From Aristotle's Teleology to Darwin's Genealogy

The Stamp of Inutility

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Translated from the Italian by James Douglas

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For Giaime Marcello

Contents

Linnaeus and Cuvier have been my two gods,
though in very different ways,
but they were mere school-boys to old Aristotle.

Charles R. Darwin, Letter to William Ogle,
Down, February 22, 1882.

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Introduction

> So what hinders the different parts [of the body] from having this merely accidental relation in nature? As the teeth, for example, grow by necessity, the front ones sharp, adapted for dividing, and the grinders flat, and serviceable for masticating the food; since they were not made for the sake of this, but it was the result of accident. And in like manner as to the other parts in which there appears to exist an adaptation to an end. Wheresoever, therefore, all things together (that is all the parts of one whole) happened like as if they were made for the sake of something, these were preserved, having been appropriately constituted by an internal spontaneity; and whatsoever things were not thus constituted, perished, and still perish.[1]

Charles Darwin inserted this extraordinary passage from Aristotle's *Physics* in a long note in 'An Historical Sketch of the Recent Progress of Opinion on the Origin of Species' with which the fourth edition of the *Origin of Species* (1866) opens, commenting: 'We here see the principle of natural selection shadowed forth, but how little Aristotle fully comprehended the principle, is shown by his remarks on the formation of the teeth.'[2] With this brief comment, very cautiously, Darwin partially transposes and then translates the ancient intuition on adaptation, extinction and randomness into the new-born system proposed by the theory of descent with modifications by variation and selection. Aristotle is thus explicitly counted among the precursors of the concept of evolution in the text which was about to irrevocably change the destiny of contemporary biology.

The interpretation proposed, however, not only errs on account of its partiality, but also represents a memorable oversight. It is true that the text contemplates the possibility of extinction and the birth of new species, which Darwin interprets in terms of the principle of natural selection. However, in addition to this, it also lays out a heuristic template that rests substantially on the idea of explaining natural processes as random. Thus, a random combination of organs leads either to the generation of adapted individuals – that is, of species that preserve themselves – or to the generation of non-adapted individuals – that is, of species that become extinct. It is randomness that is Aristotle's main theme here. Darwin's interpretation is, therefore, partial.

Darwin's interpretation, moreover, demonstrates a memorable oversight because when the passage is drawn to his attention – by way of a letter from Clair James Grece[3] – he completely mistakes the origin of the ancient intuition, most likely because he had never opened Aristotle's *Physics*.[4] The notion that contemplated the extinction of species and thus 'shadows forth' the principle of natural selection is not Aristotle's, but Empedocles'; in fact, in its entirety the last phrase of the quoted passage reads: 'and whatsoever things were not thus constituted, perished, and still perish, as Empedocles says of his "man-faced oxen".'[5] Actually, here, Aristotle is discussing Empedocles' biological theory in order to subject it to a ferocious critique aimed at demolishing its basic presupposed theoretical principles. The systematic recourse to randomness had to be proscribed, or rather marginalized, in favour of an eminently finalistic approach. More precisely, the priority given to the search for 'final causes' was emphasized, as emerges unequivocally from what follows immediately after the passage cited by Darwin:

> Such and suchlike are the arguments which may be urged in raising this problem; but it is impossible that this should really be the way of it. For all these phenomena and all natural things are either constant or normal, and this is contrary to the very meaning of luck or chance. [...] Accordingly, if the only choice is to assign these occurrences either to coincidence or to purpose, and if in these cases chance coincidence is out of the question, then it must be purpose. But, as our opponents themselves would admit, these occurrences are all natural. There is purpose, then, in what is, and in what happens, in Nature.[6]

This is an argument that – as we shall see in Chapter 1 – is nothing but a restatement of the solidly teleological orientation at the basis of the entire Aristotelian naturalist edifice, both in physics and in life sciences, centring on the thesis that 'all provisions of nature are means to an end, or must be regarded as coincidental to such means.'[7] In short, in all his treatises Aristotle never tires of repeating that nature does nothing in vain, nothing useless, nothing superfluous, nothing random, nothing without a purpose; hence the affirmation of the age-old motto *natura nihil frustra facit* (nature does nothing in vain). It is a motto that should be understood not so much as a general regulatory principle of enquiry but rather as a fundamental theoretical presupposition. Every part, every organ of every living being has an explicit end; therefore, analysis must always strive to demonstrate that everything is useful directly, or indirectly, for a specific purpose. The paramountcy of the principle of utility is established. In Aristotelian terms, it is always the 'final cause' that must be identified.

This teleological framework rests in turn on a second presupposition, concerning the structure of the overall system of living species, according to which nature has made, and then distributed, organs to each species with the aim of ensuring its preservation. Indeed, Aristotle considers and then reaffirms the classical notion that nature, behaving like a wise man, adopts a pseudo-egalitarian criterion for the distribution of 'means of defence' – that is to say, of organs and mental faculties so that all living species are able to preserve themselves over time notwithstanding constant conflicts between them (predators *versus* prey, and so on). What follows is a static and harmonious equilibrium which precludes, *pace* Empedocles, the possibility of any species becoming extinct. This permanence is further supported, on an ontological level, by the so-called 'essentialist' thesis, according to which each species can be traced back to an unalterable and unengenderable essence, given always and forever – thus fixed for eternity – which is passed down (through semen) from generation to generation. Essentialism thus radically marginalizes the epistemic significance of contingent and random variations observed in generational processes.

In short, when, in undertaking an enterprise of such momentous importance, Aristotle proceeded to construct the life sciences from scratch, he developed an extraordinary naturalist edifice of great analytical complexity and theoretical refinement. At the same time, he created the openly anti-Empedoclean teleological, essentialist and fixist framework, which Darwin's theory subverts. The closer Darwin may be to Empedocles's intuition, the further away he is from the theory effectively outlined by Aristotle. In other words, while, with regard to Empedocles, we may be dealing with a meaningful but actually rather vague convergence, with regard to Aristotle, the distance is clearly defined and on deeper analysis is revealed to be a direct counter-position. Schematically, the three core elements of the theory of descent with modifications by variation and selection give a clear and precise negation of the three cornerstones of the Aristotelian framework. (1) The descent with modifications thesis is set against the ahistorical thesis of the fixity of species. (2) The appreciation of individual variations is set against anti-random essentialism. (3) The recourse to natural selection, and so to extinction, is set against immanent functionalist organs/ends teleology and its systemics. It is precisely this radical counter-position that makes Darwin's oversight so significant and interesting, in the first instance, on a historiographical level.

Darwin's misunderstanding throws light, in an extraordinarily emphatic way, on the nineteenth-century disavowal of the fact that the traditional fixist, essentialist and teleological framework had Aristotelian roots. The disavowal is based on eighteenth-century scientific culture, when the influence of the Peripatetic treatises had become ever more indirect. This was because it was being exerted increasingly through the writings of sixteenth- and seventeenth-century authors, such as Cesalpino and Harvey – all openly Aristotelian – and then through naturalists, such as Ray and others, in whom it was partially clothed in a markedly theological disguise. This disavowal and disguise in the late seventeenth century is attributable to many factors. Amongst others, there was the decline in the authority of Aristotle as a natural scientist occasioned by the great seventeenth-century scientific revolution, as well as the revival of the centrality of creationist dogma within the framework of natural history. This long-term process continued into the twentieth century. Despite the fact that in the last decades of that century many contributions emerged showing how, in the realm of the life sciences, the Aristotelian framework was still very much alive throughout the first half of the seventeenth century (see the works of Pagel, Schmitt and Berti), very little was written on the influence, direct and especially indirect, that Aristotle exerted on natural theology and on the overall conceptual framework of traditional natural history in the eighteenth and nineteenth centuries. Indeed, most of these studies concentrate in particular on the positive impact of the Aristotelian tradition on the seventeenth-century progress in the life sciences, starting from their appreciation of observation, cardiocentrism and epigenism – the influence of the latter orientation was actually also analysed in the eighteenth century. However, the dialectic between the late seventeenth- and then eighteenth-century heritage of the theoretical Peripatetic system in its entirety and the emergence of transformist and evolutionary theories that signalled its demise, has hardly ever been tackled. What I hope to achieve with this work is to contribute to the reconstruction of this development in its entirety.

I will proceed from the basic thesis that (a) the conceptual system, the template, or what I prefer to call the framework, which almost uninterruptedly determines the course of modern natural history up to the birth of evolutionary biology is of an Aristotelian mould, and that (b) the evolutionary revolution is therefore to be interpreted as the abandonment and overturning of this framework. This approach immediately implies a revision of the classic argument of the perfect and exact correspondence between fixism and creationism in favour of a more nuanced vision of their convergences, which rests on a broader reconstruction of the traditional fixist framework, both in theoretical and historiographical terms. When the historical perspective is opened up, so as to proceed from the origins of the traditional concept, it becomes clear that its cornerstones rest rather on the reception and reinterpretation of the Aristotelian treatises begun by late medieval Scholasticism and revived in the Renaissance. In more detail, I will try to show that it was primarily on the theoretical and conceptual structure (teleology, essentialism, fixism, and so on), on the analytical and doctrinal apparatus (empirical observations, classifications, dissections, and so on), and on the categorical equipment (notions of 'species', the form/material dichotomy, and so on) of the life sciences forged by Aristotle that the multiple variants of late medieval and Renaissance creationist doctrines and, especially indirectly, eighteenth- and nineteenth-century natural theologies were projected, re-modulated and readapted.

The idea that will be my guiding light in this is that it is not the meagre Old Testament conceptual apparatus, nor least of all its literal interpretation, that provides the principles, the tools and the methods utilized to re-establish and develop natural history throughout the course of modernity. Under a more or less thick religious skin, the theoretical kernel remained as Aristotle had devised. What this means is that I do not share the classic historiographical thesis that tends to consider the dogma of creation the most important element in the overall theoretical framework of the traditional fixist vision. The creationist dogma, although absolutely central throughout modernity, did not invalidate the Peripatetic system. On the contrary, it was reconciled, from the thirteenth century onwards – as happened in the realm of physics – with the atemporal and eternalist structure derived from the 'photographic' approach also adopted by Aristotle in his treatises on living things. The entire system of species, like the order of the cosmos, continued to be understood as fundamentally static, governed by an overall equilibrium which guaranteed forever the preservation of each species, whose adaptation to their own environment nature had wisely provided for. It was always against this teleological nucleus, around which the concept of the 'admirable adaptation' of species was developed, presented moreover in the religious guise of natural theology, that the first transformist and evolutionary theorists, Darwin included, had to measure themselves. By adopting this historical perspective, the direct contraposition of Darwinian theory and Aristotelian concept which we began with is therefore configured as an overturning of the teleological, fixist and essentialist tradition.

Now, this reinterpretation of the general course of modern natural history and of the evolutionary revolution, undertaken from the perspective of the centuries-old persistence and then abandonment of the Peripatetic heuristic teleological apparatus, opens up several promising, relatively unexplored, avenues both on the historiographical and theoretical fronts. I will attempt to develop them gradually, proceeding with a rigorously chronological reconstruction, from the past to the present, from Aristotle to Darwin, in the hope that the succession of topics and lines of argument may be more linear, more fluid and easier to follow. For greater clarity I have divided the text into two parts: Part I is dedicated to an outline and acknowledgement of the supremacy of the teleological framework driving the modern Aristotelian tradition from its original foundation to its late medieval revival, and on to Linnaeus' eighteenth-century *systema*. It is a trajectory that, having outlined the structure of the Peripatetic edifice, I will rapidly retrace: I will consider only some of the authors that I believe are expressions of scientific-philosophical tendencies and long-term schools of thought. Part II is dedicated to the scientific milestones which led to a (partial and relative) resolution in Darwin, due to the crisis the traditional framework underwent in the eighteenth century, especially in the debate between Lamarck and Cuvier. Here, I concentrate mostly on the framework of the theory of descent with modification in relation to the heritage of ancient teleology. My approach ultimately leads me to a brief overview of the fundamental revisions effected in the twentieth century of the system of the *Origin of Species*. The two parts each contain three chapters, arranged as follows.

In Chapter 1, starting from the criticism levelled at Empedocles, I will briefly reconstruct the theoretical framework of the life sciences devised by Aristotle. I will especially concentrate on the three pillars that would be inherited by modern natural history: the thesis on the fixity and immutability of species over time; the correlated essentialist concept, which systematically marginalizes the theoretical role of randomness; and the teleology immanent in nature. I will concentrate on this last element in particular. In fact, teleology represents the fundamental pillar upon which Peripatetic physiological anatomy is constructed, centring on the idea of the solid and atemporal correspondence between organs and functions and thus also on the priority accorded to functions. Furthermore, I will sketch the related systemic concept underlying the empirical analysis, according to which living species are in a harmonious equilibrium that precludes their extinction. Species are distributed along a *scala naturæ* at the top of which stands humankind. While tracing these coordinates, at the same time, I will focus attention on the question of the inutility or indeed harmfulness of certain organs discussed in the ancient treatises, such as the wings of flightless birds, the unseeing eyes of the mole and the antlers of deer. These were themes which posed serious problems for Aristotle, and for which he never managed to find a perfectly coherent solution, thus leaving lacunae, tensions and even contradictions nestling at the heart of his system. And it was these identical questions that were taken to heart, after many centuries, by the young Darwin, who used them as a tool to undermine the ever-pervasive recourse to final causes in the new-born science of 'biology'.

In Chapter 2 I will come to the late medieval and modern Aristotelian tradition. I will proceed here from the thesis that, exactly as in the case of physics and astronomy, Western life sciences were re-established thanks fundamentally to the reception, assimilation, institutionalization, reinterpretation and conciliation with the creationism of the theoretical, categorical and doctrinal apparatus gleaned from the *corpus aristotelicum* which occurred especially from the thirteenth century onwards. I will therefore depart again from the classic and almost undisputed historiographical thesis that the natural sciences were reborn as Aristotelian sciences, and remained so until about the middle of the sixteenth century, to concentrate instead on the life sciences. I will give a brief overview of the development of life sciences until the late sixteenth century, to then concentrate on the radical separation of these sciences from physics and astronomy.

I will show in detail how the criticism put forward by Galileo of the epistemological framework of Aristotle's physics revolved particularly around an endorsement of mathematization (in many ways of a Platonic nature). Galileo's approach was one that was not efficaciously transposed – despite reiterated attempts on the part of the Cartesians – to the realm of living things, as is crystal clear in the methodological nature of Harvey's revolution, and more generally in his contributions to physiology. Harvey in fact returned to and explicitly revived the teleological framework developed by Aristotle, linking it to a distinct experimentalism, so bringing it up to date in a Galilean sense too. This was the system that remained predominant, although no longer exclusive, in the life sciences.

In Chapter 3 I will proceed rapidly with a reconstruction of certain turning points along the path taken by modern natural history, concentrating on the period that stretches from about the middle of the seventeenth century to the middle of the eighteenth century, continuing to proceed from the perspective of the influence of the Aristotelian apparatus. I will maintain that it held an indirect supremacy: even though there was a process of gradual disavowal and in a certain sense repression of the Peripatetic paternity of the traditional teleological, fixist and essentialist framework, its theoretical nucleus continued to remain the original Aristotelian one. I will deal first with Ray, showing how his natural theology fundamentally represents a form of 'Christianised Aristotelianism' (as John Greene defined it).[8] I will then move on to Linnaeus' *systema*, again highlighting the principal lines of continuity between his concept of *œconomia naturæ* and the Aristotelian heritage, despite the ruptures and novelties introduced by the great eighteenth-century naturalist.

So, in Part I, I will try to show that in the realm of the life sciences the theoretical pillars of the Peripatetic edifice, regrafted on to Western culture in the late medieval period and revived in the Renaissance, survived not only Galileo's breakthrough, but also the entire seventeenth-century scientific revolution, to arrive, renewed in an experimental sense, at the eighteenth century. In other words, disregarding an analysis of the mathematicizing tendencies of the Cartesians, which I consider relatively marginal with respect to the path followed by the majority of the protagonists of natural history, I will try to support the thesis that the persistence of the fixist, essentialist and especially teleological framework which extended up to the first transformist and evolutionary theories can, and in my opinion must, be interpreted as a long-term effect of post-Renaissance Aristotelianism, as an expression of the *longue durée* of this framework. It amounts to an attempt to relocate it within the grand traditions of thought that determined the coming into being of the life sciences from the late Middle Ages, passing through the seventeenth-century revolution, up to the late nineteenth century.

In Chapter 4, which opens Part Two, I will sketch the main turning points in the crisis of the Aristotelian framework, in a certain way emerging around the middle of the eighteenth century on philosophical ground from authors such as Maupertuis and La Mettrie, but then triggered in fact by the transformist theories proposed by the naturalists, in the strict sense of the word, in the following decades, and exacerbated at the dawning of the nineteenth century by the contributions of Lamarck. Concentrating on the negative aspect of this process of abandonment, I will show that Lamarck's work can also be reinterpreted as an attempt to demolish the traditional fixist, essentialist and teleological framework to be found in the Aristotelian heritage. I will then emphasize how, despite these repeated attacks, the fixist system continued to play a leading role in the international community until around the middle of the nineteenth century. In this regard, I will adopt the concepts of 'crisis' and 'hegemony' to underline the fact that we are dealing with a now only relative supremacy, reaffirmed from time to time through bitter conflict between antithetical positions regarding the theoretical cornerstones of the edifice of natural history. I will concentrate in particular on the spirited defence of the fixist system undertaken by Cuvier, who comes to represent the last great heir and exponent of the modern Aristotelian tradition. With the adoption of a historiographical perspective centred on the long-term persistence of the Peripatetic system, it will become possible to elucidate the vicissitudes of so named 'fixism'. It will also then be possible to trace the process from the indisputable supremacy of fixism to the crisis which befell it, and which was initially only partially resolved by its revival.

In Chapter 5, moving from France to England, I will try to reconstruct the main stages of the process by which Darwin, picking up the threads of the crisis in which the fixist thesis had landed itself and so reworking the previous transformist contributions (from Erasmus Darwin to Lamarck), arrived at an original solution to the classic question of 'admirable adaptation'. This is a problem concerning the theoretical nucleus which was incessantly reintroduced by natural theologians especially in the Anglophone world. It is indeed the tradition reintroduced in the late seventeenth century by authors such as Ray and taken up again at the beginning of the nineteenth century by Paley and others. In this regard, I will show how Darwin's overcoming of this classic question amounts substantially to the elaboration of a framework capable of eclipsing the functionalist and systemic teleological system originally conceived by Aristotle and then inherited and developed in modernity.

Close up, we shall see how the young Darwin originally discussed his first intuitions of the mechanism of natural selection in the literal sense of a 'final cause' and how he at the same time expressed a strong resistance, along the lines of Bacon, to readopting such an instrument. This resistance, in a very brief period of time, took the form of a theoretical battle against the pervasive recourse made to final causes. This battle was developed above all in terms of an epistemic appreciation of those aborted and atrophied organs bearing, that is, the 'stamp of inutility'. Darwin thus understands these organs as direct evidence of the 'absence of final causes' and thus, more generally, of the inadequacy and contradictoriness of traditional natural theology. The latter, which thus has recourse to 'final causes', betrays the fact that it contains within itself, as its basic theoretical nucleus, the ancient finalistic concept devised by Aristotle.

In Chapter 6 I will focus attention on the teleological character attributed to one of the meanings of the principle of natural selection, rereading it in the light of Aristotelian theory. Here, I will propose a reinterpretation of the classical convergences observed between Darwinian selection and Peripatetic teleology (see especially the work of Lennox and Gotthelf) not as evidence of the currency of Aristotle's thinking in the evolutionary context but rather as theoretical archaisms: signs, traces of the process of gradual abandonment of the framework and traditional conceptual apparatus that develops in the course of the construction of the theory of descent by modification. While again recalling the ambivalence shown by the young Darwin with regard to the discussion of final causes, I will show it was especially the systematic recourse to extinction that rendered his juvenile orientation ever more obsolete. I will come to some of the twentieth-century revisions made to the teleological character of Darwinian selection and to the full re-evaluation of randomness reintroduced by 'modern evolutionary synthesis' (that is, the theory generated by combining genetics and Darwinism) and never abandoned since. I will conclude with a very brief discussion of the teleologism of the contemporary adaptationist programme (along the lines laid out by Gould and Lewontin).

So in Part II, I will try to reconstruct the profile of the evolutionary revolution, from a negative point of view, as a process of gradual overturning of the theoretical framework conceived by Aristotle and guiding modern natural history. This is a breakthrough that would come to be reconfigured, with respect to the seventeenth-century scientific revolution, as a diachronic detachment from the self-same original theoretical stock, but that was achieved thanks to a fundamentally historical, and not mathematical, approach. I will insist in particular on immanent critique, developed on the level of physiological anatomical analysis, with regard to the recourse to final causes and on the level of the related principle that *natura nihil frustra facit*. It is criticism that contemplates an endorsement of randomness. This is a perspective which at the same time as it recalls the two axes of historicity and randomness, precluded by Aristotle's system, I believe allows us to reinterpret the evolutionary revolution – borrowing the celebrated definition by Alexandre Koyré of the seventeenth-century revolution in physics as 'the revenge of Plato',[9] and retaining the sense of the Darwinian quotation from the passage from *Physics* – as 'the revenge of Empedocles'.

Part I

The Aristotelian Teleological Tradition

1
The Original Framework

1 Consistency

The original framework conceived by Aristotle in constructing the edifice of the life sciences is quite coherent, despite the wealth of suggestions, perspectives, analyses, definitions, conceptual shifts, methods of classification, principles and assumptions that fill the vast amount of literature dedicated to them. There is a consistency deriving in the first place from the theoretical centrality attributed to teleology and to the search for final causes. This perspective emerges from the brilliant and celebrated passage in which, in the first book of *Parts of Animals*, Aristotle resolutely defends the dignity in studying every living thing, even the most humble of plants and animals, precisely because in such scientific activity the purposefulness present in the works of nature is discovered, and consequently, the realm of Beauty is revealed.

> Of the works of Nature there are, we hold, two kinds: those which are brought into being and perish and those which are free from these processes throughout all ages. The latter are of the highest worth and are divine, but our opportunities for the study of them are somewhat scanty, since there is but little evidence available to our senses to enable us to consider them and all the things that we long to know about.
>
> We have better means of information, however, concerning the things that perish, that is to say, plants and animals, because we live among them; and anyone who will but take enough trouble can learn much concerning every one of their kinds.

> Yet each of the two groups has its attractiveness.[...] [I]t now remains to speak of animals, and their Nature. So far as in us lies, we will not leave out any one of them, be it never so mean; for though there are animals which have no attractiveness for the senses, yet for the eye of science, for the student who is naturally of a philosophic spirit and can discern the causes of things, Nature which fashioned them provides joys which cannot be measured. If we study mere likeness of these things and take pleasure in so doing, because then we are contemplating the painter's or the carver's Art which fashioned them, and yet fail to delight much more in studying the works of Nature themselves, though we have the ability to discern the actual causes – that would be a strange absurdity indeed.
>
> Wherefore we must not betake ourselves to the consideration of the meaner animals with a bad grace, as though we were children; since in all natural things there is somewhat of the marvellous. There is a story which tells how some visitors once wished to meet Heraclitus, and when they entered and saw him in the kitchen, warming himself at the stove, they hesitated; but Heraclitus said, 'Come in; don't be afraid; there are gods even here.' In like manner, we ought not to hesitate nor to be abashed, but boldly to enter upon our researches concerning animals of every sort and kind, knowing that in not one of them is Nature or Beauty lacking.
>
> I add 'Beauty,' because in the works of Nature purpose and not accident is predominant; and the purpose or end for the sake of which those works have been constructed or formed has its place among what is beautiful.[1]

Proceeding from the realm of Beauty, in the effective development of his research into living things, the priority attributed to the end to which organisms have been constructed comes to be translated into a somewhat negatively nuanced motto, which would leave its mark on the entire course of modern natural history: *natura nihil frustra facit* (nature does nothing in vain). This is a principle that is continually reiterated and made use of: Aristotle mentions it dozens of times, often varying its form, but not its substance. Nature never does anything in vain, does nothing useless, does nothing superfluous and does nothing by chance or without an aim but always wisely and to an end.[2] It is a purpose that ultimately coincides with the well-being of the organisms themselves and with their preservation. More precisely, every mechanism of nature is designed to generate, devise, produce, predispose, prepare and distribute parts, organs and faculties that will be useful for organisms. Utility, and also the lack of extravagance or superfluousness, therefore becomes the controlling factor in the analysis of the mechanisms of living nature.

This idea, which is also expressed in an image of domestic economy, quite faithfully reflects the way in which many close examinations elaborated in the corpus were developed: 'Like a good housekeeper, Nature is not accustomed to throw anything away if something useful can be made out of it.'[3] Utility reigns supreme.

Given the centrality of teleology, and proceeding from the perspective of clarifying the cornerstones which would then form the basis of modern natural history, I will immediately show the two other pillars on which the Aristotelian edifice of the life sciences were constructed. They are the marginalization of a systematic recourse to randomness and the correlated essentialist concept of the fixity and immutability of species over time, safeguarded on the dual planes of epistemology and ontology. While sketching the main points, I will concentrate on the basic concept of Peripatetic physiological anatomy. I will demonstrate that nature, which never does anything randomly, but wisely shapes organs with the aim of guaranteeing organisms a certain vital function and not vice versa, thus ensures the preservation of the species. It also achieves a perfect and solid correspondence both between organs and functions and between species and the environment. The fixity of species over time, complementing the immutability of the environment, and more generally the cosmos, is at the same time also guaranteed by a functionalist perspective: the wisdom of nature is such that it has always ensured, and will always ensure, a perfect adaptation to every living being, forestalling in this way any possibility that any species could become extinct.

Finally, we shall see that this rigorously teleological framework did, however, pose problems to Aristotle himself, primarily because he identified and discussed obviously useless parts and organs, as in the conspicuous case of the wings of birds 'not adapted to flight'. To confront this difficulty, he had recourse to both the level of necessity and the classical concept by which nature, adopting a compensatory criterion of distribution, concedes a single means of defence to each species, thus guaranteeing the overall equilibrium of the system. This is a criterion that is shown to be pseudo-egalitarian when one considers the hierarchism of living forms, at the apex of which humankind stands supreme. And it will be in continuing an analysis of the tensions generated by the teleological-functionalist approach that I will finally seek to show how Aristotle, in tackling the problems of parts and organs that are not only obviously useless but in his opinion also actually damaging, such as the antlers of deer, may have placed within his own analytical framework some questions subsequently proving to be inimical to the integrity of his postulates. That same acute, profound and uninhibited capacity for observation and the collecting of empirical data which contributed in such a decisive way to the extraordinary Peripatetic naturalistic edifice on the one hand clashes with, and on the other is absorbed and neutralized by, the relative consistency of that teleological, essentialist and fixist framework whose basic theoretical principles held sway up to the turn of the nineteenth century just when, from a different perspective, the question of inutility was being put forward again.

2 To the margins

Aristotle's criticism of Empedocles' historic concept of living beings – which later aroused the interest and admiration of Darwin – also took into consideration the theory of generation that it presupposed:

> For the things which come-to-be naturally all come-to-be, either always or generally, in a particular way, and exceptions or violations of the invariable or general rule are the results of chance and luck. What, then, is the reason why man always or generally comes-to-be from man, and why wheat (and not an olive) comes-to-be from wheat? Or does bone come-to-be, if the elements are put together in a certain manner? For, according to Empedocles, nothing comes-to-be by their coming together by chance but by their coming together in a certain proportion. What, then, is the cause of this? [...]. No: the cause is the substance of each thing and not merely, as he says 'a mingling and separation of things mingled'; and chance, not proportion, is the name applied to these happenings: for it is possible for things to be mixed by chance. The cause, then, of things which exist naturally is that they are in such-and-such a condition, and this is what constitutes the nature of each thing, about which he says nothing. There is nothing 'About the Nature of Things' in his treatise. And yet it is this which is the excellence and the good of each thing, whereas he gives all the credit to the mixing process.[4]

Given the decisive priority of the beauty and the good of the substance of each thing, randomness was thus not banished: in fact, a decisive role in certain specific generative processes is attributed to it. Such a possibility having been recognized, it is, however, immediately marginalized and undermined on both the analytical and theoretical levels. It is marginalized in the sense that Aristotle adopts the general principle by which 'chance and lucky events are the contrary of that which always or normally is or comes to pass'.[5] More specifically, within the realm of living things, he employs the notion of randomness to explain the deformations of maimed organisms, thus transposing his general principle to the specific principle by which 'nature does nothing in vain, and omits nothing essential, except in maimed or imperfect animals'.[6] Maimings and imperfections are thus interpreted as the outcome of accidental – that is, potentially infinite – causes. In more detail, in the course of the realization of a finite datum (*telos*), events exist, potentially unknown to us, which break up the linearity of the causal chain, thus precluding the full and 'correct' realization of the intended process. These events are therefore 'exceptional' in the sense of being irregular, sporadic deviations which do not always nor generally occur[7] and which within the ambit of reproductive processes give life to maimed and imperfect organisms or 'monsters'.

Such marginalization of randomness, accomplished by means of the frequency of accidental deviations, is accompanied by the radical undermining of its theoretical-systematic basis, as emerges from the analysis of particular individual differences. Aristotle indeed also attributes processes of a random nature to certain slight differences observed in single organisms of the same genus: 'We must now study the "conditions" in respect of which the parts of animals differ. I mean such conditions of the parts as the following: blue and dark colour of the eyes, high and deep pitch of the voice, and differences of colour and of hair or feathers. Some of these conditions are found throughout certain classes of animals; some occur irregularly, and a striking instance of this is afforded by the human species'.[8] Given this fundamental distinction between the characteristics belonging to a genus and those inscribed within them randomly, Aristotle can neutralize the capacity of the latter:

> When we come to consider these conditions and all others like them, we must not suppose that the same sort of cause is operative as before, for there are certain conditions which are not characteristics belonging to Nature in general, nor peculiarities proper to this or that particular class of animal; and whatever the quality of such conditions may be, in no instance is either existence or its formation 'for the sake of something'. Thus, the existence and the formation of an

> eye is 'for the sake of something', but its being blue is not – unless this condition is a peculiarity proper to the particular class of animal.[9]

Thus, such accidental characteristics, certainly attributable to random processes, are removed from the definition of the class and, in this way, undermined at source, while at the same time the primary function attributed to the essence, as well as to necessity, comes speculatively into play: 'And further, in some cases this condition has nothing to do with the *logos* of the animal's being; instead of that, we are to assume that these things come-to-be by necessity, and so, their causes must be referred back to the matter and to the source which initiated their movement.'[10]

3 Fixed in time

The abovementioned theoretical centrality, conferred on the level of essences, species and genera with regard to the individual, rests in turn, although indirectly, on the presupposed basis of the fixity and immobility of the species. Here, too, we can again refer to the criticism directed against the systematic recourse to randomness:

> So Empedocles was wrong when he said that many of the characteristics which animals have are due to some accident in the process of their formation [...]: he was unaware (a) that the seed which gives rise to the animal must to begin with have the appropriate specific character; and (b) that the producing agent was pre-existent: it was chronologically earlier as well as logically earlier: in other words, men are begotten by men, and therefore the process of the child's formation is what it is because its parent was a man. Similarly too with those that appear to be formed spontaneously [...].
>
> So the best way of putting the matter would be to say that because the essence of man is what it is, therefore a man has such and such parts, since there cannot be a man without them. If we may not say this, then the nearest to it must do, viz. that there cannot be a man at all otherwise than with them, or, that it is well that a man should have them. And upon these considerations follow: Because man is such and such, therefore the process of his formation must of necessity be such and such and take place in such a manner; which is why first this part is formed, then that. And thus similarly with all the things that are constructed by Nature.[11]

Thus, it is because humans have such essence that they have these parts – essence that is passed down from generation to generation, through seed; and so, it is because it must be either in absolute terms or at least because it is good that it should be so, therefore not by random processes. This basic notion dovetails perfectly with the concept of the fixity and immutability of species (*eide*) outlined in *Metaphysics*: the *eidos* of single living things represents, and reproduces in their offspring, the form of the species (*eide*); in animals, this is done through sperm, which 'contains the form potentially'.[12] It is more than plausible to understand that species are for this reason eternal and certainly immutable, although this is not directly stated. Since in fact 'no one generates or creates the form (*eidos*)', nor is *eidos* subject to corruption,[13] it necessarily follows that living species, as species, cannot be subject to modifications: they are always and forever fixed in time. The incessant generations and corruptions of living beings therefore seem to be inscribed within a granite-like eidetic framework: immutable, ingenerable and eternal.[14]

It is certainly true that in his voluminous treatises Aristotle did not always maintain a clear distinction between genus (*genos*) and species, and he also failed to provide a single definition of the two notions.[15] It is also true that Aristotle contemplated processes of hybridization, spontaneous generation and the hereditariness of acquired characteristics.[16] Despite his contemplation of these processes, it is equally true that the thesis of the immutability of species (and/or genera) clearly stands out at the descriptive level, as emerges in *Generation of Animals*: 'if the products were dissimilar from their parents, and yet able to copulate, we should then get arising from them yet another different manner of creature, and out of their progeny yet another, and so it would go on *ad infinitum*. Nature, however, avoids what is infinite, because the infinite lacks completion and finality, whereas this is what Nature always seeks.'[17] And again it emerges, especially where we read: 'Of the things which are, some are eternal and divine, others admit alike of being and not-being [...] that which comes into being is eternal in the manner that is open to it. Now it is impossible for it to be so numerically, since the "being" of things is to be found in the particular, and if it really were so, then it would be eternal; it is, however, open to it to be so specifically. That is why there is always a class of men, of animals, of plants.'[18]

This idea that plants and animals could participate in eternity on the level of the genus led to a reinforcement of the overall perspective directed at privileging the processes of generation and preservation of the species on the level of single individuals, as also emerges in *On the Soul*:

> For this is the most natural of all functions among living creatures, provided that they are perfect and not maimed, and do not have spontaneous generation: *viz.*, to reproduce one's kind, an animal producing an animal, and a plant a plant, in order that they may have a share in the immortal and divine in the only way they can; for every creature strives for this, and for the sake of this performs all its natural functions. 'That for sake of which' has two meanings: (1) that for the purpose of which, and (2) that for the benefit of which. Since, then, they cannot share in the immortal and divine by continuity of existence, because no perishable thing can remain numerically one and the same, they share in these in the only way they can, some to a greater and some to a lesser extent; what persists is not the individual itself, but something in its image, identical not numerically but specifically.[19]

The concept of the immutability of species over time thus provides one of the fundamental cornerstones of both the epistemological and the ontological frames of reference of the life sciences. Despite the ontological priority originally granted to the substance, such disciplines came to involve the study of entire species as immutable essences in themselves, thus disregarding single individuals.[20] This theoretical shift was in turn in a certain sense a paradoxical consequence of the comprehensive operation undertaken by Aristotle when he proceeded to revolutionize Plato's dualistic framework. His logical and radical critique of the master was in fact driven, from the beginning, by the desire to adhere closely to the substance and thus by the attempt to overturn the relationship of truth between the particular and the universal. Aristotle was therefore looking for a way to bridge the irreducible gap outlined by Plato between sensible reality and ideas which he resolutely denied the existence of. The notion of species to which in the end he granted priority is, however, directly echoed in Plato's notion of the ideal form. This notion thus inherited the character of immutability, ingenerability and incorruptibility. When the Platonic notion of ideal form is transposed to the level of nature, on the basis of a theoretical transition which could also be understood as a passage from transcendence to immanence, it gives rise to the thesis of the fundamental immobility of living species as well as of the cosmos itself.

This last consequence was, however, not necessary in the Platonic framework, as is shown by the various doctrinal fluctuations concerning it.[21] In *Timaeus*, for example, within a finalistic and hierarchized framework, it is true that the god operates 'by moulding it ["this part of the work which was still undone"] after the nature of the Model' – as indeed 'Reason perceives Forms existing in the Absolute Living Creature, such and so many as exist therein did He deem that this World also should possess.'[22] However, as far as sensible reality is concerned, at the same time a (mythical) degenerative theory is proposed according to which all living things are generated by humankind and continue to transform themselves one into the other:

> And the tribe of birds are derived by transformation, growing feathers in place of hair, from men who are harmless but light-minded – men, too, who, being students of the worlds above, suppose in their simplicity that the most solid proofs about such matters are obtained by the sense of sight. And the wild species of animal that goes on foot is derived from those men who have paid no attention at all to philosophy [...]. On this account also their race was made four-footed and many-footed, since God set more supports under the more foolish ones, so that they might be dragged down still more to the earth. And inasmuch as there was no longer any need of feet for the most foolish of these same creatures, which stretched with their whole body along the earth, the gods generated these footless and wriggling upon the earth. And the fourth kind, which lives in the water, came from the most utterly thoughtless and stupid of men [...]. Thus, both then and now, living creatures keep passing into one another in all these ways, as they undergo transformation by the loss or by the gain of reason and unreason.[23]

Against Plato, and also against Empedocles, the Aristotelian life sciences instead were developed into a system which excluded a priori the possibility of adopting an historical perspective: the eidetic structure immanent in the natural order upon which the incessant movement and the birth and death of sublunary living beings is deployed, could not but be eternal, just as eternal – correspondingly – as the duration of the cosmos had to be.[24] In other words, that typically Aristotelian 'photographic' epistemological style prevailed, leading him to interpret the structures at the base of nature as static and eternally immutable.

4 Tools

In the field of physiological anatomy, it is always the recourse to the teleology immanent in nature that sustains the extraordinary functionalistic concept of organs and faculties proposed by Aristotle. Here, the ultimate end is the preservation of organisms themselves: 'an animal must have sensation, if it is a fact that nature does nothing in vain. For all provisions of nature are means to an end, or must be regarded as coincidental to such means. Any body capable of moving from place to place, if it had no sensation, would be destroyed, and would not reach the end which is its natural function.'[25] In short, if it does not have sensation, 'it will be impossible for the animal to survive'.[26] Thus, given the premise that every natural thing exists to some end, directly or indirectly and that nature does nothing in vain, in the sense that its every manifestation is directed towards the pursuance of an end, the faculties and more generally the parts of animals, which are natural things, must therefore also have an end ascribable to the ultimate aim of survival.[27]

And that the ultimate end may coincide almost perfectly with the preservative function attributed to organs and faculties emerges, for example, where we read that 'those senses which act through external media, such as smell, hearing and vision, belong to such animals as are capable of locomotion. To all those which possess them they are a means of preservation, in order that they may be aware of their food before they pursue it, and may avoid what is inferior or destructive'.[28] Even the emotions, correlated with the specific physiological anatomical characteristics of species, can be interpreted, in some cases at least, as mechanisms utilized by nature for the purpose of their preservation, as is shown in the emblematic case of fear: 'When the Sepia is frightened and in terror, it produces this blackness and muddiness in the water, as it were a shield held in front of the body'; a necessary reaction which demonstrates, in this case and in similar cases, that 'Nature makes good use of this residue at the same time for the animal's defence and preservation'.[29] Although not all the residues can be attributed directly to a final purpose, Aristotle nevertheless succeeds in attributing them indirectly, as is clear in the example of bile: 'just as the bile elsewhere in the body is a residue or colliquescence, so this bile around the liver is a residue and serves no purpose – like the sediment produced in the stomach and the intestines. I agree that occasionally Nature turns even residues to use and advantage, but that is no reason for trying to discover a purpose in all of them. The truth is that some constituents are present for a definite purpose, and then many others are present of necessity in consequence of these.'[30]

Clinging firmly to his basic teleological framework, in his masterpiece of comparative physiological anatomy, the *Parts of Animals*, Aristotle reaffirms that 'the body is an instrument; as well the whole body as each of its parts has a purpose, for the sake of which it is'.[31] He thus articulates the relationship between organs, ends and functions within an eminently finalistic argument: 'Now, as each of the parts of the body, like every other instrument, is for the sake of some purpose, viz. some action, it is evident that the body as a whole must exist for the sake of some complex action. Just as the saw is there for the sake of sawing and not sawing for the sake of the saw, because sawing is the using of the instrument, so in some way the body exists for the sake of the soul, and the parts of the body for the sake of those functions to which they are naturally adapted.'[32]

Ideally, then, a single function should be connected to each organ, even if that is not always possible:

> Consider the elephant's trunk: this is its organ of smell; but the elephant uses it as a means of exerting force as well as for the purposes of nutrition. Compare with this the string of insects: when, as in some of them, it is ranged alongside the tongue, not only do they get their sensation of the food by means of it, but they also pick up the food with it and convey it to the mouth [...]. It is better, when it is possible, that one and the same organ should not be put to dissimilar uses [...]. And thus, whenever it is possible to employ two organs for two pieces of work without their getting in each other's way, Nature provides and employs two. Her habits are not those of the coppersmith who for cheapness' sake makes you a spit-and-lamp-stand combination. Still, where two are impossible, Nature employs the same organ to perform several pieces of work.[33]

From a close analysis of physiological anatomical structures and species behaviour, it thus emerges that, although the ideal model would be 'one organ for one function', it happens that, 'compelled' by necessity, nature may 'often' adopt the model of 'one organ for more than one function'.[34] Just as it is in the inverse: a single function can be carried out by more than one organ, for example, 'the bladder is present in animals to serve precisely the same purpose as the kidneys'.[35] And it is always necessity, defined in relation to the essence of each species, that represents a sort of constraint on the workings of nature. Nature is in a certain way obliged to confront its 'limited possibilities', as we read in *Progression of Animals*: 'We must begin our inquiry by assuming the principles which we are frequently accustomed to employ in natural investigation, namely by accepting as true what occurs in accordance with these principles in all the works of nature. One of these principles is that nature never creates anything without a purpose, but always what is best in view of the possibilities allowed by the essence of each kind of animal; therefore, if it is better to do a thing in a particular manner, it is also in accordance with nature.'[36]

Referring to necessity and the constraints imposed by the essence of each individual species, Aristotle can thus elucidate two series of questions that he is particularly interested in. Firstly, he accounts for the fact that some species may not have specific organs: for example, 'The reason why snakes are footless is, first, that nature creates nothing without a purpose but always with a view to what is best for each thing within the bounds of possibility, preserving the particular essence and purpose of each.'[37] Secondly, he accounts for the fact that organs may have a well-defined structure: for example, 'For men bend their arms concavely and their legs convexly, but quadrupeds bend their front legs convexly and their back legs concavely [...]. The reason is that nature never does anything without a purpose, as has been said before, but creates all things with a view to the best that circumstances allow. [...] [I]t is clearly essential that the leg after being bent should become straight again, the point at which the leg is thrust forward and the shin remaining at rest.'[38]

5 Adaptations

Within the abovementioned coordinates, Aristotle was able to devise an overall heuristic strategy capable of taking account of, firstly, the presence of particular organs directed at performing functions of preservation; secondly, the constraints imposed by the material dimension (necessity) of the particular physiological anatomical structures at play each time; and thirdly, the particular behaviours of diverse species in their natural environment – as is evident in an impressive passage from *Parts of Animals*:

> Some birds are poor fliers: heavy birds, which spend their time on the ground and feed on fruits; or birds that live on and around the water. [...]. Some of these instead of wings have as a means of defence 'spurs' on their legs. The same bird never possesses both spurs and talons, and the reason is that Nature never makes anything that is

> superfluous or needless. Spurs are of no use to a bird that has talons and can fly well: spurs are useful for fights on the ground, and that is why certain of the heavy birds possess them, while talons would not be merely useless to them but a real disadvantage: they would stick in the ground and impede the birds when walking. [...]
>
> This state of affairs is the necessary result of the process of their development. There is earthy substance in the bird's body which courses along and issues out and turns into parts that are useful for weapons of offence. [...] Again, sometimes this substance makes the legs long; and in some birds, instead of that, it fills in the spaces between the toes. Thus it is of necessity that water birds either are web-footed, simply, or (if they have separate toes) they have a continuous fan or blade, as it were, running the whole length of each toe and of piece with it.
>
> From the reasons just stated it is clear that feet of this sort are the result of necessity, it is true; but they conduce to a good end and are meant to assist the birds in their daily life, for these birds live in the water, and while their wings are useless to them, these feet are useful and help them to swim. They are like oars to a sailor or fins to a fish. A fish that has lost its fins can no longer swim; nor can a bird whose webs have been destroyed.
>
> Some birds have long legs, owing to their living in marshes; for Nature makes the organs to suit the work they have to do, not the work to suit the organ. And these birds have no webs in their feet because they are not water birds, but because they live on ground that gives under them, they have long legs and long toes, and most of them have additional joints in their toes.[39]

Analysis of the structure of organs in relation to the environment and of organisms' way of life thus confirms the thesis that organs have an end and that this end is translated into a specific function directed at contributing towards their preservation. And it is precisely in view of this specific function that nature, once and for all, makes the organs, and not vice versa ('Nature makes the organs to suit the work they have to do, not the work to suit the organ', where the operation is understood to be originary). Since it is nature itself which provides for the preservation of organisms, directly assigning suitable organs, it can only take its cue from the functions, that is, the ends, that indeed make their preservation possible: to proceed inversely would be entirely senseless. It would be equally absurd to assign parts that 'would not be merely useless to them but a real disadvantage'[40] or to distribute them to those incapable of adopting them. In other words, 'Nature, like a sensible human being (*phronimos*), always assigns an organ to the animal that can use it'.[41] Securely positioned within strategic argumentation of overwhelming circularity, this is the teleological, as well as anthropomorphic, foundation of Aristotle's entire functionalist anatomical-physiological edifice.

