-molecular) taxonomists among professional biologists is sharply decreasing (Coleman 2015). Nonetheless, phenotypic studies are still crucial for the inventory of biodiversity—think about the need to correctly identify cryptic species—and for understanding evolutionary trends, given that selective pressures act on individual phenotypes. Fortunately, in the last few years, the scientific community became aware of the imbalance between genotyping and phenotyping efforts and started an international interdisciplinary venture to fix it (Dayrat 2005; Fiorani and Schurr 2013). Adding machine learning and/or multivariate statistics to digital image and/or spectroscopic analysis led to high throughput phenotyping and the new discipline of phenomics (Houle et al. 2010). High throughput phenotyping has so far been used in biotechnology contexts—both medical (Maier et al. 2017) and agricultural (Crain et al. 2018)—but not yet applied to the inventory of biodiversity, except for the artificial biodiversity of agronomic traditional plant landraces (Costa et al. 2015). For instance, the recent global initiative (Soltis 2017) to digitalize the 350.000.000 specimen stored in 3.500 herbaria all over the world may provide the conditions for automated pipeline image analysis and therefore high throughput phenotyping, fostering the understanding of plant biodiversity. Altogether, these emerging trends suggest that a combination of digital image analysis and artificial intelligence techniques has the potential to boost the phenotypic characterisation of the species inventory.

The use of air-born and satellite images for biodiversity studies is not new, but also here the application of automated artificial intelligence-supported image analysis (Keramitsoglou et al. 2004) may help making operational biodiversity units other than species (communities, habitats), as suggested by some contributions to Part II. Also, the new generation of earth observation satellites, with their increased capacity for remotely estimating ecosystem functions (e.g., photosynthetic production, Joiner et al. 2011) may help making operational the concepts of process-based and function-based approaches to biodiversity conservation defended in other contributions to Part II. Moreover, the emerging extension of bioinformatics to phenotypic analysis, through the development of controlled phenotypic ontologies (Mungall et al. 2010), led to the novel concept of "computable phenotypes" (Lussier and Liu 2007; Deans et al. 2015). Phenotypic ontologies, in conjunction with ecological ontologies (Madin et al. 2007), open new avenues to unravel evolutionary trends. This putative in-depth understanding of phenotypes might contribute to the integration between ecology and evolution, a need emphasized in several contributions to Part II. All these new approaches are strongly interdisciplinary.

Interdisciplinary science still faces, however, a series of constraints (institutional, financial, sociological, epistemological, Vasbinder et al. 2010; Marques da Silva and Casetta 2015) that must be overcome to foster biodiversity knowledge.

Part III discusses the problem of biodiversity definition and its consequences for conservation policies, also addressing the possible relation between mainly epistemological issues (such as measuring, inventorying and, indeed, defining biodiversity) and mainly axiological and moral issues (i.e., concerning, respectively, the possible value of biodiversity and our correct behaviour towards it). This discussion is not new. In the early 1970s Arne Naess developed the concept of "methodological vagueness" (Glasser 1998). The aim was to broaden the support basis of his deep ecology political project. Arguably, the vagueness of the biodiversity concept might play a similar role in biodiversity conservation. The incapacity to clearly identify the object to be conserved might not be an unbearable burden, since targeting a set of closely related objects might have an additive positive effect on biodiversity conservation (albeit this could be a problem when resources are scarce and a prioritisation of conservation targets is needed). Even if we come to a universally shared definition of biodiversity, the ethical question whether we should be committed to biodiversity conservation remains, and the axiological problem persists. Some contributions to Part III address the tension between local and global values. In this respect, moral and political philosophy, for instance theoretical bioethics and environmental ethics, may provide useful resources to enlighten conservation policies. At the same time, part of moral philosophy provides compelling arguments against cultural relativism. This is not to deny, however, that there are cultural differences between societies and that these differences might dictate different biodiversity conservation policies. In fact, institutions such as as the Indigenous Peoples' Biodiversity Network are deeply concerned with this issue. Here, theoretical bioethics might help. For instance, Engelhardt Jr. (1986), working in a medical bioethics context, argued that in multicultural societies there are fundamental incommensurable moral tenets. His bioethical system, therefore, renounces to achieve the ultimate bioethical "truth" and, instead, provides a framework to reach "minimum operational agreements" between multicultural stakeholders, i.e., it becomes a framework for "moral diplomacy". Efforts to clarify the intrinsic value of natural diversity, however, still persist in environmental ethics. Departing from peculiar systems of environmental aesthetics, contemporary authors such as Allen Carlson (2000) and Holmes Rolston III (2002) aim to provide a universal system of recognition of the intrinsic value of natural diversity. Ongoing global scientific, technological, conceptual and normative efforts aim to provide better policies and programs for biodiversity conservation. The success in preventing the so called Big Sixth mass extinction is dependent on this global interdisciplinary collective effort.

Needless to say, the aim of this book is neither to provide a set of contributions that are exhaustive of the virtually unlimited issues raised by biodiversity studies and conservation, nor to solve problems once and for all. The attempt is rather to provide a tool for teaching and for research on a topic that by its own nature is hugely complex and multidisciplinary, without falling into the temptation of simplifying the conceptual and practical challenges involved. On the contrary, we think that bringing such challenges to the fore and thematising them might be a fruitful research approach. We hope the reader will enjoy the book and, above all, find it stimulating and useful.

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