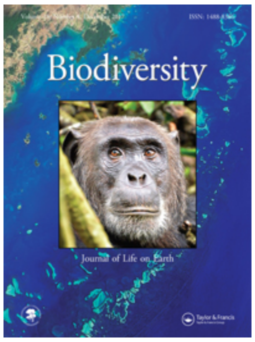

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A century of biodiversity: some open questions and some answers

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Introduction

The study the biodiversity is not just an attempt to understand the differences or similarities between species, habitats or genomes. It also includes an understanding of how nature regulates the processes that characterise ecosystems and ensure their functionality. It means as well to increase the ability to predict the impact of current and future anthropogenic actions on nature (Midgley et al. 2002).

Biodiversity is what makes the Earth a unique planet. In the Universe, for all we know, or at least in our galaxy, life is the exception rather than the rule (Dick 1999). And even if a day when we are able to document the presence of living beings on other planets will come, this will also be an exception. The appearance of life is a phenomenon that has always fascinated mankind since without it, our human species would have never existed and no hairless biped would have studied life, with great admiration, and destroyed it with equal force (Cardinale et al. 2012).

Species themselves are a mystery like the very existence of life (Wiley 1978). Why has evolution led to the 'endless beautiful forms', as Charles Robert Darwin called them, instead of letting one, amazingly adapted, dominate the evolutionary line?

In recent years the advancement of ecological sciences allowed a better understanding of some fundamental biodiversity patterns (Gaston 2000). In less than a few decades most of the answers to the key issues about biological diversity have been enriched with new hypotheses and theories (Ricklefs 2004). However, many other questions are still open.

Some (partially or completely) resolved questions about biodiversity

(a) What is biodiversity?

Most ecological models that try to explain biodiversity are too simplistic and are often considered outdated (Cazzolla Gatti 2011; Connell 1980). Moreover, recently, the principles based on competitive exclusion (Gause 1934) for the explanation of biodiversity have been criticised from both theoretical and empirical approaches (Cazzolla Gatti 2016a).

It has been, therefore, suggested that niches are important to attain a genetic equilibrium that favours species (Levine and HilleRisLambers 2009) and facilitates the creation of new niches (Gatti, Hordijk, and Kauffman 2017a). What has emerged is that to reach a thorough understanding of the evolutionary dynamics of biodiversity, which could somehow explain the current distribution patterns and mechanisms of coexistence, we must consider both the biogeographic and phylogenetic approaches (Cazzolla Gatti 2016b; Pimm et al. 2014).

(b) Why are there so many species in the world?

The idea that life needs other life forms in order to continue to exist, and thrive, has been frequently stressed in the last years (Bastolla et al. 2009; Cazzolla Gatti 2011). Thanks to species by-products which emerged when the first living organism appeared on Earth this has certainly favoured the evolution of other species (Wilkinson 2006). Over time, biodiversity emerged (Cazzolla Gatti 2016a; 2017a; Guill and Drossel 2008).

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A new formulation of the ecological niche concept – which no longer sees a niche as a static set of conditions and rules referred to any species, but rather as a dynamic evolution of potential and unprestatable 'biological spaces dependent on the species diversity' – has been proposed (Cazzolla Gatti 2011). This network of relationships is enriched with new connections each time a node is produced by the network (i.e. through facilitation, autopoiesis and autocatalysis; Gatti, Hordijk, and Kauffman 2017a).

(c) What are the main drivers of biodiversity evolution?

After a critical review of the different kinds of speciation, over the years many authors have attempted to understand why the competitive exclusion principle has long been considered as a general low to explain biodiversity (Connell 1980; Tilman 1994; Vandermeer et al. 2002). Some of them argued that the likely reason lies in the fact that ecologists have not questioned some of the principles of natural selection. A new conceptual model was recently proposed (Cazzolla Gatti 2016a). It was developed in an attempt to unify the new trends in biodiversity and evolutionary science. It argues in favour of the importance of avoidance of competition, cooperation, biological history, symbiosis (endosymbiosis and endogenosymbiosis) and three-dimensionality, as the main forces that structure the biological diversity of ecosystems.