And it is this same attitude, by which nature works with intrinsic wisdom, adapting organisms in the 'best' way possible to their own environment on the basis of their 'mode of life'[42] that also leads Aristotle to criticize the historical reading proposed by Empedocles also from the perspective of the relationship between species and their 'habitat' or 'corresponding region':

> Empedocles is mistaken in saying that the creatures which contain most heat and fire live in the water, thereby escaping the excess of heat that lies in their nature, in order that, since they are short of coolness and fluid, they may be saved by the contrary character of their habitat; for fluid is less hot than air. But it is quite absurd that every such animal should be born on dry land and then migrate to the water; for most of them, one might say, have no feet. Yet he, describing how they are first formed, says that they are born on dry land, but that they escape from it and reach the water [...].
>
> As for the explanation which Empedocles gives, in a sense what he tries to establish is reasonable, but his account is not correct. For while those who suffer from excess of any condition find relief in places or seasons of a contrary nature, their constitution is best preserved in the region corresponding to it [...].
>
> What I mean is this: if nature were to form anything out of wax, she would not preserve it by placing it in a hot atmosphere, nor if she had made a thing out of ice; for it would be rapidly destroyed by its contrary [...]. If, then, the matter of which all bodies are composed is the wet and the dry, naturally that which is constituted of wet and cold lives in water [and if it is cold, will live in the cold], but what is constituted of the dry will live in the dry.
>
> For this reason trees do not grow in water, but in the earth.[43]

Admittedly highlighting the perfectly consistent linkage between the 'first formation' and the 'corresponding region' of each species, Aristotle could not but further reinforce the circularity of his theoretical framework: if species, which are fixed and inextinguishable, are adapted ingeniously by nature in the best way possible, at the same time taking account of their specific mode of life and their environment, it can only be 'quite absurd' to hypothesize that they may have needed to abandon this same environment. The solid correspondence between organs and functions necessarily implies an equally steadfast correspondence between species and environment. If it were not so, nature would not be wise. By this *reductio ad absurdum*, Aristotle affirms that nature would certainly not place a wax statue in the sun. In both cases, sensible immediacy is unfailingly called upon to support and sustain this epistemological attitude which, resisting any historical approach, aims constantly to register existence photographically: because as it is apparently undeniable that 'wheat (and not an olive) comes-to-be from wheat', it is also true that 'trees do not grow in water, but in the earth.'

6 Means of defence

The rigorously teleological-functionalist framework applied to physiological anatomy created a number of problems for Aristotle, however. As is clear from the long passage on the characteristics of birds quoted above, he indeed also explicitly identified and discussed the presence of more or less 'useless' parts, such as the wings of 'heavy birds'. These useless parts he found in very many other cases: within the ambit of feathered creatures not adapted to flight, he also noted for example that 'among birds, the peacock's tail is at one season of no service because of its size, at another useless because the bird moults'.[44]

Notwithstanding this observation, Aristotle strained to hold on to the validity of the teleological framework by referring both to the dimension of necessity (as in the abovementioned case of bile) and to the dual criteria of compensation: external, of a systematic and distributive nature, and internal, regarding the growth of the different parts. The latter, correlated with necessity, is quite simple and refers to the principle made explicit for example with regard to the relationship between the brain and the spinal cord: 'Nature is always contriving to set next to anything that is excessive a reinforcement of the opposite substance, so that the one may level out the excess of the other.'[45]

In the even thornier question, it is significant that Aristotle typically referred directly to the external criterion from the perspective of the tenets of basic teleological assumptions – of wings that do not fly: the antlers of deer are not only useless but in his opinion are 'more of a nuisance to them than a help':

> In some animals the horns are a useless appendage, and to these Nature has given an additional means of defence. Deer have been given speed (because the size of their horns and the numerous branches are more of a nuisance to them than a help). So have the antelopes and the gazelles, which, although they withstand some attackers and defend themselves with their horns, run away from really fierce fighters. The Bonasus, whose horns curve inwards to meet each other, protects itself when frightened by the discharge of its excrement. There are other animals that protect themselves in the same way. Nature, however, has not given more than one adequate means of protection to any one animal.[46]

Aristotle here makes an appeal to a sort of distributive equity: nature assigns to each species one single efficient means of protection. Thus, in deer, which are fast, the antlers would have to be useless; otherwise, there would be two means of defence. It is an idea that he explains in general terms right from the premise: 'The polydactylous animals, moreover, have no horns because they possess other means of defence. Nature has given them claws or teeth to fight with, or some other part capable of rendering adequate defence';[47] exactly as for artiodactyls without horns, nature has 'given means of safety and self-defence of a different order – the speed, for instance, which Nature has given to horses, or the enormous size which camels have (and elephants even more), which is sufficient to prevent them from being destroyed by other animals. Some, however, have tusks, for instance swine, although they are cloven-hooved.'[48]

The uselessness of antlers in deer is thus justified by reference to the principle by which nature grants just one means of defence to each species. But what is this principle based on in turn? In my opinion such a criterion of equity fundamentally represents an expression of the concept adopted mostly implicitly by Aristotle, according to which there is a comprehensive harmonious equilibrium by means of which species, although in conflict one with the other, cannot become extinct. The basic model for this is evident, in a so-to-say 'applied' form, in a notable passage on dolphins and selachians:

> Fish differ also with regard to the mouth. Some have their mouth right at the tip, straight in front; others have it underneath (*e.g.* the dolphin and the selachians) and that is why they turn on to their backs to get their food.

> It looks as if the Nature made them do this partly to preserve other animals from them, for they all prey on living things, and while they are losing time turning onto their backs the other things get away safely; but she did it also to prevent them from giving way too much to their gluttonous craving for food, since if they could get it more easily they would presently be destroyed through repletion. Another reason is that their snout is round and small and therefore cannot have much of an opening in it.[49]

When Aristotle shifts his focus from the level of comparative anatomy, which he clearly favours, to that of the analysis of systematic relations between living species, which in itself he almost never discusses, he applies the concept of harmonious equilibrium. It is an equilibrium that can only be based on an egalitarian distribution of organs and faculties. Rather than discussing this concept as such, Aristotle therefore seems to take it for granted. And for this reason, it can be understood why he may rely with certainty on the principle by which 'Nature has not given more than one adequate means of protection to any one animal' without further elaborating its meaning. In effect, this is a classic and widespread vision in the thinking of the Ancient Greek World; clear testimony is offered, for example, in the marvellous myth narrated by Protagoras in the eponymous Platonic dialogue. This myth also reintroduced the idea that man, unlike other animals, is 'naked, unshod, unbedded, unarmed':

> There was once a time when there were gods, but not mortal creatures [...]. When they [gods] were about to bring these creatures to light, they charged Prometheus and Epimetheus to deal to each the equipment of his proper faculty. [...] [I]n dealing Epimetheus attached strength without speed to some, while the weaker he equipped with speed; and some he armed, while devising for others, along with an unarmed condition, some different faculty for preservation.
>
> To those which he invested with smallness he dealt a winged escape or an underground habitation; those which he increased in largeness he preserved by this very means; and he dealt all the other properties on this plan of compensation. In contriving all this he was taking precaution that no kind should be extinguished; and when he had equipped them with avoidances of mutual destruction, he devised a provision against the seasons ordained by Heaven, in clothing them about with thick-set hair and solid hides, sufficient to ward off

> winter yet able to shield them also from the heats, and so that on going to their lairs they might find in these same things a bedding of their own that was native to each; and some he shod with hoofs, others with claws and solid, bloodless hides. Then he proceeded to furnish each of them with its proper food, some with pasture of the earth, others with fruits of trees, and others again with roots; and to a certain number for food he gave other creatures to devour: to some he attached a paucity in breeding, and to others, which were being consumed by these, a plenteous brood, and so procured survival of their kind.
>
> Now Epimetheus, being not so wise as he might be, heedlessly squandered his stock of properties on the brutes; he still had left unequipped the race of men, and was at a loss what to do with it. As he was casting about, Prometheus arrived to examine his distribution, and saw that whereas the other creatures were fully and suitably provided, mas was naked, unshod, unbedded, unarmed; and already the destined day was come, whereon man like the rest should emerge from earth to light. Then Prometheus, in his perplexity as to what preservation he could devise for man, stole from Hephaestus and Athena wisdom in the arts together with fire – since by no means without fire could it be acquired or helpfully used by any – and he handed it there and then as a gift to man.[50]

Confronted with such a traditional vision, Aristotle proceeded to both demythologize it and intensify the importance of hierarchy among species, at the apex of which stands humankind, also from the point of view of the organs of defence:

> Now it must be wrong to say, as some do, that the structure of man is not good, in fact, that it is worse than that of other animal. Their grounds are: that man is barefoot, unclothed, and void of any weapon of force. Against this we may say that all the other animals have just one method of defence and cannot change it for another: they are forced to sleep and perform all their actions with their shoes on the whole time, as one might say; they can never take off this defensive equipment of theirs, nor can they change their weapon, whatever it may be.
>
> For man, on the other hand, many means of defence are available, and he can change them at any time, and above all he can choose what weapon he will have and where. Take the hand: this is as good

> as a talon, or a claw, or a horn, or again, a spear or a sword, or any other weapon or tool: it can be all of these, because it can seize and hold them all.
>
> And Nature has admirably contrived the actual shape of the hand so as to fit in with this arrangement. It is not all of one piece, but it branches into several pieces; which gives the possibility of its coming together into one solid piece, whereas the reverse order of events would be impossible. Also, it is possible to use them singly, or two at a time, or in various ways. Again, the joints of the fingers are well constructed for taking hold of things and for exerting pressure.[51]

Here, Aristotle is mounting direct criticism of the classical Protagorean thesis of the anthropological deficit, in favour of a clear hierarchical scale which locates humankind in a position of distinct superiority with respect to other living things. Indeed, he explicitly outlines a *scala naturæ* which sets forth the continuity, graduality and at the same time distinct hierarchization of living things: ‘Nature proceeds from the inanimate to the animals by such small steps that, because of the continuity, we fail to see to which side the boundary and the middle between them belongs. For first after the inanimate kind of things is the plant kind, and among these one differs from another in seeming to have more share of life.’[52] Thus, placed at the top of the great chain of being is the human genus: ‘Man is the only one of the animals known to us who has something of the divine in him, or if there are others, he has most. This is one reason why we ought to speak about man first [...]. Another and obvious reason is that in man and in man alone do the natural parts appear in their natural situation: the upper part of man is placed towards the upper part of the universe. In other words, man is the only animal that stands upright.’[53] The human being, therefore, is not only ‘the biped most in accordance with nature’, or in other words well disposed with regard to the spatial hierarchy of the universe,[54] but it is also the human being that comes to represent the parameter of perfection against which all other living things are measured.[55]

Proceeding from this notion, Aristotle also disputes the historical approach proposed by Anaxagoras (and by Empedocles) in favour of an eminently ahistorical vision:

> And since man stands upright, he has no need of legs in front; instead of them Nature has given him arms and hands. Anaxagoras indeed asserts that it is his possession of hands that makes man the most

> intelligent of the animals; but surely the reasonable point of view is that it is because he is the most intelligent animal that he has got hands. Hands are an instrument; and Nature, like a sensible human being, always assigns an organ to the animal that can use it (as it is more in keeping to give flutes to a man who is already a flute-player than to provide a man who possesses flutes with the skill to play them); thus Nature has provided that which is less as an addition to that which is greater and superior; not *vice versa*.
>
> We may conclude, then, that, if this is the better way, and if Nature always does the best she can in the circumstances, it is not true to say that man is the most intelligent animal because he possesses hands, but he has hands because he is the most intelligent animal. We should expect the most intelligent to be able to employ the greatest number of organs or instruments to good purpose; now the hand would appear to be not one single instrument but many, as it were an instrument that represents many instruments. Thus it is to that animal (viz. man) which has the capability for acquiring the greatest number of crafts that nature has given that instrument (viz. the hand) whose range of uses is the most extensive.[56]

In this attack directed at his predecessors some of the basic theoretical presuppositions of the entire framework forcefully re-emerge; as Mario Vegetti has stressed, 'since the organ adapts to the function, it is clear that such a structuring of the hands depends on the most complex functions that appertain in any case to humankind. And since the function is nothing but a preconstituted and permanent dimension of the *ousia*, so it is the human *ousia* that conditions the organization and utilization of the hands; and the essential character of such *ousia* is obviously intelligence. For Aristotle it thus makes no sense to speak of a temporal development from the hands to intelligence, just as the more or less vague evolutionary theories of the fifth century, from Empedocles to Anaxagoras himself, have no sense.'[57] In other words, we are dealing with the classic de-historicized and eminently photographic framework that distinguishes the epistemological style from the entire naturalistic Aristotelian body of work.

While anti-historical essentialism may be re-emerging, the traditional concept of equilibrium continues to provide the frame of reference within which specific physiological anatomical analyses fall. In short, while Aristotle may set up a distinct hierarchization amongst animal forms, re-establishing the indisputable primacy of humankind on all fronts, at the same time he resumes the classical principle of an egalitarian distribution of organs. It is a principle he defines as a form of compensation, such that each species, in relation to others, along a perfect hierarchical scale, is compensated for its deficits with respect to those species similar to them, as emerges for example in the case of insects: 'Those that have fewer feet are winged by way of compensation.'[58] And it is a form of compensation such as to guarantee its reproduction, as is the case with fish eggs: 'This is why the eggs are quite small when they are discharged and why they grow quickly: they are small because the uterus is not roomy enough to hold so large a number of eggs, and they grow quickly to prevent the destruction of their kind which would occur as a result of their formation. Even as it is, the majority of the fetations that are laid externally get destroyed. That is why the fish tribe is prolific: Nature makes good the destruction by sheer weight of numbers.'[59] And the same criterion of compensation is again referred to in a speculative sense just before the passage that continues: 'There are also some fishes, such as the one known as *belone*, which burst asunder owing to the *size* of the eggs, the fetations of this fish being large instead of numerous; here Nature has taken away from their number and added to their size.'[60] This is the principle, also used from the point of view of internal composition ('Nature gives something to one part of the body only after she has taken it from another part'),[61] which throws light partially, on reflection, on the presence of useless parts: the underused or unused wings of heavy birds, for example, are compensated for, from a systemic point of view, by the presence of webbed feet, while extra speed compensates for the antlers of deer.

7 Unseeing eyes

From this internal perspective on the teleological Aristotelian framework, on close examination it emerges that nature's equity, or rather, considering the hierarchization of the *scala naturæ*, its compensatory pseudo-equity, does not coherently and satisfactorily take account of the presence of blatantly useless organs, and even less so of harmful ones. The wings of heavy birds, and even more so the antlers of deer, reveal a sort of theoretical vacuum which Aristotle in one sense tends to ignore, and in another he tries to fill with a certain indifference, as is shown in the passage which introduces the discussion on deer. Indeed, we first read that 'In the lower animals teeth have one common function, namely, mastication; but they have additional functions in different groups of animals. In some they are present to serve as weapons, offensive and defensive, for there are animals which have them both for offence and defence',[62] and after a detailed explanation of various forms of teeth, we read that 'no animal has saw-teeth as well as tusks; for Nature never does anything without purpose or makes anything superfluously.'[63] This is followed by an important general conclusion:

> At this point we should make a generalization, which will help us both in our study of the foregoing cases and of many that are to follow. Nature allots defensive and offensive organs only to those creatures which can make use of them, or allots them 'in a greater degree', and 'in the greatest degree' to the animal which can use them to the greatest extent. This applies to stings, spurs, horns, tusks, and the rest. Example: Males are stronger than females and more spirited; hence sometimes the male of a species has one of these parts and the female has none, sometimes the male has it 'in a greater degree'. Parts which are necessary for the female as well as for the male, as for instance those needed for feeding, are of course present though 'in a less degree'; but those which serve no necessary end are not present. Thus, stags have horns, does do not.[64]

This explanation, which would certainly be cogent if a reason for the use of antlers were provided, thus lacks an objective: if their presence is compensated for by speed, what Aristotle instead observed was that they did not perform any 'necessary function', and especially that 'the size of their horns and the numerous branches are more of a nuisance to them than a help', then specifying that 'deer alone have horns that are solid throughout; and deer alone shed their horns: this is done on purpose to get the advantage of the extra lightness, of necessity, owing to the weight of the horns.'[65]

Aristotle's difficulty in accounting for the uselessness of parts and faculties is already evident when we read that 'nature allots defensive and offensive organs only to those creatures which can make use of them, or allots them "in a greater degree", and "in the greatest degree" to the animal which can use them to the greatest extent'.[66] With this formulation Aristotle almost seems to want in some way to de-emphasize the fact that nature, in a general sense, could assign to certain species organs which they could not use, which are useless. But if they are useless, the principle by which the function has priority over the organ can only implode, as does the basic principle that nature never does anything in vain. In this regard, it is necessary to remember the following two principles: first, 'Nature, like a sensible human being (*phronimos*), always assigns an organ to the animal that can use it';[67] second, 'Nature never does anything without purpose or makes anything superfluously'. This is the principle by which Aristotle is able constantly in his analysis to use the *reductio ad absurdum* according to which nature does not assign organs that would be 'useless'.[68] Now, given such principles, how can we interpret the fact that nature has in fact dispensed wings that do not fly or, even worse, harmful antlers? The profound contradictoriness of Aristotle's argument becomes even more evident in the detailed explanation of the absence of horns in female deer: 'the females have lost their horns because they would be not only useless but dangerous. The horns are indeed of no more use to the males, but they are less dangerous because the males are stronger.'[69] The difficulty is clear: nature first assigns some useless parts, thus violating the general principles at the heart of the overall theoretical teleological framework. But in some cases it takes them away, as in the case of female deer, so that nature, rather than conducting itself like a wise man, would seem to behave like a madman. Finally, horns are left to the males, even though they are not only useless to them but even harmful, an empirical fact that again violates the fundamental postulates.

Besides confirming the fact that necessity frequently plays the role of a mere convenient theoretical auxiliary which is used to provide *ad hoc* explanations designed to conserve basic teleological assumptions, the fact that nature goes back on itself, assigning and removing 'so as to remedy' in a certain way its own errors,[70] also means that on the eidetic level the possibility that species and genera can be subject to random processes of development is precluded. In this regard, the case of the sightless eyes of the mole, which in a certain sense are glaringly and blatantly useless, is illuminating. Aware, with his customary acumen, of the difficulty of this question, Aristotle did not try to avoid discussion in this case either, but he resolved it by enclosing the mole within the confines of a maimed and undeveloped genus: 'all the senses are possessed by all such animals as are neither undeveloped nor maimed; even the mole, we find, has eyes under the skin.'[71] An analogous and even more explicit solution is proposed in the detailed examination of the mole undertaken in *Historia animalium*:

> Now man and the footed Vivipara, and in addition the blooded Ovipara, all plainly possess all these five [senses], though there may exceptionally be a single kind which has become stunted, the mole, for example. This animal lacks the sense of sight: it has no visible eyes, but if the skin (which is thick) be removed from the head at

> the external place where eyes are normally, the eyes are found in an impaired condition, complete with all the parts belonging to genuine eyes: they have the 'black', and that which is inside the black, the pupil as it is called, and the fatty part which surrounds it, but these are smaller than in visible eyes. There is no external sign of these owing to the thickness of the skin, which suggests that in the course of development the natural process was stunted.[72]

'Stunted', as in other cases of the malformations, deformities or imperfections of certain species,[73] occurring in 'the course of development' of 'a single kind', should not of course be understood in any sense as more or less vaguely 'evolutionary', but rather in relation to a parameter of hierarchical 'perfection' at whose apex is mankind. Such a misunderstanding would undermine the entire theoretical framework of the convergence of form and essence, as well as the axiom by which it is nature that originally gives organisms organs suitable to their preservation. In short, it is certainly true that Aristotle takes into consideration particularly thorny issues regarding the overall teleological framework, derived from close and precise observation of particular parts and organs. Despite his consideration of these issues, it was Aristotle himself who precluded the possibility of systematically developing any historical – Empedoclean, for example – interpretation by on the contrary favouring a clearly fixist, essentialist and teleological vision which was thus both ahistorical and strongly hierarchical. Here, the relative consistency in the basic theoretical suppositions of the overall framework makes its weight felt. Questions such as those regarding the sightless eyes of the mole, which might have contributed to the development and problematization of the framework, do not in fact receive cogent responses.

It was Charles Darwin who clearly revealed the difficulties, tensions, paradoxes and intrinsic contradictions generated by the discussion of useless and harmful organs within the theoretical framework of traditional physiological anatomy. Parts and organs bearing 'the stamp of inutility', such as the wings of birds that cannot fly and the sightless eyes of moles but also the antlers of deer and the tail of the peacock, were interpreted as direct testimony of the 'absence of a final cause' and thus, more generally, as evidence of the 'strange difficulty' of the traditional theory. But prior to this, throughout the course of modern natural history, from its late medieval rebirth to the end of the eighteenth century, it was the teleological, essentialist and fixist framework invented by Aristotle, and later elaborated in a creationist sense, that predominated.

2
For and Against Aristotle

1 Regrafting and divergences

The origins of the modern Aristotelian tradition date back to the reintroduction that began between the twelfth and thirteenth centuries of the *corpus aristotelicum* into Western culture, when it was taken up again, translated and institutionalized, and so it was placed at the basis of reborn Western science. Despite the discussions and reiterated condemnations which followed the widespread circulation of the Aristotelian treatises, even once the eternalist thesis had been banned it continued to play a leading role in academic curricula and more generally in late medieval culture. In other words, 'in the later middle ages, Aristotle's writings on logic and natural philosophy formed the centrepiece of university studies in the arts and provided an essential preparation for a career in medicine, law or theology, while his works on ethics, poetics and politics were widely read and discussed by a learned public increasingly educated in the methods of the cultural movement we now know as "humanism".'[1] In short, from the thirteenth century, 'the history of medieval thought was primarily the history of the reception, interpretation and utilization of the philosophy of Aristotle',[2] such that in the course of the fourteenth century, although certainly with some significant revisions and corrections, his natural philosophy came to 'coincide substantially' with Western natural sciences.[3]

While attention may have been focused on the theories of living things, two main periods can be distinguished in the process of the reintroduction of the Aristotelian system: the first revolves especially around the great thirteenth-century traditions of Scotus and Moerbeke and later the comments on the treatises, in particular the mammoth work of Albertus Magnus. A second phase, of even wider importance, developed during the Renaissance, culminating in the works of sixteenth-century authors such as Vesalius and Cesalpino. It is especially in the contributions of the latter that we find an emblematic testimonial as to how the fixist, essentialist and teleological framework, and the doctrinal and analytical Aristotelian corpus, now renewed and extended, was ferried into the seventeenth century.

From the first decades of the seventeenth century, though, in the wake of the Copernican revolution, there was an acceleration of the process by which the traditional system of Aristotelian physics was radically contested. The Aristotelian treatises, however, continued to exert a 'cultural hegemony' – as Charles Schmitt has written – in academic curricula until around halfway through the seventeenth century.[4] Now, this abandonment brought about a radical divergence between the physical and life sciences. Due to the impressive weight of the sixteenth-century Peripatetic school, the latter indeed continued to be substantially guided by traditional theoretical principles.

Such a divergence can of course be interpreted from a multiplicity of different perspectives. Here, I focus on a factor that, although not the only one, is certainly of primary significance: the role of the teleological framework of the naturalistic system established by Aristotle. While indeed the mathematization of physics undertaken by Galileo may have entailed the abandonment of final causes, and of the entire qualitative conceptual toolbox associated with it, recourse to teleology continued to constitute one of the fundamental pillars of the life sciences. This dynamic clearly emerges – as we shall now see – as soon as we consider the divergences between the physical sciences, on the one hand, with criticism levelled directly by Galileo at the teachings of Aristotle and, on the other, the life sciences, with the resumption and reintroduction of these teachings, also in an experimental sense, undertaken by William Harvey.

2 Reception and institutionalization

Let us start again from the beginning: the Aristotelian treatises on the life sciences were reintroduced extensively in the Latin West especially because of the translation from the Arabic by Michael Scotus of the *History of Animals*, the *Parts of Animals* and the *Generation of Animals* produced between approximately 1210 and 1220 and later coupled with a new translation, this time directly from the Greek, by William of Moerbeke, in 1260, which also included the *Movement of Animals* and the *Progressions of Animals*.[5] Scotus' *De animalibus*, soon taken up and included in the curricula of the faculties of arts, is the first great act in the resumption and institutionalization of natural history as established by Aristotle.[6] The allegorical and symbolic tradition of medieval bestiaries, with its encyclopaedic catalogues and moralistic slant, thus came to be integrated within the Aristotelian naturalist approach.[7]

Beside the gradual but widespread diffusion of the new Aristotelian scientific knowledge in milieux and genera different from those of the university canon within faculties of arts (from medicine to pastoral use, and so on),[8] the extensive commentary by Albertus Magnus in *De animalibus libri XXVI*, written between 1256 and 1263 (which could also be supported by Moerbeke's translation) was particularly significant for the future reception of Aristotle's teachings. In his work, going against the mathematicized Platonism of Oxford, Albertus reintroduced the vision of 'immanent' forms and especially Aristotle's doctrine of causes,[9] readapting its empirical methodology and enriching and sometimes correcting the material also as a result of new observations. Thus he went on to complete his vast project, begun around 1250, directed 'deliberately and systematically at paraphrasing and commenting on the entire corpus of Aristotle, with the aim of creating a complete "scholastic manual" of the philosophy of Aristotle and his followers for a Latin public'.[10] It is not by chance that Albertus concluded his monumental work by observing the following:

> The book of animals is now complete and in it the entire work of their natures has been completed. In it I have held as my governing rule that I have set forth the words of Peripatetics as well as I could. Nor can anyone detect that which I myself feel about natural science [*philosophia naturali*]. But rather, if he should have a doubt about something, let him compare the things said in our books with those sayings of the Peripatetics and then let him either criticize me or agree with me, saying that I was the interpreter and expositor of their learning.[11]

On close analysis, *De animalibus* is presented in a three-part scheme. The first part is devoted to an extensive, detailed and complete exposition of the three great treatises of Aristotle; the paraphrasing is always accompanied by discussion of the theses of other exponents of the Aristotelian and Christian traditions, as well as his own opinions, which include, in order, the ten books of the *History of Animals* (Books 1–10), the four of the *Parts of Animals* (Books 11–4), and the five of the *Generation of Animals* (Books 15–9). The second part of *De animalibus*, on the other hand, engages in a brief in-depth analysis of the degrees of animals' perfections and imperfections, with ample reference to Aristotle's *On the Soul*, in which Albertus expounds his theses on various questions, from domesticability, virtue and the position of mankind (Books 20–1). Lastly, the third part offers a classic encyclopaedic catalogue of animals, based mostly on Thomas of Cantimpré's *Liber de natura rerum*, in its turn written between 1225 and 1240 (Books 22–6), in which the traditional medieval-type classification is developed in the light of the 'scientific' themes dealt with in the Aristotelian *corpus*.[12] Such comprehensive treatment testifies to both a fundamental continuity with Aristotle's teachings – as well as a hybridization of them within the medieval tradition – and Albertus' relative freedom of interpretation in essentially relying on the distinction between Aristotle's knowledge of 'natural' processes and ignorance of 'supernatural' ones.[13] And it is especially on the continuity that I would like to focus attention, first looking at its anthropocentrism, and then making an in-depth analysis of the reintroduction of the teleological approach and the issue of the fixity of species.

From the opening lines, and thereafter continuously in the course of his commentary, Albertus insists on the fact that the human being is 'the most perfect animal'; thus slotting the overall structure of Aristotle's physiological anatomical analyses within the anthropocentric framework of Christianity itself.[14] From this perspective, the process of the institutionalization of Aristotle's teachings pursued by Albertus was significantly supported by the position that Aristotle himself attributed to mankind in the *scala naturæ*. It was indeed certainly not difficult to emphasize the many passages – from *Parts of Animals* to *Progression of Animals*, from *On the Soul* to *History of Animals* and so on[15] – in which the ancient philosopher had maintained that mankind represented the most perfect living being, the only one endowed with *nous* and having free hands and an erect stature, which placed it at the highest point of the scale. This is a position at the same time perfectly consistent with the geocentric and anthropocentric vision taken up by Albertus (and by other Scholastics), which underlined how the human body was perfectly aligned with respect 'to the upper part of the world' and the 'lower', so remaining faithful to the Aristotelian treatises, for example, where he writes:

> Further, in terms of the organs of the senses and the powers of the soul, the human alone among all the animals participates in the hand, which is alone the organ of organs and the organ of operative

> intellect [...]. It is clear, then, that the human participates in certain organs beyond the way in which all the other animals participate, and thus even in the organic composition of the body he is more perfect than all the bodies of animals and more perfect than the animals themselves.
>
> Moreover, the shape of the body reveals this itself. For since three [different] diameters compose every body, that body will be more perfect and more natural that participates up and down of the natural diameters. The longitudinal diameter measures up and down, and only in the human is it the same above (which is the upper part of the world) and the same below (which is the lower part of the world). It is similar for the latitudinal diameter. [...] [T]he organs of the body in the human have a greater perfection of distinction than in any other of the other animals.[16]

This is the alignment of humankind within the structure of the universe that Aristotle claimed repeatedly, for example in *History of Animals*:

> In man more than in any other animal the upper and the lower parts of the body are determined in accordance with what is naturally upper and lower: in other words, upper and lower in man correspond with upper and lower in the universe itself. Similarly, in man, front and rear, right and left as applied to these parts, have their proper natural meaning. In some of the other animals this is not so all; in some the distinctions exist but in a somewhat confused manner. Of course, in all animals the head is up above with regard to the creature's own body; but, as I have said, man is the only animal which, when fully developed, has the head up above in the sense in which 'up' is applied to the universe.[17]

However, the question I would like to focus more attention on concerns the fact that Albertus faithfully reaffirms the teleological pillar of Aristotle's treatise, both in his negative reference to the marginalization of randomness, linked to the essentialist concept of species, and in the positive sense of the centrality of a final cause. He indeed continually reiterates the theoretical centrality of the form, also paraphrasing Aristotle's critique of Empedocles – for example where he writes: 'Thus do generation and those doing the generating exist for the sake of the form, which is the substance producing the thing generated. It is not the case that, on the contrary, the formal substance exists for the sake of generation and for the sake of those doing generating. This is why Empedocles erred in his opinion that there is no purpose in nature but that each and every thing comes to be through a cause accidentally. [...] For Empedocles did not say that there is a final cause in natural things.'[18] Albertus goes on to refer to Aristotle's theory of generation by which sperm transmits form, making a direct association with the *Metaphysics*:

> However, Empedocles did not know that the sperm of generation has to have the sort of formative power which leads to *his* form and no other, and that that which made this power in the sperm existed before it did, just as it is the human who is generating who gives the formative power to sperm. As a result, the form and end in nature precede the potential not only by definition but even in time, just as was proven in the ninth book of the *First Philosophy* [*Metaphysics* 1050a5–2b]. Certainly a human generates a human, so that the form of the one generated is produced from the form of the one generating, and thus it is in all natural things, which Empedocles erroneously believed are generated *per se* without a cause.[19]

In short, faithfully following Aristotle, Albertus admits randomness within the epistemic order,[20] but he weakens its importance in favour of the role of final causes.

Such an approach thus considers both the negative principle by which 'nature does nothing uselessly'[21] or 'nature does nothing superfluous'[22] and the positive principle by which 'nature does all things either out of necessity or because it is best done in this or that way';[23] or, in other words, the thesis by which 'nature always proceeds according to the better way';[24] or, more concisely, 'nature does only the best possible job'.[25] Albertus, thus, also confirms and restates the foundational parallel between art and nature, attributing to the latter a sort of anthropomorphic wisdom, as emerges, for example, when he discusses the Aristotelian argument that 'possessing hands is not the reason for his intellect, but rather, to the contrary, the possession of intellect is the reason he has hands.'[26] In this case he adopts exactly the same argument used by Aristotle against Anaxagoras:[27] 'Because the human alone has the most intellect of all the animals, he suitably takes from nature an organ suited for many movements and all its other functions. For pipes are given to a piper rightly and reasonably since he has in him the principle which is the art of piping and which is suited to using the pipes. Just as it is in artists who imitate nature, so it is in nature. For nature, since she does what is best in all case, supplies that which has less to the greater.'[28] More generally, he reasserts the image of 'a clever and wise nature' that provides for the creation of organs and individually necessary parts, such as the fingernails.[29]

As far as the argument regarding the fixity of species is concerned, Albertus recognized that it was already included, although not dealt with as an issue in itself, in the treatises of Aristotle – for example, when he faithfully reaffirmed and emphasized the Aristotelian principle by which, over and above the particular processes of putrefaction, it remains true that 'generation never happens from semen unless the one generating and the one generated are from the same species, either immediately or through a medium. [...] For otherwise it would go on into infinity through dissimilars, and nature abhors infinity.'[30] In other words, 'if generation always progressed through dissimilar ones, thus dissimilarity would go on infinitely. Nature rejects this since what is infinite is imperfect and nature always strives for perfection and the perfected.'[31] Having faithfully appropriated the Aristotelian concept of species reproduction, Albertus then relocates it in an explicitly creationist context, reinforcing species' stability, fixity and inextinguishability:

> Human reproduction is universally by means of intercourse in which the powers of the sexes are mixed together both out of the sperm of the man, the creator and maker, and out of the woman's sperm, or *gutta*, and her menstrual blood, which are the materials, as it were. As Constantine of Monte Cassino says in his book *On Intercourse* [*De coitu*], indeed the Creator, wishing the race of animals to remain in a stable and fixed manner and not to perish, saw to it that the race would not take its renewal from total destruction.[32]

This undertaking of reconciliation, which was to seal the fate of modern natural history, did not invalidate the Aristotelian framework: the eternity of immutable *eide* on the one hand, and the immutability of species created in a single act at the beginning of time on the other, indeed implied an equally static perspective, and it expressed an epistemological style which could be defined as photographic. In a similar way to what happened to the cosmos, the present form of living species was seen as remaining fixed in time, both in the past (forever – since the beginning of time), and in the future (forever – until the end of time). Nature continued to abhor the infinite and strove for completeness. The possibility that the number of species could multiply, or be reduced via extinction, was therefore excluded.

In summary, it was the overall vision of the order of living things (as well as the cosmos) established by Aristotle, and the conceptual and categorical tools correlated with it, that provided the scaffolding for reborn Western naturalistic thinking. Despite the reiterated condemnation of Aristotle's multiple theses and texts, among which those concerning the eternity of the cosmos, but also the origin of living things and in particular humankind stood out,[33] the original framework, now Christianized, continued to exert extraordinary influence. Or rather, in an even more obvious way than in the thirteenth century, from about the middle of the fourteenth century, Aristotelianism predominated uncontested. 'When, in 1346, Pope Clement VI exhorts, in a famous letter to the University of Paris, students to follow the courses on Aristotle and his recognised commentators, the process of the assimilation of official Christian doctrine seems complete. Not only is Aristotle no longer dangerous: he now appears, to the upper hierarchy, as a bulwark against the "new tendencies".'[34]

3 Rebirth

While Aristotle's treatises on living things were reintroduced to, gradually hybridized with and reconciled with Christianity from the thirteenth century, a broad, widespread and profound interest in natural history as such (that is, not secondary, as for example in the case of medicine, and so on) was reborn only in the second half of the fifteenth century. It was then that, due also to the new translations by Theodore Gaza, texts such as *History of Animals*, *Parts of Animals* and *Generation of Animals*,[35] as well as Pliny's *The Natural History* (which in turn reconsiders many themes of Aristotle),[36] came to play an ever more significant role within the sphere of *scientia naturalis*. It is therefore a second regrafting, or re-establishment, which was also supported by new commentaries on the treatises,[37] that out of which the great renaissance of the life sciences developed in the sixteenth century.

Trusting increasingly in direct observation,[38] physiological anatomy thus flourished, advanced especially by the School of Padua, reaching one of its high points in *On the Fabric of the Human Body* (1543) by Andreas Vesalius; zoology, in a strict sense, was reintroduced by monumental works such as those by Ippolito Salviani, Conrad Gesner and Ulisse Aldrovandi; and botany, which already into the second half of the century boasted an extraordinary contribution in *De plantis* (1583) by Andreas Cesalpino, also flourished. In a nutshell, it is safe to affirm that in all three disciplines the conceptual framework of reference, the guiding principles, and in particular the three pillars of teleology, essentialism and fixity of species of Aristotelian devising continued to remain central to biological research until the late Middle Ages. The same doctrinal innovations were taken as extensions and gradual rectifications of the descriptions and classifications offered by Aristotle and, later, by other classical writers (Galen, Pliny, and so on).

The case of Cesalpino especially, I believe, shows how the Aristotelian tradition remained solid and arrived at the seventeenth century renewed, despite the gradual decline of the geocentric cosmological model sparked by the publication of Copernicus's *The Revolutions of the Heavenly Spheres*.[39] As an academic dedicated to medicine, philosophy and botany, Cesalpino remained loyal to Aristotle on many fronts – even positioning himself against Copernicus[40] – updating and at the same time enriching the doctrinal corpus on the basis of careful empirical, especially botanical observations.

> Actually, Cesalpino, in an effort to remain fundamentally faithful to the "original" Aristotle, tries to represent fundamental questions of "primary philosophy" and a broad and extended series of questions of "physics", "biology", "botany", and so on aimed at offering some basic theoretical perspectives and also an encyclopaedia of knowledge which could be established by affirming the substantial truth and thoroughness of Aristotle's exposition but also taking into account the data and experiences that Cesalpino had accumulated on the dissecting table and by natural observation, data of which Aristotle indicates no knowledge.[41]

Cesalpino's work was fundamental, besides, in putting – in the wake of Aristotle's *Generation of Animals* – the reproductive criterion at the basis of a new and rigorous taxonomic system. The new principle permitted the classification of plants into genera and species 'in accord with the principles of traditional Scholastic logic' and especially with the centrality of research into and knowledge of Aristotelian 'essences'.[42] It was owing to this work that Cesalpino has been considered the father of modern systematic botany, as Linnaeus wrote: 'Cesalpino is the first true systematist.'[43] Equally significant was the reaffirmation, against Galen, of Aristotelian cardiocentricity (in the sense of the centrality of the heart and the blood in vital processes), with the correlated discovery of the partial circulation of the blood. Furthermore, the reintroduction of Aristotle's functionalistic teleology was just as important.[44] In short, with his botanical and physiological works, not only did Cesalpino leave to the naturalists and physicians of the late seventeenth century the legacy of a refined classificatory apparatus and a corpus of rich and precise observations, but, more generally, he contributed to the delivery of the traditional fixist, essentialist and teleological framework into the second half of the seventeenth century, despite the work undertaken in the meantime by Galileo.