(d) How is biodiversity arranged in space?

Ecologists argued that the exceptional diversity of species on Earth is, at least, partly due to the different ways in which species that are potential competitors have evolved traits that make them specialised and able to partition the exploitation of resources (Chesson 2000; Finke and Snyder 2008; Loreau and Hector 2001; Schoener 1974). However, it has been also suggested that biodiversity is autopoietic (Cazzolla Gatti 2016a; Fath et al. 2007; Ulanowicz 1998) and autocatalytic (Gatti, Hordijk, and Kauffman 2017a), because it is a system able to produce more of its own complexity than that produced by its environment. Biodiversity (as an autopoietic and autocatalytic system) requests more energy (solar light) and dissipates more entropy (waste disordered energy) than a not-autopoietic/not-autocatalytic system.

The biodiversity-related niches differentiation theory (BNDT) has been proposed to stress that the process of niches differentiation is strictly addressed and driven by species (Cazzolla Gatti 2011). This theory suggests that the number of niches in an ecosystem depends on the number of species present in a specific moment and that the species themselves allow the enhancement of niches in terms of space and number. Each species plays a fundamental role in facilitating the colonisation of the other species, by simply modifying the basic environment and exponentially increasing the available niches' dimension (Cazzolla Gatti 2011). Niches emergence is autocatalytically facilitated by the presence of biodiversity itself. The fact that biodiversity can be considered as a system of autocatalytic sets (Gatti, Hordijk, and Kauffman 2017a) offers a possible answer to the fundamental question of why so many species can coexist in the same ecosystem.

(e) Can we explain biodiversity global gradients?

For over two centuries, scientists have tried to disentangle the spatial patterns of fine-scale and global biodiversity gradients in order to understand how biodiversity is distributed on the planet (Rahbek 1995; Wallace 1878). Given that some places on Earth are home to more species than others, an important biogeographical property of biodiversity is the latitudinal gradient of species richness. Many hypotheses have been proposed – often empirically tested – to become real theories (Hillebrand 2004; Kraft et al. 2011; Wilson and MacArthur 1967) in order to explain this distribution gradient. These have been divided into two broad categories: biogeographical/evolutionary and ecological hypotheses. Almost all of them are, however, not mutually exclusive and, at the same time, do not completely explain this gradient (Currie et al. 2004; Jansson and Davies 2008).

However, one of the most corroborate ecological and evolutionary hypotheses (Hutchinson 1959; Pianka 1966) is that climate (C) influences net primary production (NPP) in such a way that, by raising/lowering the available biomass (B), and so increasing/decreasing the number of individuals (I), it 'controls' the number of species (S). So far, the C→NPP→I→S causal relationship has not been clearly demonstrated because it does not seem mediated directly by biomass (Currie et al. 2004). In other words, there is no reason to believe that areas with higher biomass would also have higher biodiversity. It could also be that a few species with many individuals accounts for most of the biomass in the ecosystems.

By suggesting that the latitudinal gradient of biodiversity can be, instead, explained as differences in the fractal dimension of the ecosystem niches, it has been shown that it is not the number of individuals or the biomass that influence species richness, but rather the extent of climate and primary production on niche variables. In other words, it has been proposed that biodiversity, in addition to being autopoietic and autocatalytic, is also fractal (Cazzolla Gatti 2016b).

(f) How much does an area and volume influence biodiversity?

The species–area relationship (SAR) is another old pattern studied in ecology (Connor and McCoy 1979). Its implications are relevant for many ecological, evolutionary, conservation and biogeographic purposes. Conversely, the associated Volume-Species Relationship (VSR) has been almost ignored although it may play a fundamental role in ecology (Cazzolla Gatti et al. 2017b), and it is relevant for many different ecological aspects, such as the estimation of minimum viable populations and species ranges, as well as the planning of protected areas, etc. This new perspective was investigated, looking at the canopy height as a proxy of the ecosystem volume (a sort of 'biospace' according to Susmel 1980), which influences plant richness in forest ecosystems (Cazzolla Gatti, Vaglio Laurin, and Valentini 2017c; Cazzolla Gatti et al. 2017b).

(g) Is there a link between ecosystem functions and biodiversity?

How biodiversity relates to ecosystem functions and productivity has been a widely studied and a highly controversial issue over the past few decades. Initially, many research approaches (Grace 1999; Leibold 1999; Tilman, Wedin, and Knops 1996; Tilman et al. 1997) showed that the relationship between species richness and NPP could be visualised as a hump-shaped or a modal curve, with richness first rising and then declining with increasing productivity. However, subsequent theoretical and empirical research, including meta-analyses, seriously diminished the acceptance of the modal pattern as a canonical relationship (Hooper et al. 2005; Thompson et al. 2009). Field experiments to test the degree to which diversity affects community productivity (e.g. biomass) have had variable results (Hector et al. 1999; Tilman, Wedin, and Knops 1996). However, a preliminary global analysis shows a correlation between plant species richness and carbon in alive biomass with an hump-shaped distribution (Cazzolla Gatti R. and Di Paola A., unpublished).

(h) How Gaia's biodiversity makes Earth alive?

The idea that life affects the development of the planetary environment, which, in turn, affects the future evolution of life in a co-evolutionary way is well-accepted now (Gould 1988). Nevertheless, since the proposal of the Gaia hypothesis (Lovelock 1972) many criticisms have been suggested (see Volk 2002 and Turney 2003 for a summary). Most of them are related to teleology, the absence of natural selection operated at universal scale and the lack of planetary reproduction (Tyrrell 2013). Even if some of the problems concerning the 'internal' logic of the idea have been resolved (Lenton 1998, 2004), whether Earth can be considered a unit of selection, and therefore Gaia can adapt according to Darwinian evolution, is still an open question. It has been recently proposed (Cazzolla Gatti Forthcoming) why and suggested how, a Gaian system composed by biotic (the biosphere) and abiotic (the geosphere-atmosphere) interacting and coevolving elements, should be considered alive, in any evolutionary senses. It has been shown that without invoking teleology, so without any foresight or planning, a Gaian planet can be considered a co-evolutionary system analogous to a multicellular body: a super-unit of selection.

Five situations according to which Gaia is able to reproduce and to transfer her planetary genome to other uninhabited or inhabited planets have been described. Then, it has also been suggested that Gaia can face exclusion–competition–coexistence states depending on the fitness of her biota compared to those of the other reproducing biospheres. This demonstrates that Gaia can reproduce and evolve in competition-cooperation with other planets. Some deep implications arise from these pieces of evidence (Cazzolla Gatti Forthcoming).

Mechanisms such as trade-offs (Wilkinson 2006), portfolio effect (Tilman et al. 1997), biodiversity-related niches differentiation (Cazzolla Gatti 2011), facilitation and avoidance of competition (Cazzolla Gatti 2016a) and insurance hypothesis (Yachi and Loreau 1999) all contribute to stabilise the effects of biodiversity on Gaia, making this latter a liveable, and an alive, planet.

(i) What is the impact of economic growth on biodiversity?

Contrary to what many economists suggest (*The Economist* 2013) development is not always good for Nature (Cazzolla Gatti 2016c). In fact, the fact that biodiversity and ecosystems are fundamental to sustain humanity and life on Earth is a well-accepted theory, but during the last three centuries (since the industrial revolution), heavy pressures due to overexploitation have been put on nature (Butchart et al. 2010; Daily and Ehrlich 1992). At the same time, environmental protection is gaining increasing interest due to a better understanding of the interconnection between human wellness and ecosystem health (Ehrlich and Ehrlich 2012).

One theory suggests the problem lies in that even if the will to follow a sustainable lifestyle in the 'Western countries' is increasing, many developing countries are currently experiencing their phase of economic growth, threatening and overexploiting their environment. By comparing the trends of the living planet index (LPI) and the human development index (HDI) in an economic-ecologic historical analysis, it has been proposed

(Cazzolla Gatti 2016c) that societies follow common patterns of development, towards a 'developed' society where each society exploits local, regional and sometimes global natural resources in order to reach its economic growth.