4 Mathematization

While Cesalpino was still trying to put together a strategy for the defence of the Ptolemaic model, Galileo was proceeding with the systematic demolition not only of traditional astronomy, but of the entire epistemological system of Aristotelian qualitative physics. It was a revolution that was to mark the end of a particular vein of the Aristotelian scientific tradition, but not of the system that had been set as the basis of seventeenth-century natural history. From the perspective of the persistence and decline of the heritage of the *corpus aristotelicum*, the separation of the two doctrinal milieux can, I believe, be attributed first of all to the fact that Galileo's undertaking relied on a form of 'mathematization' of nature, which, despite various attempts on behalf of the Cartesians, was not successfully introduced; nor did it establish itself in the life sciences. This eminently mathematical approach represented the basic line of argument in the precise and incisive criticism that Galileo levelled directly at Aristotle's teachings. It was a mathematical approach that Aristotle had disputed with the Pythagoreans and Plato and an approach that having been endorsed during the Renaissance was in the end taken up and defended by Galileo.

To briefly outline the resumption by Galileo of the Platonic mathematization of nature and the simultaneous critique of qualitative Aristotelian physics, we can start with the passage from *Dialogue Concerning the Two Chief World Systems* (1632), in which Galileo takes a stand from the start, affirming to Salviati: 'That the Pythagoreans held the science of numbers in high esteem, and that Plato himself admired the human understanding and believed it to partake of divinity simply because it understood the nature of numbers, I know very well; nor am I far from being of the same opinion.'[45] This Platonic approach directly contradicts Aristotle. Simplicio defends Aristotle thus:

> If I must tell you frankly how it looks to me, these appear to me to be some of those geometrical subtleties which Aristotle reprehended in Plato when he accused him of departing from sound philosophy by

> too much study of geometry. I have known some very great Peripatetic philosophers, and heard them advise their pupils against the study of mathematics as something which makes the intellect sophistical and inept for true philosophizing; a doctrine diametrically opposed to that of Plato, who would admit no one into philosophy who had not first mastered geometry.[46]

And again, the following exchange between Salviati and Simplicio is typical:

> Salviati: Simplicio will not say so, though I do not believe he is one of those Peripatetics, who discourage their disciples from the study of mathematics as a thing that disturbs the reason and renders it less fit for contemplation.
>
> Simplicio: I would not do Plato such an injustice, although I should agree with Aristotle that he plunged into geometry too deeply and became too fascinated by it. After all, Salviati, these mathematical subtleties do very well in the abstract, but they do not work out when applied to sensible and physical matters. For instance, mathematicians may prove well enough in theory that *sphaera tangit planum in puncto*, a proposition similar to the one at hand; but when it comes to matter, things happen otherwise. What I mean about these angles of contact and ratios is that they all go by the board for material and sensible things.[47]

In short, having outlined the opposition between the Platonic and Pythagorean approaches, on the one hand, and that of Aristotle, on the other hand, Simplicio remarks emphatically: 'I still say, with Aristotle, that in physical (*naturali*) matters one need not always require a mathematical demonstration.'[48] This is an argument that faithfully retraces Aristotle's postulate, as emerges for example in *Metaphysics*: 'Mathematical accuracy is to not to be demanded in everything, but only in things which do not contain matter. Hence this method is not that of natural science, because presumably all nature is concerned with matter.'[49] This is about the fundamental Aristotelian distinction between mathematics and physics: 'number, line and figure' are concepts that 'will be found to be independent of movement', so that mathematics itself deals mainly with immobile and separate entities, the opposite of what pertains to physics.[50] Owing to the partition between the celestial sphere and the sublunar world, this position led Aristotle on the one hand to 'apply' geometry to astronomy, or rather to the movement of celestial spheres, and on the other to place some physical disciplines (especially optics and harmonics) in a position subordinate to mathematics.[51] Hence, he opposed Pythagorean, and then Platonic, mathematization[52] (and to the theory of the ideas correlated with it),[53] for which nature, in its entirety, could and had to be interpreted with mathematical instruments.

The alternative Galilean approach thus implied abandonment of the fundamental categories of the qualitative analysis carried out by Aristotle, as is seen in the thorny issue of motion, with regard to which Simplicio declares: 'Philosophers occupy themselves principally about universals. They find definitions and criteria, leaving to the mathematicians certain fragments and subtleties, which are then rather curiosities. Aristotle contented himself with defining excellently what motion in general is, and showing the main attributes of local motion.'[54] Now Galileo overturned the perspective, writing incisively that 'the art of proof' is acquired 'by the reading of books filled with demonstrations – and these are exclusively mathematical works, not logical ones.'[55] In so doing he brought to its culmination the process – one of the cyphers of Renaissance Platonism which Cassirer had already attributed to Cusano – by which 'in the place of formal syllogistics, comes the logic of mathematics'.[56] If then Aristotle's overall epistemological system was a refined 'development' of geometry,[57] this was a return to the original model: the mathematization of nature. In this way, Galileo – not only the fully Neoplatonist Kepler[58] – was able to hark back to *Timaeus*, which presents an intrinsically and thus entirely mathematized *physis* (nature): a cosmos shaped by the Demiurge on the basis of 'numerical proportions',[59] 'by means of forms and numbers':[60] 'As we stated at the commencement, all these things were in a state of disorder, when God implanted in them proportions both severally in relation to themselves and in their relations to one another, so far as it was in any way possible for them to be in harmony and proportion'[61] – hence, a universe intelligible in terms of geometric figures, beginning with the triangle, and arithmetical ratios (the mathematical astronomy of *The Republic* was going in the same direction).[62] This was a system that is echoed in the celebrated passage from Galileo's *The Assayer* on the book of Nature:

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wonders about in a dark labyrinth.[63]

Or again, when Galileo wrote to Fortunato Liceti in 1641: 'But I really prize the book of philosophy that remains perpetually open before one's eyes; but because it is written in a script different from our alphabet, it can't be read by everyone: and it is the characters of that book, the triangles, squares, circles, spheres, cones, pyramids and other mathematical figures that make for most suitable reading.'[64] In addition to his free re-elaboration of the Platonic myth of *Timaeus*[65] – 'a curious mix of mythical cosmogony and celestial mechanics, of theology and mathematical physics'[66] – Galileo overlooked the rest in order to adopt one, and only one, of the theoretical kernels: the mathematization or geometrization of *physis*. It is from this perspective that Alexandre Koyré has defined the rebirth of Renaissance physics, with a certain pathos, as 'the revenge of Plato.'[67]

To sum up, within the ambit of the physical sciences, the waning of Aristotle's qualitative and teleological system came about especially (although certainly not only) because of the mathematical, hence quantitative, approach. As Koyré has concluded:

> This, in turn, implies the disappearance – or the violent expulsion – from the scientific thought of all considerations based on value, perfection, harmony, meaning, and aim because these concepts, from now on *merely subjective*, cannot have a place in the new ontology. Or, to put it in different words: all formal and final causes as modes of explanation disappear from – or are rejected by – the new science and are replaced by efficient and even material ones. Only these latter ones have right of way and are admitted to existence in the new universe of hypostatized geometry, and it is only in this abstract-real (Archimedean) world, where abstract bodies move in an abstract space, that the laws of being and of motion of the new – the classical – science are valid and true.
>
> It is easy now to understand why classical science – as has been said so often – replaced a world of quality with one of quantity: just because, as Aristotle already knew quite well, there are no qualities in the world of numbers or in that of geometrical figures. There is no place for them in the realm of mathematical ontology.
>
> And even more, it is easy now to understand why classical science – as has been seen so seldom – has substituted a world of being for the world of becoming and change: just because, as Aristotle has said too, there is no change and no becoming in numbers and in figures. But, in doing so, it was obliged to reframe and to reformulate or rediscover its fundamental concepts, such as those of matter, motion, and so on.[68]

Other commentators have even maintained that what had to be removed was the recourse to causes *tout court*,[69] recalling, among others, the noted passage in which Galileo affirms: 'The present does not seem to me to be an opportune time to enter into the investigation of the cause of the acceleration of natural motion, concerning which various philosophers have produced various opinions [...]. Such fantasies, and others like them, would have to be examined and resolved, with little gain. For the present, it suffices our Author that we understand him to want us to investigate and demonstrate some attributes [*passiones*] of a motion so accelerated (whatever be the cause of its acceleration).'[70]

In any case, it remains clear that recourse to direct observation was not certain, as such, to represent the methodological cornerstone of the Galilean revolution of the Aristotelian system. With regard to the centrality attributed to what is obtained 'by means of the senses, experiments, and observations',[71] Galileo himself explicitly, repeatedly and rightly made reference to Aristotle,[72] addressing the principle by which 'sensible experiments were to be preferred above any argument built by human ingenuity',[73] and, confronting those Aristotelians bent on 'blindly' rereading the ancient texts,[74] he asserted: 'if Aristotle had been present [...], if Aristotle should see the new discoveries in the sky he would change his opinions and correct his books and embrace the most sensible doctrines'.[75] It is certainly true that in the Peripatetics' naturalistic treatises the experience on which induction would have had to be based was indeed often disregarded (especially in physics but less so in biology). Galileo himself emphasized this when discussing the question of weight: 'it is clear that Aristotle could not have made that trial; yet you want to persuade us that he did so because he says that the effect "is seen".'[76] And it is also true that the Galilean method certainly did not confine itself to merely recording sense data.[77] That said, it remains in any case clear that from the perspective of the methodological appreciation of sense experience, Aristotle's teachings continued to be a precious resource.

In conclusion, one of the key turning points in the Galilean revolution of the Aristotelian tradition was the fact that 'whereas [...] Aristotle began with empirical observation of qualities to rise to the discovery of the essence, and from this he deduced properties, Galileo began with the experience of quantities to rise to the discovery of mathematical law and from this he deduced further quantitative properties.'[78] The latter was the approach that ushered in the decline of the entire categorical apparatus correlated with the traditional teleological framework: the pervasive and direct recourse to 'final causes' was banished, while the 'form/matter' dichotomy itself, like the fundamental notion of 'essence', simply lost their meaning within Galilean science. And it was due to the process of abstraction and mathematization that it was possible to 'abandon the level of common sense, of appreciable qualities, of immediate experience,'[79] in order to build the new doctrinal framework of seventeenth-century physics.

5 Teleological experimentalism

Having clarified the methodological centrality of the mathematization of physics, I believe it is now possible to better understand why the life sciences continued to operate within the traditional framework, integrating it ever more closely with the new-born experimental method. The major and most renowned anatomists, zoologists and botanists of the seventeenth century indeed developed their lines of research within the Aristotelian tradition, assigning a definitely epistemological priority to the teleological dimension both within the ambit of physiological anatomy research inherent in individual living organisms, and as regards the basic equilibrium among living species. The basic conceptual categories ('form', 'essence', 'species', 'end' and 'purpose') and the basic theoretical framework (fixist, essentialist and teleological) therefore were still those established by Aristotle. The attempts by the Cartesians to directly transpose the quantitative and anti-finalistic approach of physics to the life sciences therefore remained relatively marginal, in the sense that they did not manage to undermine the Aristotelian tradition, which continued to be predominant.

Deprived of massive recourse to mathematization, the renewed appreciation of observation in fact came to provide essential support in maintaining and indeed reintroducing the original framework. In brief, unlike in physics, in the life sciences the updated Aristotelian tradition continued to guide research, as is evidenced in the rather important case of William Harvey: the great seventeenth-century innovator of physiological anatomy and embryology openly declared his reintroduction of Aristotle on all fronts, thus following and in fact reviving the scholarship of the sixteenth-century School of Padua. What happened was that 'moving in the world of Paduan Aristotelianism would therefore appear to have been more conducive to Harvey's discovery than a breakaway from it', so that, more generally – continues Walter Pagel – 'The view that it was opposition to Aristotle which ushered in and was largely responsible for the rise of modern science in the late sixteenth and in the seventeenth centuries is one-sided and misleading. At all events it does not apply to biology and medicine. It may suffice to recall the foundation of modern systematical Botany by the Aristotelian Cesalpino and that of Zoology by Gesner, Aldrovandi, Rondeletus and Coiter who were all perceptibly influenced by Aristotle, and so were Fabricius, the teacher of Harvey, and Glisson who came after him.'[80]

In more detail, about the discovery of the circulation of the blood published in *An Anatomical Disquisition on the Motion of the Heart and Blood in Animals* (*De motu cordis*, 1628),[81] it has often been written that – although anticipated by Cesalpino both in content and in method[82] – it represented a 'Copernican revolution' in animal physiology. While its overall impact on the course of Western scientific and philosophical thinking may have been incomparably inferior to that of Copernicus's *De revolutionibus*, it is also true that this was an extraordinary discovery, accomplished within the Aristotelian tradition. On a methodological level, this discovery recalls in the first place the sixteenth-century reappraisal of observation, which was developed by authors such as Vesalius and Cesalpino.[83] Harvey continued to favour the use of direct observation in contrast with the blind reading of ancient texts:

> My dear colleagues, I had no purpose to swell this treatise into a large volume by quoting the names and writings of anatomists, or to make a parade of the strength of my memory, the extent of my reading, and the amount of my pains; because I profess both to learn and to teach anatomy, not from books but from dissections; not from the positions of philosophers but from the fabric of nature; and that because I do not think it right or proper to strive to take from the ancients any honour that is their due, nor yet to dispute with the moderns, and enter into controversy with those who have excelled in anatomy and been my teachers.[84]

Exactly like Galileo, in the middle of the century, Harvey thus explicitly declared himself to be privileging 'the book of Nature' in contrast with the books in which even the opinions of the most authoritative scholars of nature were expressed:

> But that these are erroneous and hasty conclusions is easily made to appear: like phantoms of darkness they suddenly vanish before the light of anatomical inquiry. Nor is any long refutation necessary where the truth can be seen with one's proper eyes; where the inquirer by simple inspection finds everything in conformity with reason; and where at the same time he is made to understand how unsafe, how base a thing it is to receive instruction from other's comments

> without examination of the objects themselves, the rather as the book of Nature lies so open and is so easy of consultation. [...]
>
> For although it is a new and difficult road in studying nature, rather to question things themselves than, by turning over books, to discover the opinions of philosophers regarding them, still it must be acknowledged that it is the more open path to the secrets of natural philosophy, and that which is less likely to lead into error.[85]

Again in the wake of Galileo, Harvey made recourse to observation, strengthened through the use of instruments such as the magnifying glass,[86] in a strictly and openly 'experimental' sense, thus endorsing the measurement and as a consequence the quantitative dimension of the phenomena analysed.[87] Besides, he had already thoroughly incorporated empirical data resulting from close examination of reason and experimentation, as is shown, by way of an example, in his resolute reinterpretation (in the second *Treatise* of the *Two Anatomical Treatises on the Circulation of the Blood*, 1649) of the Aristotelian concept of the relationship between demonstration and recourse to the senses outlined in *Generation of Animals*:

> Were nothing to be acknowledged by the senses without evidence derived from reason, or occasionally even contrary to the previously received conclusions of reason, there would now be no problem left for discussion. Had we not our most perfect assurances by the senses, and were not their perceptions confirmed by reasoning, in the same way as geometricians proceed with their figures, we should admit no science of any kind; for it is the business of geometry, from things sensible, to make rational demonstration of things that are not sensible; to render credible or certain things abstruse and beyond sense from things more manifest and better known. Aristotle counsels us better when, in treating of the generation of bees, he says: 'Faith is to be given to reason, if the matters demonstrated agree with those that are perceived by the senses; when the things have been thoroughly scrutinized, then are the senses to be trusted rather than the reason.' [Aristotle *Generation of Animals*] Whence it is our duty to approve or disapprove, to receive or reject everything only after the most careful examination; but to examine, to test whether anything have been well or ill advanced, to ascertain whether some falsehood does not lurk under a proposition, it is imperative on us to bring it to the proof of sense, and to admit or reject it on the decision of sense.[88]

This method of research, unlike what was happening in physics,[89] was thus carried forward under the banner of Aristotelianism, even though the new-born experimental technique was in fact rather distant from the original trust accorded to the senses.

It was, however, much closer to the teleological approach: not only in the sense that the blood was understood to be more or less indirectly consistent with the model of a final cause,[90] but more generally because the basic mechanisms of nature continued to be thought of in eminently finalistic as well as often anthropomorphic terms. It is a perspective that is evident throughout *De motu cordis*, for example, where on the one hand the principle by which 'nature always does that which is best' is reiterated,[91] and on the other that 'nature, ever perfect and divine, doing nothing in vain, has neither given a heart where it was not required, nor produced it before its office had become necessary.'[92] And again where 'the consummate providence of nature' is noted: in the blood '[t]here is a certain though small and inappreciable proportion of chyle or unconcocted matter mingled with this blood, nature has interposed the liver, in whose meandering channels it suffers delay and undergoes additional change, lest arriving prematurely and crude at the hart, it should oppress the vital principle.'[93] Or where these diverse meanings are explained together: 'perfect nature does nothing in vain, and suffices under all circumstances, we find that the nearer the arteries are to the heart, the more do they differ from the veins in structure.'[94] In the same vein is the explanation of compensatory mechanisms: 'diluting them with a large quantity of warm blood, (for we see that the quantity returned from the spleen must be very large when we contemplate the size of its arteries,) they are brought to the porta of the liver in a state of higher preparation; the defects of either extreme are supplied and compensated by this arrangement of the veins.'[95]

In brief, on the methodological level, the discovery of the circulation of the blood – which in turn was inscribed within the tradition of cardiocentrality[96] – is also proof of the merging of Aristotelian teleology with the experimental re-evaluation of the quantitative element:

> And sooth to say, when I surveyed my mass of evidence, whether derived from vivisections, and my various reflections on them, or from the ventricles of the heart and the vessels that enter into and issue from them, the symmetry and size of these conduits, – for nature doing nothing in vain, would never have given them so large a relative size without a purpose [...]; I began to think whether there might not be *a motion, as it were, in a circle*. [...] Which motion we may be

> allowed to call circular, in the same way as Aristotle says that the air and the rain emulate the circular motion of the superior bodies.[97]

Taking this into account, it is understandable why, in concluding the introduction to his last great work, the celebrated *Anatomical Exercises on the Generation of Animals*, published just after the middle of the seventeenth century (*Exercitationes de generatione animalium*, 1651), Harvey proudly claimed to be following in the footsteps of Aristotle and Hieronymus Fabricius:

> Wherefore, courteous reader, be not displeased with me, if, in illustrating the history of the egg, and in my account of the generation of the chick, I follow a new plan, and occasionally have recourse to unusual language. Think me not eager for vainglorious fame rather than anxious to lay before you observations that are true, and that are derived immediately from the nature of things. That you may not do me this injustice, I would have you know that I tread in the footsteps of those who have already thrown a light upon this subject, and that, wherever I can, I make use of their words. And foremost of all among the ancients I follow Aristotle; among the moderns, Fabricius of Aquapendente; the former as my leader, the latter as my informant of the way.[98]

6 Chicks

The broad reworking of Aristotle's embryological theories in the *Exercitationes,* already outlined in *De motu*,[99] and renamed 'epigenesis',[100] would form a fundamental option, obviously Aristotelian and already re-proposed by Albertus Magnus,[101] in the debates on the issue in the following two centuries. It is Aristotelian because Harvey's text substantially represents a critical, innovative and intelligent commentary on the main theses of Aristotle and the interpretations and corrections offered in turn by Hieronymus Fabricius. We have therefore a confirmation of the centrality of Aristotle's treatises (in particular of *Generation*, *History* and *Parts of Animals*) in the most advanced embryological (and zoological) research in the middle of the seventeenth century. As Harvey writes, although perhaps with a certain excess of modesty: 'Aristotle, among the ancients, and Hieron. Fabricius of Aquapendente, among the moderns, have written with so much accuracy on the generation and formation of the chick from the egg that little seems left for others to do.'[102]

What I would now like to focus attention on concerns especially the fact that in his analysis Harvey continued, as in *De motu cordis*, to adopt an overall concept of nature in the teleological sense derived directly from Aristotle, the gist of which is contained in the continuously reprised motto, 'for nothing in nature's works is fashioned either carelessly or in vain';[103] in other words, 'if you carefully weigh the works of nature, you will find that nothing in them was made in vain, but that all things were ordered with a purpose and for the sake of some good end',[104] so that the recourse to randomness continued to be marginalized.[105] The teleology emerges in the general sense in which Harvey proposed firstly to show 'what parts are first, and what are subsequently formed by the great God of Nature with inimitable providence and intelligence, and most admirable order. Next we shall inquire into the primary matter out of which, and the efficient cause by which generation is accomplished, and also the order and economy of generation, as observed by us.'[106] This finalism, directed against Empedocles and Democritus, is correlated with nature, whose 'divine' character is explained primarily in teleological form:

> Nor do they err less who, with Democritus, compose all things of atoms; or with Empedocles, of elements. As if *generation* were nothing more than a separation, or aggregation, or disposition of things. It is not indeed to be denied, that when one thing is to be produced from another, all these are necessary, but generation itself is different from them all. I find Aristotle to be of this opinion; and it is my intention, by-and-by, to teach that out of the same albumen (which all allow to be uniform, not composed of diverse parts,) all the parts of the chick, bones, nails, feathers, flesh, &c. are produced and nourished. Moreover, they who philosophize in this way, assign a material cause [for generation], and deduce the causes of natural things either from the elements concurring spontaneously or accidentally, or from atoms variously arranged; they do not attain to that which is first in the operations of nature and in the generation and nutrition of animals; viz. they do not recognize that efficient cause and divinity of nature which works at all times with consummate art, and providence, and wisdom, and ever for a certain purpose, and to some good end; they derogate from the honour of the Divine Architect, who has not contrived the shell for the defence of the egg with less of skill and of foresight than he has composed all the other parts of the egg of the same matter, and produced it under the influence of the same formative faculty.[107]

In a strictly teleological sense Harvey also describes a direct link between the eternal movements of the cosmos[108] and eternal reproduction of species,[109] which in turn represents the 'final end' assigned to each individual by nature:

> We therefore see individuals, males as well as females, existing for the sake of preparing eggs, that the species may be perennial, though their authors pass away. And it is indeed obvious, that the parents are no longer youthful, or beautiful, or lusty, and fitted to enjoy life, than whilst they possess the power of producing and fecundating eggs, and, by the medium of these, of engendering their like. But when they have accomplished this grand purpose of nature, they have already attained to the height, the *acme* of their being, – the final end of their existence has been accomplished; after this, effete and useless, they begin to wither, and, as if cast off and forsaken of nature and the Deity, they grow old, and, a-weary of their lives, they hasten to their end.[110]

I believe, moreover, that it is interesting to point out how Harvey so faithfully reprises Aristotle to the point that he goes beyond the traditional fixist thesis set out in the creationist framework, to directly adopt the ancient eternalist concept of species (alongside that of spontaneous generation),[111] as is patently obvious when he tackles that most classical of questions regarding the chicken and the egg:

> And first, it is manifest that a fruitful egg cannot be produced without the concurrence of a cock and hen: without the hen no egg can be formed; without the cock it cannot become fruitful. But this view is opposed to the opinion of those who derive the origin of animals from the slime of the ground. And truly when we see that the numerous parts concurring in the act of generation, – the testes and vasa deferentia in the male, the ovarium and uterus and blood-vessels supplying them in the female – are all contrived with such signal art and forethought, and everything requisite to reproduction in a determinate direction – situation, form, temperature, – arranged so admirably, it seems certain, as nature does nothing in vain, nor works in any round-about way when a shorter path lies open to her, that an egg can be produced in no other manner than that in which we now see it engendered, viz., by the concurring act of the cock and hen. Neither, in like manner, in the present constitution of things, can a cock or hen ever be produced otherwise than from an egg. Thus the cock and the hen exist for the sake of the egg, and the egg, in the same way, is their antecedent cause; it were therefore reasonable to ask, with Plutarch, which of these was the prior, the egg or the

> fowl? Now the fowl is prior by nature, but the egg is prior in time; for that which is the more excellent is naturally first; but that from which a certain thing is produced must be reputed first in respect of time. Or we may say: this egg is older than that fowl (the fowl having been produced from it); and, on the contrary, this fowl existed before that egg (which she has laid). And this is the round that makes the race of the common fowl eternal; now pullet, now egg, the series is continued in perpetuity; from frail and perishing individuals an immortal species engendered. By these, and means like to these, do we see many inferior or terrestrial things brought to emulate the perpetuity of superior or celestial things.[112]

Finally, I would like to point out how in this text Harvey also reprises the immanent teleology of Aristotle's legacy in relation to the functions of organs (generally aimed at the soul):[113] 'to the cock, therefore, as well as to the hen, are given the organs requisite to the function with which he is intrusted';[114] more generally: 'when we see the eyes adapted for vision, the bill for taking food, the feet for walking, the wings for flying, and similarly the rest of its parts, each to its own end, we must conclude, whatever the power be which creates such an animal out of an egg, that it is either the soul, or part of the soul, or something having a soul, or something existing previous to, and more excellent than the soul, operating with intelligence and foresight.'[115] From an epigenetic perspective – given that in the admirable products of the egg and the semen 'nothing is vain, or inconsiderate, or accidental, but all conduces to some good ends'[116] – what follows holds firm: 'it is a law of nature that no parts or instruments be produced before there be some use for them, and the faculty be extant which employs them.'[117] A law thus integrated: 'Aristotle then subjoins another cause to this order, viz.: "That as nature does nothing in vain or superfluously, it follows that she makes nothing either sooner or later than the use she has for it requires." That is to say, those parts are first engendered whose use or function is first required.'[118] The discussion of the dimension of necessity comes to explicitly justify, as it did in Hieronymus Fabricius, the ambivalence of recourse to the superfluity of a nature here understood to be 'a fond and indulgent mother.'[119]

7 Procreations preordained

Harvey also reprises the traditional teleological approach with regard to equilibrium among species, whose 'immortality' is also guaranteed from an ecological perspective. Although mostly indirectly, in his treatises it emerges that the functioning of nature continues to be based on a model of distributive pseudo-equity which ensures the preservation of the species. In the discussion on the number of birds' eggs, for example, in fact retracing what Aristotle had written about the small eggs of fish, which shows how 'nature makes good the destruction by sheer weight of numbers',[120] Harvey adopts an eminently compensatory model:

> The number of eggs serves the same end as abundance of conceptions among viviparous animals – they secure the perpetuity of the species. Nature appears to have been particularly careful in providing a numerous offspring to those animals which, by reason of their pusillanimity or bodily weakness, hardly defend themselves against the attacks of others; she has counterbalanced the shortness of their own lives by the number of their progeny. 'Nature', says Pliny, 'has made the timid tribes among birds more fruitful than the bold ones.' All generation as it is instituted by nature for the sake of perpetuating species, so does it occur more frequently among those that are shorter-lived and more obnoxious to external injury lest their race should fail. Birds that are of stronger make, that prey upon other creatures, and therefore live more securely and for longer terms scarcely lay more than two eggs once a year. Pigeons, turtle and ring-doves, that lay but a couple of eggs, make up for the smallness of the number by the frequency of laying, for they will produce young as often as ten times in the course of a year. They therefore engender greatly although they do not produce many at time.[121]

And again, with regard to the difficult question of the distribution of 'organs of defence and offence' provided for by nature according to criteria of pseudo-equity, the thesis proposed by Harvey represents another almost perfect 'borrowing' of the concept set forth by Aristotle in *Parts of Animals* (which is in turn a particular reworking of the Protagorean myth), here encapsulated in an extraordinary interpretation of the relationship between male ornamentation and competition:

> Man comes into the world naked and unarmed, as if nature had destined him for a social creature, and ordained him to live under equitable laws and in peace; as if she had desired that he should be guided by reason rather than be driven by force; therefore did she endow him with understanding, and furnish him with hands, that he might himself contrive what was necessary to his clothing and

> protection. To those animals to which nature has given vast strength, she has also presented weapons in harmony with their powers; to those that are not thus vigorous, she has given ingenuity, cunning, and singular dexterity in avoiding injury.
>
> Ornaments of all kinds, such as tufts, crests, combs, wattles, brilliant plumage, and the like, of which some vain creatures seem not a little proud, to say nothing of such offensive weapons as teeth, horns, spurs, and other implements employed in combat, are more frequently and remarkably conferred upon the male than the female. And it is not uninteresting to remark, that many of these ornaments or weapons are most conspicuous in the male at the epoch when the females come into season, and burn with desire of engendering. And whilst in the young they are still absent, in the aged they also fail as being no longer wanted.
>
> Our common cock, whose pugnacious qualities are well known, so soon as he comes to his strength and is possessed of the faculty of engendering, is distinguished by his spurs, and ornamented with his comb and beautiful feathers, by which he charms his mates to the rites of Venus, and is furnished for the combat with other males, the subject of dispute being no empty or vainglorious matter, but the perpetuation of the stock in this line or in that; as if nature had intended that he who could best defend himself and his, should be preferred to others for the continuance of the kind. And indeed all animals which are better furnished with weapons of offence, and more warlike than others, fall out and fight, either in defence of their young, of their nests or dens, or of their prey; but more than all for the possession of their females. Once vanquished, they yield up possession of these, lay aside their strut and haughty demeanour, and, crestfallen and submissive, they seem to consume with grief; the victor, on the contrary, who has gained possession of the females by his prowess, exults and boastfully proclaims the glory of his conquest.
>
> Nor is this ornamenting anything adventitious and for a season only; it is a lasting and special gift of nature, who has not been studious to deck out animals, and especially birds only, but has also thrown an infinite variety of beautiful dyes over the lowly and insensate herbs and flowers.[122]

And this is the teleological concept that was to continue to predominate right up to the eighteenth century. Before considering in what form and via which channels, I would like to conclude this description of the seventeenth-century distinction between the life sciences and physics.

8 The last stronghold

In short, with Galilean mathematization on the one hand and the revival of teleology on the other, I believe it is now more clear in what sense the separation between the physical sciences and the life sciences may also be understood as an opposition 'between a biomorphic-qualitative vision of nature, in the case of the Aristotelians, and mechanical-quantitative, in the case of Galileo', where the former systematically privileges the recourse to final causes.[123] The point is that even in the life sciences the traditional framework was defined in an experimental sense. Since, however, the direction of mathematization was not followed, experimentalism, enhanced by new instruments (beginning with the microscope), was perfectly combined with the traditional Aristotelian system. So it was that anti-finalistic mechanicism and Cartesian-type mathematization were rejected by Harvey and, from him onwards, they remained relatively marginalized and did not spread among the protagonists of natural history in the second half of the seventeenth and then eighteenth centuries. So it was that while in epistemic praxis physicists and astronomers, around the first decades of the seventeenth century, stopped looking for final causes and essences, zoologists, botanists and anatomists continued to constantly search for them. The three updated pillars of the Aristotelian fixist, essentialist and teleological framework therefore survived the seventeenth-century revolution substantially intact: natural history came to represent the last bastion of the *scientia naturalis* inherited from the reception, institutionalization and reinterpretation of the treatises of Aristotle, and teleology constituted its most solid stronghold.

3
Indirect Supremacy

1 Persistence

If we take a bird's eye view of the course of natural history over the arc of time that extends from about the middle of the seventeenth century to the middle of the eighteenth century, we note that Aristotle's fixist, essentialist and teleological framework substantially holds its ground. Although its paternity is gradually disowned and in a certain sense disguised; and although significant innovations are introduced into this field of enquiry, both quantitatively and qualitatively especially in the sphere of systematics; and, finally, although repeated attempts are made to import Cartesian notions into the field, the framework holds fast. Despite Aristotle's being cited less and less, from the point of view of the three fundamental principles, at this time natural history can still legitimately be interpreted as a form of 'Christianized Aristotelianism':

> For my part, I would argue that the systematic natural history of Tournefort, Ray, Linnaeus, and others was in many respects simply a Christianized Aristotelianism, although much narrower in scope than Aristotle's biology. True, Ray's world was created, Aristotle's eternal, but in either case the species were fixed and given. Aristotle postulated final causes in nature to explain the adaptations of plants and animals, Ray a transcendent Creator; in either case nature did nothing in vain. Aristotle distinguished between essential and accidental characters in defining kinds of animals; Ray employed the same distinctions in arriving at species and constructing his systems of classification, adding, however, the novel idea that the members of each species were related by common descent.[1]

Here, John Greene highlights the persistence in the seventeenth and eighteenth centuries of the three theoretical pillars that I have so far tried to reconstruct from the re-establishment of the Aristotelian framework in both the late Middle Ages and the Renaissance. The first, the fixist concept, had been reconciled with the dogma of creation since the thirteenth century. The second, the teleological perspective, especially in the positive sense of the recourse to 'final causes', is understood to be a theoretical tool designed to take account both of the functionality of organs and the compensatory equilibrium precluding the possibility of any one species becoming extinct. And the third is the correlated, essentialist notion of species, cemented in the priority that is attributed to form, which marginalizes the role of accidental, or rather random, variations. Beyond the radical innovations concerning systematics developed especially from the end of the seventeenth century, the way I see it is that we are dealing with an indirect supremacy that testifies to the strong position that the Aristotelian model held in the field of natural history in the post-Newtonian age.

2 Long shadows

I also share Greene's historiographical approach when he sees the work of the English naturalist John Ray as a sort of litmus test: this is emblematic of the persistence of the Aristotelian framework within the field of natural history in the late seventeenth century and at the same time of its transformation and partial camouflage in an emphatically theological context. Also, due to the work of Ray, who made a decisive contribution to the renewal of systematics, the traditional teleological framework having by now declined into a decidedly experimental mode, was brought into the eighteenth century. My extremely brief sketch of this process of transition, after referring to the central issue of the recourse to final causes, will concentrate on the two sides of traditional teleology in both its systemic and functionalist aspects, which can easily be seen in the work *The Wisdom of God Manifested in the Works of the Creation* (first edition, 1691, fourth edition, 1704). This is a text, continually reprinted throughout the eighteenth century, which had an extraordinary influence up to Paley's *Natural Theology* (first edition 1802): the archdeacon not only 'imitated' it, but actually 'extensively plagiarised' it.[2]

On the philosophical side, Ray declares from the start that he is opposed to Descartes and his attempt at 'excluding and banishing all Consideration of final Causes from Natural Philosophy, upon Pretence, that they are all and every one in particular undiscoverable by us;

and that it is Rashness and Arrogance in us to think we can find out God's End, and be Partakers of his Councils.'[3] Ray here moves decisively against systematic recourse to mechanical randomness, quoting (in Greek) Aristotle's motto by which 'nothing that happens by chance will always happen in the same way',[4] and restating the criticism of Descartes outlined by Harvey, 'with whom for the main I do consent', while observing the limits of mechanicism: 'the greatest of all the particular *Phaenomena*, is the Formation and Organization of the Bodies of Animals, consisting of such Variety and Curiosity, that these mechanic Philosophers being no way able to give an Account thereof from the necessary Motion of Matter, *unguided by Mind for Ends*, prudently therefore break off their System there, when they should come to Animals, and so leave it altogether untouch'd.'[5]

Ray also takes up Boyle's approach from the beginning: 'This confident Assertion of Des Cartes is fully examin'd and reprov'd by that honourable and excellent Person, Mr. Boyle, in his *Disquisition about the Final Causes of Natural Things*'.[6] Boyle's text (1688), which for that matter also drew from Harvey,[7] was in fact explicitly dedicated to delivering harsh criticism both of the materialistic Epicurean tradition, which endorsed a systematic recourse to randomness – that is, chance – and Cartesian mechanicism.[8] While it is true that Boyle maintained that he was reworking the teachings of Aristotle in a much reduced way,[9] as far as the specific fields of anatomy and zoology were concerned the thesis and argumentation he developed were very often a simple rehashing of Aristotle's, albeit stated and reinterpreted in a distinctly creationist and anthropocentric manner. This was an undertaking that Boyle in a certain sense laid claim to, asserting:

> The bare Speculation of the Fabrick of the World, without considering any part of it, as destinated to certain (or determinate) Uses, may still leave Men unconvinc'd, that there is any Intelligent, Wise, and Provident Author and Disposer of Things: Since we see generally the Aristotelians (before some of them were better Instructed by the Christian Religion) did, notwithstanding the Extent, Symmetry, and Beauty of the World, believe it to have been Eternal. And tho' They, whatever their Master thought, did not believe it to have been created by God; yet, because they asserted that Animals, Plants, &c. act for Ends, they were oblig'd to acknowledge a Provident and Powerful Being, that maintain'd and govern'd the Universe, which they call'd *Nature*: Tho' they too often dangerously mistook, by sometimes confounding this Being with God himself; and at other times,

> speaking of it as Co-ordinate with him, as in that famous Axiom of *Aristotle*, *Deus & Natura nihil faciunt frustra*.[10]

Thus we have a sort of critical revision of Aristotle's teachings, as is also evident when Boyle, recognizing that 'Aristotle, who expressly teaches, that Nature does nothing in vain, and rightly judg'd, that the Action of Natural Agents tended to certain Ends, takes notice of this Difficulty; but seems rather to Shift it off rather than resolve it'.[11] In short, in terms of reintroducing the guiding principle of Aristotelian physiological anatomy, suffice it to remember the argument according to which the 'End' of the parts of animals (and plants) is to ensure 'the welfare of the whole Animal himself, as he is an entire and distinct System of organized parts, destined to preserve himself and propagate his *Species*'. Hence, 'Final Causes' continued to represent the guiding principle of the life sciences.[12]

On reinterpreting his position from the perspective of the persistence of the Aristotelian tradition, Ray finds himself firmly in the anti-Cartesian camp, advanced in the English-speaking world by scientists such as Harvey and Boyle, who defended and reintroduced Aristotelian teleology to the natural sciences, more particularly in the field of the life sciences, albeit with rather significant corrections and innovations.[13] The first classic argument adopted by Ray to defend the legitimacy of the recourse to final causes – for that matter also substantially employed by Boyle[14] – deserves mention because it would continue to enjoy extraordinary good fortune:

> For first, Seeing (for Instance) that the Eye is employ'd by Man and all Animals for the Use of Vision, which, as they are fram'd, is so necessary for them, that they could not live without it; and God Almighty knew that it would be so; and seeing it is so admirably fitted and adapted to this Use, that all the *Wit* and *Art* of Men and Angels could not have contriv'd it better, if so well; it must needs be highly absurd and unreasonable to affirm, either that it was not design'd at all for this Use, or that it is impossible for Man to know whether it was or not.[15]

Although transfigured, there is an almost leaden echo here of the ancient Aristotelian objection to Empedocles' concept: it is absurd to think that organs were not formed, assembled and distributed with a view to their precise function, usefulness and aim. Nature, which never does anything in vain, adapts organs to functions, not functions to organs, aiming for the good of the organism, certainly not acting in a random and senseless way. Organs are, literally, nothing but tools created for particular uses, predisposed in that sense by nature.

Ray's undertaking, drawing on the centuries-old heritage of 'Christianized Aristotelianism', thus exerts some pressure on shifting the teleological dimension attributed to the wisdom (*phronesis*) of nature from the level of immanence towards the level of the divine. At the same time, Ray goes in search of forces, entities and mechanisms of transmission (intelligent plastic nature, and so on) distinct from Aristotle's. The point is, though, that the finalistic theoretical nucleus remains the same. The engraving of the woodpecker's two-toed feet, which 'Disposition (as Aldrovandis well notes) Nature, or rather the Wisdom of the Creator, hath granted to Woodpeckers, because it is very convenient for the climbing of Trees', is typical.[16] What was the wisdom of nature has once again, with some uncertainty, been projected directly into the dimension of the divine; from the point of view of the analysis of anatomical and physiological dispositions, the difference is, however, irrelevant.

3 Subtext

In this finalistic context it is not difficult to show how Ray reintroduced compensatory teleology correlated with the argument of the pseudo-egalitarian distribution of 'means of defence', defining it explicitly in a systemic sense, and presenting it in providential guise:

> Thirdly, I shall remark the Care that is taken for the Preservation of the Weak, and such as are expos'd to the Injuries, and preventing the Increase of such as are noisome and hurtful; for as it is a Demonstration of the divine Power and Magnificence to create such Variety of Animals, not only great but small, not only strong and courageous, but also weak and timorous; for is it no less Argument on his Wisdom to give to these Means, and the Power and Skill of using them, to preserve themselves from the Violence and Injuries of those. [...] the rest that have no such Armature, should be endu'd with great Swiftness or Pernicity; and not only so, but some also have their Eyes stand so prominent, as the *Hare*, that they may have their Enemy always in their Eye; and long, hollow, moveable Ears, to receive and convey the least Sound, or that which comes from far, that they be not suddenly surprized or taken (as they say) napping. [...]
>
> So, that there are none destitute of some Means to preserve themselves, and their Kind; and these Means so effectual, that notwithstanding all the Endeavours and Contrivances of Man and Beast to

> destroy them, there is not to this Day one *Species* lost of such as are mention'd in Histories, and consequently and undoubtedly neither of such as were at first created.
>
> Then for Birds of Prey, and rapacious Animals, it is remarkable what Aristotle observes, That they are all solitary, and go not in Flocks, 'No bird of prey is gregarious'. Again, that such creatures do not greatly multiply, 'they reproduce little'. They for the most part breeding and bringing forth but one or two, or at least a few Young Ones at once: Whereas they that are feeble and timorous are generally multiparous; or, if they bring forth but a few at once, as Pigeons, they compensate that by their often breeding, viz. every Month but two throughout the Year; by this Means providing for the Continuation of their Kind.[17]

This compensatory equilibrium is placed in the context of a systemic anthropocentrism[18] that exacerbates the tensions inherent in the *corpus* – one may recall the famous passage from *Politics* in which it is maintained that plants exist for the sake of animals, and animals for the sake of humankind – while explicitly and faithfully restating Aristotle's argument that humankind is also superior to other animals from the perspective of their means of defence:

> If now I should go about to reckon up the several Uses of this Instrument, Time would sooner fail me than Matter. [...] this is the only Instrument for all Arts whatsoever, no Improvement to be made of any experimental Knowledge without it. Hence (as *Aristotle* saith well) they do amiss that complain that Man is worse dealt with by Nature than any other Creatures; whereas they have some Hair, some Shells, some Wool, some Feathers, some Scales, to defend themselves from the Injuries of the Weather, Man alone is born naked and without all Covering; whereas they have natural Weapons to defend themselves and offend their Enemies, some Horns, some Hoofs, some Teeth, some Talons, some Claws, some Spurs and Beaks; Man hath none of all these, but is weak feeble, and unarm'd sent into the World: why, a Hand, with Reason to use it, supplies the Uses of all these, that's both a Horn and a Hoof, a Talon and a Tusk, etc. Because it enables us to use Weapons of these and other fashions, as Swords, and Spears, and Guns.[19]

Moreover, given that there is an 'exact Fitness of the Parts of the Bodies of Animals to every one's Nature and Manner of Living',[20] Ray continues to adopt Aristotle's guiding principle according to which 'nature never does anything in vain or superfluous', and 'every Part in Animals is fitted to its Use.'[21] With regard to the centrality of use and usefulness, the similarity to Aristotle is revealed rather as a tacit retake, as is evident typically in the discussion of those organs that may seem entirely 'useless', thus the result of random events, such as nipples in male humans:

> The Body of Man may thence be prov'd to be the Effect of Wisdom, because there is nothing in it deficient, nothing superfluous, nothing but hath its End and Use. So true are those Maxims we have already made use of: *Natura nihil facit frustra*, and *Natura non abundat in superfluis, nec deficit in necessariis*, no Part that we can well spare [...]. Only it may be doubted to what Use the Paps in Men should have. I answer, partly for Ornament, partly for a kind of Conformity between the Sexes, and partly to defend and cherish the Heart; in some they contain Milk, as in a Danish Family we read of in *Bartholine's Anatomical Observations*; however, it follows not that they or any other Parts of the Body are useless because we are ignorant. [...] Nature hath not given Paps to Men either to no purpose, or for meer Ornament, but, if need requires, to supply the Defect of the Female, and give Suck to the Young.
>
> Had we been born with a large Wen upon our Faces, or a *Bavarian* Poke under our Chins, or a great Bunch upon our Backs like *Camels*, or any the like superfluous Excrescency, which should be not only useless but troublesome, not only stand us in no stead, but also be ill-favour'd to behold and burdensome to carry about, then we might have had some Pretence to doubt whether an intelligent and Bountiful Creator had been our Architect; for had the body been made by Chance, it must in all likelihood have had many of these superfluous and unnecessary Parts. But now seeing there is none of our Members but hath its Place and Use, none that we could spare, or conveniently live without, ere it but those we account Excrements, the Hair of our Heads, or the Nails on our Fingers ends, we must needs be mad or sottish, if we can conceive any other that that an infinitely good and wise God was our Author and Former.[22]

So even the nipples of male humans have a purpose. Actually, they have many functions: ornament, symmetry, and protection for the heart. Thus neither they nor other parts are useless. This argument is nothing more than a slightly modified version of the one set forth in *Parts of Animals*:

> Between the arms in man (in other animals between the forelegs) is what is known as the breast. In man the breast is broad, and reasonably so, for the arms are placed at the side and so do not in any way prevent this part from being wide. In the quadrupeds, however, it is narrow, because as they walk about and change their position the limbs have to be extended forwards. And in this account, in quadrupeds the mammae are not on the breast. In man, on the other hand, as the space here is wide, and the parts around the heart need some covering, the breast is fleshy in substance and the mammae are placed on it and are distinct. In the male they are themselves fleshy for the reason just given. In the female the Nature employs them for an additional function (a regular practice of hers, as I maintain), by storing away in them nourishment for the body has two parts, the right and the left.[23]

Ray's analysis is not, however, simply unoriginal; more generally, it represents a weakening of those themes that for Aristotle continued in some way to represent issues that, while not open, were at least less contentious. The question of the eyes of the mole is typical of Ray's de-problematization: he gradually transforms its evident problematics into yet more proof of crystal-clear and omnipresent providence, so that its anomalous and ostensible blindness is turned almost into a virtue:

> A second and no less remarkable Instance, I shall produce, out of Dr. *More's Antidote against Atheism*, lib. 2 cap. 10 in a poor and contemptible Quadruped, the Mole.
>
> First of all (saith he) her Dwelling being under Ground, where nothing is to be seen, Nature hath so obscurely fitted her with Eyes, that Naturalists can scarcely agree, whether the hath any Sight at all or no. [...] But for Amends, what she is capable of for her Defence and Warning of Danger, she has very eminently conferr'd upon her; for she is very quick of hearing, (doubtless her subterraneous Vaults are like Trunks to convey any Sound a great Way.) And then her short Tail and short Legs, but broad Fore-feet armed with sharp Claws, we see by the Event to what purpose they are, she so swiftly working herself under Ground, and making her Way so fast in the Earth, as they that behold it cannot but admire it. Her Legs therefore are

> short, that she need dig no more than will serve the mere Thickness of her Body: And her fore-feet are broad, that they may scoup away much Earth at a Time: and she has little or no Tail [...]. [I]t had been dangerous to draw so long a Train behind her; for her Enemy might fall upon her Rear, and fetch her out before she had perfected and got full Possession of her Works: Which being so, what more palpable Argument of Providence than she?[24]

Apart from adaptation, Ray also makes use of absurd argumentation, including the consideration of why the mole does not have a long tail, which would be not only useless but even burdensome. Yet again, he refers to Aristotle's teachings, rendering them inflexible, as in many other analogous cases – for example, the symmetry of paws:

> To the Fitness of all the Parts and Members of Animals, to their respective Uses, may also be referred another Observation of the same Aristotle: "All Animals have even Feet", not more on one Side than another; which, if they had, would either hinder their walking, or hang by not only useless, but also burthensome. For though a Creature might make a limping Shift to hop, suppose with three Feet, yet nothing so conveniently or steddily [*sic*] to walk or run, or indeed to stand; so that we see Nature hath made choice of what is most fit, proper, and useful: They have also not only an even Number of Feet, answering by Pairs one to another, which is as well decent as convenient, but those too of an equal Length, I mean, the several Pairs; whereas were those on one side longer than they on the other, it would have caus'd an inconvenient halting or limping in their going.[25]

In conclusion, while we may be confronted with a stiffening of resolve, de-problematization and massive pressure towards the anthropocentric and the providential, I believe that what emerges from even these brief passages is the extraordinary influence, both direct and indirect, exerted by Aristotle's legacy on one of the most important naturalists of the late seventeenth century, especially with regard to the centrality of the teleological approach to the dual systemic and functionalist levels.

4. Œconomia naturæ

The giant of systematics of the first half of the seventeenth century, Linnaeus, had a determining influence on cementing the supremacy of the teleological, essentialist and fixist framework of Aristotelian origin, although in his later writings, his granite certainties began to crumble. Linnaeus in fact encountered Aristotle as a young boy and, as was normal at the time, his thinking was shaped by his texts – the first book in Latin that he was able to read at home was *History of Animals*, a gift from his father.[26] In brief, as far as the fixist thesis is concerned, in his *Foundations of Botany* (*Fundamenta botanica*, 1736), in an aphorism destined to become famous, the very young naturalist left no shadow of a doubt: 'We count as many species as the Infinite Being created in the Beginning.'[27] Just after the middle of the century, while still adopting a notion of 'form' clearly derived from Aristotle, in *The Science of Botany* (*Philosophia botanica*, 1751) the forty-four-year-old Linnaeus explained:

> 157. We reckon the number of SPECIES (155) as the number of different forms that were created in the beginning. – The 5 classes of plants. The number of species is the number of different forms produced by the infinite Being from the beginning; and these forms have produced more forms, according to the laws laid down, but always ones that are similar to themselves. Therefore the number of species is the number of different forms or structures that occur today. [...] That NEW SPECIES can come to exist in vegetables is disproved by continued generation, propagation, daily observations, and the cotyledons. [...]
>
> 159. We say that there are as many GENERA (155) as there are similarly constructed fruit-bodies produced by different natural species (157). *Cesalpino*. 'If the genera are confused, it is inevitable that everything will be confused'. [My] *Classes Plantarum* 6. 'That all genera and species are natural is confirmed by things that are revealed, discovered, and observed.' [My] *Systema naturæ* veg. 14. 'Every genus is natural, made in the first place such as it is; for this reason it is not be capriciously split or stuck [to another], for pleasure, or according to each man's theory.[28]

While in late maturity Linnaeus came to support the thesis that new species may be born by crossbreeding, also being open to recourse to randomness,[29] his previous works sanctioned the persistence of the fixist thesis, correlated in turn with a classification of a fundamentally 'essentialist' stamp.[30] Following Ray's line of thought, and 'Christianized Aristotelianism' in a more general sense, Linnaeus moreover reaffirmed the Aristotelian motto in a creationist sense, excluding the possibility of extinction: 'He [the Deity] who has ordered all things with the most singular wisdom, and has regulated the number of the offspring of every kind of animal with a proportion so exact, employed certainly as accurate a calculation in creating them. He has done nothing in vain, nothing inconsistent with the laws he has once laid down.'[31]

Having outlined these fundamental concepts, I would now like to concentrate on the endurance and reinterpretation of the third cornerstone of the traditional framework: teleology, now defined above all in a systemic sense, by Ray. In this regard I believe Linnaeus's vision of the 'economy of nature', which also comes to be understood in the literal terms of 'final causes', is fundamental: '*Œconomia* and *Politia Naturæ* are two important arguments drawn at the same time from all the three kingdoms of nature, and demonstrate theology, or final causes; for what purpose every thing was created; and the connection that subsists among created things, as to their production, conservation, and destruction.'[32]

Within this context, the teleological concept of *systema naturæ* operates on two fundamental, closely interrelated but distinct levels. The first concerns 'the ultimate end which God proposed in all his works', which is now understood as 'to make manifest the divine glory'. The second pertains to 'intermediate ends', and it is for this reason that teleology operates in an immanent way. This dual level emerges somewhat clearly in the dissertation, *Œconomia naturæ*, by Biberg, a student of Linnaeus, submitted in 1749 – in the opening of which we read:

> §. 1. By the Œconomy of Nature we understand the all-wise disposition of the Creator in relation to natural things, by which they are fitted to produce general ends, and reciprocal uses.
>
> All things contained in the compass of the universe declare, as it were, with one accord the infinite wisdom of the Creator. For whatever strikes our senses, whatever is the object of our thoughts, are so contrived, that they concur to make manifest the divine glory, i.e. the ultimate end which God proposed in all his works. Whoever duly turns his attention to the things on this our terraqueous globe, must necessarily confess, that they are so connected, so chained together, that they all at the same end, and to this end a vast number of intermediate ends are subservient. But as the intent of this treatise will not suffer me to consider them all, I shall at present only take notice of such as relate to the preservation of natural things. In order therefore to perpetuate the established course of nature in a continued series, the divine wisdom has thought fit, that all living creatures should constantly be employed in producing individuals; that all natural

> things should contribute and lend a helping hand to preserve every species; and lastly, that the death and destruction of one thing should always be subservient to the restitution of another.[33]

The 'ultimate End' is treated on a strictly theological level, and in this regard Linnaeus outlines a concept analogous in tenor to other theological-philosophical systems of the eighteenth century (see for example his *Nemesis Divina*).[34] Still included in this context is the absolutist anthropocentric finalism found in various texts of the Linnaean school,[35] an obvious example of which is the then celebrated – *Cui bono?* (by Gedner, another of his students). This text re-proposes a notion centred on a thesis as simple as it is radical, according to which 'the three kingdoms of nature were created for the use of man, since to him alone is granted the prerogative of converting their inhabitants to his own advantage.'[36] The old Aristotelian motto according to which 'nature never does anything in vain' is thus explicitly reinterpreted in the light of this extreme anthropocentrism. Something that, with regard to the Aristotelian heritage, went decisively beyond the tensions and contradictions nestling in the *corpus*. It is true that in a passage from a renowned text such as *Politics* Aristotle had proposed a perfectly analogous thesis, writing:

> So that clearly we must suppose that nature also provides for them in a similar way when grown up, and that plants exist for the sake of animals and the other animals for the good of man, the domestic species both for his service and for his food, and if not all at all events most of the wild ones for the sake of his food and of his supplies of other kinds, in order that they may furnish him both with clothing and with other appliances. If therefore nature makes nothing without purpose or in vain, it follows that nature has made all the animals for the sake of men. Hence even the art of war will by nature be in a manner an art of acquisition (for the art of hunting is a part of it) that is properly employed both against wild animals and against such of mankind as though designed by nature for subjection refuse to submit to it, inasmuch as this warfare is by nature just.[37]

However, in the (voluminous) literature on the life sciences, alongside the anthropocentrism centred on the hierarchy of the *scala naturæ*, the basic concept that was adopted instead revolved around an immanent-type teleology:[38] the functioning and correlation of living beings is here based on a principle of distributive equity by virtue of which nature assigns to each species the necessary organs (the 'means of defence') so that they may preserve themselves, so as to preclude the possibility of their extinction. And it is precisely the restating of this teleological concept that makes Linnaeus an outstanding exponent of the Aristotelian tradition.

This said, let us return to the functioning and internal equilibrium of the *systema naturæ*, to which Linnaeus definitely made more significant scientific contributions. From this perspective, exactly as in the traditional framework, the immanent teleology of the *œconomia naturæ* operates on two inseparably interrelated planes: the overall equilibrium between species and their morphological adaptation. With regard to the first, Linnaeus, like all the great naturalists straddling the seventeenth and eighteenth centuries, reintroduces the classic concept of systemic equilibrium:

> If we consider the end for which it pleased the Supreme Being to constitute such an order of nature, that some animals should be, as it were, created only to be miserably butchered by others, it seems that his Providence not only aimed at sustaining, but also keeping a just proportion amongst all the species; and so prevent any one of them increasing too much, to the detriment of men, and other animals. For it if be true, as it is most assuredly, that the surface of the earth can support only a certain number of inhabitants, they must all perish, if the same number were doubled, or tripled.[39]

As Camille Limoges has stressed, 'the economy of nature is essentially a way of conceiving the finalized interaction between natural bodies, due to which an unalterable equilibrium is preserved in time'; in detail: 'In this conception of the economy of nature the constantly preserved equilibrium between populations of species is defined as a proportion. This proportion is not really an effect of the interactions between natural phenomena, but rather the principle that regulates them'. In short: 'An economy of nature conceived as an exact self-reproduction in infinity implies, as principal postulate, a teleology that the school of Linnaeus, far from rejecting, proposed as the principal requirement to be displayed.'[40]

In turn, this teleology immanent in the overall equilibrium of nature is translated into the perfect adaptation of organisms to their own environment. Here too, the ancient 'wisdom' of nature continues to be conceived in creationist terms, as is evident in *The Oeconomy of Nature*: he demonstrates 'how providentially the Creator has furnished every animal with such clothing, as is proper for the country where they live, and also how excellently the structure of their bodies is adapted to their particular way of life; so that they seem to be destined solely to the places, where they are found.'[41] From this perspective, Linnaeus was thus able to describe perfectly, at close quarters, the functioning and morphology of each and every living being (especially plants) exactly as happened in the ancient theoretical framework put forward by Aristotle, the circular hermeneutic conceit of which was capable of taking account of any phenomenon whatsoever relating to living things. There were innumerable examples, one of which is particularly clear. For example, explaining the phenomenon of the diffusion and propagation of seeds, Linnaeus writes:

> Nature has elevated the seed vessels of plants upon trunks or high stems, that their ripe seeds may be carried a great way by the wind.
>
> If we regard the figure of the capsules of vegetables, we shall find them opening at the apex; lest the seeds should drop out even when ripe, without being widely dispersed by the wind: the Hyoscyamus has a cover on the top of the seed vessel, which opens horizontally when they arrive at maturity, but they do not fall out unless the plant be strongly shaken, that the seeds may be very widely scattered: without this cover of the capsule they would be in danger of perishing by drought, or germinating by moisture there. That some seeds may be dispersed at a great distance from the parent plant, nature has furnished them with something like wings, and a pappous down, by which, after they come to maturity, they are carried up in the air, and have been known to fly to the distance of 50 miles. The divine wisdom has ordered in others, that their containing vessels should expel them as soon as they are ripe, and often dart them to a great distance.[42]

The theoretical structure is yet again the traditional one of the Aristotelian School, as we have seen in Ray and even before that in Harvey: given any living being, almost any one of its morphological characteristics can be interpreted as an element contributing finalistically to its preservation or propagation. This is a thesis that presupposes that nature, or the Creator, has given species all the characteristics necessary for them with regard to their environment and their preservation from extinction.

5 Short shadows

Despite Linnaeus's often being considered the great eighteenth-century successor to Aristotle (and Scholastic philosophy) especially with regard to systematics, his influence is in my opinion decidedly less significant than that exerted by the fixist, essentialist and teleological framework as a whole. Aristotle was in fact interested especially in describing the multiplicity of living things, in understanding their functioning as well as their classification of course, without, however, being concerned with establishing stable, universally valid taxonomic criteria (among other issues there is, for example, the overlapping of the crucial categories of 'species' and 'genera'). In short, Aristotle modulated the adoption of taxonomic criteria according to the fields of enquiry and questions dealt with from time to time; there cannot be 'any serious doubts over the absence of any Linnaean-style taxonomy from Aristotle's zoology.'[43]

On the other hand, in modern times, especially after Cesalpino – who, not by chance, Linnaeus considered 'the first true systematist' – an ever increasing interest develops in the identification of criteria that were the most stable, as well as the most conclusive, possible to accommodate and thus classify 'the essence' of living species. It was this orientation that gave rise to the ever richer and more refined botanical and zoological classifications of the sixteenth, seventeenth and eighteenth centuries, which Linnaeus considered a task like Adam's naming of the animals. Although this task was thus secondary in the Aristotelian treatises, this fact notwithstanding, its undertaking developed within the 'Aristotelian tradition'. The classifications, for which specific criteria were adopted, never cast doubt on the overall theoretical framework of reference. On the contrary, they provided further proof, empirical proof, of its cornerstones.

The elasticity and relative nonchalance demonstrated by Aristotle in relation to the various classifications of living beings, and especially with respect to the criteria thus adopted, became factors which in a paradoxical way contributed to the persistence of his theoretical framework. Some of these classifications were revealed to be very effective – for example, the one concerning animals with and without blood. The paradoxical effect determined by this elasticity is clear in the case of Cesalpino: the micro-tradition inaugurated by the sixteenth-century Aristotelianist, which established modern systematics on the basis of reproductive criteria, indeed had leverage over both epistemological essentialism and the reproductive finalism originated by Aristotle. It was these two elements that Linnaeus took up – thus from this perspective following the Aristotelian line that can be traced schematically back through Cesalpino, Ray and Harvey – and reintroduced via his 'artificial method'. In short, the rationality on which the artificial method was based 'was found in the idea, ascribed by Linnaeus to William Harvey, that all life must necessarily arise only from preexisting life [...]. These ideas led to Linnaeus's emphasis upon the taxonomic importance of the reproductive parts. From Cesalpino, who had based his botanical inquiries upon Aristotelian teachings, Linnaeus learned that the "final cause" of plants was propagation and that reproduction was thus an essential function of the plant.'[44]

However, if the privileging of reproductive criteria could be anchored to texts such as *Generation of Animals* or *Parts of Animals*, this was certainly not the only option revealed by the Aristotelian treatises. While in these texts indeed the broad classificatory criteria of physiological anatomy were privileged,[45] in the early and encyclopaedic *History of Animals* a crucial role was played rather by the ethological and ecological dimension.[46] It was precisely this last criterion that Buffon, adversary par excellence of the Linnaean method, was able to recall. While for the moment passing over the thorny issues of the fixity or not of species, and of their definition in relation to individuals,[47] I shall limit myself to recalling that while defending his 'natural method' and thus the necessity of adopting a plurality of taxonomic criteria, Buffon refers explicitly to *Historia animalium*:

> Aristotle begins his *History of Animals* by establishing the general differences and resemblances between various kinds of animals. Instead of dividing them on the basis of small special characteristics such as the Moderns do, he gathers historically all the facts and all the observations which bear on the general resemblances and the sensible characteristics. He draws these characteristics from the form, color, size, and all the exterior qualities of the whole animal, as well as from the number and position of its organs, from the size, movement, and form of its limbs, and from the likenesses or dissimilarities which are found in a comparison of these same parts. And he everywhere gives examples in order to make himself better understood. He also considers differences among animals in their style of life, their actions and their habits, their places of habitation, etc. He speaks of organs which are common to all animal and essential to them, and of those which they may lack and which are indeed missing in many kinds of animals. [...]

> This work of Aristotle's appears to me like a table of materials which might have been extended with the greatest care for many thousands of volumes filled with descriptions and observations of all kinds. It is the most learned abridgment that has ever been made, if science is, indeed, the history of facts. And even if one were to suppose that Aristotle had drawn from all the books of his time that which he put into his own, the plan of the work, its distribution, the choice of examples, the exactness of the comparisons, a certain form in the ideas, which I shall gladly describe as philosophic in character, all this does not leave one in doubt for even an instant that he was himself far richer than those from whom he supposedly borrowed.[48]

This utilization of the Treatises I believe may be a symptom of the fact that in the course of the eighteenth century the awareness both of the overall structure of the Aristotelian framework, and its internal tensions and contradictions, and of the extraordinary impact it had had on the development of the life sciences was gradually being lost. Besides, in the Linnaean School direct references to Aristotle are somewhat rare and vague, although in truth they may have been rather closer than Buffon to the traditional fixist, essentialist and teleological line.[49]

This sort of collective absent-mindedness, which is partially discernable even in Ray, does not however signify, as I hope I have shown, that the Aristotelian framework had been abandoned. On the contrary, having survived the seventeenth-century revolution, it continued to play a decisive role, although by now in a largely indirect form. Not only the naturalists' fundamental conceptual apparatus (notions of 'species', 'essence', 'form', and so on), but also the basic principles and guidelines of natural history which continued to predominate throughout the first half of the eighteenth century came from the bedrock of Aristotle and his followers. While, in the context of systematics, the shadows cast by the ancient treatises are in my opinion rather short, those of the three cornerstones – the fixity of species, immutable essences and functionalist and systemic teleology – continued to lengthen.

Part II
The Evolutionary Revolution

4
Crisis and Hegemony

1 Under pressure

From about the middle of the eighteenth century, especially in Francophone Europe, the three cardinal points of the traditional Aristotelian framework were repeatedly subjected to discussion, particularly in the fields of philosophy and medicine. Despite pursuing often heterogeneous general theoretical ends, authors such as Maupertuis, de Maillet and La Mettrie revisited the ancient 'materialistic' and 'mechanistic' tradition represented by authors such as Empedocles, Democritus and Lucretius, repeatedly attacking the fixist thesis, the correlated essentialist anti-random concept, and the basic teleological assumptions upon which the classic static and harmonious equilibrium between inextinguishable species rested. In his *System of Nature* (1751), for example, while combining multiple perspectives and requirements (from a rejection of Cartesianism to a defence of epigenism, and so on), Maupertuis mounted an attack on traditional fixism, and made decisive use of randomness, as is evident in paragraphs XLIV and XLV, in which he discusses the formation of species:

> XLIV. It is possible, on the contrary, that there may be structures so resistant that they prevail from the first generation over all the preceding structures, and eliminate their previous habits.
>
> XLV. How is it possible to explain that from only two individuals the multiplication of many diverse species was derived? Their origin could be attributed to certain fortuitous developments, among them that the elementary parts did not preserve the order of their animal father and mother: every degree of error will have given life to a new species and because of repeated deviations the infinite diversity of

> the animals that we see today will have been determined. This diversity is perhaps destined to increase over time, even if in the course of centuries imperceptible increments may occur.[1]

Even more radical were the alternative theses opposed to fixism and teleologism put forward by the physician and philosopher La Mettrie, friend and fellow citizen of Maupertuis, who found La Mettrie refuge from French and Dutch persecution at the court of Frederick II in Berlin. Amongst other works published here was the *System of Epicurus* (1750), in which, distancing himself from his previous Cartesianism, La Mettrie outlined theses on the formation of species which somewhat faithfully retraced those of Empedocles, as is seen in one of the passages which, much later, became renowned:

> XIII. The first generations must have been very imperfect. One must have lacked an oesophagus, another a stomach, vulva or intestines, and so on. It is obvious that the only animals which were able to live, survive and propagate their species were those which happened to be provided with all the elements necessary for reproduction and which, in a word, lacked no essential part. Likewise, those which were deprived of some absolutely necessary part died, either shortly after their birth, or at least without reproducing themselves. Perfection was no more achieved in a day in nature than in art. [...]
>
> XV If even today nature relaxes her vigilance to such an extent, if she is capable of such a surprising mistake, how much more frequent must similar games have been in the past! Such far-reaching distraction, so to say, such exceptional, extraordinary absent-mindedness, explains all those to which nature must have been subject in the distant past when reproduction was uncertain, difficult, ill-established and equivalent to trials rather than masterstrokes.
>
> XVI Through what an infinite number of combinations must matter have passed before reaching the only combination which could result in a perfect animal, and through how many others before reproduction reached the degree of perfection it enjoys today!
>
> XVII The natural consequence is that only those to whom lucky combinations finally gave eyes and ears, formed and placed exactly like ours, had the faculty of seeing, hearing and so on.[2]

Here, La Mettrie almost seems to be playing with the idea of tacitly criticizing Aristotle by defending Empedocles's position, which Aristotle had fiercely attacked – thus deliberately approaching the limits of absurdity, without however exceeding them: 'I do not see why it should be absurd to make an intelligent being come from a blind cause'.[3] This was an assertion that, besides its polemical and debunking intent, had a serious target: the teleological system of the traditional framework, literally the recourse to 'final causes':

> XX. Everything written by physicians and naturalists on the use of the parts of animate bodies has always seemed totally unfounded to me. All their reasoning on final causes is so superficial that if Lucretius refuted them so badly, he must have been as poor a physician as he was a great poet.
>
> XXI. The eyes were made in the same way as sight or hearing is lost and recovered, and as a particular body reflects sound or light. No more artifice was needed to construct the eye or the ear than to fabricate an echo.[4]

Proceeding in this direction, La Mettrie also makes fun of Aristotle's celebrated analogy between Nature and Art, subverting its meaning: 'XXIII. Art's fumblings to imitate nature give us an idea of what nature's were like.'[5]

Philosophers proceeded to deconstruct the teleological underpinning of the traditional framework of the life sciences from half way through the eighteenth century, doing so above all from within. This caused the theoretical scaffolding to implode. They outlined visions and concepts according to which species were seen as the result of historical processes. On the other hand, among naturalists, in the strictly philosophical sense of the word, the analogous process strictly speaking was to develop only in the following decades. Buffon was certainly one of the first to move in this direction. He had once been close to the epigenist orientation, yet in a way that was not only ambivalent but also openly contradictory. With his theory of degeneration (1766), he adopted an eminently historical perspective on the formation of species.[6] The fixist thesis was, however, subjected to a radical critique on the part of a substantial minority of the community of naturalists, among whom were many of Buffon's own students, especially in the last decade of the eighteenth century, when the question of extinction relating to the interpretation of new fossil finds was forcefully reintroduced.

2 Elephant bones

Since the seventeenth century the traditional Aristotelian-medieval concept which took fossils to be 'jokes of nature' (*lusus naturæ*), that is, inorganic formations randomly resembling organic forms, had been abandoned. Fossils thus came to represent an important element in the construction of a new science of the Earth. Until about the middle of the eighteenth century, however, the interpretation of fossil discoveries did not have a direct impact on the fixist concept. This is typically demonstrated by the nonchalance with which Linnaeus included them in his theory of the gradual and constant development of the lands of the Earth (also an alternative to the theory of the Great Flood).[7] Things changed significantly only when Buffon, in the early 1760s, reintroduced the discussion on extinction. Buffon maintained that the fossilized remains of the mammoth that had been found in Siberia in the first years of the century and those of the 'elephant bones' found in North America by Baron de Longueil in 1739, were proof of the existence of a 'prodigious mammoth' then extinct.

The debate seemed, however, to rapidly come to an end in favour of the thesis put forward by Daubenton, and endorsed by Buffon: the fossils belonged to exemplars of the species of the common elephant. The extraordinarily large teeth found together with other bones must have been those of a hippopotamus, having got mixed up with those of the elephant. In the 1770s and 1780s, however, new exciting discoveries led the community of naturalists, especially the French, to the conviction that both the Siberian and American fossils should be attributed to extinct species.[8] The consecration of this thesis was offered in 1796 by Georges Cuvier, the brilliant young student of comparative anatomy who had arrived in Paris the year before, and was destined to become one of the key figures of international natural history throughout the first three decades of the nineteenth century. In his *Memoir on the Species of Elephants, Both Living and Fossil* (1796),[9] Cuvier demonstrated in an unequivocal way that both the Siberian and American fossils were proof of two extinct species of elephants.

The traditional fixist and teleological framework was thrown into crisis from within: if there was irrefutable proof of the extinction of certain species, what was left of the traditional concept of *œconomia naturæ*? If the workings of nature were based on a static and harmonious equilibrium guaranteeing the preservation of each species, from their origins to the end of time, how can extinction be explained? A gap had opened. In France it was Cuvier himself who promptly tried to plug it by resorting to a strategy long and widely tested in the more strictly geological sphere: catastrophism. Extinctions, testified to by an ever increasing mass of fossil finds, were due to unexpected natural catastrophes. These led to migrations by other species that proceeded to occupy the regions which had been rendered free. As he clarified in his *Memoir on the Species of Elephants, Both Living and Fossil*:

> All these facts, consistent among themselves, and not opposed by any report, seem to me to prove the existence of a world previous to ours, destroyed by some kind of catastrophe, being whose place has been filled by those that they exist today, which will perhaps one day find themselves likewise destroyed and replaced by others.[10]

So, the fixist thesis remained solid: living species were those created at the beginning of time, although some of them had subsequently disappeared as a result of the vicissitudes of creation. However, not all the participants in the discussion, which was arousing the interest of an ever increasing number of both practitioners and the general public, were in agreement with Cuvier.[11] It was then that, among the dissenting voices, that of Jean-Baptiste de Lamarck began to stand out.[12]

3 The challenger

Around 1799–1800 Lamarck abruptly abandoned his convictions of many decades on the fixity of species (and on the impossibility of spontaneous generation). Going against Cuvier (from whom he had previously adopted a classificatory system),[13] Lamarck laid the foundations for a broadly transformist theory.[14] Relying also on theses and visions outlined by naturalists before him, whom he himself had promoted and reintroduced,[15] and rejecting the catastrophist thesis, Lamarck quickly published what can be considered the manifesto of the transformist theory. This above all defined the new concept within the overall epistemological framework of his 'terrestrial physics'.[16] The *Introduction* published at the beginning of the *Système des Animaux sans vertèbres* (1801) clearly outlines the thesis: all living species were nothing but the 'result of [environmental] circumstances' (the influence of climate, temperature, habits, and so on). The typical case discussed at the beginning by Lamarck was that of the feet of birds:

> The bird, attracted by need to water in search of prey on which to live, spreads the digits of its feet when it wants to strike the water and to move across the surface. The skin, which joins these digits at their base thus gets the habit of stretching. So in time the large membranes joining the digits of ducks, geese, etc. were formed as we now see them.

> But the bird whose manner of life accustoms it to perching on trees has necessarily, in the end, toes that are stretched and constructed in another way. Their claws are lengthened, sharpened, and curved into hooks for gripping the twigs on which they rest so often.
>
> In the same way one feels that the bird of the shore that dislikes swimming, and which none the less needs to approach the water to find its prey, is continually exposed to sinking in the mud; but, wishing to avoid the immersion of its body, its feet will get into the habit of stretching and lengthening. The effect of this, for those birds which continue to live in this manner over generations, will be that the individuals will be raised as if on stilts, on long naked legs, that is to say legs bare of feathers up to the thigh and often beyond.[17]

The traditional fixist framework was thus abandoned: the form and functioning of the organs that allowed the adaptation of organisms to their environment were no longer an original given. They were no longer part of the pseudo-egalitarian distribution of nature, or of the Creator, made once and for all, and aimed at guaranteeing a static equilibrium. The form and functioning of organs were now understood to be the result of an historical process. In Lamarck – as previously in Linnaeus – there seems to be no acknowledgement that the traditional concept was of Aristotelian origin. Apart from the mere record of the continuity that united Aristotle and Linnaeus concerning the division between animals with and without blood[18] (changed in 1797 by Lamarck to the distinction between vertebrates and invertebrates), there is no significant reference to the *corpus*. He sees the caesura created by his transformist theory only in relation to the generic fixist tradition.

Nevertheless, it is possible to hypothesize, following Richard Burkhardt, that his choice to open his 'manifesto' with ornithology, and more particularly with the classic question of birds' feet, may be a tacit polemic against the traditional system of natural theology:

> The choice is an interesting one, for these birds seem never to have been of special interest to Lamarck before. It seems that in coming to believe in organic mutability he realized he would have to account somehow for the general observation that animals tend to be admirably suited to their particular modes of existence. Using examples that had been explained previously in the framework of natural theology, he supplied an explanation of his own for the phenomenon: 'It is not at all the form either of the body or its parts that gives

> rise to habits or the way of life of animals, but, to the contrary, the habits, the way of life, and all the influential circumstances which have with time formed the body and parts of the animals.'[19]

It is therefore the habits, the way of life and the environmental circumstances that, in the course of time, have shaped the bodies and parts of animals, and not vice versa. Referring to the 'framework of natural theology', Burkhardt draws attention to the celebrated *Le Spectacle de la Nature* by Antoine Pluche, of which Lamarck owned the first edition, and particularly to the *Entretien XI*, dedicated to birds,[20] in which the *abbé* offers a classically teleological explanation for the issue concerning the finality of the various forms of birds, and more particularly of beaks, feet, and so on:

> For what Reason then is there such a prodigious Variety in their Wings, their Bills, their Claws, and every other Part? Are all these different Forms no more than the Play of Nature; or do they tend to any particular Purpose?
>
> *Count*. The Inequality you observe in the Bills of these Creatures does not correspond with the Differences you discover in the Noses of Men; for in these an Inch or less constitutes all the Diversity between the longest and shortest. In every other Particular the Structure and Use are the same; whereas, in the various Species of Animals, the Bill, the Talons, the Dimensions of their Wings, and generally all the Parts of their Bodies are calculated for the Accommodation of their Wants. They are a Set of Implements proportioned to the Nature of their Labours and Manner of Life. [...]
>
> The Woodpecker should be provided with hooked Claws, in order to grasp the Branches where he fastens. Long Legs would be useless to him for his Attainment of what lies under the Bark; but a strong and pointed Bill was necessary for him to find out, by darting it up and down the Branches, what Places are void and rotten. [...]
>
> The Heron, quite contrary to the Woodpecker, is mounted aloft, his Legs and Thighs are very long, and entirely destitute of Plumage; he has a great Length of Neck, and an enormous Bill, very sharp and jagged at the Extremity. What Reason can be assigned for a Figure which at first seems so extravagant? The Heron feeds on Frogs and little Shell-fish, as well as the other Fish he finds in Fens, or near the Shores of Rivers and the Sea. He wants no Feathers on his Thighs to enable him to march through the Water and Slime; but very long

> Legs are exceeding useful to him, as they qualify him for running more or less in the Water, along the Shores where the Fish usually resort for their Food.[21]

There is provocation as well as a challenge to the framework of natural theology, although it is true that in those same years interest in ornithology had been rekindled on various fronts and so the choice could have been determined for other reasons. In any case, in his *Zoological Philosophy* (1809), Lamarck presented the fixist concept as simply the theory which had always predominated: 'The almost universally received belief is that living bodies constitute species distinguished from one another by unchangeable characteristics, and that the existence of these species is as old as nature herself. This belief became established at a time when no sufficient observations had been taken, and when natural science was still almost negligible.'[22]

While continuing to develop his own transformist theory (up to the *Histoire naturelle des animaux vertèbres* published between 1815 and 1822), Lamarck worked mostly on the principles of 'the dynamic of fluids', and more generally within the context of an extraordinarily complex physical and biological theory.[23] Ignoring this positive aspect, I would like here to limit myself to suggesting that, on the negative side, it was understood by Lamarck himself as an alternative not only to the fixist concept but also to traditional teleology. This is made crystal clear in a fine passage from the *Histoire*, brought to light by Pietro Corsi in opposition to interpretations that insisted on the presumed teleology:

> It is above all in living bodies, particularly in animals, that it seemed possible to perceive an aim in the workings of nature. In this case, too, the aim is no more than a simple appearance and not a reality. In fact, in every type of particular organization of these bodies there exists an order of things – prearranged by causes that have gradually been established – which is limited to leading to – through the progressive development of parts determined by circumstances – something that appears to be an aim, but is actually no more than a necessity.[24]

4 The last great heir

The radical critique of the traditional framework advanced by the transformist theory, this time brought forward from within the community of naturalists itself, was immediately received as a challenge which called into question one of the fundamental theoretical pillars of all of natural history, or rather contributed to the shaping of the newly born 'biology'.[25] The champion of the traditional vision was once again Cuvier. From the end of the eighteenth century, he had openly expressed his opposition to the theory of the degeneration of species, maintaining that the theory of a common progenitor was equivalent to the dissolution of all of natural history:

> Whatever the influence of the climate in causing variations in animals, certainly this influence is not of the greatest importance: and to say that it could change all the proportions of the skeleton and structure of the teeth, is the same as to suggest that all quadrupeds are derived from one single species; and that the differences that there are between species are no more than successive degenerations: in a word, it would be the same as to annihilate natural history in its entirety, since its object would consist of nothing but variable forms and transient types.[26]

At the beginning of the 1810s, Cuvier strengthened his defence: in the *Recherches sur les ossemens fossils* (1812) – particularly in the introductory chapter, which was later revised and finally republished as a separate volume with the title *Discours sur les révolutions de la surface du globe* (1825, after a previous version in 1821) – he gave greater credence to the catastrophist theory, marginalizing the possibility of adopting a reading of terrestrial transformations in terms of 'gradual' passages: 'these repeated irruptions and retreats of the sea have neither been slow nor gradual; most of the catastrophes which have occasioned them have been sudden'.[27]

At the same time, Cuvier explicitly criticized the transformist thesis, adopting a strategy which was later to rebound with enormous success. This approach was to draw attention to the absence of fossils, attesting to the presence of 'intermediate forms':

> The following objections has already been started against my conclusions. Why may not the presently existing races of mammiferous landquadrupeds be mere modifications or varieties of those ancient races which we now find in the fossil state, which modifications may have been produced by change of climate and other local circumstances, and since raised to the present excessive difference, by the operation of similar causes during a long succession of ages?
>
> This objection may appear strong to those who believe in the indefinite possibility of change of forms in organized bodies, and think that during a succession of ages, and by alterations of habitudes, all the species may change into each other, or one of them give birth to

> all the rest. Yet to these persons the following answer may be given from their own system: If the species have changed by degrees, as they assume, we ought to find traces of this gradual modification. Thus, between the *palœotherium* and the species of our own days, we should be able to discover some intermediate forms; and yet no such discovery has ever been made. Since the bowels of the earth have not preserved monuments of this strange genealogy, we have a right to conclude, That the ancient and now extinct species were as permanent in their forms and characters as those which exist at present; or at least, That the catastrophe which destroyed them did not leave sufficient time for the production of the changes that are alleged to have taken place.[28]

Cuvier thus once again insisted on the solid fixity of species, directly counter-posing it to the transformist thesis:

> From all these well-established facts, there does not seem to be the smallest foundation for supposing, that the new genera which I have discovered or established among extraneous fossils, such as the *palœotherium*, *anoplotherium*, *megalonyx*, *mastodo*n, *pterodactylis*, &c. have ever been the sources of any of our present animals, which only differ so far as they are influenced by time or climate. Even if it should prove true, which I am far from believing to be the case, that the fossil elephants, rhinoceroses, elks, and bears, do not differ farther from the presently existing species of the same genera, than the present races of dogs differ among themselves, this would by no means be a sufficient reason to conclude that they were of the same species; since the races or varieties of dogs have been influenced by the trammels of domesticity, which these other animals never did, and indeed never could experience.
>
> Farther, when I endeavor to prove that the rocky strata contain the bony remains of several genera, and the loose strata those of several species, all of which are not now existing animals on the face of our globe, I do not pretend that a new creation was required for calling our present races into existence. I only urge that they did not anciently occupy the same places, and that they must have come from some other part of the globe.[29]

When, around 1820, the transformist thesis was gaining increasing consensus, Cuvier in a certain sense glossed over it. Only later, at the threshold of the 1830s, did he go over to the 'counter attack',[30] although in an indirect way. He criticized the thesis of Geoffroy Saint-Hilaire, who, somewhat ambivalently, had declared himself in favour of transformism. In the dispute Geoffroy referred briefly to Aristotle in a way that I would define as rhetorical.[31] The success achieved by Cuvier in his criticism of Geoffroy's thesis on the unity of organic composition was thus transformed, although rather indirectly, into a victory for the fixist thesis, which was for this reason reinforced.

This recovery, or rather defence of the fixist thesis was linked, moreover, to an eminently teleological approach, which William Coleman, in an already well-known study, had placed in direct correlation with 'the modest revival in the late eighteenth century of Aristotelian biological doctrines', or more particularly of the 'adoption of Aristotle's teleological conception of life'.[32] He had also noted the importance of the direct reading of the treatises of Aristotle to the formation of Cuvier's thinking, highlighting among other evidence one of the young naturalist's letters,[33] in which, upon explaining to his friend Pfaff his ambitious project for the reform of natural history, he wrote: 'Both works of Aristotle, *History of Animal*s and *On the Parts of Animals*, which the more I study the more I admire [...] were the first steps towards a scientific description of natural history' – despite the fact that they contained 'many erroneous facts and an insufficient penetration of the laws of nature'.[34]

There is thus clear evidence of the study of Aristotle's two great works and of the high regard in which they were held by the young Cuvier. However, it is also true that the references to Aristotle are accompanied by the recollection of numerous other classics of natural history and that their range was circumscribed. Even later, moreover, Cuvier continued to grant to the works of Aristotle a place of paramount importance in the history of naturalist thinking,[35] despite considering them well below the great achievements of the eighteenth and nineteenth centuries; this is seen for example when he writes about the history of ichthyology:

> In the progress of ichthyology three main stages are recognizable. Initially, for many centuries, as in all branches of natural history it was composed of only partial observations. Aristotle, 350 years before our era, began a body of doctrine, but it was weak and, relying only on ideas and rules that were hardly verified, was deprived of any sure means of distinguishing the species. During more than eighteen hundred years, those who wrote about natural history limited themselves to copying Aristotle or commenting him. But in the middle of the sixteenth century Rondelet, Belon, and Salviani returned to

> true observation; and in rectifying and extending what Aristotle had written, they gave ichthyology a good basis in descriptions and drawings of a number of well-determined species. At the end of the seventeenth century Willughby and his colleague John Ray were the first to try to classify these species according to a method based on distinctive elements deduced from their organization; finally, in the middle of the eighteenth century, Artedi and Linnaeus completed this undertaking, establishing well-defined genera and locating within these certain clearly defined species.[36]

It is also significant that Cuvier reintroduced a teleological approach,[37] reinterpreting it in the literal terms of a recourse to 'final causes',[38] as well as a certain essentialism – although it is true that these two factors were collocated within an extraordinarily complex epistemological edifice which was in many aspects and issues somewhat distant from that of the ancient philosopher.