Further overexploitation of natural resources, during the growing phase of human populations, would impede to keep alive most of the global biodiversity and ensure the providing of ecosystem services that sustain humanity.

(j) What are the effects of climate change on biodiversity?

Climate change alone is expected to threaten with extinction approximately one quarter or more of all species on land by the year 2050, surpassing even habitat loss as the biggest threat to life on land (https://chge.hsph.harvard.edu/climate-change-and-biodiversity-loss). One of the main reactions of ecosystems to climate variations is the change of species distribution. Displacements of entire biological communities to the poles and the mountain tops to cope with the rising temperatures and expand the distribution areas to past prohibitive places have been revealed (Beckage et al. 2008; Thomas, Bulman, and Wilson 2008). The same species composition of ecosystems is changing (Bunker et al. 2005; Lemoine, Schaefer, and Böhning-Gaese 2007). The species richness changes and this affects ecosystem function (Hellmann et al. 2008; Levinsky et al. 2007; Rahel and Olden 2008). Even the structure of ecosystems is rapidly changing in response to climate variations (Banerjee, Cazzolla Gatti, and Mitra 2017; Phillips et al. 2009; Biggs et al. x2007).

There is much evidence suggesting how the grasslands and savannahs, along with coral reefs and mangroves, are among the most endangered ecosystems (Biggs et al. 2008; Del Grosso et al. 2008; Lough 2008; Salazar, Nobre, and Oyama 2007). Within the American prairies trees are expanding and replacing herbaceous plants, and fires no longer follow historical seasonal trends with the typical herbivores of these ecosystems moving northward or, otherwise, to the tops of mountains. Individual species, by varying the distribution ranges, are also changing the dispersion centres and their abundances (Carroll 2007; Moritz et al. 2008). Specialist species and those with reduced areal receive special attention by ecologists because they risk more than generalist species (Clavel, Julliard, and Devictor 2011; Doody et al. 2006).

Yet, it has been shown (Hannah 2014) that climate change is also accelerated by positive feedbacks due to some species expansion (e.g. the albedo effect due to the invasion of glaciated areas by vegetation).

Some open questions about biodiversity

In the previous section, a summarised review of the answers (partial or almost final) to some of the big questions about biodiversity has been proposed. Here I will resume some open questions that still remain unanswered. Most of these issues, still in need of a solution, will address future research plans for biodiversity.

(a) Why are some species abundant and others rare?

Ecological communities are composed of species, some of which are very abundant, and others which are highly rare. It is commonplace to consider the high evenness and low dominance as an indicator of high diversity, but this is not always true for all ecosystems. It is interesting to observe that usually a handful of species contributes to most of the abundance of a sample, while the rare species contribute to the diversity of the system. There is a great debate on the role of rare and dominant species (Lyons et al. 2005; Emery and Gross 2007). The first appears to ensure resilience (the ability to recover from a disturbance) of the ecosystem, while the dominant species are often called keystone species as they ensure the maintenance of ecosystem functions (Gaston and Fuller 2008; Mouillot et al. 2013; Smith and Knapp 2003).

Species-abundance distributions (SAD) and related plots have the ability to shed light on the processes that determine the biological diversity of a given ecosystem (Cazzolla Gatti 2014; Magurran 2004). Nevertheless, there is still a need for a much better understanding of the processes that influence the relative abundance of species, and that determines why some species are abundant and others are rare (Magurran 2013; Messina et al. 2016). A better understanding of the processes that shape diversity over both macroecological and local assemblage scales (McGill 2011) will be fundamental to answer the question around why species abundances are as uneven as they are.

(b) Is the intermediate disturbance hypothesis testable?

It is well known in ecology that environmental disturbances may affect the diversity at a species community level (Gaedeke and Sommer 1986; Hubbell et al. 1999; Müller et al. 2002). However, the diversity can also moderate the severity of the disturbance leading to the variation of the frequency, intensity or duration of the effective biomass loss in community with different initial numbers of species (Sousa 1984). Many studies have attempted to empirically test the intermediate disturbance hypothesis (IDH). The IDH, originally presented as an explanation for plants and sessile species (e.g. corals and trees) diversity, argues that an intermediate disturbance frequency or intensity can maximise diversity (Hutchinson 1953; Molino and Sabatier 2001).