In conclusion, while the multiple acknowledgements of Aristotle made explicitly by Cuvier and while the convergences between their two systems need to be carefully contextualized and relativized, I nevertheless believe, if we take account of his vigorous defence of the fixist thesis, of a certain revival of essentialism and of fundamental teleologism, that Cuvier can legitimately be considered the last great descendant and innovator of the modern Aristotelian tradition. This is an interpretation that is substantially confirmed from within, by the schematic historical representation introduced by Cuvier, according to which there are three fundamental phases: first, natural history was born with Aristotle; second, it continued to proceed along strictly Aristotelian lines over many centuries; third, it was renewed or rather amended and extended especially in an experimental sense, and it reached its apex thanks to authors such as Linnaeus and naturally Cuvier himself. The eminent naturalist was, however, the last outstanding exponent of this tradition. Despite the defensive strategies employed and the tenacious resistance mounted, the hegemony of the Aristotelian framework was by now approaching its end.

5
Darwin's Breakthrough

1 Haunted

In the eyes of the young Charles Darwin, the traditional fixist, essentialist and teleological framework had found itself in an increasingly deep crisis since the end of the eighteenth century. In his opinion, this crisis was caused primarily by two principal issues: (1) the thesis of a common progenitor had been underpinned by a growing mass of empirical data (fossils, geographical distribution, and so on) and by ever more stringent morphological analyses (homology, embryological relations, and so on); (2) it had been possible to think in terms of processes of temporal duration much longer than those that were still being hypothesized half way through the previous century (geological succession, and so on). Notwithstanding this, the transformist concepts – beginning with those proposed by Erasmus Darwin and, especially, by Lamarck[1] – had not succeeded, in Darwin's opinion, in offering a 'satisfactory' response to the burning question continually reiterated by the supporters of fixism, especially in the Anglophone world on the admirable adaptation of species. A convincing résumé of this situation is offered in the *Origin of Species* itself:

> In considering the Origin of Species, it is quite conceivable that a naturalist, reflecting on the mutual affinities of organic beings, on their embryological relations, their geographical distribution, geological succession, and other such facts, might come to the conclusion that species had not been independently created, but had descended, like varieties, from other species. Nevertheless, such a conclusion, even if well founded, would be unsatisfactory, until it could be shown how the innumerable species inhabiting this world have been modified,

> so as to acquire that perfection of structure and coadaptation which justly excites our admiration.[2]

If species had not been adapted to their environment from their origins, but their adaptation instead derived from one species to another, naturalists needed to demonstrate the mechanism by which a process of gradual modifications could have led to their admirable adaptation. How could such 'perfection of structure and co-adaptation' have been reached? This was the question that had been obsessing Darwin for years:

> From September 1854 onwards I devoted all my time to arranging my huge pile of notes, to observing, and experimenting, in relation to the transmutation of species. During the voyage of the *Beagle* I had been deeply impressed by discovering in the Pampean formation great fossil animals covered with armour like that on the existing armadillos [...]. It was evident that such facts as these, as well as many others, could be explained on the supposition that species gradually become modified; and the subject haunted me. But it was equally evident that neither the action of the surrounding conditions, nor the will of the organisms (especially in the case of plants), could account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life, – for instance, a woodpecker or tree-frog to climb trees, or a seed for dispersal by hooks or plumes. I had always been much struck by such adaptations, and until these could be explained it seemed to me almost useless to endeavour to prove by indirect evidence that species have been modified.[3]

In order to face the question of the gradual modifications of species head-on, it was thus necessary, at close quarters, to tackle the admirable adaptation of every organism to its own conditions of life and, above all, the 'perfection' of its parts and organs. This was the task Darwin undertook on returning from his voyage on the *Beagle*, without concealing the problems it entailed, as is seen in an entry from 1838 in the *Notebooks*: 'We never may be able to trace the steps by which the organization of the eye passed from simpler stages to more perfect preserving its relations. – the wonderful power of adaptation given to organization. – This really [*sic*] perhaps [*sic*] greatest difficulty to whole theory'.[4] This difficulty represents a mirror image of the strongest argument of the traditional theory: the admirable structure of the eyes continued to represent emblematic and crystal-clear proof of the fact that nature, which never does anything in vain, always proceeded wisely, and could only have given to species the necessary organs from their origins, adapting them perfectly to the given environmental conditions. Overcoming the difficulty thus immediately implied calling the basic principles of the traditional framework into question.

A way out of the impasse for the young naturalist came in the same year (1838). By exerting leverage particularly on extended geological time and reinterpreting Malthus's law of the geometrical growth of populations, Darwin intuited the fundamental dynamic that would allow him to construct an alternative theoretical framework: he identified the 'sifting' mechanism, which, like the pressure exerted by 'a hundred thousand wedges', operates on individual variations, mostly minimal and often random, so as to take account, over long periods of time, of the adaptation and coming into being of the new species. This is the mechanism to which in the *Sketch* of 1842 he gave the name 'natural selection':

> Natural Selection. De Candolle's war of nature, – seeing contented face of nature, –may be well at first doubted; we see it on borders of perpetual cold. But considering the enormous geometrical power of increase in every organism and as every country, in ordinary cases ⟨countries⟩ must be stocked to full extent, reflection will show that this is the case. Malthus on man, – in animals no moral [check] restraint – they breed in time of year when provision most abundant [...]. If proof were wanted let any singular change of climate occur here, how astoundingly some tribes increase, also introduced animals, the pressure is always ready, – capacity of alpine plants to endure other climates, – think of endless seeds scattered abroad, – forests regaining their percentage, – a thousand wedges are being forced into the œconomy [*sic*] of nature.[5]

By giving shape to the theory of descent with modifications by variation and selection, Darwin had at last found a coherent solution to the issue of 'admirable adaptation' from a genealogical perspective. Such a perspective at the same time amounted to the deconstruction of the teleological, essentialist and fixist framework of Aristotelian origin. It also included the rejection of any systematic and pervasive recourse to final causes in two senses: (1) the functionalist sense, that is, that final causes are immanent in nature – in this case they are rejected in favour of a search for laws; (2) the essentialist anti-random sense of final causes – in this case they are rejected in favour of an epistemic re-evaluation of the role of randomness.

It is, however, significant that Darwin initially intuited the selective mechanism in the literal sense of a 'final cause', only later to engage – as we shall now see – in an authentic theoretical battle against this same conceptual template. The battle ended in the broad valorization of those aborted and atrophied organs, thus reiterating the 'stamp of inutility', which attested explicitly to 'the absence of a final cause' on the level of morphology. This was the level that was privileged by the supporters of the traditional theory of admirable adaptation. Having invented this new framework, Darwin had succeeded in freeing himself of his obsession. He had overcome the greatest difficulty of his theory and at the same time forged an extremely solid objection to the teleological concept which held that every organ, predisposed from its origins by the wisdom of nature, which never does anything in vain, was constantly brought back within the frame of 'final causes'.

2 A hundred thousand wedges

From the start, the main instrument that enabled the abandonment of the traditional framework was thought of, or rather intuited, in the literal terms of a 'final cause'. This becomes clear from the first written testimony in which the image of the wedges occurs, which in 1842 led to the concept of 'natural selection',[6] the celebrated page 135 of *Notebook D* written on 28 September, 1838:

> – The final cause of all this wedging, must be to sort out proper structure, & adapt it to changes. – to do that for form, which Malthus shows is the final effect (by means however of volition) of this populousness on the energy of man. One may say there is a force like a hundred thousand wedges trying force ~~into~~ [*sic*] every kind of adapted structure into the gaps ~~of~~ [*sic*] in the oeconomy of nature, or rather forming gaps by thrusting out weaker ones.[7]

The theoretical framework sketched by the young Darwin in order to take account of the gradual adaptation of species from Malthus' vision of growth was thus thought of as touching on the most classical teleological 'toolbox': that of final causes. It had in any case been used in the previous year,[8] and then again at the beginning of 1838: 'I can scarcely doubt final cause is the adaptation of species to circumstances by principles, which I have given'.[9] The adaptation itself, inserted into a dynamic temporal framework, was considered a 'final cause'.

The origins of this recourse to 'final cause' are certainly numerous, among others we should remember, for example, the passage by Erasmus Darwin where, in his *Zoonomia*, discussing the spurs of birds, he emphasized:

> The birds, which do not carry food to their young, and do not therefore marry, are armed with spurs for the purpose of fighting for the exclusive possession of the females, as cocks and quails. It is certain that these weapons are not provided for their defence against other adversaries, because the females of these species are without this armour. The final cause of this contest amongst the males seems to be, that the strongest and most active animal should propagate the species, which should thence become improved.[10]

Apart from Erasmus, I believe mention must be made of Herschel's *Preliminary Discourse*, which Darwin read in his last year at Cambridge, and it is significant because of the overall methodology developed by the young Darwin. In this text, though briefly outlining the Galilean and Newtonian critique of Aristotle's physics, Herschel not only failed to deal with the fact that his doctrine of causes had also been subject to criticism, but he also adopted a fundamentally apologetic attitude towards final causes. It is true that in discussing the classic question of 'real cause' he showed a certain scepticism, such as when he wrote:

> This one instance of the obscurity which hangs about the only act of direct *causation* of which we have an immediate consciousness, will suffice to show how little prospect there is that, in our investigation of nature, we shall ever be able to arrive at a knowledge of ultimate causes, and will teach us to limit our views to that of laws, and to the analysis of complex phenomena by which they are resolved into simpler ones, which, we must consent to regard as causes.[11]

However, Herschel did not seem to give up on this same hope and, especially, seemed to reintroduce the cogency of the concept of final cause or fact in a broadly Newtonian sense: 'The discovery of a new law of nature, a new ultimate fact, or one that even temporarily puts on that appearance, is like the discovery of a new element in chemistry.'[12]

Such a convergence between final or ultimate causes and the laws of nature is thus such as to confer on the former a significance different from that of the Aristotelian original: it is not a matter of the ends which nature pursues in shaping individual organisms and their particular organs, with the aim of ensuring their preservation, but rather the 'laws' of the organization of the general system of living beings. From this point of view, Darwin's interpretation of the action of sifting the hundred thousand wedges in terms of 'final cause' approaches the Herschelian acceptation inasmuch as it distances itself from the Aristotelian meaning in the strictest sense. And in any case, the ultimate end, adaptation, and hence preservation, still fell within the ambit of the teleological Peripatetic tradition. The proof of such unequivocal proximity is that the finalistic conceptual tools very soon became suspect in the eyes of Darwin himself.

3 Barren virgins

From the autumn of 1838, most likely in November, Darwin began to show that he had certainly become more aware of the weight of the theoretical heritage of those 'final causes' which he was going to draw on:

> The Final cause of innumerable eggs is explained by Malthus.— [is it anomaly in me to talk of Final causes: consider this?] – consider these barren Virgins.[13]

I believe this extremely concise note clearly shows the tension and doubt that afflicted the young naturalist when he proceeded to deconstruct the fixist framework by adopting certain conceptual tools. Darwin was in fact using the conceptual tools which, even though new, were modelled in part on the same conceptual devices which had formed the basis of the traditional framework: 'the final cause'. And he used them despite his rereading of 'final causes' in the broadly Newtonian sense.

The mechanism for 'sorting out' from which the principle of 'selection' was born may have been intuited in terms of a 'final cause', albeit in the shadow of the concept of 'law'. At the same time, Darwin was developing an awareness that recourse to this classic teleological framework had to be avoided. It is significant that by doubting the traditional template he was reminded of the image of 'barren Virgins' described by one of the most renowned and radical anti-Aristotelians in the history of modern philosophical thinking, Francis Bacon, who wrote: 'For the inquisition of Final Causes is barren, and like a virgin consecrated to God produces nothing'.[14] Darwin most likely took the motto indirectly via William Whewell.[15]

The growing distrust with regard to final causes, and the inversely proportional faith in laws, also emerges from another note from the end of September 1838:

> This unwillingness to consider Creator as governing by laws is probably that as long as we consider each object an act of separate creation, we admire it more, because we can compare it to the standard of our own minds, which ceases to be the case when we consider the formation of laws invoking laws. & giving rise at last even to the perception of a final cause.[16]

What this means, in short, is a privileging, on a methodological level, of the idea that 'everything derives from certain great and simple laws'.[17] The critics have rightly concentrated on the Newtonian model, and in certain ways the Baconian one, which were adopted by the young Darwin when he proceeded to discover and identify the 'laws' of living things. In so doing, he reconstructed one of the threads that link him to the seventeenth-century scientific revolution. It has, moreover, been emphasized how the negative aspect of this operation concerned the gradual deconstruction of teleology undertaken by natural, especially Anglophone, theology, from which Darwin had taken his first steps (Paley, but also Henslow, Sedgwick and Whewell).[18] It seems to me that less attention has been paid to the fact that this same operation came to involve an explicit criticism of those 'final causes' which modern natural history had inherited directly from the Aristotelian *corpus*.

As soon as it is seen from this perspective, and Bacon's celebrated motto resounds like an incitement to action, the breakthrough effected by Darwin on biology, following the lines of eighteenth-century criticism of the teleological approach adopted by natural theology, assumes the following profile: a deconstruction of the Aristotelian tradition that had survived the seventeenth-century revolution substantially intact, while at the same time being revised in the context of experimentation. The life sciences, too, were proceeding now, in the first half of the nineteenth century, towards the gradual deconstruction of the Peripatetic finalistic framework, so much so that the concept of 'final cause' itself was banished. Unlike what had happened in physics at the time of Galileo, Darwin did not proceed by privileging a quantitative, mathematical approach. In fact, he showed, on the one hand, the 'absence' of final causes, the inefficacy of these 'barren Virgins', on the level at which they had always revealed their greatest efficacy – that is, morphology. On the other hand, he went on to adopt an eminently historical approach. In the milieux of the new-born evolutionary biology, it was not the mathematization but the historicization of nature that signalled the twilight of the teleology of Aristotelian origin.

4 The stamp of inutility

From the negative perspective of deconstruction, it was in the field of morphology that Darwin launched a genuine attack on the traditional teleological structure by identifying and emphasizing the flaws of the foundational model. According to this model, nature, or the Creator himself – from the point of view of the teleological-functionalist theoretical nucleus, there is no difference between the two – had, since the origins of living organisms, provided organs perfectly adapted to the organisms' respective environments. This provision is an admirable adaptation which in its turn confirmed (in a circular way) the necessary recourse to final causes. As Darwin noted in April 1839 in one of his notebooks, there was morphological evidence proving the absence of a final cause with regard to the formation and (non-)functionality of particular organs:

> Who can say, how much structure is due to external agency, without final cause either in present or past generation — thus cabbages growing like Nepenthes — cases of pidgeons with tufts &c. &c. here there is no final cause yet it must be effect of some condition of external circumstances, results of complicated laws of organization; as we see there strange plumage in pidgeons yet no change of habits, so no ~~cause~~ [*sic*] corresponding change in Birds of Paradise. — All that we can say in such cases is that the plumage has not been so injurious to bird as to allow any other kind of animal to usurp its place — & therefore the degree of injuriousness must have been exceedingly small. — This is far more probable way of explaining, much structure, than attempting anything about habits —
>
> No one can be shocked at absence of final cause.
>
> Mammae in man & wings under united elytra[19]

The impossibility of attributing men's nipples, or the wings under united elytra, or the tufts of pigeons, or even the plumage of pea-hens to final causes,[20] in Darwin's eyes, converged directly and perfectly with the question of admirable adaptation defined in terms of the creationist doctrine, as attested to by another passage from his notebooks: 'When one sees nipple on man's breast, one does not say some use, but ~~no~~ sex not [*sic*] having been determined, — so with useless wings under elytra of beetles. — born from beetles with wings & modified. — If simple creation surely would have been born without them.'[21] Whether it was about the wisdom of nature or of the Creator, Darwin highlighted the impotence of a concept that, beginning with the idea of a direct and original distribution of organs to immutable species, did not manage to coherently deal with the fact that some organs prove to be patently useless. Inutility here means, firstly, that such organs are not designed for anything, in the sense that they do not have the aim of contributing to the survival of the organism. Secondly, he considered that they could have a certain 'damaging' or 'harmful' or 'injuring' effect, although to a 'minimal' degree, so as not to entail the extinction of the species. The traditional teleological-functionalist system, by which each organ is designed with finalistic logic, is revealed to be faulty.

On the historiographical level, the perfect convergence of the two notes from the *Notebooks* – one centred on the inefficacy of the recourse to 'final causes', the other on the impotence of the doctrine of 'creation' – I believe offers further confirmation of how the theoretical system that is the basis of natural theology in the eighteenth and nineteenth centuries (questioned by Darwin) derived from the heritage of the teleological framework devised by Aristotle. If Aristotle's paternity was also disavowed, in effect repressed, 'the repressed' re-emerges at the same moment that Darwin was explicitly tackling the burning question of perfect adaptation in the light of the template of 'final causes'. Over and above the strictly religious (extensive and profound) presuppositions and repercussions of natural theology, the conceptual structure, the theoretical core was still that originally devised by Aristotle. Arguing against Empedocles, he put at the centre of his anatomical, physiological and morphological analysis the assumption that every single organ should be understood in finalistic-functional terms; and, more generally, every natural phenomenon should be part of the scheme by which, on the one hand, 'nature never does anything in vain' and, on the other, '[t]here is purpose in what is, and in what happens in Nature'.[22]

Continuing his work on this flaw in the traditional system, over the years Darwin endorsed the entire phenomenal sphere which, in the *Origin of Species*, would give rise to the entry *Rudimentary, Atrophied and Aborted Organs* – that is, bearing 'the stamp of inutility':

> Organs or parts in this strange condition, bearing the plain stamp of inutility, are extremely common, or even general, throughout nature. It would be impossible to name one of the higher animals in which some part or other is not in a rudimentary condition. In the mammalia, for instance, the males possess rudimentary mammæ; in snakes one lobe of the lungs is rudimentary; in birds the 'bastard-wing' may safely be considered as a rudimentary digit, and in some species the whole wing is so far rudimentary that it cannot be used for flight.[23]

Again, 'the logger-headed duck, which has wings incapable of flight, in nearly the same condition as in the domestic duck [...] the burrowing tucu-tucu, which is occasionally blind, and then at certain moles, which are habitually blind and have their eyes covered with skin',[24] and more in general all rudimentary organs, provided clear empirical proof of the incapacity of the fixist and teleological framework to deal adequately with morphological analysis. Darwin thus explicitly emphasizes, not without a certain malignance, that the presence of such organs represented a 'strange difficulty' for 'the old doctrine of creation'.[25] The question, however, was not 'old' but ancient: it had been explicitly discussed by Aristotle when, even in fundamental texts such as *Parts of Animals* and *History of Animals*, he had sought to include, at the expense of incoherence, exactly the same organs to which Darwin now referred – the wings of flightless birds, the blind eyes of the mole and the antlers of deer, but also the peacock's tail and human male nipples – in the teleological framework he had conceived.

Once the question had been brought to light and an alternative solution found – as we shall soon see – no matter how refined the arguments aimed at fixing the flaw, the 'burden of proof'[26] passed to the supporters of the traditional framework. At this stage, the power relations between the contesting protagonists had been overturned from this perspective too. For the theorists of the fixist concept, the task of mounting a defence, in the face of such a linear argument, was far from simple: if nature, or the Creator, had wisely shaped organisms from their origins in the way that they appear to us today, taking care to provide them with the necessary organs, why were they given patently useless parts? What sense could there have been in distributing unseeing eyes, or flightless wings, or horns that were actually harmful or injurious?

Darwin had validated an 'anomaly' that had been embedded at the heart of the traditional system since its Aristotelian conception: the teleological, and at the same time fixist, pillar had been undermined from within. As Thomas Huxley emphasized in one of his prompt reviews of the *Origin*, when referring to useless and rudimentary organs, 'the doctrine of final causes will not help us to understand the anomalies in the structures of living things'.[27] Conversely, Darwin's theory was reinserted within the grand and noble tradition of Bacon and Galileo, and it proved capable of adducing a more incisive 'true cause' than that proposed by his precursor Lamarck. It now revealed – still according to Huxley – a field of research free 'from the charming but sterile Virgins' "Final Causes"'.[28]

5 Metamorphoses

From a positive, constructive perspective, the new-born genealogical system was capable of effectively resolving the anomaly of the traditional theory: the rudimentary organs, atrophied and aborted, could be understood as living testimony to the history of the species, as archaisms. For Darwin, we were predominantly dealing with parts which once must have performed some function useful to the organism but which, in the course of modifications, had lost this function and now, therefore, represented the 'record of a former state of things'.[29] They became like 'the letters in a word, still retained in the spelling, but become useless in the pronunciation, but which serve as a clue for its derivation'.[30]

The recourse to final causes was therefore being replaced by a genealogical approach in which the entire process of formation and adaptation of species was historicized. At the same time, it passed over the most conspicuously functionalist version of the solid teleological assumption of Aristotelian origin. In other words, the solid, static and atemporal correspondence between an organ and one or more functions, which had guided the path of natural history through the course of modernity, was replaced by an eminently historical convergence:

> Any change in structure and function, which can be effected by small stages, is within the power of natural selection; so that an organ rendered, through changed habits of life, useless or injurious for one purpose, might be modified and used for another purpose. An organ might, also, be retained for one alone of its former functions. Organs, originally formed by the aid of natural selection, when rendered useless may well be variable, for their variations can no longer be checked by natural selection.[31]

Darwin had again shown the way to an alternative manner of discussing the relationship between organs, ends and functions – that is, by historicizing it: an organ 'may become rudimentary for its proper purpose, and be used for a distinct one: in certain fishes the swim-bladder seems to be rudimentary for its proper function of giving buoyancy, but has become converted into a nascent breathing organ or lung. Many similar instances could be given.'[32] It is not, therefore, only about a coherent problematization of the relationship between an organ and the carrying out of one or more the carrying out of one function or more than one, or of a function carried out at the same time by more than one organ, which Aristotle had actually already repeatedly discussed, but it is the fact that it passed over the solid traditional teleological assumption according to which the form (the organ) always follows the function (the end), in the sense that it is engineered by nature, once and for all, to carry out one particular function or more than one.

The traditional teleological and fixist architecture having been abandoned, the possibility was opened up on the morphological front of also explaining the affinity between different species in genealogical terms. This is made clear in an extraordinary passage from the *Sketch*:

> Nothing more wonderful in Nat. Hist, than looking at the vast number of organisms, recent and fossil, exposed to the most diverse conditions, living in the most distant climes, and at immensely remote periods, fitted to wholely different ends, yet to find large groups united by a similar type of structure. When we for instance see bat, horse, porpoise-fin, hand, all built on same structure, having bones with same name, we see there is some deep bond of union between them, to illustrate this is the foundation and objects <?> <of> what is called the Natural System; and which is foundation of distinction <?> of true and adaptive characters. Now this wonderful fact of hand, hoof, wing, paddle and claw being the same, is at once explicable on the principle of some parent-forms, which might either be <illegible> or walking animals, becoming through infinite number of small selections adapted to various conditions. We know that proportion, size, shape of bones and their accompanying soft parts vary, and hence constant selection would alter, to almost any purpose <?> the framework of an organism, but yet would leave a general, even closest similarity in it. [...] The unity of type in past and present ages of certain great divisions thus undoubtedly receives the simplest explanation. [...] if with wing, paddle, hand and hoof, some common structure was yet visible, or could be made out by a series

> of occasional monstrous conversions, and if traces could be discovered of <the> whole having once existed as walking or swimming instruments, these organs would be said to be metamorphosed, as it is they are only said to exhibit a common type. [...] But this unity of type through the individuals of a group, and this metamorphosis of the same organ into other organs, adapted to diverse use, necessarily follows on the theory of descent [...] here we can see that possibly a walking organ might <?> be converted into swimming or into a gliding organ and so on to a flying organ. But such gradual changes would not alter the unity of type in their descendants, as parts lost and soldered and vertebræ. [...] Now according to our theory during the infinite number of changes, we might expect that an organ used for a purpose might be used for a different one by his descendant, as must have been the case by our theory with the bat, porpoise, horse, &c., which are descended from one parent.[33]

Thus it was that one of the secrets of homology, a concept that had stood side by side with the classical concept of analogy,[34] was revealed: 'The fore-limbs, for instance, which once served as legs to a remote progenitor, may have become, through a long course of modification, adapted in one descendant to act as hands, in another as paddles, in another as wings'.[35] And again in the *Origin of Species* Darwin clarified the theoretical importance of the fact that homologous parts and organs could be 'used for as widely different purposes as it is possible to conceive':

> Nothing can be more hopeless than to attempt to explain this similarity of pattern in members of the same class, by utility or by the doctrine of final causes.[36]

The attempt to refer to the theory of final causes or the principle of utility is in vain because, just as in the case of useless organs, homology could now be explained only in genealogical, dynamic and temporal terms. The traditional eternalist and ahistorical framework was thus made ineffective precisely because it was incapable of adopting a perspective that by then had become eminently historical. In short, for Darwin, homologies are the products of history. The traditional theory, which deals with analogies in terms of ends, is thus not only ineffective but misleading: homologous organs can in fact be used for 'different purposes'. This concept undermines the traditional model according to which every single organ was assigned forever, with a view to the accomplishment of one or more specific functions.[37]

6 Variations

The genealogical deconstruction of the traditional teleological framework which centred on the recourse to final causes at the same time implied a revolutionary reassessment of individual random variations. This opened the way to the systematic recourse to randomness within the ambit of the new-born evolutionary biology. From this point of view too, the theory of descent with modifications by variation and selection can be interpreted as an overturning of the theoretical framework originally devised by Aristotle and inherited by modern natural history. While Aristotle was aiming to structurally marginalize randomness, Darwin again begins to endorse it.

From the moment Darwin began to construct the new theory centred on the idea of natural selection, he could not fail to endorse those random individual variations that selection itself was going to operate on. Indeed, it was necessary for him to have a factor that introduced the variables on which natural selection could function. In a note from his juvenile notebooks, for example, in a way as simple as it is incisive, he wrote: 'Suppose six puppies are born & it so chances, that one out of every hundred litters is born with long legs & in the Malthusian rush for life, only two of them live to breed, if circumstances determine that, the long legged one shall rather oftener than any other one. survive. [sic] in ten thousand years the long legged race will get the upper hand'.[38] Working from this basic intuition, in the *Origin of Species* randomness came to play a rather significant role, albeit supported by reference to the Lamarckian theory of the hereditariness of characteristics acquired by habit, use and non-use, and by the fact that Darwin could not fail to come into conflict with the inaccessibility of that 'black box' which would later be opened up by genetics:

> I have hitherto sometimes spoken as if the variations — so common and multiform with organic beings under domestication, and in a lesser degree with those under nature — were due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation. Some authors believe it to be as much the function of the reproductive system to produce individual differences, or slight deviations of structure, as to make the child like its parents. But the fact of variations and monstrosities occurring much more frequently under domestication than under nature, and the greater variability of species having wide

> ranges than of those with restricted ranges, lead to the conclusion that variability is generally related to the conditions of life to which each species has been exposed during several successive generations.[39]

Beyond this more than legitimate suspension of judgement regarding the mysterious laws of variation, in various other passages from the *Origin of Species* (and in many other works)[40] Darwin frequently referred to 'chance' in the strict sense, thus placing it within the epistemic order and attributing to it a significant role.[41] Here, too, we are faced with a breakthrough. It was a breakthrough that contributed significantly to the reversal of the basic direction inherent in the life sciences since their late medieval and Renaissance rebirth in the shadow of the *corpus aristotelicum*. Aristotle indeed undertook an operation explicitly aimed at privileging teleology at the expense of randomness, disempowering its role and confining random variations to the margins of the essentialist construct (see the case of eye colour). In this respect, Darwin proceeded to change direction and go so far as to reverse it. When the *systema naturæ* was historicized, attention was immediately shifted from the search for constants and essences, with all the difficulty that such a task continued to entail, to the slight 'individual differences' by which it became possible to reconstruct a structural wedge of the process by which species came to gradually modify themselves in the course of time.[42] Variations, also random ones, thus acquired 'maximum importance' in the new framework:

> The many slight differences which appear in the offspring from the same parents, or which it may be presumed have thus arisen, from being observed in the individuals of the same species inhabiting the same confined locality, may be called individual differences. No one supposes that all the individuals of the same species are cast in the same actual mould. These individual differences are of the highest importance for us, for they are often inherited, as must be familiar to every one; and they thus afford materials for natural selection to act on and accumulate, in the same manner as man accumulates in any given direction individual differences in his domesticated productions.[43]

The entire phenomenal ambit represented by the processes of 'deviation' of the single organism in relation to the species to which it belongs, or rather in relation to the variety, or even better, in relation to every generative process – determined also by random processes – thus came to be configured in this way as one of the engines of the historical process of species' becoming. As in the case of the analysis of useless organs, the breakthrough was not merely in the recognition of the existence of individual variations, due to more or less frequent and diffuse random effects, which Aristotle had already clearly discussed (eye colour, and so on). Rather it was the theoretical role attributed to them within the new-born genealogical framework that represented one of the salient points of Darwin's theory: individual micro-differences became the material on which the incessant modification of species came to be deployed. From this perspective, I suggest that it was only with Darwin's breakthrough that within the ambit of biology, 'substances', or rather individual offspring, became central again. More precisely, without any uncertainty they reacquired that ontological and epistemological centrality which Aristotle had in large measure renounced. In fact, Darwin attributed to species and/or genera a priority with respect to individuals on the epistemological and, thus ontological, level.

The traditional frame of reference was overturned by historicity and variability: generation was no longer interpreted as aimed at guaranteeing the transmission of an immutable form within a fundamentally static natural system and cosmos. On the contrary, generation, which is located within the frame of a world in constant flux, came to be understood as an indispensable source of those individual variations by which species were able over time to adapt themselves to the modifications of their own environment. This is testified to in an annotated passage, which is illuminating from this perspective, from July 1837 when the young Darwin, who by then had assimilated the great teachings of geology and the earth sciences in general, was still making reference to final causes:

> We know world subject to cycle of change, temperature and all circumstances which influence living beings. —
>
> We see living beings the young of living beings, become permanently changed or subject to variety, according to circumstances, — [...] hence we see generation here seems a means to vary, or adaptation. [...] There may be unknown difficulty with full grown individual with fixed organization thus being modified; — therefore generation to adapt & alter the race to changing world. —
>
> On other hand, generation destroys the effect of accidental injuries, on which if animals lived forever, would be endless (that is, with our present systems of body and universe therefore final cause of life.[44]

7 Revolutions

In summary, with the theory of descent with modifications by variation and selection, Darwin managed to happily bring to an end the process of the deconstruction of the traditional Aristotelian fixist, essentialist and teleological framework begun towards the end of the eighteenth century with the first transformist theories. He replaced it with a new, coherent and relatively complete framework. Tackling the question of admirable adaptation head-on, he managed to demonstrate the intrinsic contradictoriness of the traditional theoretical teleological-functionalist cornerstone. He provided evidence of the 'absence of a final cause' in a multitude of morphological elements, which patently bore the 'stamp of inutility'. At the same time, he identified the mechanism capable of coherently accounting for the gradual modification of species from a genealogical perspective: natural selection operating on individual variations. This is a principle that immediately implied a significant, yet still uncertain, reassessment of randomness and the abandonment of anti-random essentialism. The three pillars had been demolished: not only had the thesis of the fixity of species over time been abandoned, along with its correlative thesis on inextinguishability, which in reality had been extremely weak for several decades before the publication of the *Origin of Species*, but also the theoretical teleological nucleus around which the concept had revolved. This made way for a new overall vision of living nature, supported both by empirical data and by the identification of a wide-ranging principle or 'law'.

So it was that the study of natural history in its entirety, instead of dissolving, as Cuvier still dreaded at the beginning of the century, was solidly replanted in evolutionary soil. As Darwin wrote, explaining himself, there was going to be a 'considerable revolution':

> When the views advanced by me in this volume, and by Mr. Wallace, or when analogous views on the origin of species are generally admitted, we can dimly foresee that there will be a considerable revolution in natural history. Systematists will be able to pursue their labours as at present; but they will not be incessantly haunted by the shadowy doubt whether this or that form be a true species. [...] In short, we shall have to treat species in the same manner as those naturalists treat genera, who admit that genera are merely artificial combinations made for convenience. This may not be a cheering prospect; but we shall at least be freed from the vain search for the undiscovered and undiscoverable essence of the term species.[45]

Debates about the literally 'revolutionary' character impressed on eighteenth-century and nineteenth-century biology by the Darwinian breakthrough have continued for some time. In recent decades, a significant part of the discussion has been influenced, directly or indirectly, by the work of Thomas Kuhn; and in more recent years precise and important contributions have emerged on the theme.[46] In this regard, I believe that two series of considerations, amongst others, should be taken into account.

The first is that the Darwinian revolution cannot be placed within the rigid standard form and especially the duration (of approximately two decades) of the scientific revolutions traced in *The Structure of Scientific Revolutions*. On the contrary, from this perspective, it instead represents a clear counterexample: it falsifies the thesis according to which historical documentation serves to demonstrate that 'evidence' for such a 'structure' 'comes from the history of biological as well as of physical science'.[47]

Given that Kuhn's hypothesis was above all an open invitation to work on the theme, and not a proven thesis, only brief and scattered references to the evolutionary revolution emerge, sometimes in open contrast with each other. In regard to the processes of assimilation of a revolutionary paradigm, Darwin is inserted between Copernicus, Newton and Planck,[48] but in another passage the formation and process of assimilation of Darwin's theory is succinctly discussed in a particularly methodological way.[49] In yet another passage, as in some of Kuhn's other texts, he moves towards a parallelism with Franklin, vaguely and indirectly suggesting that in both cases it would have been prompted by pre-paradigmatic conditions.[50] In any case, the fact remains that the Darwinian revolution, and even more the evolutionary revolution as a whole, forcefully breaks out of the temporal limits of Kuhn's model, both backwards and forwards in time.[51] It certainly presents an incomparably greater complexity than that of the revolution caused by the invention of electricity.

That said, it should nevertheless be recognized that, despite his unfortunate parallelism, Kuhn explicitly acknowledged with hindsight that

> When Darwin first published his theory of evolution by natural selection in 1859, what most bothered many professionals was neither the notion of species change nor the possible descent of man from apes. The evidence pointing to evolution, including the evolution of man, had been accumulating for decades, and the idea of evolution had been suggested and widely disseminated before. [...] All the

well-known pre-Darwinian evolutionary theories – those of Lamarck, Chambers, Spencer, and the German *Naturphilosophen* – had taken evolution to be a goal-directed process.[52]

But also on looking ahead, despite placing it in his 'conversion' category, Kuhn noted, also citing it, the passage in which Darwin wrote 'Although I am fully convinced of the truth of the views given in this volume under the form of an abstract, I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all viewed, during a long course of years, from a point of view directly opposite to mine. [...] [B]ut I look with confidence to the future,—to young and rising naturalists, who will be able to view both sides of the question with impartiality.'[53]

The second series of considerations concerns the conceptual apparatus adopted by Kuhn in relation to his analysis of the Copernican revolution. We are moving towards something hinted at in the passage above. After acknowledging criticism of the rigidity and one-sidedness of the standard model, as well as some of the fundamental notions connected to it, starting with that of 'normal science', I believe that both revisions of the concept, as 'paradigm', but also as 'crisis' can still be fruitful in reconstructing the outline of the evolutionary revolution. This is the case especially if such notions are interpreted in the light of their use in relation to the Copernican revolution. With that, I return to Kuhn's argument, which is inclined to follow his more eminently 'naturalistic' approach and which revisits the historiographical questions tackled in *The Copernican Revolution*. In these questions, the significance of Copernicus' theory is likened from the start to that of Darwin.[54]

Just as the physical-astronomical revolution represented the abandonment of the long-standing Aristotelian-Ptolemaic paradigm, the other revolution seems to me to represent the overturning of what in Kuhn's terms could be understood as an Aristotelian-Scholastic paradigm. I have preferred, however, to define the paradigm as a 'framework' of Aristotelian origin. The concept of 'framework', meant in the sense of the theoretical system represented by particular guiding principles – in this case by the fixist thesis, anti-random essentialism and immanent teleology – seems to me to adequately cover the wide range of the tradition of natural history research developed within it, over a period that could be defined as trans-epochal. When the relative compactness of such a framework is reconstructed, it becomes possible to clearly understand the continuity of the tradition and, consequently, the 'crisis' which it experienced when its guiding principles began to be questioned. It is also possible to clarify those conflicts which arose so distinctly, for example, between Lamarck and Cuvier.

In short, we have linked so-named 'fixism' to the processes of the reception, institutionalization, Christianization, medieval and Renaissance reinterpretation and then the experimental updating in the seventeenth century of the cornerstones derived from Aristotle's treatises. After our having established this connection, the process of the late eighteenth-century crisis of the Aristotelian 'framework', the disintegration of its hegemony and its definitive nineteenth-century overturning seems to me to become clearer. And it is because of the centrality of the overcoming of the Aristotelian matrix that I believe the evolutionary revolution can and should be aligned with the physical-astronomical revolution: while Galileo abandoned quality, essences and final causes in favour of mathematization, Darwin dismissed final causes, essences and the fixity of species by historicizing living things.[55]

8 Genealogies

In conclusion, with the publication of the *Origin of Species*, natural history, which had been born with Aristotle's *historia*, hence with an eminently ahistorical and teleological orientation, gave way to the history of nature. The new-born evolutionary biology had taken a giant step forward. Having changed the way it was looked at, nature itself had changed the way it looked.[56] Darwin had succeeded in consecrating the inception of a very wide programme of research, which would be carried forward along the lines of genealogy and 'laws', the future accomplishment of which, prophetically and even rhetorically, he was hoping for in his very last pages:

> A grand and almost untrodden field of inquiry will be opened, on the causes and laws of variation, on correlation, on the effects of use and disuse, on the direct action of external conditions, and so forth. The study of domestic productions will rise immensely in value. A new variety raised by man will be a more important and interesting subject for study than one more species added to the infinitude of already recorded species. Our classifications will come to be, as far as they can be so made, genealogies; and will then truly give what may be called the plan of creation. The rules for classifying will no doubt become simpler when we have a definite object in view. We possess no pedigrees or armorial bearings; and we have to discover and trace the many diverging lines of descent in our natural genealogies, by

characters of any kind which have long been inherited. Rudimentary organs will speak infallibly with respect to the nature of long-lost structures. Species and groups of species which are called aberrant, and which may fancifully be called living fossils, will aid us in forming a picture of the ancient forms of life. Embryology will often reveal to us the structure, in some degree obscured, of the prototypes of each great class.

When we can feel assured that all the individuals of the same species, and all the closely allied species of most genera, have within a not very remote period descended from one parent, and have migrated from some one birth-place; and when we better know the many means of migration, then, by the light which geology now throws, and will continue to throw, on former changes of climate and of the level of the land, we shall surely be enabled to trace in an admirable manner the former migrations of the inhabitants of the whole world. [...]

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.[57]

6
Dry Branches

1 Obsolescence

The theory of descent with modifications by variation and selection represented a fundamental pivot in the process of the overturning and replacement of the traditional fixist and essentialist framework, whose theoretical stronghold had always been the teleological cornerstone of Aristotelian origin. However, despite the battle declared against the recourse to 'final causes' undertaken by Darwin from his early years, and then tenaciously prosecuted in his maturity, even in the last edition of the *Origin of Species* he continued to adopt an acceptance of selection of clearly teleological origin alongside a non-finalistic one: 'Natural selection may modify and adapt the larva of an insect to a score of contingencies, wholly different from those which concern the mature insect; and these modifications may affect, through correlation, the structure of the adult. So, conversely, modifications in the adult may affect the structure of the larva; but in all cases natural selection will ensure that they shall not be injurious: for if they were so, the species would become extinct.'[1]

Selection, which provided for modifications as long as they were not injurious, and so avoiding the extinction of the species, had an explicitly positive end: 'And as natural selection works solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection.'[2] Here, 'good' is also defined in terms of an 'advantage': 'Natural selection, it should never be forgotten, can act solely through and for the advantage of each being.'[3] The mechanism is defined in the converging terms of good and advantage, acquiring a productive, active, plastic and even anthropomorphic dimension: 'As two men have sometimes independently hit on the same invention, so in the several foregoing cases it appears that natural selection, working for the good of each being, and taking advantage of all favourable variations, has produced similar organs, as far as function is concerned, in distinct organic beings, which owe none of their structure in common to inheritance from a common progenitor.'[4]

From this perspective it is certainly possible to interpret selection in the light of ancient Aristotelian teleology, particularly in light of the principle according to which 'nature creates nothing without a purpose but always with a view to what is best for each thing within the bounds of possibility, preserving the particular essence and purpose of each'[5] or, more briefly, the thesis according to which 'out of given conditions, nature is always the cause of that which is the better'.[6] In other words, a function analogous to that conferred in ancient times on nature in its totality can be attributed to selection: the 'bounds of possibility' of nature, although reduced to a temporal dimension entirely alien to Aristotle's perspective, can be understood in terms of the variations available from time to time on which selection operates. But above all, the idea that nature always 'chooses' according to what is 'better' for each individual living being can be reinterpreted in parallel with the fact that selection 'works solely by and for the good of each being'. Following this line, James Lennox, historian of biology and an eminent Aristotle scholar, in an article as well received as it is contested, wrote that 'Darwin essentially re-invented teleology.'[7]

This interpretation of the principle of selection in a finalistic, philologically unexceptionable sense, is, however, in my opinion not only one-sided, but amounts to an inverted reading of the Darwinian revolution. It is one-sided because it does not consider the constitutive relationship between selection and extinction, where indeed the first 'entails' the second.[8] It is inverted because the circular selection-extinction effect rendered obsolete both the ancient teleological concept of nature and the finalistic significance conferred on the principle of natural selection itself. I will now try to elucidate this apparently paradoxical effect, this tension immanent in the two aspects of selection. I believe it is a symptom of and at the same time evidence of the decades-long pursuit that led Darwin to develop the genealogical framework described in the *Origin of Species*. It was a path in the course of which Darwin gradually abandoned the traces of the ambivalent recourse to final causes current in his younger years, and especially the analogy, as productive as it was insidious, between natural and artificial selection.[9] We can schematically divide this development into three principal phases.

In the first phase Darwin effectively 're-invented' teleology, but in such a way that the principle of selection, originally understood in the literal terms of a 'final cause', rendered the fixist concept obsolete. Abruptly abandoning direct recourse to a 'final cause', in a second phase Darwin proceeded to develop the concept of natural selection mostly on the basis of a model of artificial selection. This was a perspective that implied the readmission of an unavoidably teleological orientation, even though it was newly formed. In a third and final phase, Darwin proceeded to work on the elaboration and refinement of an overall doctrinal and theoretical system and a correlated conceptual toolbox. This phase indirectly implied the obsolescence of the teleological gloss given to the principle of natural/artificial selection. It was as if the scaffolding employed in the construction of the new edifice had collapsed under the weight of the construction itself. Over the years Darwin became ever more aware that the instrument used to overturn the traditional framework had to be rethought and corrected in the light of the overall system that had been taking shape. He went ahead in this direction, despite remaining in some ways bound to the original approach, right up until his last writings.

2 A double-edged sword

It was first and foremost the unavoidably finalistic character inherent in the model of artificial selection that set the persistence of traditional teleology on a new path. The transition from the artificial to the natural level clearly shows how the analogy led to the reinstatement of an anthropomorphic model – for example, in the *Sketch of 1842*:

> 1. But if every part of a plant or animal was to vary <illegible>, and if a being infinitely more sagacious than man (not an omniscient creator) during thousands and thousands of years were to select all the variations which tended towards certain ends ([or were to produce causes <?> which tended to the same end]), for instance, if he foresaw a canine animal would be better off, owing to the country producing more hares, if he were longer legged and keener sight, – greyhound produced. If he saw that aquatic (animal would need) skinned toes. If for some unknown cause he found it would advantage a plant, which <?> like most plants is occasionally visited by bees & c.: if that plant's seed were occasionally eaten by birds and were then carried on to rotten trees, he might select trees with fruit more agreeable to such birds as perched, to ensure their being carried to trees [...]. Who,

> seeing how plants vary in garden, what blind foolish man has done in a few years, will deny an all-seeing being in thousands of years could effect (if the Creator chose to do so), either by his own direct foresight or by intermediate means, – which will represent <?> the creator of this universe.[10]

The consequence was that the 'selecting power of nature' is 'infinitely wise compared to those [*sic*] of man.'[11] With the passing of the years Darwin continued along this path; in 1857, for example, he wrote:

> 2. Now suppose there were a being who did not judge by mere external appearances, but who could study the whole internal organization, who was never capricious, and should go on selecting for one object during millions of generations; who will say what he might not effect? [...]
>
> 3. I think it can be shown that there is such an unerring power at work in *Natural Selection* (the title of my book), which selects exclusively for the good of each organic being.[12]

The infallible power of natural selection, aimed at the benefit of each living thing, had replaced the micro-utility pursued by mankind in its micro-undertaking of selection. The many decades of work on the analogy between artificial and natural selection, or rather on the 'application' of the former to the realm of the latter, repeatedly claimed by Darwin himself,[13] finally achieved the clarity of the definition provided in the *Origin of Species*: 'I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection, in order to mark its relation to man's power of selection'.[14] From artificial selection, in the strict sense of the voluntary or unconscious choice made by farmers and breeders to shape particular breeds on the basis of their necessities and desires (productive, aesthetic, and so on), Darwin thus recouped both the term 'selection' and the conceptual model:

> Variability is not actually caused by man; he only unintentionally exposes organic beings to new conditions of life, and then nature acts on the organization and causes it to vary. But man can and does select the variations given to him by nature, and thus accumulates them in any desired manner. He thus adapts animals and plants for his own benefit or pleasure. He may do this methodically, or he may do it unconsciously by preserving the individuals most useful or pleasing to him without any intention of altering the breed. It is certain that he can largely influence the character of a breed by selecting, in each

> successive generation, individual differences so slight as to be inappreciable except by an educated eye. This unconscious process of selection has been the great agency in the formation of the most distinct and useful domestic breeds. That many breeds produced by man have to a large extent the character of natural species, is shown by the inextricable doubts whether many of them are varieties or aboriginally distinct species.
>
> There is no reason why the principles which have acted so efficiently under domestication should not have acted under nature. In the survival of favoured individuals and races, during the constantly-recurrent Struggle for Existence, we see a powerful and ever-acting form of Selection.[15]

Given that the same principles are at stake in the two selective processes, their difference fundamentally concerned the quantitative dimension, the pervasiveness, the range:

> As man can produce, and certainly has produced, a great result by his methodical and unconscious means of selection, what may not natural selection effect? Man can act only on external and visible characters: Nature, if I may be allowed to personify the natural preservation or survival of the fittest, cares nothing for appearances, except in so far as they are useful to any being. She can act on every internal organ, on every shade of constitutional difference, on the whole machinery of life. Man selects only for his own good: Nature only for that of the being which she tends.[16]

Now, the classic question I would like to draw attention to is how artificial selection, occupied as it is with living organisms, could have been utilized (and indeed could still be today) to analyse certain particular mechanisms of these beings, as well as to demonstrate, among other things, their fundamental 'plasticity'. These mechanisms include those inherent in the laws of heredity, which in Darwin's time were shrouded in the darkest of shadows, However, although artificial selection had (and still has) living organisms as its objective, and not inorganic material that could be transformed into artifacts, it was (and is) an unequivocally teleological and literally anthropic activity. It is primarily a human activity aimed at achieving particular objectives by way of intentional choices. If certain final results may be obtained unconsciously, that does not detract from the fact that the mechanism revolves around 'choices', precisely an undertaking of 'selection' in the literal sense.

And so, by transposing the model of artificial selection to the level of processes and natural laws, Darwin accomplished a feat as extraordinarily effective and productive on the analytical-explanatory level as it was terribly insidious on the theoretical-methodological level: it was a double-edged sword. By establishing this principle he indeed 'resolved' the ancient question of admirable adaptation. However, at the same time, he attributed to selection that eminently teleological character inherent in all anthropically orientated activities. The model implied a restatement of the ancient teleological position: 'Man selects only for his own good: Nature only for that of the being which she tends.' An aim was reattributed to Nature; more precisely the aim of doing 'the good of each organic being', just as had happened in the tradition born with Aristotle.

3 *Techne*

I believe that a very brief analysis of Aristotle's discussion of the relationship between *physis* and *techne* may now shed light on the approach adopted by Darwin regarding the relationship between the artificial and natural levels. This time we will consider it from a perspective not so much historical as purely conceptual. The attribution to Nature of a teleological as well as eminently anthropomorphic character is clearly evident in Aristotle's famous argument: since *techne*, which imitates nature, has a purpose, so will nature: 'if artificial processes are purposeful, so are natural processes too'; it is an argument that presupposes that in turn 'art imitates nature.'[17] Thus, a circular hermeneutic apparatus is generated that justifies the teleological character attributed to the two dimensions: the idea itself that art imitates nature is actually the reverse side of projecting the model of technique onto nature.[18] Thus, here, we have a dual projection that leads to the adoption of a naturalistic model that is in a strict sense anthropomorphic.

Certainly in Darwin, the objective of anthropic activity is not inanimate matter that can be transformed into artefacts. Moreover, it is part of an overall theoretical apparatus intentionally directed at avoiding a hypostasis of nature, by identifying a 'law' in it. However, in the basic parallelism between artificial and natural selection, a short circuit can be found similar to the one in Aristotle. Artificial selection, which has a purpose, is not in fact understood only as an 'experimental' field of inquiry into certain mechanisms inherent in reproductive processes, but it is originally adopted as a model of how natural selective activity actually works; thus, the latter also has a purpose. From this perspective, the difference between the two processes is not due to the existence or not of a purpose but only due to the final beneficiary of such a purpose: the advantage or benefit of mankind in one case, of the organism in the other. This, briefly, is what led Darwin to maintain repeatedly and clearly maintain that selection occurred 'for the good of each organic being'.

Furthermore, the circularity is also evident in the other direction, in the sense that artificial selection in turn reproduces, 'unconsciously' as Darwin wrote, natural selective activity. It follows that the functioning of a natural principle comes to correspond to that of art, and the functioning of the latter to that of nature: 'But when man is the selecting agent, we clearly see that the two elements of change are distinct; variability is in some manner excited, but it is the will of man which accumulates the variations in certain directions; and it is this latter agency which answers to the survival of the fittest under nature.'[19] The natural mechanism is thus analogous to art:

> We have seen that man by selection can certainly produce great results, and can adapt organic beings to his own uses, through the accumulation of slight but useful variations, given to him the hand of Nature. But Natural Selection, as we shall hereafter see, is a power incessantly ready for action, and is as immeasurably superior to man's feeble efforts, as the works of Nature are to those of Art.[20]

Quantitatively superior, not qualitatively different. Superiority close to what William Harvey, around the middle of the seventeenth century, still following the Aristotelian parallel between art and nature, had attributed to Nature when he wrote:

> And if in the domain and rule of nature so many excellent operations are daily effected surpassing the powers of the things themselves, what shall we not think possible within the pale and regimen of nature, of which all art is but imitation? And if, as minister of man, they effect such admirable ends, what, I ask, may we not expect of them, when they are instruments in the hand of God?[21]

Although by now he was moving away from the idea of an intrinsically historicized nature, Darwin would continue to think of living beings in parallel with mechanical invention, as is evident again in the following passage from the *Origin of Species*, borrowed in turn from the *Essay* of 1844:

> When we no longer look at an organic being as a savage looks at a ship, as something wholly beyond his comprehension; when we regard every production of nature as one which has had a long history; when we contemplate every complex structure and instinct as the summing up of many contrivances, each useful to the possessor, in the same way as any great mechanical invention is the summing up of the labour, the experience, the reason, and even the blunders of numerous workmen; when we thus view each organic being, how far more interesting,– I speak from experience,– does the study of natural history become![22]

In conclusion, it is true that in the course of time the analogy between the two selective modalities was being gradually refined. And it is true that the parallel between anthropic mechanisms and processes and living beings certainly did not manifest the markedly anthropomorphic and one-sided teleological traits of the Aristotelian approach. But it is also true that Darwin, allowing himself to be urged by his youthful intuition, never gave up linking living organisms and artefacts, and, especially, never gave up interpreting the functioning of nature in parallel with *techne*, although it was only in certain aspects and from a circumscribed perspective.

4 On the cusp

'Darwin's main error, in a nutshell, was to see natural selection working on entire species through time as directly analogous to the selective breeding done by small groups of farmers, horticulturalists, or animal breeders – a mistake perpetuated to this day in some quarters of evolutionary biology.'[23] It was an 'error' that allowed him to offer a solution to the question of adaptation different from the traditional fixist and teleological one, but also led him to give a teleological attribution to the principle of natural selection. The principle, despite this, as Niles Eldredge stresses, is also understood as a 'passive filter', thus not in a teleological, let alone anthropomorphic sense.[24] From this point of view, the *Origin of Species*, like other masterpieces of the history of science, finds itself on a cusp: on the one hand, it signals the abandonment of a centuries-old tradition; on the other, it initiates a process of re-equilibrium and restructuring of the framework at the head of an alternative tradition. While the theory of descent with modifications by variation and selection may have represented a parting of the ways in the history of the newly founded evolutionary biology, its roots had to be firmly in the past. Although alternative, the responses were born of ancient problems, whose traditional treatment was bound to restrict, within certain limits, the responses to a similar structure. This tension clearly emerges in the establishment of the principle of 'natural selection' and in the continual consideration given to noting its semantic inadequacy: 'In the literal sense of the word, no doubt, natural selection is a false term.'[25] False, but adopted nevertheless, and vice versa.

And moreover, unlike other masterpieces in the history of science, the overall concept set out in the *Origin of Species* was, paradoxically, such as to render the teleological meaning of the principle of natural selection adopted therein obsolete, as is seen in the conclusion of a passage in which Darwin directly links natural selection to an observation of Paley's:

> Natural selection will never produce in a being any structure more injurious than beneficial to that being, for natural selection acts solely by and for the good of each. No organ will be formed, as Paley has remarked, for the purpose of causing pain or for doing an injury to its possessor. If a fair balance be struck between the good and evil caused by each part, each will be found on the whole advantageous. After the lapse of time, under changing conditions of life, if any part comes to be injurious, it will be modified; or if it be not so, the being will become extinct as myriads become extinct.[26]

In this short text the apparent initial proximity to natural theology gradually becomes an unbridgeable distance: the possibility that a modification could be 'injurious' and that the organism become extinct, 'as myriads become extinct', in fact at the same time paradoxically renders obsolete the teleological thesis according to which nature, but also selection itself, acts 'by and for the good of each'. Obsolete because, as Darwin himself writes in the *Origin of Species*, selection 'entails' extinction,[27] and it does so in two senses.

The first is that selection can only ever have a double effect: if something is 'positively' selected, there must necessarily be something else that at the same time is 'discarded'. This is a question rarely discussed explicitly by Darwin, but it emerges for example when he writes: 'there is no need to separate single pairs, as man does, when he methodically improves a breed: natural selection will preserve and thus separate all the superior individuals, allowing them freely to intercross, and will destroy all the inferior individuals.'[28] Thus, there is simultaneously preservation and destruction. The second sense, continually noted, is that modified, and so 'selected' descendants almost systematically 'supplant' and 'conquer' their progenitors, the species of origin.[29]

These are the two factors that render totally obsolete the ancient teleological concept that nature operates 'for the better', or 'for the good' of all living organisms. These factors cannot fail to cause problems for the thesis, which is reaffirmed by Darwin himself, that 'natural selection works solely by and for the good of each being.'[30] In the context of the overall system set out in the *Origin of Species*, this thesis is exposed as archaic, and attributable to the legacy of a conceptual template belonging to an outdated concept.

5 Archaisms

By proceeding from the ancient question of admirable adaptation, Darwin did not completely detach himself from the traditional teleological template of Aristotelian origin. However, at the same time, the system he outlined made this very template obsolete. This system was also a result of the discussion and endorsement of the 'complex action of natural selection, entailing extinction and divergence of character'.[31] In the wake of the conquests achieved in the *Origin of Species*, but by now free from the necessity of having to tackle and resolve ancient issues, biologists and philosophers in the course of the twentieth century got on with the work of revising the principle of natural selection itself. In this way, they eased the tensions immanent in the *Origin of Species*: natural selection, in a strict sense, does not 'select' anything, because otherwise it would be necessary to hypostasize a principle: nature, and its ancient wisdom. The main instrument adopted by Darwin to oust the supremacy of fixism was updated again in the light of the results that his own original configuration had produced. We can interpret the process of adaptation with the help of the notion of 'exaptation',[32] or we can interpret it in a classic way.[33] In any case it remains true that in general it cannot be presupposed that natural selection has modelled structures or behaviour aimed at the particular function that can be observed today.[34] Parts, and organisms themselves, emerge from a historical process that sees the mechanism of natural selection as providing the random variations which it operates on, as well as many other associated causes, on multiple levels, so that in the end the process assumes an eminently contingent character: 'All existing species are the result of a unique historical process which began when life had its origins, a process that could have gone in many different directions from the direction it effectively did take. Evolution is not a linear unfolding, but a moving itinerary, historically contingent, that unravels through the space of possibilities'.[35] In more systematic terms:

> A great deal of the body of biology research and knowledge consists of narrative statements. The reconstruction of the history of living organisms by paleontologists is a historicist enterprise, and all of systematics (the science of inferring evolutionary relationships among organism) is an attempt to tell the story of the common ancestry of organisms [...]. Evolutionary biology, like historical geology, soil science, and cosmology, is a historical science. It is the purpose of all these sciences to provide a correct narrative of the sequence of past events and an account of the causal forces and antecedent conditions that led to that sequence. Moreover, all these historical sciences assume the existence of several forces simultaneously operating and include the importance of chance, viewed either ontologically or epistemologically. The actual event is seen as the nexus of these forces and their chance perturbations.[36]

The latter, I believe, is the point of view adopted by Michael Ghiselin on the thesis put forward by James Lennox according to which 'Darwin essentially re-invented teleology'. More generally, this can be further extended to the multiple attempts at interpreting selection in the light of Aristotelian teleology, such as the one by the equally famous scholar of Aristotle, Allan Gotthelf.[37] It is certainly true that Lennox is right, on the philological level, to identify a teleological meaning of selection in the Darwinian *corpus*. On the other hand, Ghiselin's almost disgruntled reaction I believe is due to the fact that, proceeding from within the evolutionary system, he seems worried and even alarmed when confronted by the obstinate resistance to approaches that had become obsolete. In this case he is alarmed by the 'pernicious influence' still exercised by 'teleological thinking'.[38] Holding firm to this perspective, I believe it may be productive to analyse the convergences between selection and Aristotelian teleology: not to try to demonstrate the currency of the latter, or as Gotthelf writes, to see 'what we, in our time, may yet have to learn from Aristotle's biological and philosophical work',[39] but rather to make the archaisms of Darwinian theory – that is, the dry branches of the Aristotelian tradition – more evident.

6 Corals

Throughout the twentieth century there was also broad development of Darwin's ideas relating to the fact that once extinction had been attributed a systematic function within the genealogical system, the by now historicized concepts of 'admirable adaptation' and of 'perfection' and 'imperfection' of organic beings became entirely relative:

> Thus a distinguished German naturalist has asserted that the weakest part of my theory is, that I consider all organic beings as imperfect: what I have really said is, that all are not as perfect as they might have been in relation to their conditions; and this is shown to be the case by so many native forms in many quarters of the world having yielded their places to intruding foreigners. Nor can organic beings, even if they were at any one time perfectly adapted to their conditions of life, have remained so, when their conditions changed, as well as the numbers and kinds of its inhabitants, have undergone many mutations.[40]

The conditions of life having changed, organs could prove to be instruments of preservation that were so feckless, ineffective and unsuitable as to lead to the extinction of the entire species. The possibility of radical transformations of the environment and of extinctions having been acknowledged, the convergence not only between organs and functions, but also more generally between organisms and their ecological niches, could not but assume an eminently contingent character.[41]

The theoretical role attributed to extinctions was to have a determining influence on the new image of the history of life. This was depicted by the young Darwin as coral: 'The tree of life should perhaps be called the coral of life, base of branches dead; so that passages cannot be seen.'[42] He continued to insist on dead branches in the *Origin of Species*:

> From the first growth of the tree, many a limb and branch has decayed and dropped off; and these fallen branches of various sizes may represent those whole orders, families, and genera which have now no living representatives, and which are known to us only in a fossil state. As we here and there see a thin straggling branch springing from a fork low down in a tree, and which by some chance has been favoured and is still alive on its summit, so we occasionally see an animal like the Ornithorhynchus or Lepidosiren, which in some small degree connects by its affinities two large branches of

> life, and which has apparently been saved from fatal competition by having inhabited a protected station. As buds give rise by growth to fresh buds, and these, if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever-branching and beautiful ramifications.[43]

This is an image that in recent decades has been associated with the less noble but perhaps more meaningful image of the bush; in Stephen Jay Gould's words: 'Life is a copiously branching bush, continually pruned by the grim reaper of extinction, not a ladder of predictable progress.'[44] With this definition not only can it be observed that ancestral forms very often survive their own descendants, but account also needs to be taken of both the intertwining of the lines of descent and, especially, of the continual work of pruning undertaken by extinctions, including mass extinctions. These processes can in turn be traced back to a wider geological and paleontological context (from the theory of tectonic plates, to new excavations, and so on). The new theoretical models, supported by empirical analyses, and ongoing fossil finds allowed the reconstruction of multiple processes of crisis and extinction. These led to successive, previously unthinkable and inexplicable 'adaptive radiations'. These are studies that caused estimates of the number of branches falling in the course of the history of living things to grow exponentially: a continual tally of dry branches.

7 Circularity

If natural selection in its anachronistically teleological sense can be traced back to the heritage of the Aristotelian framework, I believe the by now well-known criticism levelled by Gould and Lewontin at the contemporary adaptationist programme can also be re-examined from this perspective. The two authors in fact stressed the paradoxical inversion of the order of cause and effect that occurs when the results of the evolutionary process – that is, current adaptations – are understood as the ends of the selective process, so that a circular apparatus is created in which the explanations provided from time to time cannot fail to tally.[45] This is nothing but a restatement of the same circularity that characterized the teleological apparatus at the basis of the extraordinary physiological anatomical analysis developed in Aristotle's *Parts of Animals*.

Here, too, as we have seen in particular in Aristotle's close examination of birds' wings and feet, given that it provides for the preservation of organisms by assigning them suitable organs, nature can only proceed from functions and ends. Indeed, to proceed the other way round would be senseless; just as it would be absurd to assign them to those who cannot make use of them: 'Nature, like a sensible human being (*phronimos*), always assigns an organ to the animal that can use it'.[46] In this way, Aristotle was able to take account of each admirable adaptation observable in nature: ducks, for example, have webbed feet as a function of their environment and way of life. In fact, they live (also) in water, therefore they must swim, and they swim because they have webbed feet, which nature has assigned them, thus ensuring their preservation. Just as flamingos have extended, but not webbed, feet, because they live in water, but they do not swim, and so webbed feet (like the spurs of raptors) 'would not be merely useless to them but a real disadvantage'.[47] In effect, they have been provided with extended but not webbed feet, equipped with toes with numerous articulations. Typical in this regard is the following dense passage from Aristotle's *Progression of Animals*:

> Web-footed birds swim with their feet. They are bipeds, because they take in breath and respire; they are web-footed, because they live in the water, for their feet being of this kind are of service to them in place of fins. They do not have their legs, as the other birds do, in the centre of the body, but placed rather towards the back; for since they are short-legged, their legs being set back are useful for swimming. This class of bird is short-legged because nature has taken away from the length of their legs and added to their feet, and has given thickness instead of length to the legs and breadth to the feet; for, being broad, they are more useful than if they were long, in order to force away the water when they are swimming.
>
> XVIII. It is for a good reason, too, what winged animals have feet, while fishes have none. The former live on dry land and cannot always remain up in the air, and so necessarily have feet; but fishes live in the water, and take in water and not air. Their fins, then, are useful for swimming, whereas feet would be useless.[48]

Here, we have a circular hermeneutic apparatus.[49] Given that nature assigns each organ to those who can make use of it, and not vice versa, which would be absurd, and assigns it with a view to its function, and not vice versa, which would be senseless, no case can be found in which any living organism would not fit into this template. We are faced here with a theoretical apparatus whose all-pervasive and all-inclusive nature led Aristotle to set aside any dissonant element with casual nonchalance. The teleology that was at the foundation of his theoretical edifice led the ancient philosopher to a sort of neutralization of the problematics posed by obviously useless and, especially, harmful or injurious parts. Although he clearly identified and discussed such parts, they did not actually seem to pose a serious problem to him. Thus, just as was the case in his treatment of casual individual variations, although recognizing and discussing these parts, Aristotle immediately marginalizes them. In short, the wisdom attributed to nature is such that Aristotle seems to preclude the possibility of seriously contemplating the hypothesis that it could systematically behave in an irrational, random way without an aim or predetermined end.

In the adaptationist paradigm, selection seems to have taken the place of the ancient wisdom of nature. The preservative function of the webbed feet of ducks, for example, again becomes the end 'for which', in the course of time, selection has worked, as did nature, although more generously and rapidly, in Aristotle. In this way, any anatomical structure, including the ones most difficult to explain, such as the horns of deer, which tormented Darwin himself,[50] can be explained in a recursive manner, as Gould and Lewontin emphasize: 'A suite of external structures (horns, antlers, tusks) once viewed as weapons against predators, become symbols of intraspecific competition among males (Davitashvili 1961). [...] We do not attack these newer interpretations; they may all be right. We do wonder, though, whether the failure of one adaptive explanation should always simply inspire a search for another of the same general form, rather than a consideration of alternatives to the proposition that each is "for" some specific purpose.'[51]

This 'way of thinking', or as I would prefer to say this style of teleological thinking, is represented in caricature by Voltaire's Pangloss, according to which '[e]ach trait plays its part and must be as it is'.[52] This was actually invented and applied to analysis of the life sciences (in a much more refined form) by their founder: 'So the best way of putting the matter would be to say that because the essence of man is what it is, therefore a man has such and such parts, since there cannot be a man without them. If we may not say this, then the nearest to it must do, viz. that there cannot be a man at all otherwise than with them, or, that it is well that a man should have them.'[53] On the other hand, as Lewontin has recently written, almost echoing Darwin's battle nearly two centuries ago against the recourse to 'final causes', 'it is absolutely not true that each part carries out a function. Many parts of organisms are epiphenomenal consequences of modifications which have taken place in the course of development, or residues without any function inherited from distant ancestors. Only the almost religious conviction that everything in the world has a purpose can drive us to look for a functional explanation of fingerprints'.[54] Not everything has a purpose.

Thus, the vein of analysis of useless parts developed by Darwin and at the time attributed to non-use (as in the classic case of the blind eyes of the mole) continues.[55] But Darwin's insights into a perspective that detached itself from the utility/inutility–beneficial/injurious template were also developed. These are evident, for example, in the following autobiographical note – which confirms how, with the passing of time, he gradually detached himself from his embrace of teleology by means of the principle of selection:

> I have altered the fifth edition of the 'Origin' so as to confine my remarks to adaptive changes of structure; but I am convinced, from the light gained during even the last few years, that very many structures which now appear to us useless, will hereafter be proved to be useful, and will therefore come within the range of natural selection. Nevertheless, I did not formerly consider sufficiently the existence of structures, which, as far as we can at present judge, are neither beneficial nor injurious; and this I believe to be one of the greatest oversights as yet detected in my work. I may be permitted to say, as some excuse, that I had two distinct objects in view; firstly, to shew that species had not been separately created, and secondly, that natural selection had been the chief agent of change, though largely aided by the inherited effects of habit, and slightly by the direct action of the surrounding conditions. I was not, however, able to annul the influence of my former belief, then almost universal, that each species had been purposely created; and this led to my tacit assumption that every detail of structure, excepting rudiments, was of some special, though unrecognized, service. Any one with this assumption in his mind would naturally extend too far the action of natural selection, either during past or present times.[56]

The entire field of enquiry of 'useless' parts of animals has moreover greatly benefited from the opening by genetics of the 'black box', which has attributed both the harmful and neutral parts, interpreted in terms of anti-adaptive and non-adaptive variations, to 'side effects' of genetic mutations. Anchored to the randomness of mutations by which phenotypical variations are deployed, these analyses have contributed to multiplying the dimensions in which systematic recourse is necessarily made to randomness.[57]

8 Revenge

In conclusion, while Alexandre Koyré, with a certain *pathos*, defined the Galilean revolution of Aristotelian physics as '*la revanche de Platon*' (the revenge of Plato),[58] in our case we could, parsing our initial passage from Empedocles that was criticized in *Physics* and endorsed by Darwin, perhaps deem it the revenge of Empedocles. Obviously, I do not mean Empedocles's concept in its literal sense – in many respects, starting with his reference to the extinction of 'man-faced oxen', it is only a mythical fantasy. Instead, I mean we are dealing with a 'revenge', since Empedocles endorsed two basic concepts that Aristotle constantly criticized: first, the adoption of an eminently historical perspective, capable of radically relativizing the relations between living beings and the natural environment and of contemplating extinction within it; second, the reintroduction of systematic recourse to randomness, so as to endorse contingency and fracture the linearity of pre-ordained causal chains and, with them, the static nature of immutable species.

Without these two concepts, it would not have been possible to escape from the template of admirable adaptation and at the same time abandon that pervasive recourse to final causes which in a circular way ensured and justified its retention. Nor would it have been possible to dismiss the principle by which nature does nothing in vain, does nothing useless, random or superfluous, but always aims, directly or indirectly, for the good of every living being. And at the same time it would also not have been possible to begin to laboriously construct an alternative system to the teleological, essentialist and fixist one devised in antiquity by Aristotle, which was absorbed and reintroduced by Scholastic philosophers, and then placed at the forefront of modern natural history in the Renaissance.

Therefore, we have a momentous scientific revolution, marked this time not by mathematization and quantification but by historicization: from the transition from ahistorical natural history to the history of life or, rather, to evolutionary biology. The new system, or if you will the new theoretical framework, was and indeed is marked by the radical historicization of living things: not only have modern taxonomies been transformed into genealogies, but the image of life itself has assumed the form of coral, of a tree or of a bush, which has been marked, pruned or cut back by an uninterrupted series of extinctions. Biology, the discipline that embraces physiology and anatomy and which was once deemed the best proof of the persistence of a recourse to final causes, became a historical science that has proved to be unintelligible if read in the light of the principle that *natura nihil frustra facit*. This old principle now belongs to an eminently photographic epistemological style. Suffice it to think, for example, of all those organisms that bear, in their anatomical and physiological constitutions, the plain stamp of inutility.

Notes

Introduction

1. C. R. Darwin (1866) *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, 4th edn (London: Murray), p. 13, note; the note was always republished up to the last edition: see C. R. Darwin (1872) *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, 6th edn (London: Murray), p. 13, note, the edition that from now on I will refer to as *Origin of Species*; Darwin introduces the passage cited as follows: 'Aristotle, in his Physicae Auscultationes (lib. 2, cap. 8, s. 2), after remarking that rain does not fall in order to make the corn grow, any more than it falls to spoil the farmer's corn when threshed out of doors, applies the same argument to organization: and adds (as translated by Mr. Clair Grece, who first pointed out the passage to me).' The passage is in Aristotle *Physics* II, 8, 198b 16 ff.
2. C. R. Darwin *Origin of species*, cit., p. 13, note.
3. Grece's letter containing the passage from Aristotle received around 1864–65 has been lost; in another letter dated 12 November 1866, Clair James Grece (quoted explicitly from the fourth edition onwards), reminds Darwin: 'You may recollect me as having some year or two since pointed out to you a passage from Aristotle, showing that "Natural Selection" was known to the ancients', in F. Burkhardt *et al*. (eds) (2004) *The correspondence of Charles Darwin* (Cambridge: Cambridge University Press), vol. 14: 1866, p. 386.
4. On this question see the detailed and rigorous historical reconstruction by A. Gotthelf (1999) 'Darwin on Aristotle', *Journal of the History of Biology*, 32, 3–30, p. 8 and note 3, pp. 16 ff.
5. For the last part of the passage see Aristotle *The Physics*, trans. P. H. Wicksteed and F. M. Cornford (Cambridge Mass. and London: Harvard University Press, 1957), II, 8, 198b 31 ff.
6. Aristotle *Physics*, cit., II, 8, 198b-199a.
7. Aristotle *On the Soul*, trans. W. S. Hett (Cambridge Mass. and London: Harvard University Press, 1964), III, 12, 434a.
8. J. C. Greene (1992) 'From Aristotle to Darwin: Reflections on Ernst Mayr's *Growth of Biological Though*', *Journal of the History of Biology*, 25, n. 2, 257–84, pp. 268–9.
9. See A. Koyré (1956) 'Influence of Philosophical Trends on the Foundation of Scientific Theories' in P. Frank (ed.) *The Validation of Scientific Theories* (Boston: Beacon Press), p. 197.

1 The Original Framework

1. Aristotle *Parts of Animals*, trans. A. L. Peck (Cambridge Mass. and London: Harvard University Press, 1968), I, 5, 644b–645a.

2. See for example Aristotle *Parts of Animals*, cit., III, 1, 661b 24–5: 'Nature never does anything without purpose or makes anything superfluously'; I, 641b 12–3: 'whatever Nature makes she makes to serve some purpose'; see also Aristotle *Generation of Animals*, trans. A. L. Peck (Cambridge Mass. and London: Harvard University Press, 1963), II, 6, 744a 36–9: 'Another such part is the eyelid. Now, as Nature does nothing that is superfluous or pointless, it is plain that she will not do anything too late or too soon, for in that case what was done would be either pointless or superfluous.'
3. Aristotle *Generation of Animals*, cit., II, 6, 744b 16–8, which continues: 'In housekeeping the best of the food available is reserved for the freemen; the residue left over from this as well as the inferior food goes to the servants, and the worst of all goes to the domestic animals.'
4. Aristotle *On Coming-To-Be and Passing-Away*, trans. E. S. Forster (Cambridge Mass. and London: Harvard University Press, 1965), II, 6, 333b.
5. Aristotle *On the Heavens*, trans. W. K. C. Guthrie (Cambridge Mass. and London: Harvard University Press, 1968), I, 12, 283a 32 ff.; see also II, 8, 290a 31: 'Nature makes nothing in haphazard fashion'; 289b 25–7; II, 5, 288a 2–3.
6. Aristotle *On the Soul*, cit., III, 12, 432b 21–3; on this issue, see D. Quarantotto (2005) *Causa finale, sostanza, essenza in Aristotele. Saggio sulla struttura dei processi teleologici e sulla funzione del* telos (Napoli: Bibliopolis), pp. 104–8, 47–79, 99 ff.
7. See Aristotle *The Physics*, cit., II, 4, 196b ff.
8. Aristotle *Generation of Animals*, cit., V, 1, 778a 16 ff.
9. Aristotle *Generation of Animals*, cit., V, 1, 778a 16 ff.
10. Aristotle *Generation of Animals*, cit., V, 1, 778a 16 ff.
11. Aristotle *Parts of Animals*, cit., I, 1, 640a 19ff.; see also I, 1, 641b 25 ff. On Empedocles, see (DK) A 70, A 72; B 61; B 102; B 103 I,1, B3r B3v B4r.
12. Aristotle *The Metaphysics*, trans. H. Tredennick (Cambridge Mass. and London: Harvard University Press, 1968), VII, 9, 1034a 34–1034b2: 'And it is the same with natural formations as it is with the products of art. For the seed produces just as do those things which function by art. It contains the form potentially, and that from which the seed comes has in some sense the same name as the products'; see also 7, 1032a20–5.
13. Aristotle *The Metaphysics*, cit., VII, 3, 1043b 16–9: 'It has been clearly demonstrated elsewhere that no one generates or creates the form; it is the individual thing that is created, and the compound that is generated'; see also VII, 15, 1039b 20–7; VIII 5, 1044b 21–6.
14. Even James G. Lennox (2001) 'Are Aristotelian Species Eternal?' in J. G. Lennox *Aristotle's Philosophy of Biology. Studies in the Origins of Life Sciences* (Cambridge: Cambridge University Press), although radically contesting the thesis that forms are eternal, and emphasising the tensions in Aristotle's explanations, had in any case to recognise that genera including living species were definitively eternal. See p. 131: 'a. A number of passages in the central books of the *Metaphysics* argue that the form does not come to be. b. Three passages (one each from *De anima*, *De generatione animalium*, and *De generatione et corruptione*) say something about reproduction and being eternal – although just what it is they say is by no means clear. My thesis is that this evidence, when properly understood, will support the claim that

there is an eternal generation of organisms which are one in form and that, as a consequence of this, kinds including species, are eternal. The evidence does not, however, support the claim that Aristotelian forms are eternal.'

15. On this issue see the classic D. M. Balme (1962) '"Genos" and "Eidos" in Aristotle's Biology', *The Classical Quarterly*, *New Series*, vol. 12, n. 1, 81–98, especially pp. 84 ff.; on the differences between the treatises, in particular between *History of Animals* and *Parts of Animals*, see M. Vegetti (2007) 'Ontologia e metodo. La critica aristotelica alla dicotomia in *De partibus animalium I 22–4* in M. Vegetti *Dialoghi con gli antichi*, S. Gastaldi *et al.* (eds) (Sankt Augustin: Academia Verlag), especially pp. 134, 139 ff.
16. See for example Aristotle *History of Animals*, trans. A. L. Peck (Cambridge Mass. and London: Harvard University Press, 1970), books IV-VI, V, 1, 539a-b; and *History of Animals*, trans. D. M. Balme (Cambridge Mass. and London: Harvard University Press, 1991), books VII–X, VII, 6, 585b; *Generation of Animals*, cit., I, 17, 721b, 724a.
17. Aristotle *Generation of Animals*, cit., I, 1, 715b 12–5; on crosses between different species, and their barrenness, see also II, 7, 745b ff.
18. Aristotle *Generation of Animals*, cit., II, 1, 731b 25 ff.
19. Aristotle *On the Soul*, cit., II, 4, 415a 27 ff.
20. See in this regard M. Vegetti (1996), *I fondamenti teorici della biologia aristotelica nel «De partibus animalium»* in Aristotele *Opere biologiche*, 2nd edition, (eds) D. Lanza and M. Vegetti (Torino: UTET), especially p. 491. The thesis put forward by Balme claiming that Aristotelian biology is not essentialist is well-known, see especially D. M. Balme (1987) 'Aristotle's Biology Was Not Essentialist' in A. Gotthelf and J. G. Lennox (eds) *Philosophical Issues in Aristotle's Biology* (Cambridge: Cambridge University Press); for a riposte to this interpretation, see G. E. R. Lloyd (1991) 'Aristotle's zoology and his metaphysics: the status questionis. A critical review of some recent theories' in G. E. R. Lloyd *Methods and Problems in Greek Science* (Cambridge: Cambridge University Press), especially pp. 380 ff.
21. See for example Plato *Sophist*, 265c–e; on this type of division, see Plato *Statesman*, 263c ff.
22. See Plato *Timaeus*, trans. R. G. Bury (Cambridge Mass. and London: Harvard University Press, 1966), 39e ff.
23. Plato *Timaeus*, cit., 91d–92c.
24. See for example Aristotle *On Coming-To-Be and Passing-Away*, cit., II, 10, 336b 25ff.: 'As has already been remarked, coming-to-be and passing-away will take place continuously, and will never fail owing to the cause which we have given. This has come about with good reason. For nature, as we maintain, always and in all things strives after the better; and "being" (we have stated elsewhere the different meanings of "being") is better than "not-being", but it is impossible that "being" can be present in all things, because they are too far away from the "original source". God, therefore, following the course which still remained open, perfected the universe by making coming-to-be a perpetual process; for in this way 'being' would acquire the greatest possible coherence, because the continual coming-to-be of coming-to-be is the nearest approach to eternal being.' Recently, Matthen has brought to light the parallelism between the eternity of the universe and the eternity of the kinds of living beings. See M. Matthen (2009) 'Teleology in living

things' in G. Anagnostopoulos (ed.) *A Companion to Aristotle* (Malden and Oxford: Wiley-Blackwell), especially pp. 344–5. Although I agree partially with Sedley's interpretation of the central role of teleology in Aristotle on the cosmic and biological levels, and on the 'eternal' nature attributed to species, I have a different vision of the continuity between Plato and Aristotle; see D. Sedley (2007) *Creationism and Its Critics in Antiquity* (Berkeley, Los Angels and London: University of California Press) chapter 4, especially pp. 179 ff., and 194 ff.

25. See Aristotle *On the Soul*, cit., III, 12, 434a 5 ff.
26. See Aristotle *On the Soul*, cit., III, 12, 434a 25 ff.
27. See for example also Aristotle *Parts of Animals*, cit., II, 7, 652b 7–8: 'The brain is present in order to preserve the animal organism as a whole.'
28. Aristotle *On Sense and Sensible Objects* in *Parva Naturalia*, trans. W. S. Hett (Cambridge Mass. and London: Harvard University Press, 1964), 1, 436b 18 ff.
29. See Aristotle *Parts of Animals*, cit., IV, 5, 679a; on the strictly psycho-physiological elements of the analysis of emotions, see also III, 4, 667a 15 ff.; II, 4, 650b 26 ff.; IV, 692a 20 ff.; *Movement of Animals*, trans. E. S. Forster (Cambridge Mass. and London: Harvard University Press, 1968), 7, 701b.
30. Aristotle *Parts of Animals*, cit., IV, 2, 677a.
31. Aristotle *Parts of Animals*, cit., I, 1, 642a 11–3.
32. Aristotle *Parts of Animals*, cit., I, 5, 645b 14 ff.
33. Aristotle *Parts of Animals*, cit., IV, 6, 682b–683a.
34. See for example Aristotle *Parts of Animals*, cit., II, 16, 659b–650a: 'This double function of the human lips, to facilitate speech as well as to protect the teeth, may be compared with that of the human tongue, which is unlike that of any other animal, and is used by Nature for two functions (a device of hers we have often noted), (a) to perceive the various tastes, and (b) to be the means of speech'; on the proboscis, see also II, 16, 658b–659a; on the dual function of the tongue, and on the breathing of air, see also *On the Soul*, cit., II, 8, 420b 15 ff.
35. Aristotle *Parts of Animals*, cit., III, 7, 670b.
36. Aristotle *Progression of Animals*, trans. E. S. Forster (Cambridge Mass. and London: Harvard University Press, 1968), 2, 704b.
37. Aristotle *Progression of Animals*, cit., 8, 708a.
38. Aristotle *Progression of Animals*, cit., 12, 711a.
39. Aristotle *Parts of Animals*, cit., IV, 12, 694a–694b.
40. This is an argument that recurs frequently. See for example also Aristotle *Parts of Animals*, cit., II, 9, 654b: 'An isolated bone could never discharge the function for which all bones exist; for, being discontinuous and disconnected from the rest, it could never serve as the means either for bending or for straightening a limb; but worse than that, it would be a source of harm, like a thorn or an arrow sticking in the flesh'; III, 1, 662a 31ff.: 'Biting and carnivorous fishes have mouths of this sort; in the non-carnivorous ones it is on a tapering snout, and this suits their habits, whereas a gaping mouth would be useless.'
41. Aristotle *Parts of Animals*, cit., IV, 10, 687a 8 ff.
42. On the perfect arrangement of parts and the accomplishment 'out of given conditions', 'of that which is the better', see also Aristotle *Parts of Animals*,

II, 11–4; on 'mode of life', see for example III, 1, 662b: 'Every bird has a beak which is serviceable for its particular mode of life. The woodpeckers, for instance, have a strong, hard beak; so have crows, and other birds closely related to them; small birds, on the other hand, have a finely constructed beak, for picking up seeds and catching minute animals.'