Nevertheless, the diversity-disturbance curve may have a variety of different shapes and many communities show no IDH effect due to competition from either exclusion or dominance, because many species are able to use the third-dimensional space (i.e. volume) avoiding competition in the two-dimensional one (i.e. the surface) (Cazzolla Gatti 2011). Similarly, especially at low-frequency disturbance, the IDH often does not apply to mobile species because of reduced competitive exclusion (Stachowicz 2001) and to communities characterised by high complexity of habitats and, therefore, with a greater volume of niche (Cazzolla Gatti et al. 2017b). In general, the disturbance decreases species diversity only when it is high in frequency or intensity in the experimental manipulations (Kondoh 2001).

To better answer the question whether the IDH is correct, it is important to consider that a disturbance for one species can be a benefit for another and that it is impossible to know what a disturbance is without prior experimentation (Bertrand et al. 2009). Moreover, richness and evenness respond differently to disturbances and this can be the reason why IDH applies at some times and not others (Sommer 1995). To test the IDH, it is fundamental to know life histories and dominance/rarity patterns of the analysed community.

(c) Is there a maximum amount of the global biodiversity?

If biodiversity is indeed autocatalytic (Gatti, Hordijk, and Kauffman 2017a), does it follow a sigmoidal growth over time, as every autocatalytic reaction normally does? Consider, for example, the trends of the number of genera during the Phanerozoic Eon (Rohde and Muller 2005), which follows a hyperbolic growth curve. If the answer to the above question is positive, this curve should (in absence of major catastrophic events) eventually reach a saturation and show a sigmoidal curve. Can we predict it by, for instance, the differential equation of the BNDT (Cazzolla Gatti 2011)?

(d) What is a species?

'The species – wrote Albert Mousson (1849), a Swiss physicist and biology enthusiast – is the total of individuals, interconnected by descent and reproduction, maintaining unlimited reproductive capabilities'. Later Mayr (1942) proposed the biological species concept (BSC) that 'species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups'. However, he terms 'reproductively isolated' should be taken quite loosely, allowing for limited gene exchange (Coyne and Orr 2004).

The problem of BSC arises when working with asexual microorganisms, particularly bacteria. In this case, a useful approach is to take into account that despite the relative free incorporation of novel genes in this group of species, there are some 'non-exchangeable' genetic sequences between lineages, because the recombinant form would kill or be harmful (Sherratt and Wilkinson 2009). This fact can be a good way to discern if a bacterial species has 'reproductively isolated sequences' in order to apply the BSC.

Yet, given the gap between DNA-based concepts (mainly for asexual species) and the traditional morphospecies notion (mainly for sexual species), the question is how much genetic difference justifies a new species?

(e) Are neutral approaches useful for understanding biodiversity?

Neutral models are based on the idea that a minimal set of assumptions and variables could explain a system (Gotelli and McGill 2006). In ecology, random distributions are assumed to be tested against different hypotheses. In other words, the *simplest* explanation is frequently the *best*. The theory of island biogeography (MacArthur and Wilson 2015) was one of the first null models in ecology. Then, Stephen P. Hubbell (2001) proposed the unified neutral theory of biodiversity and biogeography (UNTB), which assumes that all species belonging to the same trophic level of an ecological community are 'neutral' in relation to their evolutionary fitness. This implies that there are no real differences between the niches of each species and their success being dictated by the randomness of the moment.

Although this theory predicts very well the distribution of species by means of a dynamic balance of immigration, speciation and extinction, its main merit is its ability in reassessing the importance of niches in the maintenance of biodiversity (Dornelas, Connolly, and Hughes 2006). In fact, the UNTB cannot be easily transferred in nature where a number of variables, such as environmental heterogeneity, biotic communities, and coevolution, move the debate in favour of the differentiation of niches (that is: species are unique).

The lognormal distribution model fits more data sets of biological diversity than the neutral model of biodiversity (McGill 2003). Yet, it has been shown (Gaston and Chown 2005) that neutrality can be considered as the basis for the subsequent separation of ecological niches.