43. Aristotle *On Respiration* in *Parva Naturalia*, trans. W. S. Hett (Cambridge Mass. and London: Harvard University Press, 1964), 14, 477a–b; see also immediately before this: 'Each class has its sphere of life in the region appropriate to its preponderating element'; on migrations, hibernations, and so on see Aristotle *History of Animals*, cit., VIII, 12–7.
44. Aristotle *Progression of Animals*, cit., 10, 710a.
45. Aristotle *Parts of Animals*, cit., II, 7, 652a.
46. Aristotle *Parts of Animals*, cit., III, 2, 663a.
47. Aristotle *Parts of Animals*, cit., III, 2, 662b 30 ff.
48. Aristotle *Parts of Animals*, cit., III, 2, 662b 30 ff.
49. Aristotle *Parts of Animals*, cit., IV, 13, 696b 24ff.; see in this regard also Aristotle *History of Animals*, cit., VIII, 2, 591b 23 ff.: 'Now the other fishes catch the smaller ones straight ahead in their mouths, when in their natural swimming attitude. But the selachians and dolphins and all cetaceans turn over on their backs to take them; for their mouth is below. Hence the smaller fishes tend more to survive: otherwise it is thought there would be few altogether, for the dolphin's quickness and voracity seem to be astonishing.' See here also, mentioned just previously, the case of the mullet, 591a 28 ff.: 'Their spawn is not eaten by any creature, hence they occur in large numbers; but when grown, then they are eaten by the other fishes and especially by the archarnas.'
50. Plato *Protagoras*, trans. W. R. M. Lamb (Cambridge Mass. and London: Harvard University Press, 1977), II, 320d–321d.
51. Aristotle *Parts of Animals*, cit., IV, 10, 687a–b.
52. Aristotle *History of Animals*, cit., VIII, 1, 588b 4ff.; see also for example *Parts of Animals*, cit., IV, 5, 681a 10ff.: 'Nature passes in a continuous gradation from lifeless things to animals, and on the way there are living things which are not actually animals, with the result that one class is so close to the next that the difference seems infinitesimal.'
53. Aristotle *Parts of Animals*, cit., II, 10, 656a 7ff.; similarly, see Aristotle *History of Animals*, cit., I, 15, 494a–494b; on the position of animals and man on the 'scale of creation', see also Aristotle *On Respiration*, XIII, 477a 11ff.
54. See for example Aristotle *Progression of Animals*, cit., 5, 706b 2ff: 'Now since there are three regions, the superior, the middle, and the inferior, bipeds have their superior part in a position corresponding to the superior region of the universe, polypods and footless animals in a position corresponding to the middle region, and plants in a position corresponding to the inferior region. […] [B]ipeds have it [the superior part] in a position corresponding to the superior region because they are erect, especially man, the biped most in accordance with nature.'
55. See for example Aristotle *Parts of Animals*, cit., IV, 10, 686a 24ff.: 'Man is the only animal that stands upright, and thus is because his nature and essence is divine. […] Compared with man, all the other animals are dwarf-like. […] [A] ll animals are less intelligent than man.' See for example G. E. R. Lloyd 'The

invention of nature' in G. E. R. Lloyd *Methods and Problems in Greek Science*, cit., especially p. 428 f.: 'Throughout Aristotle's zoology the human species is the yardstick by which other animals are measured. In humans alone, indeed, the upper parts are directed towards the upper parts of universe. In humans *alone*, he is prepared to say (*De Partibus Animalium* 656a10ff.), the *natural* parts are *according* to nature. What is normal of natural in the animal kingdom is evidently no matter, here, of counting heads or species, but arrived at by reflection on the principles instantiated in the animals assumed to be *superior*, or more particularly in the species assumed to be supreme, namely humans.'

56. Aristotle *Parts of Animals*, cit., IV, 10, 687a 7ff.
57. M. Vegetti (1996) 'I fondamenti teorici della biologia aristotelica nel *De partibus animalium*', cit., p. 532 f, own translation.
58. Aristotle *Parts of Animals*, cit., IV, 6, 682–b 6–7.
59. Aristotle *Generation of Animals*, cit., III, 4, 755a 25ff.
60. Aristotle *Generation of Animals*, cit., III, 4, 755a 25ff.
61. Aristotle *Parts of Animals*, cit., II, 9, 658a.
62. Aristotle *Parts of Animals*, cit., III, 1, 661b 1ff.
63. Aristotle *Parts of Animals*, cit., III, 1, 661b 1ff.
64. Aristotle *Parts of Animals*, cit., III, 1, 661b 27ff.
65. Aristotle *Parts of Animals*, cit., III, 2, 663b 12ff.
66. See also Aristotle *Parts of Animals*, cit., IV, 8, 684a 28ff.: 'Nature always assigns an instrument, either exclusively or in a better form, to those that can use it. This holds good for tusks, teeth, horns, spurs and all such parts which serve animals for assistance and offence.'
67. Aristotle *Parts of Animals*, cit., IV, 10, 687a 8 ff.
68. Aristotle returns constantly to this argument: see for instance *Parts of Animals*, cit., IV, 11, 691b: 'Of course this sideways motion is useful to animals which possess grinder-teeth; but it is of no use to those which lack grinders, and so not one of them has it. Nature never makes or does anything that is superfluous'; see also 684a, 675a. He argues in the same way also in relation to parts that would be clearly harmful in for example II, 654b: 'An isolated bone could never discharge the function for which all bones exist; for, being discontinuous and disconnected from the rest, it could never serve as the means either for bending or for straightening a limb; but worse that that, it would be a source of harm, like a thorn or an arrow sticking in the flesh'; see also 693a, and of course in the case of the spurs of birds cited above; see also *Generation of Animals*, cit., for example II, 4 739b: 'We find the situation reversed in the theory that the woman as well as the man emits semen [...]. Such a performance is superfluous, and Nature does nothing which is superfluous'; 5, 741b: on different genders: 'if it could, the existence of the male would have no purpose, and Nature does nothing which lacks purpose.'
69. Aristotle *Parts of Animals*, cit., III, 2, 664a.
70. That nature 'remedies' its own errors emerges shortly afterwards in *Parts of Animals*, cit., III, 3, 665a 7 ff.: 'This will suffice to show why some animals have an epiglottis and some not; how Nature has contrived it so as to remedy the unsatisfactory position of the windpipe in front of the oesophagus.'
71. Aristotle *On the Soul*, cit., III, 1, 425a 9–11.
72. Aristotle *History of Animals*, cit., IV, 8, 533a 1ff.; see also, I, 9, 491b.

73. There are multiple cases: see among the many, for example, Aristotle, *Parts of Animals*, cit., III, 8, 671a 15ff.: 'Exception to this are the Tortoises: though scaly-plated they have a bladder. In them the natural formation has simply been stunted'; *History of Animals*, cit., VIII, 2, 589b 29ff.: 'The nature of all these seems as thought it has been distorted, just as some males become feminine in appearance and some females masculine-looking'; *Progression of Animals*, cit., 19, 714b 7ff.: 'A question may be raised as to what is the movement of testaceans [...]. Must all this class be regarded as maimed and as moving in the same way as an animal with feet if one were to cut off its legs, or as analogous to the seal and bat, which are quadrupeds but malformed?'

2 For and Against Aristotle

1. M. W. F. Stone (2002) 'Aristotelian and Scholasticism in Early Modern Philosophy' in S. Nadler (ed.) *A Companion to Early Modern Philosophy* (Oxford: Blackwell), p. 9.
2. L. Bianchi (1997) 'L'acculturazione filosofica dell'Occidente' in L. Bianchi (ed.) *La filosofia nelle Università. Secoli XIII-XIV* (Firenze: La Nuova Italia), p. 18f.
3. L. Bianchi (2002) 'Le scienze nel Quattrocento. La continuità della scienza scolastica, gli apporti della filologia, i nuovi ideali di sapere' in C. Vasoli *Le filosofie del rinascimento*, ed P. C. Pissavino (Milano: Bruno Mondadori), p. 94.
4. See C. B. Schmitt (1975) 'Philosophy and Science in Sixteenth-Century Universities: Some Preliminary Comments' in J. E. Murdoch and E. D. Sylla (eds) *The Cultural Context of Medieval Learning* (Dordrecht-Boston: Reidel), p. 489: 'It must be stressed that there was a very marked continuity in university philosophy and science teaching during the period just mentioned, ca. 1350–1650. [...] Aristotelianism maintained its hold for so long. Despite flaws – which were evident to many from antiquity onwards – it still covered such a wide range that no other system could challenge its cultural hegemony'; more generally, see C. B. Schmitt (1973) 'Towards a Reassessment of Renaissance Aristotelianism', *History of Science*, XI, 159–93, p. 163: 'Aristotelianism did not end with Copernicus, nor even with Galileo and Bacon. In fact, it thrived throughout the sixteenth century, as it never had before, and was still in full bloom for most of the seventeenth century.' For a more up-to-date view on the persistence of late 'Scholasticism' still focussing on final causes within the ambit of physics, which extends beyond the middle of the eighteenth century, see for example M. J. Osler (2001) 'Whose Ends? Teleology in Early Modern Natural Philosophy', *Osiris*, 2nd Series, vol. 16, Science in Theistic Contexts: Cognitive Dimensions, 151–68, in particular pp. 153 ff.
5. On the translation by Scotus, see for example A. M. I. van Oppenray (1999) 'Michael Scot's Arabic-Latin Translation of Aristotle's *Books on Animals*' in C. Steel *et al.* (eds) *Aristotle's Animals in the Middle Ages and Renaissance* (Leuven: Leuven University Press), pp. 31 ff.; for a more comprehensive view, see for example J. Brams (2003) *La riscoperta di Aristotele in Occidente* (Milano: Jaca Book), especially pp. 76–9, which emphasizes the success of the translation

by Scotus of the treatises on living bodies in relation to the subsequent translation by Moerbeke; see also B. G. Dod (1982) 'Aristoteles latinus' in N. Kretzmann *et al.* (eds) *The Cambridge History of Later Medieval Philosophy* (Cambridge: Cambridge University Press), especially pp. 47–52, 58 f., 62–4; see also K. F. Kitchell Jr. and I. M. Resnick (1999) 'Introduction' in Albertus Magnus *On Animals. A medieval «Summa Zoologica»* (Baltimore and London: John Hopkins University Press), vol. I., p. 39, which backdates the drafting to 1210.

6. On the inclusion of the treatises on living bodies in the statutes of faculties of arts in the twelfth, thirteenth and fourteenth centuries, see for example S. Perfetti (2004) 'I libri *De animalibus* di Aristotele e i saperi sugli animali nel XIII secolo', and G. Federici Vescovini (2004) 'La tradizione dei *Parva Naturalia* nell'insegnamento universitario medievale (secoli XIII e XIV)', both in C. Crisciani *et al.* (eds) *Parva Naturalia. Saperi medievali, natura e vita* (Pisa and Roma: Istituti Editoriali e Poligrafici Internazionali).
7. On the gradualness of the transition in the thirteenth century, also analysed from an iconographic perspective, see for example M. Camille (1999) 'Bestiary or Biology? Aristotle's Animals in Oxford, Merton College, MS 271' in C. G. Steel *et al.* (eds) *Aristotle's Animals in the Middle Ages and Renaissance*, cit.
8. See S. Perfetti (2004) 'I libri *De animalibus* di Aristotele e i saperi sugli animali nel XIII secolo', cit., pp. 145 ff.
9. See in this sense K. F. Kitchell Jr. and I. Michael Resnick (1999) 'Introduction', cit., especially pp. 22–30.
10. See K. F. Kitchell Jr. and I. M. Resnick (1999) 'Introduction', cit., p. 18; on the chronology of the composition of the text, see pp. 34 ff.
11. Albertus Magnus *On Animals*, cit., b. 26, cap. XXXVI, p. 1764.
12. On the model adopted by Thomas da Cantimpré and its reprisal in Albertus, see S. Perfetti (2004) 'I libri *De animalibus* di Aristotele e i saperi sugli animali nel XIII secolo', cit., pp. 164–6.
13. See for example L. Bianchi (1997) 'La struttura del cosmo' in L. Bianchi (ed.) *La filosofia nelle Università*, cit., p. 279 f.
14. See Albertus Magnus *On Animals*, cit., b. 1, cap. I: 'Here begins the first book on animals, which is on the members of Animals and especially of the most perfect animal, which is the human'; see also b. 21, cap. I: 'On the Highest Perfection of Animal Which Is the Human'.
15. See for example Aristotle *Parts of Animals*, IV, 10, 686a 24ff.; *History of Animals*, I, 15, 494a 26ff.; *Progression of Animals*, 5, 706b 2ff; *On Respiration*, XIII, 477a 11ff.; *On the Soul*, cit., II, 3; II, 9, 421a 15ff.
16. Albertus Magnus *On Animals*, cit., b. 21, tr. 1, cap. I, 6, pp. 1412–13. For a detailed analysis of the substantial reutilizing of Aristotle's concept, and the particular reinterpretations and modifications brought to them by Albertus Magnus, see for example G. Guldentops (2000) 'Albert the Great's Zoological Anthropocentrism', *Micrologus*, VIII, 1, 217–35, especially, 222–9, 234.
17. Aristotle *Parts of Animals*, cit., II, 10, 656a 7ff.
18. Albertus Magnus *On Animals*, cit., b. 11, tr. 1, cap. I, 23, p. 866. On the marginalization of randomness, faithfully reproduced from *Physics*, and on the complementary centrality of final causes, reiterated in *De animalibus*, see W. A. Wallace (1980) 'Albertus Magnus on Suppositional Necessity in the Natural Sciences' in J. A. Weisheipl (ed.) *Albertus Magnus and the Sciences*

(Toronto: Pontifical Institute of Mediaeval Studies), especially pp. 14–116, 120ff.
19. Albertus Magnus *On Animals*, cit., b. 11, tr. 1, cap. I, 24, p. 866.
20. See also in this sense B. M. Ashley (1980) 'St. Albert and the Nature of Natural Science' in J. A. Weisheipl (ed.) *Albertus Magnus and the Sciences*, cit., p. 94.
21. See for example Albertus Magnus *On Animals*, cit., b 16, tr. 2, cap. V, 121, p. 1221 f.
22. See for example Albertus Magnus *On Animals*, cit., b. 12, tr. 3, cap. VI, 211, p. 976.
23. See for example Albertus Magnus *On Animals*, cit., b. 15, tr. 1, cap. III, 13, p. 1090.
24. See for example Albertus Magnus *On Animals*, cit., b. 21, tr. 1, cap. VII, 44, p. 1434.
25. See for example Albertus Magnus *On Animals*, cit., b. 13, tr. 3, cap. VI, 212, p. 976.
26. Albertus Magnus *On Animals*, cit., b. 14, tr. 1, cap. XI, 31, p. 1058.
27. See Aristotle *Parts of Animals*, cit., IV, 10, 687b 7ff.
28. Albertus Magnus *On Animals*, cit., b. 14, tr. 1, cap. 11, 32, pp. 1059.
29. Albertus Magnus *On Animals*, cit., b. 14, tr. 1, cap. 11, 37, p. 1061. On the 'wisdom' of nature in relation to fish eggs, see also b. 17, tr. 1, cap. 4, 29, p. 1251: 'Thus a wise nature made many eggs in fish so that she might recover by sheer number what is corrupted in them'; Albertus shows explicitly that he shares this concept of the wisdom and intelligence of nature; see also b. 16, tr. 1, cap. VII, 42–3, p. 1176 f.
30. Albertus Magnus *On Animals*, cit., b. 17, tr. 2, cap. 2, 55, p. 1265.
31. Albertus Magnus *On Animals*, cit., b 15, tr. 1, cap. 1, 4, p. 1086; see in the same sense also b. 15, tr. 1, cap. VIII, 42, p. 1103.
32. Albertus Magnus *On Animals*, cit., b. 22, tr. 1, cap. I, 1, p. 1440.
33. See for example the classic E. Grant (1971) *Physical Science in the Middle Ages* (New York: Wiley), especially pp. 24 ff., a p. 27 f. Grant recalls: 'Among the propositions derived from Averroes we find not only the eternity of the world (article 87), but also the claims *that there was no first man, nor will there be a last; on the contrary there always was and always will be generation of man from man* (article 9)'; for a comprehensive and up-to-date view of the reiterated condemnations of Aristotelian texts, see L. Bianchi (1997) 'Le università e il "decollo scientifico" dell'Occidente' in L. Bianchi (ed.) *La filosofia nelle università*, cit., pp. 36–41.
34. See E. Randi (1990) 'L'aristotelismo dei teologi' in L. Bianchi and E. Randi (eds) *Le verità dissonanti* (Roma and Bari: Laterza), p. 57 f.
35. On the new fifteenth-century translations of *Historia animalium*, *De partibus animalium* and *De generatione animalium* by Teodoro Gaza, completed around 1454 and published in Venice in 1476 (*De animalibus*), see for example S. Perfetti (2000) *Aristotle's zoology and its Renaissance commentators (1521—1601)* (Leuven: Leuven University Press), pp. 12 ff.; on the basic faithfulness of Gaza to Aristotle, see for example J. Monfasani (2006) 'Aristotle as Scribe of Nature: The Title-Page of MS Vat. Lat. 2094', *Journal of the Warburg and Courtauld Institutes*, n. 69, 193—205, especially pp. 200 ff. On the extraordinary success of *Historia* in the history of Western zoology, see also M. Vegetti (2004) 'Biologia' in E. Berti (ed.) *Guida ad Aristotele* (Roma and Bari: Laterza), especially p. 198.

36. On the positive reception of Pliny's *Historia* during the Renaissance, see for example L. Bianchi (2002) *Le scienze nel Quattrocento*, cit., pp. 103—6.
37. For an overview of the first generation of Renaissance exegeses of *De partibus animalium*, see for example S. Perfetti (1999) *Three Different Ways of Interpreting Aristotle's 'De partibus animalium': Pietro Pomponazzi, Niccolò Leonico Tomeo and Agostino Nifo* in C. G. Steel *et al.* (eds) *Aristotle's Animals in the Middle Ages and Renaissance*, cit., pp. 298 ff.
38. See for example L. Bianchi (2003) '*Rusticus mendax*: Marcantonio Zimara e la fortuna di Alberto Magno nel Rinascimento italiano' in L. Bianchi *Studi sull'aristotelismo del Rinascimento* (Padova: il Poligrafo), especially pp. 218 ff., which insists on a revision of the empirical observations proposed by Albertus.
39. More precisely, N. Copernicus *De revolutionibus orbium cœlestium*, published in 1543 but previewed in 1540 by Retico summary, *De libris revolutionum narratio prima*, and from an extract from the book before 1542, *De lateribus et angulis triangulorum*.
40. See for example E. Grant (1984) *In Defense of the Earth's Centrality and Immobility: Scholastic Reaction to Copernicanism in the Seventeenth Century* (Philadelphia: The American Philosophical Society), pp. 5–8, which concerning Copernicanism is distinguished from the start by its conciliatoriness, the 'accommodation' proposed by Cesalpino in 1571, aimed at maintaining the earth at the centre of the universe, making it subject to a circular movement impressed on it from an external source.
41. See A. Capecci (1991) 'Meccanicismo e finalismo nella biologia di Andrea Cesalpino' in L. Conti (ed.) *Medicina e biologia nella rivoluzione scientifica* (Assisi: Porziuncola), p. 42.
42. See P. R. Sloan (1972) 'John Locke, John Ray, and the Problem of the Natural System', *Journal of the History of Biology*, vol. 5, n. 1, 1–53, pp. 9 ff. and p. 13: 'Cesalpino had provided in the *De plantis* the theoretical basis that taxonomic biology required for its separation from the utilitarian concern of the herbalists and apothecaries. The acceptance of the principle of the subordination of characters meant that a logical distribution of plants into genera and species in accord with the principles of traditional Scholastic logic could now be made. And, more importantly, the theoretical justification now supplied by Cesalpino for assuming that the basis for logical division selected for this subordination, in this case the reproductive parts of the plant, were in fact "essential" in the full Aristotelian meaning of the term, meant that a logically consistent classification could now also claim to yield demonstrative knowledge of essences, the goal of Aristotelian science, thereby warranting the claim to the title of a "natural" classification.'
43. C. Linnaeus *Philosophia botanica* (1751), trans. S. Freer (Oxford and New York: Oxford University Press, 2003), a. 51: 'Cesalpinus est Fructista et primus verus Systematicus'; see also G. Barsanti (1992) *La scala, la mappa, l'albero. Immagini e classificazioni della natura fra Sei e Settecento* (Firenze: Sansoni), p. 166.
44. See on this issue A. Capecci (1991) 'Meccanicismo e finalismo nella biologia di Andrea Cesalpino', cit., pp. 55 ff.
45. Galileo Galilei *Dialogue Concerning the Two Chief World Systems – Ptolemaic & Copernican*, trans. S. Drake, foreword A. Einstein, 2nd edn (Berkeley and Los Angeles: University of California Press, 1967), p. 11 (E.N. p. 35).

46. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 397 (E.N. p. 423).
47. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 203 (E.N. p. 229). See in the same sense Galileo Galilei *Two New Sciences*, trans. S. Drake (Madison: The University of Wisconsin Press, 1974), pp. 12–3 (E.N. 50–2).
48. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 14 (E.N. p. 38), see also p. 230 (E.N. p. 256).
49. Aristotle *Metaphysics*, cit., II, 3, 995a 14–7.
50. See Aristotle *Physics*, cit., II, 2, 193b 22–194a12; see also II, 7, 198a 14–21; III, 5, 204a 34 ff.; see also Aristotle *On the Heavens*, cit., III, 1, 299a 10 ff.; on this differentiation, see W. Leszl (1975) *Il 'De ideis' di Aristotele e la teoria platonica delle idee* (Firenze: Olschki), pp. 325–7.
51. On the geometrization of astronomy and circumscription of the sphere of 'applied mathematics', see W. Leszl, *Aristotele. Le matematiche e la fisica*, unpublished manuscript.
52. See for example Aristotle *Metaphysics*, cit., I, 9, 991a 32–4.
53. On Aristotle's critique of the theory of ideas, see W. Leszl (1975) *Il 'De ideis' di Aristotele e la teoria platonica delle idee*, cit., especially pp. 279–304.
54. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 163 f. (E.N. p. 189 f.).
55. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 35 (E.N. pp. 59 f.), see also ivi pp. 197–203 (E.N. 224–9). Slightly more level-headed, Sagrado in Galileo Galilei *Two New Sciences*, cit., p. 132 f. (E.N. 175), given that in any case here Simplicio recognized that 'if I were to begin my studies over again, I should try to follow the advice of Plato and commence from mathematics' p. 93 (E.N. 135).
56. E. Cassirer (1964) *The Individual and the Cosmos in Renaissance Philosophy*, trans. M. Domandi (New York and Evanston: Harper & Row), p. 52; he continues by saying that it is about (p. 54) 'that study of nature that leads from Cusanus through Leonardo to Galileo and Kepler'; on the central role of mathematics especially for Leonardo and on his influence on Galileo, see also pp. 151–7, 161—4; on the relationship with Aristotelian physics see pp. 174 ff. For a comprehensive overview of the comparison between Plato and Aristotle in the fifteenth century, see the classic E. Garin (1994) 'Platonismo e aristotelismo dalla *comparatio* alla *concordia*', in E. Garin *Il ritorno dei filosofi antichi* (Napoli: Bibliopolis), pp. 79–95.
57. See in this sense E. Berti (1993) *Profilo di Aristotele*, 2nd edn (Roma: Studium), p. 117.
58. On the Pythagorism and Platonism of Kepler and Galileo, and on their different articulations, see M. Bucciantini (2003) *Galileo e Keplero. Filosofia, cosmologia e teologia nell'Età della Controriforma* (Torino: Einaudi), pp. 73, 108, 186–7, pp. 295–306, 314 ff. H. Butterfield in the classic (1958) *The Origins of Modern Science* (London: Bell & Sons), p. 90, emphasizes 'that, in both Kepler and Galileo, Patonic and Pythagorean influences played an important role in the story'. L. Geymonat (1969) *Galileo Galilei*, 2nd edn (Torino: Einaudi), pp. 45–7, 131–8, 160–1, 166, 222–34, 245–53, stresses the counter-position of Kepler's Neo-Platonism with Galileo's relative Platonism, interpreted as 'a tool of logic (in the Aristotelian sense of the term)'.

59. Plato *Timaeus*, cit., 56c.
60. Plato *Timaeus*, cit., 53b.
61. Plato *Timaeus*, cit., 69b, see also 36a ff.
62. See for example the classic W. D. Ross (1951) *Plato's Theory of Ideas* (Oxford: Clarendon Press), p. 126, who highlights the passage of the construction of the four elements through 'combinations of triangular planes, and the provision, so curiously prophetic of modern physics, which it makes for transmutation of elements by rearrangement of the triangles that constitute them.' On the relationship between the astronomy presented in *The Republic* and the mathematization of *Timaeus*, as well as Kepler's harmony, see F. F. Repellini (2003) 'Astronomia e armonica' in M. Vegetti (ed.) *Platone. La Repubblica* (Napoli: Bibliopolis), vol. V, especially pp. 556–63. On the relationship between science and mathematics outlined by Plato and restated during the Renaissance, see also the overview of A. C. Crombie (1986) 'Experimental Science and the Rational Artist in Early Modern Europe', *Daedalus*, 115 (3), 49–74, especially pp. 51ff.
63. Galileo Galilei *The Assayer*, in *Discoveries and Opinions of Galileo*, ed. and trans. S. Drake (New York: Doubleday, 1957), p. 237 f.
64. Letter from Galileo to Fortunato Liceti, 11 January 1641, in Galileo Galileo *Le Opere di Galileo Galilei* (Firenze: Barbera, 1937), vol. XVIII, p. 295.
65. See for example Galileo Galilei, *Dialogue Concerning the Two Chief World Systems*, cit., pp. 20–1 (E.N. 44–5); Galileo Galilei *Two New Sciences*, cit., pp. 232–3 (E.N. pp. 283–284).
66. A. Koyré (1973) 'Aristotélisme et platonisme dans la philosophie du Moyen Age', in A. Koyré *Études d'histoire de la pensée scientifique* (Paris: Gallimard), p. 31.
67. See A. Koyré (1956) 'Influence of Philosophical Trends on the Foundation of Scientific Theories', cit., p. 127: 'Fifteen years ago, I called the revolution of the 17th century "la revanche de Platon." But, as a matter of fact, it was an alliance, an alliance with Democritus, that decided the old strife and enabled Plato to defeat Aristotle.' See on the same theme also A. Koyré (1978) *Galileo Studies*, trans. J. Mepham (Stanford Terrace: Harvester Press), pp. 157 ff.; and especially with regard to the discussions of Francesco Buonamici and Jacopo Mazzoni, see A. Koyré (1968) 'Galileo and Plato', in A. Koyré *Metaphysics and Measurement* (London: Chapman & Hall), 1968, pp. 32–43.
68. A. Koyré (1965) *Newtonian Studies* (Cambridge Mass.: Harvard University Press), pp. 7–8.
69. See for example S. Drake (1980) *Galileo* (Oxford: Oxford University Press), especially pp. 10–3, who then takes sides against the thesis of Platonic influence on Galileo: see pp. 33–7, 70–1.
70. Galileo Galilei *Two New Sciences*, cit., p. 158 f. (E.N. p. 202).
71. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 51 (E.N. p. 75).
72. On the joint presence in Galileo of various traditions of Platonism, Aristotelianism, and so on, see P. Rossi (1997) *La nascita della scienza moderna in Europa* (Roma and Bari: Laterza), p. 126. See on the contrary L. Geymonat (1969) *Galileo Galilei*, cit., especially pp. 131–8, 222 ff., who, harking back in particular to late Galileo, while recognizing as certain 'Platonic influence' (p. 134), in the end considers him 'the true perpetuator of Aristotle' because

of the priority accorded to experience (pp. 230–1), as well as the same logic that was 'integrated into mathematics' (p. 244).

73. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 32 (E.N., p. 57); see also pp. 50–1 (E.N. 75–6), pp. 55–7 (E.N. 80–1).
74. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., pp. 112–33 (E.N., pp. 138–9), especially 112f.: 'I applaud the reading and careful study of his works, and I reproach only those who give themselves up as slaves to him in such a way as to subscribe blindly to everything he says and take it as an inviolable decree without looking for any other reasons.'
75. Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 110 (E.N. p. 136). See also p. 131 (E.N. 157): 'if Aristotle were here [...]'; p. 50 (E.N., p. 75): 'I declare that we do have in our age new events and observations such that if Aristotle were now alive, I have no doubt he would change his opinion'; see also p. 320 (E.N. 348).
76. Galileo Galilei *Two New Sciences*, cit., p. 69 (E.N. p. 110).
77. See for example Galileo Galilei *Dialogue Concerning the Two Chief World Systems*, cit., p. 328 (E.N. p. 355f.): 'were it not for the existence of a superior and better sense than natural and common sense to join forces with reason, I much question whether I, too, should not have been much more recalcitrant toward the Copernican system than I have been since a clearer light than usual has illuminated me.'
78. See E. Berti (2004) 'Il metodo risolutivo degli aristotelici e la "resolutio" dei matematici' in E. Berti *Nuovi studi aristotelici* (Brescia: Morcelliana), p. 271.
79. See P. Rossi (1997) *La nascita della scienza moderna in Europa*, cit., pp. 4–8, which having synthesized the cardinal points of Aristotelian physics and demonstrated their 'greater proximity to so-called common sense' concludes: 'Modern Science was not born out of the generalization of empirical observations, but out of a analysis capable of *abstraction*, a capacity, that is, to abandon the realm of common sense, of perceptible qualities, of immediate experience. The main instrument that made possible conceptual revolution of physics was, as is well known, the *mathematization* of physics'; on the weight of Platonism and Aristotelianism on Galileo, see p. 126; see in the same sense A. Koyré (1968) 'Galileo and Plato', cit., pp. 18, 22–7. On the centrality of the reference to 'common sense' in the geocentric and geostatic concept of Aristotle and Ptolemy, see also the classic E. Grant (1971) *Physical Science in the Middle Ages*, cit., especially pp. 61–4.
80. See W. Pagel (1967) *William Harvey's Biological Ideas. Selected Aspects and Historical Background* (Basel and New York: S. Karger), p. 335.
81. More precisely *Exercitatio anatomica de motu cordis et sanguinis in animalibus*.
82. For an up to date view of the issue, see A. Capecci, *Meccanicismo e finalismo nella biologia di Andrea Cesalpino*, cit., who, having criticized the attempt to rehabilitate Cesalpino in a positivistic sense (pp. 34 ff.), emphasizes, following Pagel, how the proximity between Cesalpino and Harvey 'is due to their common adherence to Aristotle and Peripatetic tradition' (p. 40), going on to examine it more closely (pp. 55 ff.).
83. On the direct influence of Vesalius on Harvey, see for example W. Pagel (1967) *William Harvey's Biological Ideas*, cit., pp. 146 ff., 224 ff.
84. See W. Harvey *An Anatomical Disquisition on the Motion of the Heart and Blood in Animals*, in *The Works of William Harvey*, trans. R. Willis (1848) (New York and London: Johnson Reprint Corporation, 1965), p. 7.

85. W. Harvey *Anatomical Exercises on the Generation of Animals*, in *The Works of William Harvey*, cit., 'Introduction', p. 151 f. (167); see also Exercise 44, p. 332 f. (348), where the centrality of 'experimental anatomical study' is asserted over mere book culture.
86. See for example W. Harvey *An Anatomical Disquisition on the Motion*, cit., p. 29 (31): 'even in wasps, hornets and flies, I have, with the aid of a magnifying glass, and at the upper part of what is called the tail, both seen the heart pulsating myself, and shown it to many others.'
87. See W. Harvey *An Anatomical Disquisition on the Motion*, cit., pp. 13 ff. (13 ff.), 16 (16): 'If any one will perform Galen's experiment of dividing the trachea of a living dog'.
88. W. Harvey, *A Second Disquisition to John Riolan, Jun., in which Many Objections to the Circulation of the Blood Are Refuted*, in *The Works of William Harvey*, cit., p. 131 (131).
89. Harvey seems to continue to maintain also in physics an Aristotelian vision; see for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 26, p. 272 (286 f.): 'The egg consequently is a natural body endowed with animal virtues, viz. principles of motion and rest, of transmutation and conservation; it is, moreover, a body which, under favourable circumstances, has the capacity to pass into an animal form; heavy bodies indeed do not sink more naturally, nor light ones float, when they are unimpeded, than do seeds and eggs in virtue of their inherent capacity become changed into vegetables and animals. So that the seed and the egg are alike the fruit and final result of the things of which they are the beginning and efficient cause.'
90. See for example W. Pagel (1967) *William Harvey's Biological Ideas*, cit., p. 43, p. 332 f.; on the centrality and fruitfulness in Harvey of the search for the 'final cause', see for example W. Pagel (1969–1970) 'William Harvey Revisited', *History of Science*, vol. 8, 1–81, vol. 9, 1–41, especially part I (1969), pp. 3–4. On blood as a 'final cause', see E. Berti (2004) 'Harvey e Aristotele' in E. Berti *Nuovi studi aristotelici*, cit., p. 292, who refers again to Pagel: 'the heart in fact, for Harvey, is only the motoric cause of the circulation of the blood, while the blood is, as we have seen, not only the material cause, but also the formal, i.e. it contains the vital impulse, the soul, the form. In affirming the primacy of this, therefore, Harvey in a certain sense is more Aristotelian than Aristotle himself.'
91. W. Harvey *An Anatomical Disquisition on the Motion*, cit., p. 39 (41).
92. W. Harvey *An Anatomical Disquisition on the Motion*, cit., p. 82 (84).
93. W. Harvey *An Anatomical Disquisition on the Motion*, cit., pp. 72–3 (74).
94. W. Harvey *An Anatomical Disquisition on the Motion*, cit., p. 83 (85).
95. W. Harvey *An Anatomical Disquisition on the Motion*, cit., p. 75 (76).
96. See for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 53, p. 392 (409): 'we should be ready to admit with Aristotle that the heart (an organ made up of ventricles, auricles, vessels, and blood) was in truth the principle and primogenate part of the body, its own prime and essential element having been the blood, both in the order of nature and of genetic production.'
97. W. Harvey *An Anatomical Disquisition on the Motion*, cit., pp. 45–6 (48).
98. W. Harvey *Anatomical Exercises on the Generation*, cit., Introduction, p. 166 f. (180); see also Exercise 48 p. 350 (366). For a concise overview of the relationship with Fabricius, see for example A. Cunningham (2006) 'Fabrici and Harvey', in G. Ongaro *et al* (eds) *Harvey e Padova* (Treviso: Antilia).

99. See for example W. Harvey *An Anatomical Disquisition on the Motion*, cit., pp. 28 (30), 74 (75).
100. On the definition of 'epigenesis', see for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 45, p. 334 (350): 'The structure of these animals commences from some one part as its nucleus and origin, by the instrumentality of which the rest of the limbs are joined on, and this we say takes place by the method of epigenesis, namely, by degrees, part after part; and this is, in preference to the other mode, generation properly called.' On the modern meaning attributed by Harvey to the term 'Epigenesis', an alternative to the preformist concept, see for example W. Pagel (1967) *William Harvey's Biological Ideas*, cit., pp. 233 ff.
101. On links with Albertus Magnus, see for example W Pagel (1969–70) 'William Harvey Revisited', cit., part II (1970), pp. 22–6, 33–4.
102. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 14, p. 226 (239).
103. In this version it is repeated for example in W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 39, p. 312 (328).
104. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 41, p. 319 (335).
105. See for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 55, p. 413 (431): 'Thus far have we followed Aristotle['s] [...] the perfection of nature, which in her works does nothing in vain and has no short-comings, but still does that in the best manner which was best to be done. Hence in generation [...] in circumstances where she acts freely and by election; for sometimes she works under compulsion, as it were, and beside her purpose, as when through deficiency or superabundance of material, or through some defect in her instruments, or is hindered or her ends by external injuries.'
106. W. Harvey *Anatomical Exercises on the Generation*, cit., Introduction, p. 164 (178); on the predisposed plan, efficient from the start in producing the chick, see also, Exercise 50, p. 366 (381).
107. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 11, p. 207 (220).
108. See for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 50, pp. 369–70 (384–85).
109. On the circularity of species, see also W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 13 and 14, p. 225 f. (239), especially where he writes: 'The eternity of things is connected with the reciprocal interchange of generation and decay; and as the sun, now in the east and then in the west, completes the measure of time by his ceaseless revolutions, so are the fleeting things of mortal existence made eternal through incessant change, and kinds and species are perpetuated though individuals die.' He insists on the 'circular pattern which ensures eternal duration of the species'; see W. Pagel (1967) *William Harvey's Biological Ideas*, cit., p. 274 f.; see also pp. 261 ff., 333.
110. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 28, p. 286 (301); see also Exercise 26, p. 271 (286): the egg is 'the mid-passage or transition stage between parents and offspring, between those who are, or were, and those who are about to be; it is the hinge and pivot upon which

the whole generation of the bird revolves. The egg is the terminus from which all fowls, male and female, have sprung, and to which all their lives tend, – it is the result which nature has proposed to herself in their being. And thus it comes that individuals in procreating their like for the sake of their species, endure for ever. The egg, I say, is a period or portion of this eternity'.

111. See for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 38, p. 308 (324); Exercise 45, pp. 333–37 (349–52).
112. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 28, p. 284 f. (299–300).
113. See for example W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 55, p. 414 (432): 'Hence it follows, in fine, that the primogenate part must be of such a nature as to contain both the beginning and the end, and be that for whose sake all the rest is made, namely, the living principle, or soul, and that which is the potential and genital cause of this, the hearth, or in our view the blood, which we regard as the prime seat of the soul, as the source and perennial centre of life, as the generative heat, and indeed as the inherent heat; in a word, the heart is the first efficient of the whole of the instrumental parts that are produced for the ends of the soul, and used by it as instruments. The heart, according to Aristotle, I say, is that for which all the parts of animals are made, and it is at the same time that which is at once the origin and fashioner of them all.'
114. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 38, p. 309 (324).
115. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 47, p. 347 (363).
116. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 30, p. 292 (307).
117. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 55, p. 410 (428).
118. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 55, p. 411 (429).
119. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 58, p. 441 (460): 'And so it happens, in Aristotle's opinion, that the first and most essential parts are formed out of the purer and thinner portion of the colliquament, and are increased by the remaining more indifferent portion after it has undergone elaboration by a new digestion in the stomach. In the same way are the other less important parts developed and maintained. Thus as nature, like a fond and indulgent mother, been sedulous rather to provide superfluity, than to suffer any scarcity of things necessary.' See in the same sense Hieronymus Fabricius of Aquapendente *The Formation of the Egg and of the Chick*, ed. and trans. H. B. Adelmann (Ithaca and New York: Cornell University Press, 1942), for example, chapter III, p. 162: 'There is an almost infinite number of yolks in the raceme of hens; first, because the one and especial aim of Nature is to look after reproduction, and in that, so to speak, most natural office, rather to abound in superfluities than to be deficient in necessities; secondly, because not all fertile eggs are incubated and those which are incubated are not all hatched; and further, these animals and the eggs engendered in them would in large part be rendered

up for men's food, and it was, therefore, fitting that very many eggs should be produced.'

120. Aristotle *Generation of Animals*, cit., III, 4, 755 a 25ff.
121. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 59, p. 443 f. (463).
122. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 56, pp. 425–26 (444); on man's sbirth 'naked and defenceless', see also Exercise 55, p. 413 (431).
123. E. Berti (2004) 'L'aristotelismo padovano e la nascita della medicina sperimentale' in E. Berti *Nuovi studi aristotelici*, cit., p. 276; see also p. 280, and always here see E. Berti (2004) 'Il ruolo storico dell'aristotelismo nello Studio di Padova', p. 237; on the link between Aristotelian methodology and Harvey, see the previous pages (pp. 233–6).

3 Indirect Supremacy

1. See J. C. Greene (1992) 'From Aristotle to Darwin', cit., p. 268f.; see also pp. 275 ff.; see also J. C. Greene (1999) 'Reflections on Ernst Mayr's *This is Biology*', *Biology and Philosophy*, 14, 103–16, pp. 105–6.
2. See the classic C. E. Raven (1986) *John Ray, naturalist: his life and works* (Cambridge: Cambridge University Press, 1942–1950), p. 452.
3. J. Ray *The Wisdom of God Manifested in the Works of the Creation. In two parts*, 10th edn (London: William Innys and Richard Manby, 1735), p. 38.
4. J. Ray *The Wisdom of God*, cit., p. 42.
5. J. Ray *The Wisdom of God*, cit., p. 42.
6. J. Ray, *The Wisdom of God*, cit., p. 39.
7. See R. Boyle *A Disquisition about the Final Causes of Natural Things* (1688), in *The Works of Robert Boyle* (London: Pickering & Chatto, 2000), vol. 11 (2), p. 128 f.: 'And I remember that when I asked our famous Harvey, in the only Discourse I had with him, (which was but a while before he dyed) What were the things that induc'd him to think to a *Circulation of the Blood?* He answer'd me, that when he took notice that the Valves in the Veins of so many several Parts of the Body, were so Plac'd that they gave free passage to the Blood Towards the Heart, but oppos'd the passage of the Venal Blood the Contrary way: He was invited to imagine, that so Provident a Cause as Nature had not so Plac'd so many Valves without a Design'.
8. See R. Boyle *A Disquisition about the Final Causes*, cit., pp. 81–3.
9. See R. Boyle *A Disquisition about the Final Causes*, cit., pp. 82, 108 ff.
10. R. Boyle *A Disquisition about the Final Causes*, cit., p. 95.
11. R. Boyle *A Disquisition about the Final Causes*, cit., p. 110.
12. See R. Boyle *A Disquisition about the Final Causes*, cit., p. 87; see also pp. 125 ff., 151.
13. An analogous line, aimed at placing Ray in the general context of nonconformity with Cartesian tendencies after the great scientific revolution, is taken, especially in relation to the question of anthropocentrism, by J. H. Brooke (2000) '"Wise Men Nowadays Think Otherwise": John Ray, Natural Theology and the Meanings of Anthropocentrism', *Notes and Records of the Royal Society of London*, vol. 54, n. 2, 199–213, especially pp. 202 ff.