Thus, the open question is: what degree of prediction is possible with the neutral theory of biodiversity?

(f) Is the natural history of biodiversity a (predictive) science?

Most of the hypothesis proposed for the coexistence of species does not take into consideration the importance of contingencies and natural histories over biological diversity. It has been suggested (Cazzolla Gatti 2016a) that a thorough understanding of the evolutionary dynamics of biodiversity, which could somehow explain the current distribution patterns and mechanisms of coexistence must consider the biogeographic and phylogenetic pathways (Cowie and Holland 2006; Faith 2002). However, natural history has a negative reputation among classic ecologists because it is a descriptive and not experimental (which do not allow predictions) branch of science (as well as astronomy and geology). Nonetheless, natural history is the study of the specific contingencies of places and a basic knowledge of it can strengthen the ability to predict biodiversity patterns. Yet, other open questions follow: how the knowledge of the natural history of biodiversity can allow us to predict future changes in species composition? What ecological prediction, based on the natural history of biodiversity, we could be able to provide?

(g) Are there predictable rules to evaluate the success of an invasive species?

Alien species are rarely able to settle into intact ecosystems, which have not been subjected to anthropogenic stresses such as pollution, fragmentation, selective logging or hunting, etc. (MacDougall and Turkington 2005; Vaglio Laurin et al. 2016). When an allochthonous invasion takes place, it is very unlikely for the invasive species to completely eliminate the endemic one, which usually tends to reduce its own density or migrate to neighbouring areas, if it has the phenotypic plasticity to do so (DeWitt and Scheiner 2004). This could also be due to the fact that diversity increases the stability of an ecosystem (Tilman, Reich, and Knops 2006). Though, in rare cases, resource and habitat limitations may lead to the extinction of native species (Sax and Gaines 2008).

Habitat similarity, invasion frequency, human disturbances, evolutionary strategies (K or r selection) and species richness of the invaded area contribute to predicting the success of an invasive species (Kolar and Lodge 2001; Sakai et al. 2001). If we were able to measure all these variables and to estimate the biodiversity of a site, could we say with a high confidence whether an alien species will survive (and supplant others)?

(h) Is it possible to predict the effect of biodiversity on ecosystem functions?

Ecosystem function is the basal processes of an ecosystem and includes, for instance, primary production, respiration, nutrient cycling and detritivory. Numerous studies on terrestrial (Bertness and Leonard 1997; Tilman, Reich, and Knops 2006;) and aquatic (Covich, Palmer, and Crowl 1999; Power 1990; Swan and Palmer 2006) ecosystems have shown a positive correlation between biodiversity and ecosystem functions, such as productivity and respiration. However, it is still difficult to define one overarching relationship between these two variables. It seems that there is a saturation of the ecosystem function (respiration, productivity, etc.) over a certain level of richness, which follows a sort of logistic curve (Schwartz et al. 2000; Srivastava and Vellend 2005). Functional redundancy and the specific species involved (and their abundances) are key elements in this relationship.

An emerging issue is that facilitation plays an important role in increasing community diversity, which in turn influences the ecosystem function (Bruno, Stachowicz, and Bertness 2003; Cardinale, Palmer, and Collins 2002; Cazzolla Gatti 2011).

The predictability of this relationship still remains an open, and very relevant (also considering the current high anthropogenic impact on ecosystems) question about biodiversity.

(i) How many species are too few to keep ecosystems healthy?

The health level of an ecosystem is strongly dependent on its functionality (Schaeffer, Herricks, and Kerster 1988). Given there is a relationship between biodiversity and ecosystem functions, even if it is still not completely clear and difficult to predict, the minimum number of species needed to keep an ecosystem in a good status depends on the above-mentioned considerations. If enlarged on a global scale, this could provide an answer to the next query.

(j) How many groups of species (guilds) are needed to avoid Gaia collapse?

The fact that the biota on Earth can maintain in different ways, even if not always clear, favourable conditions for living beings, is now accepted with a few minor oppositions (Lovelock 2000; Margulis and Sagan 2000). The Gaia theory suggests that organisms interact with their inorganic environment on Earth to form a mutualistic–synergistic self-regulating and complex system that helps to maintain and perpetuate the conditions for life on the planet (Lenton 1988; Lenton and Lovelock 2000). This idea proved that the biosphere and the evolution of life forms affect ocean salinity, the stability of global temperature, the maintenance of a hydrosphere of liquid water, oxygen in the atmosphere, and other ecological variables that affect the habitability of Earth (Lovelock 2003). Trade-offs, by preventing that one or two species monopolise the planet, allow speciation (Wilkinson 2003). In fact, if one species would be good at everything, as a super generalist then the niche concept would be useless (Wilkinson 2006).

We know that the huge biodiversity resulting from trade-offs has a positive effect on Gaia because it stabilises the planet conditions more than if Earth were inhabited by just a few of species (Lenton and Wilkinson 2003). What we do not yet know, is how much biodiversity is needed to keep the planet alive. That is, how many species (or how many guilds) are necessary to the maintenance of favourable conditions for life on Earth? In other words, is there a kind of no-return point? Can we identify this number and the 'fundamental' species/guilds?

(k) How many, and which, species will adapt to sudden anthropogenic climate change?

Climate change is also affecting species and ecosystems, and is causing a loss of genetic diversity of populations that are confined in a shrinking area (Campbell et al. 2009; Hannah 2014).

Recently more attention has been put on the fact that the species themselves can increase (with positive feedbacks) the consequences of climate change (Araujo et al. 2005).

All this demonstrates that climate, atmosphere and biodiversity are deeply integrated and that any alteration of the balance can have unpredictable effects (Williams et al. 2008). The problem lies not so much in the change itself, given that the Earth over a 4.6 billion year period has undergone enormous climatic and geological upheavals (Crowley 2000), but rather in the rapidity of the change. The Gordian knot is the velocity with which these climatic changes are happening (Loarie et al. 2009). Up to now species have had (evolutionary) time to adapt to the slow physicochemical changes that occurred on the planet (and they, in turn, moderate them with feedbacks). Today, however, we are seeing rapid and radical changes that have occurred in just a few decades, mainly since the start of the industrial revolution (Burrows et al. 2011).

I would argue that the answer to how species will adapt to this sudden change of their ecosystems, is one of the most important questions of the Millennium.

Conclusions

It has only been in recent years that we have witnessed an alarming rate of extinction of species and the loss of ecosystems which has attracted international attention. 2010 was proclaimed by the UN the 'International Year of Biodiversity' and was an attempt to capture the attention and imagination of the world to recognise and come to terms with 'the issue of the inexorable depletion of the planet's environment as a result of the destruction of habitats and ecosystems'.

From the discovery of agriculture, through the industrial revolution and up to now, humans have reshaped landscapes, modified ecosystems and caused the extinction of many species.

The importance of biodiversity has been internationally recognised by the Convention on Biological Diversity (CBD) of 1992. It identified three main goals for humanity: '(i) conserve biological diversity; (ii) use it sustainably; and (iii) share the benefits derived from it in a fair and balanced way'.

The CBD asserts that signatory countries must meet 'a significant reduction in the rate of impoverishment of biodiversity at the global, regional and national levels with a view to contributing to poverty alleviation and to the benefit of all life on Earth'. A target was even added in 2007, during the World Summit for Durable Development of the United Nations (held in Rio de Janeiro), to the Millennium Development Goals (MDGs).

All this, however, has in no way stopped the loss of biodiversity on Earth. Economic and short-term interests of most heads of states and multinationals, the indifference of many citizens and a growing world population, especially in developing countries, are likely to undermine any international agreement. If we do not stop immediately the depletion of marine and terrestrial habitats, the study of biodiversity will be considered as the shortest duration science that has ever existed.

At this point, it is critical for us human beings to understand that equality holds in the needs, feelings, rights, duties, sense of belonging to the Earth, in accordance with the universal laws of Nature, but that diversity is, instead, in the complexity and wonder of that universal exception that is Life. Trying to answer some of the questions related to biodiversity is an attempt to know it better, to protect it more.

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