14. See R. Boyle *A Disquisition about the Final Causes*, cit., pp. 89, 98 ff., 128 f.
15. J. Ray *The Wisdom of God*, cit., p. 39 f.; see also the long examination of the eye pp. 248 ff., introduced thus: 'Another Member which I shall more particularly treat of, is the Eye, a Part so artificially compos'd and commodiously situate, as nothing can be contriv'd better for Use, Ornament, or Security; nothing to Advantage added thereto or alter'd therein.'
16. J. Ray *The Wisdom of God*, cit., p. 143.
17. See J. Ray *The Wisdom of God*, cit., pp. 135–8.
18. See J. Ray *The Wisdom of God*, cit., pp. 161 ff., where, amongst other things we read: 'and since the Omniscient Creator could not but know all the Uses, to which they might and would be employed by Man, to them that acknowledge the Being of a Deity; it is little less than a Demonstration, that they were created intentionally, I do not say only, for those Uses.'
19. J. Ray *The Wisdom of God*, cit., pp. 280–1.
20. J. Ray *The Wisdom of God*, cit., p. 139.
21. J. Ray *The Wisdom of God*, cit., p. 127.
22. See J. Ray *The Wisdom of God*, cit., pp. 227–9.
23. Aristotle *Parts of Animals*, cit., IV, 10, 688a.
24. J. Ray *The Wisdom of God*, cit., pp. 141–2. On the influence of Henry More, and more particularly the second book of *An Antidote against Atheism*, see for example C. E. Raven (1986) *John Ray, naturalist*, cit., pp. 457 ff.
25. J. Ray *The Wisdom of God*, cit., p. 154–5; see for example Aristotle *Progressions of Animals* VIII, cit., 708a.
26. See for example L. Koerner (1999) *Linnaeus: Nature and Nation* (Cambridge MT and London: Harvard University Press), p. 33: 'Both Car Linnaeus and his friend Petrus Aredi had graduated from provincial grammar schools. In these schools, which took students as far as admission to university, they had been trained in the logic and natural philosophy of Aristotle. Indeed, Linnaeus' first Latin reading at home was the *Historia animalium*. (It was a gift from his father). As a boy Linnaeus encountered the same handful of texts that a Roman boy might have. [...] Twelve hundred years after St. Augustine, in the eighteenth century, Linnaeus wrote that in the snowy farm villages along the Baltic shires, boys were flogged for not knowing Aristotle.'
27. See C. Linnaeus *Fundamenta botanica* (Amsterdam: Schouten, 1736), § 157, p. 18: '*Species tot numeramus quot a principio creavit infinitum Ens*'.
28. See C. Linnaeus *Philosophia Botanica*, cit., pp. 113–4.
29. See for example the classic J. C. Greene (1959) *The Death of Adam. Evolution and Its Impact on Western Thought* (Ames: Iowa University Press), p. 134: 'In his *System of Vegetables* Linnaeus suggested that perhaps God created only one plant of each order and then arranged intermarriages so as to form the genera, leaving nature to produce the species within each genus by further crossing. Linnaeus returned to this idea in his diary, stating that the impregnations of the original species of each genus had taken place 'accidentally'. Though he said nothing of the time required for these developments, it is clear that he was looking or a historical explanation of the origin of genera and species and that he conceived the outcome as determined to a considerable degree by chance.'
30. E. Mayr (1982) *The Growth of Biological Thought. Diversity, Evolution, and Inheritance* (Cambridge MT and London: Harvard University Press),

pp. 258–60, insists on Linnaeus' 'essentialism'; J. L. Larson (1968) 'The Species Concept of Linnaeus', *Isis*, 59, n. 3, 291–9 emphasizes the teleological intentions; on the return to the continuist Aristotelian model, see also J. L. Larson (1967) 'Linnaeus and the Natural Method', *Isis*, 58, n. 3, 304–20, pp. 316 ff.

31. C. Linnaeus 'On the Increase of the habitable Earth', trans. F. J. Brandt in *Select dissertations from the Amoenitates Academicae (1749–90)* (London: Robinson et Robson, 1781), Dissertation II, p. 82.
32. C. Linné *Linnaeus's Diary*, in R. Pulteny *et al.* (eds) *A general view of the writings of Linnaeus*, 2nd edn (London: Mawman, 1805), p. 558.
33. I. J. Biberg 'Specimen Academicum de Œconomia Naturæ, quod Praeside Carolo Linnaeo submittit I. J. Biberg d. IV Martii MDCCXLIX', Uppsala 1749, trans. *The œconomy of nature* in C. Linnaeus *Miscellaneous Tracts Relating to Natural History, Husbandry, and Physick. To Which is Added the Calendar of Flora. By Benj. Stillingfleet*, trans. Benj. Stillingfleet (London: J. Dosdley, Backer and Leight, and T. Payne, 1775; reprint New York: Arno, 1977), pp. 39–40.
34. C. Linnaeus *Nemesis Divina*, ed. and trans. M. J. Petry (Dordrecht: Kluwer, 2001).
35. See for example C. Linnaeus 'De fundamento scientiae Oeconomicae a Physica & Scientia naturali petendo', Amoenitates Academicae, ed. J. E. Gilbert (Coloniae, 1786), II, §23.
36. See C. E. Gedner 'Quaestio historico naturalis: Cui bono? Quam breviter solutam Praeside Carolo Linnaeo', Uppsala 1752 (Soulsby, n. 1691), I, V, XIV, trans. 'Of the Use of Curiosity' in C. Linnaeus *Miscellaneous Tracts Relating to Natural History*, cit., p. 161.
37. Aristotle *Politics*, trans. H. Rackham (Cambridge Mass. and London: Harvard University Press, 1978), I, 3, 1256b.
38. D. Sedley (1991) 'Is Aristotle's teleology anthropocentric?', *Phronesis*, 36 (2), 179–196, has reasserted the 'strongly anthropocentric' Aristotelian attitude, by which man (humankind) is 'the ultimate beneficiary' of natural teleological mechanisms, insofar as he is at the top of the scale; see also D. Sedley (2007) *Creationism and Its Critics*, cit., especially pp. 201–3.
39. I. J. Biberg *The oeconomy of nature*, cit., p. 119.
40. See C. Limoges (1972) 'Introduction' in C. Linné *L'Équilibre de la nature* (Paris: Vrin), pp. 9–11.
41. I. J. Biberg *The oeconomy of nature*, cit., p. 96.
42. See C. Linnaues 'On the Increase of the habitable Earth', cit., pp. 96–7.
43. G. E. R. Lloyd 'Aristotle's Zoology and His Metaphysics: the Status Questionis', cit., p. 374, who then continues: 'it is enough to record unanimity on the minimum fact that a *comprehensive systematic* classification of animals proceeding *from* the highest groups *via* their principle divisions to end with the *infimae species* all clearly identified is nowhere to be found.'
44. W. Coleman (1964) *Georges Cuvier, Zoologist. A Study in the History of Evolution Theory* s(Cambridge Mass. and London: Harvard University press), p. 20 ff.; on the persistence of the essentialism readopted by Cesalpino see also Ph. R. Sloan (1972) '*John Locke, John Ray, and the Problem of the Natural System*', cit., pp. 9–13, 51–2; on the centrality of the tradition anchored in the reproductive criterion reintroduced by Cesalpino, see G. Barsanti (1992) *La scala, la mappa, l'albero*, cit., especially pp. 130–1, 166.

45. On the centrality of the comparative anatomical physiology of *Parts of Animals*, see M. Vegetti (1996) ‘I fondamenti teorici della biologia aristotelica nel *De partibus animalium*’, cit., especially pp. 498 ff. and pp. 552 ff.
46. On the encyclopaedic nature of the work and on the ‘dimension of the living animal, of its ecology and ethology’, see M. Vegetti *Il coltello e lo stilo*, 2nd edn (Milano: Il Saggiatore), especially pp. 196–7.
47. On this issue, see G. Barsanti (2005) *Una lunga pazienza cieca* (Torino: Einaudi), pp. 89–95, 117 ff.; for an idea of the tensions regarding discussion of the relationship between individual and species on the epistemological level, see for example G-L. L. de Buffon, ‘De la Nature. Second vue’ in *Histoire naturelle*, vol. XIII (1765), I-XX, pp. I ff., trans. ‘Second View’ in *Buffon's Natural History* (London: Barr, 1792), pp. 343 ff.; J. Roger (1997) *Buffon. A Life in Natural History* (Ithaca and London: Cornell University Press), p. 314 f. and note 34, which underlines the continuity between Aristotle and Buffon, ‘probably’ mediated by William Harvey, as well as the definition of the concept of ‘species’ in reproductive terms.
48. See G. L. L. de Buffon ‘Premier discours. De la manière d'étudier et de traiter l'Histoire Naturelle’ in *Histoire Naturelle*, vol. 1, 1749, trans. J. Lyon, ‘The “Initial Discourse” to Buffon's *Histoire naturelle*: The First Complete English Translation’, *Journal of the History of Biology*, vol. 9 n. 1 (1977), 133–81, pp. 168–70.
49. See for example the gratuitous references to Aristotle in O. Söderberg ‘Specimen academicum de Curiositate naturale, quo sub Presidio Caroli Linnaei’ (Halmiae, 1748), (Soulsby 1500).

4 Crisis and Hegemony

1. P. L. Moreau de Maupertuis *Systême de la nature. Essai sur la formation des corps organisés*, in *Œuvre* (Lyon: Bruyset), nouvelle édition 1768, p. 164 f.
2. J. O. de La Mettrie (1996) *The System of Epicurus* in J. O. de La Mettrie *Machine Man and Other Writings* (Cambridge: Cambridge University Press), § XIII-XVII, pp. 84–95.
3. J. O. de La Mettrie *The System of Epicurus*, cit., § XXVIII, p. 97.
4. J. O. de La Mettrie *The System of Epicurus*, cit., § XX-XXI, p. 96.
5. J. O. de La Mettrie *The System of Epicurus*, cit., § XXIII, p. 96.
6. See G.-L. L. de Buffon ‘De la dégénération des animaux’ in *Histoire naturelle*, vol. XIV (1766), trans. ‘Of the Degeneration of Animals’ in *Buffon's Natural History*, cit.
7. See for example C. Linnaeus ‘On the Increase of the habitable Earth’, cit., pp. 85–6: ‘no man can be ignorant that the sea, not the dry land, was the place of their production; that these Conchs and bivalves are found at a certain distance from land, and not in deeps [...]. Whoever ascribes these circumstances to the Deluge, which came suddenly and was suddenly past, must be totally ignorant in Natural Philosophy; and if he sees anything, sees with the eyes of others.’
8. On this general topic, see for example J. Greene *The Death of Adam*, cit., chapter 4, ‘Lost Species’.

9. G. Cuvier (1796) *Mémoire sur les espèces d'éléphants vivantes et fossiles. Lu le premier pluviôse an IV*, published in *Mémoires de L'institut National des sciences et arts. Sciences mathématiques et physiques*, t. II, a. 7 (1799), 1–22, ed. and trans. partial M. J. S. Rudwick 'Memoir on the Species of Elephants, Both Living and Fossil', in G. Cuvier *Fossil Bones, and Geological Catastrophes* (Chicago and London: University of Chicago Press, 1997)
10. G. Cuvier (1796) 'Mémoire sur les espèces d'éléphants vivantes et fossiles', cit., p. 21, 'Memoir in the Species of Elephants, Both Living and Fossil', cit., p. 24 and note 20.
11. See also G. Cuvier (1801) 'Extrait d'un ouvrage sur les espèces de quadrupèdes dont on a trouvé les ossemens dans l'intérieur de la terre', *Journal de Physique, de Chimie et d'Histoire Naturelle*, vol. 52, 253–67, trans. M. J. S. Rudwick 'Extract from a work on the species of quadrupeds of which the bones have been found in the interior of the earth' in G. Cuvier *Fossil Bones, and Geological Catastrophes*, cit.
12. For an overview of this topic, see P. Corsi (2000) 'Lamarck: il mondo naturale si affaccia all'evoluzione', *Le Scienze*, III/ 18, 111, p. 42.
13. See P. Corsi (1988) *The Age of Lamarck. Evolutionary Theories in France 1790/1830* (Berkeley: University of California Press), p. 64, who recalls how in 1796 Lamarck 'announced that he intends to follow most of [the classification] introduced by the learned naturalist Cuvier', who, in turn, in 1798 'thanked Lamarck for his suggestions concerning the chapter on mollusks'.
14. On the centrality of the question of extinction in relation to fossils for the development of Lamarck's theory, in relation to Cuvier's position in the 1790s, see also the overview by R. W. Burkhardt (1972) 'The Inspiration of Lamarck's Belief in Evolution', *Journal of the History of Biology*, vol. 5, n. 2, 413–38, especially pp. 419–24.
15. On this issue, see P. Corsi (2005) 'Before Darwin: Transformist Concepts in European Natural History', *Journal of the History of Biology*, vol. 38, n. 1, 67–83, especially pp. 70 ff., who emphasizes that at the turn of the eighteenth century Lamarckism was only one of the 'evolutionary' currents, like those expressed for example by Erasmus Darwin and by German and Italian natural romantic philosophers (Gautieri).
16. See for example P. Corsi (2000) *Lamarck: il mondo naturale si affaccia all'evoluzione*, cit., pp. 45 ff.
17. J-B. de Lamarck (1801) 'Discours d'ouverture', *Système des Animaux sans vertèbres* (Paris: Deterville), pp. 13–4, trans. D. R. Newth 'Lamarck in 1800. A lecture on the invertebrate animals and a note on fossils taken from the *Système des Animaux sans vertèbres* by J. B. Lamarck', *Annals of Science*, vol. 8 (1952), 229–54, pp. 237–8.
18. See especially J.-B. de Lamarck *Zoological Philosophy. An exposition with regard to the Natural History of Animals*, trans. H. Elliot (New York and London: Hafner, 1963), pp. 61–3; for the original French edition see *Philosophie zoologique* (Paris: Dentu, 1809), pp. 115–8.
19. R. W. Burkhardt (1972) 'The Inspiration of Lamarck's Belief in Evolution', cit., p. 428; the quotation is in Lamarck *Système des Animaux sans vertèbres*, cit., p. 15.
20. Pluche in turn referred explicitly to Francis Willughby's *Ornithologiae libri tres*, published posthumously in London in 1676 by Willughby's friend and

mentor John Ray; this is an important work which, massively rehearsing the contributions of Ulisse Aldrovandi, proposed a rich and detailed classification, both morphological and ecological, also featuring 77 plates with accurate reproductions of the birds discussed, ignoring any functional explanation, and so on.

21. N. A. Pluche *Spectacle de la Nature: Or, Nature Display'd. Being Discourses on Such Particulars of Natural History as Were Thought Most Proper to Excite the Curiosity, and Form the Minds of Youth*, trans. Mr. Humphreys (London: L Davis et al., 1766), tenth edition, vol. 1, pp. 177–8; for the French edition, see *Le Spectacle de la Nature ou entretiens sur les particularités de l'Historie Naturelle* (Paris : Veuve Estienne & Fils, 1749), pp. 293–7.
22. J.-B. de Lamarck *Zoological Philosophy*, cit., p. 35f.; for the original French edition, see *Philosophie zoologique*, cit., p. 54f.
23. See P. Corsi (2000) *Lamarck: il mondo naturale si affaccia all'evoluzione*, cit., pp. 49 ff.
24. J.-B. de Lamarck (1815) *Histoire naturelle des animaux vertèbres* (Paris: Verdiere), vol. I, p. 324.
25. The term *Biologie* was coined in 1797 by Roose, but certainly Lamarck at the same time contributed decisively to defining the 'new' discipline; see in this regard G. Barsanti (1995) 'Dalla storia naturale alla storia della natura, alla biologia' in G. Cimino and B. Fantini (eds) *Le rivoluzioni nella scienza della vita* (Firenze: Olschki), pp. 87–8.
26. G. Cuvier (1796) 'Mémoire sur les espèces d'éléphants vivantes et fossiles', cit., p. 12 (passage added to the published version).
27. G. Cuvier (1817) *Essay on the Theory of the Earth*, 3th edn, ed. R. Jameson (Edinburgh: Blackwood), p. 15; the passage was reinserted also in G. Cuvier (1825) *Discours sur les révolutions de la surface du globe*, troisième édition (Paris: Dufour), p. 16.
28. G. Cuvier (1817) *Essay on the Theory of the Earth*, cit., pp. 114–5; the passage will again be inserted, slightly modified, in *Discours sur les révolutions*, cit., pp. 117–8.
29. G. Cuvier (1817) *Essay on the Theory of the Earth*, cit., pp. 125–6; the passage will again be reinserted in *Discours sur les révolutions*, cit., pp. 128–9.
30. Così P. Corsi (1978) 'The Importance of French Transformist Ideas for the Second Volume of Lyell's Principles of Geology', *The British Journal for the History of Science*, vol. 11, n. 3, 221–244, p. 241.
31. Against Cuvier's accusation that Geoffroy was more a poet than an observer, Geoffroy in fact maintained that Aristotle was a precursor of his thesis when he emphasized that 'all vertebrate animals are constructed on the same model, a principle foreseen by Aristotle', see E. Geoffroy Saint-Hilaire (1829) *Course de l'histoire naturelle des mammifères* (Paris: Pichon et Didier), *Discours préliminaire*, p. 21; see also E. Geoffroy Saint-Hilaire (1830) *Principes de philosophie zoologique* (Paris : Pichon et Didier, discutés en mars 1830), *Discours préliminaire*, pp. 15–7.
32. See W. Coleman *Georges Cuvier, Zoologist*, cit., pp. 2 f., 26.
33. See W. Coleman *Georges Cuvier, Zoologist*, cit., especially pp. 24 and 29.
34. See G. Cuvier *Briefe an C.H. Pfaff aus den Jahren 1788 bis 1792*, W. F. G. Behn (ed.) (Kiel: Schwers'sche Buchhandlung, 1845), letter of 17 November 1788, p. 65 f.

35. See for example G. Cuvier *History of the Natural Sciences. Twenty-four lessons from Antiquity to the Renaissance*, ed. T. W. Pietsch (Paris: Publication du Muséum national d'Histoire naturelle, 2012), especially lessons 7 and 8, although this is a rather descriptive presentation which emphasizes the role of comparative anatomy in *History of Animals*.
36. G. Cuvier *Historical Portrait of the Progress of Ichthyology. From its Origins to our Time*, ed. and trans. T. W. Pietsch (Baltimore: John Hopkins University, 1995), p. 5, for the French version, see *Histoire naturelle des poissons* (Paris: Levrault, 1828), Tome premier, Livre premier, p. 3 f.; see in this regard E. A. Eigen (1997) 'Overcoming First Impressions: Georges Cuvier's Type', *Journal of the History of Biology*, 30, pp. 179–209.
37. See on this theme M. Ruse (2000) 'Teleology: Yesterday, Today, and Tomorrow?', *Studies in History and Philosophy of Biological and Biomedical Sciences*, vol. 31, n. 1, 213–32, especially pp. 214–19.
38. See for example G. Cuvier *The Animal Kingdom, arranged in conformity with its organization*, trans. H. Murtrie (New York: Carvill, 1833), p. 11: 'There is, however, a principle peculiar to Natural History, which it uses advantage on many occasions; it is that of *the conditions of existence*, commonly styled *final causes*. As nothing can exist without the re-union of those conditions which render its existence possible, the component parts of each being must be so arranged as to render possible the whole being, not only with regard to itself but to its surrounding relations.' For the French edition, see *Le règne animal distribué d'après son organisation* (Paris: Déterville, 1817), p. 6.

5 Darwin's Breakthrough

1. As Egerton pointed out, correcting the autobiographical representation, before leaving on the *Beagle* Darwin had read not only Erasmus' *Zoonomia* but also Lamarck's *Système des animaux sans vertèbres* (Paris: Deterville, 1801), as emerges from the notes written in Edinburgh (1825–1827), and so it is probable, although not certain, that he had read the introduction in which the theory of the transformation of species is proposed. Darwin thus would have had direct access to Lamarck even before reading Lyell's criticism. See F. N. Egerton (1976) 'Darwin's Early Reading of Lamarck', *Isis*, vol. 67, no. 3, 452–6, pp. 454–5. What is also important is Darwin's indirect reception of Lamarck conveyed by Lyell's anti-Lamarckism: see for example P. Corsi (1978) 'The Importance of French Transformist Ideas for the Second Volume of Lyell's Principles of Geology', cit.; W. Coleman (1962) 'Lyell and the "Reality" of Species: 1830–1833', *Isis*, vol. 53, n. 3, 325–338.
2. C. R. Darwin *Origin of Species*, cit., 'Introduction', p. 2.
3. C. R. Darwin *The Autobiography of Charles Darwin, 1809–1882*. With original omission restored. Edited with appendix and notes by his grand-daughter Nora Barlow (London: Collins, 1958), p. 118 f.
4. See C. R. Darwin *Notebook C* (1838), in *Charles Darwin's Notebooks, 1836–1844. Geology, Transmutations of Species, Metaphysical Enquiries*, Paul H. Barrett *et al.* (eds) (Cambridge: Cambridge University Press), the Trustees of the British Museum 1987, now also available at http://darwin-online.org.uk, f. 175.

5. See C. R. Darwin *The Foundations of the Origin of Species, A Sketch Written in 1842 by Charles Darwin*, ed. F. Darwin (Cambridge: Cambridge University Press, 1909), Intro, I, ii, pp. 7–8.
6. See for example D. Becquemont (2009) *Charles Darwin 1837–1839: aux sources d'une découverte* (Paris: Kimé), pp. 219 ff.
7. See C. R. Darwin *Notebook D* (1838), in *Charles Darwin's Notebooks*, cit., f. 135, note of 28 September 1838.
8. The recourse to 'final causes' also emerges in C. R. Darwin *Notebook B* (1837), in *Charles Darwin's Notebooks*, cit., both with reference to the discussion of E. Darwin (1794) *Zoonomia, or, The Laws of Organic Life* (London: Johnson), vol. I, and in relation to the 'progressive development' of the species, p. 49 ('Progressive development gives final cause for enormous periods anterior to man').
9. See C. R. Darwin *Notebook C*, cit., f. 236: 'I can scarcely doubt final cause is the adaptation of species to circumstances by principles, which I have given'.
10. See E. Darwin (1794) *Zoonomia*, cit., p. 503.
11. J. F. W. Herschel *A Preliminary Discourse on the Study of Natural Philosophy*, 1 edn London 1830 (Chicago: Chicago University Press, 1987), p. 87 f. (§78): 'to the consideration of a proximate, if not an ultimate, cause'; see p. 101; on the question of *verae cause* see above pp. 144 ff.
12. J. F. W. Herschel *A Preliminary Discourse on the Study of Natural Philosophy*, cit., p. 174 (§ 184).
13. See C. R. Darwin *Macculloch. Attrib of Deity*, *Essay on Theology and Natural Selection*, 1838, in. P. H. Barrett *Early writings of Charles Darwin*, in H. E. Gruber *Darwin on man* (London: Wildwood, 1974), now also in http://darwin-online.org.uk, on the dating see the introductory note.
14. F. Bacon *Of the Dignity and Advancement of Learning* (London: Longman, 1605), Book III, beginning of Chapter V, the motto is preceded by the following: 'The operative doctrine concerning nature I will likewise divide into two parts, and that by a kind of necessity, for this division is subject to the former division of the speculative doctrine; and as Physics and the inquisition of Efficient and Material causes produces Mechanic, so Metaphysics and the inquisition of Forms produces Magic'.
15. See W. Whewell (1833) *On Astronomy and General Physics Considered with Reference to Natural Theology* (London: Pickering), Chapter VI: 'Bacon's comparison of final causes to the vestal virgins is one of those poignant sayings, so frequent in his writings, which it is not easy to forget. "Like them," he says, "they are dedicated to God, and are barren." But to any one who reads his work it will appear in what spirit this was meant. "Not because those final causes are not true and worthy to be inquired, being kept within their own province." (Of the Advancement of Learning, b. ii, p. 142.). If he had occasion to develop his simile, full of latent meaning as his similes so often are, he would probably have said, that of these final causes barrenness was no reproach, seeing they ought to be, not the mothers but the daughters of our natural sciences; and that they were barren, not by imperfection of their nature, but in order that they might be kept pure an undefiled, and so fit ministers in the temple of God'. On the reading of Whewell see for example D. Kohn (1989) 'Darwin's Ambiguity: The Secularization

of Biological Meaning', *The British Journal for the History of Science*, 22, n. 2, 215–39, especially pp. 228–30.

16. C. R. Darwin *Notebook M*, in *Charles Darwin's Notebooks*, cit., folio 154e, dating from the end of September 1838.
17. See the note, again from Autumn 1838, in C. R. Darwin *Macculloch. Attributes of Deity Vol I.* (1838), cit.: 'Now my theory makes all organic beings perfectly adapted to all situations, where in accordance to certain laws they can live.– Hence the mistake they are created for them.'
18. On the influence of Paley's teleology and the other natural theologians, see for example M. Ruse (2005) 'The Darwinian Revolution, as seen in 1979 and as seen Twenty-Five Years Later in 2004', *Journal of the History of Biology*, 38 (1), 3–17, pp. 5 ff.; M. Ruse (2000) 'Teleology: Yesterday, Today, and Tomorrow?', cit., pp. 230–1; J. Howard (1982) *Darwin* (Oxford: Oxford University Press), pp. 22 ff.; S. J. Gould (2005) *The Structure of Evolutionary Theory* (Cambridge Mass.: Harvard University Press), pp. 116 ff., and in particular on final cause in 1855 pp. 234–5. On the early abandonment of traditional teleology, see also D. Ospovat (1979) 'Darwin after Malthus', *Journal of the History of Biology*, vol. 12, n. 2, 211–30, especially pp. 214 ff., although he insists on the perspective of harmonious design. On the fundamental ambiguity of Darwinian teleology, and on its difference from that of Paley, see D. Kohn (1989) 'Darwin's Ambiguity: The Secularization of Biological Meaning', cit., especially pp. 233 ff.
19. See C. R. Darwin *Notebook E*, in *Charles Darwin's Notebooks*, cit., pages 146–7 (1839).
20. See C. R. Darwin *Notebook D*, cit., page 114 (note of 17 September 1838): 'wonderful case of Pea hen taking feathers of Peacock & spurs – no final cause here.'
21. See C. R. Darwin *Notebook B*, cit., page 84.
22. Aristotle *Physics*, cit., II, 8, 199a 1 ff.
23. See C. R. Darwin *Origin of Species*, cit., chapter 14, pp. 397 ff.; to the previous question paragraph 9 of the *Sketch of 1842, Aborted Organs* was dedicated, with examples and similar analyses, then chapter IX, *Abortive or rudimentary organs*, from the Essay of 1844, see C. R. Darwin *The Foundations of The Origin of Species. Two Essays written in 1842 and 1844*, ed. F. Darwin (Cambridge: Cambridge University Press, 1909).
24. See C. R. Darwin *Origin of Species*, cit., chapter 15, p. 415; on moles, see also chapter 5, 110.
25. See C. R. Darwin *Origin of Species*, cit., chapter 14, p. 402.
26. On this turnaround emphasized by Huxley see also P. Casini (2009) *Darwin e la disputa della creazione* (Bologna: il Mulino), pp. 94 ff.
27. T. H. Huxley (1859) 'Darwin on the Origin of Species', *The Times*, 26 December 1859, 8–9, p. 8.
28. T. H. Huxley 'Darwin on the Origin of Species', cit., p. 9; see in the same vein see also T. H. Huxley (1860) 'Darwin on the Origin of Species', *Westminster Review*, 17, 541–70, p. 548.
29. C. R. Darwin *The Origin of Species*, cit., chapter 14, p. 402.
30. C. R. Darwin *The Origin of Species*, cit., chapter 14, p. 401.
31. C. R. Darwin *The Origin of Species*, cit., chapter 14, p. 401.

32. See C. R. Darwin *The Origin of Species*, cit., chapter 14, p. 398, which is also seen in the previous case: 'An organ, serving for two purposes, may become rudimentary or utterly aborted for one, even the more important purpose, and remain perfectly efficient for the other.'
33. C. R. Darwin *Sketch of 1842*, cit., pp. 38–41.
34. For a concise overview, see for example G. P. Wagner (1989) 'The Biological Homology Concept', *Annual Review of Ecology and Systematics*, 20, 51–69, especially pp. 52 ff. in which he highlights Owen and Goethe.
35. C. R. Darwin *Origin of Species*, cit., chapter 14, p. 393. For a wider view of the theories of the hand in natural history, see C. Pogliano (2010), '*Homo hapticus*. Sulla mano umana, da Aristotele a Darwin', in L. Calabi (ed.) *Il futuro di Darwin. L'uomo* (Torino: UTET).
36. C. R. Darwin *Origin of Species*, cit., chapter 14, p. 383.
37. See on the same theme, although indirectly in relation to natural theology, J. Howard (1982) *Darwin*, cit., pp. 93–6.
38. C. R. Darwin *Macculloch. Attributes of Deity Vol I.* (1838), cit., [28^{v}]. On the fundamental re-evaluation of randomness together with the development of the idea of natural selection, see for example D. Ospovat (1980) 'God and Natural Selection: The Darwinian Idea of Design', *Journal of the History of Biology*, 13, n. 2, 169–94, pp. 183–5.
39. See C. R. Darwin *Origin of Species*, cit., chapter 5, p. 106.
40. See the incisive overview in E. Sober (2009) 'Did Darwin write the "Origin" backwards?', *PNAS*, vol. 106, suppl. 1, 10048–55, pp. 10048–50.
41. See for example C. R. Darwin *Origin of Species*, cit., chapter 4, p. 86 ff.: 'Mere chance, as we may call it, might cause one variety to differ in some character from its parents, and the offspring of this variety again to differ from its parent in the very same character and in a greater degree; but this alone would never account for so habitual and large a degree of difference as that between the species of the same genus.' On this question, see the analysis by G. Barsanti (2005) *Una lunga pazienza cieca*, cit., pp. 257–8, which recalls the other passages and emphasizes the multiple meanings and references in the semantic universe of randomness in the text (*accidental*, *incidental*, *occasionally*, *occasional*); see also T. Hoquet (2009) *Darwin contre Darwin. Comment lire l'*Origine des espèces*?* (Paris: Seuil), pp. 201 ff.
42. On the absolute centrality of variations, also considered as 'infinitesimally small differences', identified from a young age, see for example C. R. Darwin *Sketch of 1842*, cit., pp. 8 ff.
43. See C. R. Darwin *Origin of Species*, cit., chapter 2, p. 34, but see also pp. 33–5; the 'highest importance' of 'individual differences' is reiterated on p. 41.
44. C. R. Darwin *Notebook B*, cit., pp. 2–5. On the fundamental importance of especially young Darwin's studies on geology see the monumental work of S. Herbert (2005) *Charles Darwin, Geologist* (Ithaca and London: Cornell University Press).
45. C. R. Darwin *Origin of Species*, cit., chapter 15, p. 425–6; but see also the discussion on species, including 'doubtful' pp. 36–47. For a concise and bibliographically up-to-date discussion of Darwin's critique on the search for the essence of the term species, see for example M. Ereshefsky (2009) 'Darwin e la natura delle specie' in L. Calabi (ed.) *Il futuro di Darwin. La specie* (Torino: UTET), pp. 3–21.

46. See for example E. Mayr (2005) 'Do Thomas Kuhn's scientific revolutions take place?', in particularly pp. 162 ff., and E. Mayr (2005) 'Darwin's influence on modern thought', in particularly p. 97, both in E. Mayr *What Makes Biology Unique? Considerations on the Autonomy of a Scientific Discipline* (Cambridge: Cambridge University Press), where, notwithstanding the severe criticism Kuhn offers of the interpretation of the Darwinian revolution (in my opinion partially justified), he continues nevertheless to interpret Darwin's theory in terms of a 'paradigm'. See also S. Herbert (2005) 'The Darwinian Revolution Revisited', *Journal of the History of Biology*, 38, n. 1, 51–66, pp. 57 ff., and his endorsement of extinction for the 'Darwinian revolution', understood as 'generational shift': 'To use Kuhnian language, extinction was the strong anomaly'. For an up-to-date defence of the legitimacy of the concept of 'revolution' within the ambit of the history of science and in particular the 'Darwinian Revolution', see for example M. Ruse (2008) *Charles Darwin* (Malden and Oxford: Blackwell), especially chapter 12, on Kuhn pp. 300 ff.
47. See T. Kuhn (1996) *The Structure of Scientific Revolutions*, 2nd edn (Chicago: University of Chicago Press, 1962/1970), pp. xi.
48. T. Kuhn (1996) *The Structure of Scientific Revolutions*, cit., pp. 150 f.; see also T. Kuhn (1977) 'The Essential Tension: Tradition and Innovation in Scientific Research' in T. Kuhn *The Essential Tension. Selected Studies in Scientific Tradition and Change* (Chicago and London: The University of Chicago Press), p. 226.
49. T. Kuhn (1996) *The Structure of Scientific Revolutions*, cit., p. 171 f.
50. T. Kuhn (1996) *The Structure of Scientific Revolutions*, cit., pp. 19–20, 15; on Franklin, see also T. Kuhn (1963) 'The function of dogma in scientific research' in A. Crombie (ed.) *Scientific change* (London: Heinemann), pp. 356 ff.
51. See again E. Mayr (2005) 'Do Thomas Kuhn's scientific revolutions take place?', cit., pp. 164 ff.; on the 'crisis' of Darwinism ending with the 'rebirth' of evolutionism and in particular the Origin, approved by the Modern Synthesis, see for example T. Junker (2009) 'Die große Krise des Darwinismus' in E. M. Engels (ed.) *Charles Darwin und seine Wirkung* (Frankfurt am Main: Suhrkamp), pp. 231–254.
52. See T. Kuhn *The Structure of Scientific Revolutions*, cit., pp. 171.
53. See T. Kuhn *The Structure of Scientific Revolutions*, cit., p. 172; the quotation from Darwin is in C. R. Darwin *Origin of Species*, cit., chapter 15, p. 422 f.
54. See T. Kuhn (2002) *The Copernican Revolution. Planetary Astronomy in the Development of Western Thought* (Cambridge Mass. and London: Harvard University Press, 1957), p. 4.
55. On the autonomy of biology with respect to Galilean mathematicization, see for example E. Mayr (2005) 'Science and Sciences' and 'The Autonomy of Biology', both in E. Mayr *What Makes Biology Unique?*, cit.
56. He highlighted the implicitly Kantian perspective on Kuhn's 'world of appearances'. P. Hoynigen-Huene (1989) 'Idealist elements in Thomas Kuhn's Philosophy of Science', *History of Philosophy Quarterly*, 6, n. 4, 393–401; see in this regard also S. Gattei (2007) *La rivoluzione incompiuta di Thomas Kuhn* (Torino: UTET), especially p. 60.
57. C. R. Darwin *Origin of Species*, cit., chapter 15, pp. 426, 427, 429. On the 'revolution' caused by Darwin's genealogical approach also regarding the method of classification, see the recent R. A. Richards (2009) 'Classification in Darwin's *Origin*' in M. Ruse and R. J. Richards (eds) *The Cambridge Companion to the 'Origin of Species'* (Cambridge: Cambridge University Press), pp. 173–193.

6 Dry Branches

1. C. R. Darwin *Origin of Species*, cit., chapter 4, p. 67.
2. C. R. Darwin *Origin of Species*, cit., chapter 15, p. 428.
3. C. R. Darwin *Origin of Species*, cit., chapter 5, p. 119.
4. C. R. Darwin *Origin of Species*, cit., chapter 6, p. 152.
5. Aristotle *Progression of Animals*, cit., 8, 708a 10 ff.; see also 2, 704b 15 ff.
6. Aristotle *Parts of Animals*, cit., II, 14, 658a.
7. See J. G. Lennox (1993) 'Darwin was a Teleologist', *Biology and Philosophy*, 8, 409–21, p. 417.
8. See for example C. R. Darwin *Origin of Species*, cit., chapter 4, pp. 85–105, for instance p. 103: 'Whether natural selection has really thus acted in adapting the various forms of life to their several conditions and stations, must be judged by the general tenor and balance of evidence given in the following chapters. But we have already seen how it entails extinction; and how largely extinctions has acted in the world's history, geology plainly declare'; see also for example chapter 15, p. 417: 'The extinction of species and of whole groups of species, which has played so conspicuous a part in the history of the organic world, almost inevitably follows from the principle of natural selection; for old forms are supplanted by new and improved forms'.
9. Although developed from a perspective focused on the classic tradition of natural theology, and although I believe the original ambivalence has been finally rendered obsolete by the overall system, I concur with the analysis of David Kohn on the ambiguity of Darwin, where Kohn writes, in 'Darwin's Ambiguity: The Secularization of Biological Meaning', cit., pp. 233–4: 'But there is teleological language and there is teleological language. There is the teleology of Paley's natural theology, which argues that each adaptation is evidence of design, and that every evidence of design is evidence of a Providential designer. There is also the secular utilitarianism of Darwin that accounts for each adaptation by its functional utility and refers the preservation of all useful functions to a natural process termed Natural Selection. Darwin's teleology lies, ironically, in the *usefulness* produced by a *purposeless*, that is to say natural, process. [...] [H]is vision of nature remains ambiguously teleological. It is a teleology without Purpose'.
10. C. R. Darwin *Sketch of 1842*, cit., p. 6.
11. C. R. Darwin *Sketch of 1842*, cit., p. 21.
12. C. R. Darwin and A. R. Wallace, 'On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection', *Journal of the Proceedings of the Linnean Society of London*, August 1858, part II Abstract of a Letter from C. Darwin, Esq., to Prof. Asa Gray, Boston, U.S., dated Down, 5 September 1857, p. 51.
13. See for example C. R. Darwin *Origin of Species*, cit., 'Introduction', pp. 2–3; *The Autobiography*, cit., p. 119 f.; *The Variation of Animals and Plants under Domestication*, 2nd edn (London: Murray, 1875), vol. 1, p. 10.
14. C. R. Darwin *Origin of Species*, cit., chapter 3, p. 49. The classic interpretation of the 'analogy' has often been criticized even in recent decades. However, as Gildenhuys has written, partially acknowledging such criticism, it seems to me that the solution adopted in the end, by which the *Origin* definitely 'shows that artificial selection and natural selection operate in an analogous way' (p. 609), is not so far from the traditional interpretation, which in my opinion is more linear and faithful to the text. See P. Gildenhuys (2004)

'Darwin, Herschel, and the role of analogy in Darwin's origin', Stud. Hist. Phil. Biol. & Biomed. Sci., 35, 593–661, pp. 602 ff.

15. See C. R. Darwin *Origin of Species*, cit., chapter 15, p. 411; on the 'unconscious process of selection' see also chapter 4, p. 80; on the utilitarian nature of domestication, see for example chapter 1, p. 22; on the specific modalities of artificial selection, see also C. R. Darwin *The Variation of Animals and Plants under Domestication*, cit., especially vol. 2, chapter XX 'Selection by man' and chapter XXI 'Selection, continued'.
16. C. R. Darwin *Origin of Species*, cit., chapter 4, p. 65; see also chapter 15, p. 412; chapter 7, p. 178.
17. See Aristotle *Physics*, cit., II, 8, 199a 15–9: 'Indeed, as a general proposition, the arts either, on the basis of nature, carry things further than nature can, or they imitate Nature. If, then, artificial processes are purposeful, so are natural processes too; for the relation of antecedent to consequent is identical in art and in Nature'; see also II, 2, 194a 20 ff.; II, 199b 25ff.
18. See for example Aristotle *Parts of Animals*, cit., I, 1, 639b: 'Yet the Final Cause (purpose) and the Good (Beautiful) is more fully present in the works of Nature than in the works of Arts. [...] There is "absolute" Necessity, which belongs to the eternal things; and there is a "conditional" Necessity, which has to do with everything that is formed by the processes of Nature, as well as with the products of Art, such as houses and so forth. If a house, or any other End, is to be realized, it is necessary that such and such material shall be available; one thing must first be formed, and set in motion, and then another thing; and so on continually in the same manner up to the End, which is the Final Cause, for the sake of which every one of those things is formed and for which it exists. The things which are formed in Nature are in like case.'
19. C. R. Darwin *Origin of Species*, cit., chapter 5, p. 107 f.
20. C. R. Darwin *Origin of Species*, cit., chapter 3, p. 49; with regard to artificial selection, Darwin also uses the expression 'manufactory', see for example chapter 2, p. 45: 'wherever many species of the same genus have been formed, or where, if we may use the expression, the manufactory of species has been active, we ought generally to find the manufactory still in action, more especially as we have every reason to believe the process of manufacturing new species to be a slow one'.
21. W. Harvey *Anatomical Exercises on the Generation*, cit., Exercise 71, p. 509 (530).
22. C. R. Darwin *Origin of Species*, cit., chapter 15, p. 426; *Essay of 1844*, cit., p. 253; in turn, the passage restates, weakening however the analogy with 'works of art', in the *Sketch of 1842*, cit., 'Conclusion', p. 50 f.; see also *Origin of Species*, cit., chapter 6, p 152: 'As two men have sometimes independently hit on the same invention, so in the several foregoing cases it appears that natural selection, working for the good of each being, and taking advantage of all favourable variations, has produced similar organs, as far as function is concerned, in distinct organic beings, which owe none of their structure in common to inheritance from a common progenitor.'
23. N. Eldredge (2005) *Darwin. Discovering the Tree of Life* (New York and London: Norton & Company), p. 218 f.

24. See N. Eldredge (1995) *Reinventing Darwin. The Great Debate at the High Table of Evolutionary Theory* (New York: Wiley & Sons), especially chapter 1 'Setting the Table' and chapter 2 'The Heart of the Matter: Adaptation and Natural Selection', in which he stresses how the 'Ultra-Darwinists' try to transform natural selection from a simple form of the recording of facts – a filter that conditions the distribution of genes from one generation to another – into a more dynamic force that shapes and moulds the organic form in the course of time, and if Darwin at times considers the concept of selection as an active form, as Natural Artificer modelled on the breeder, for the most part, however, he means it as a passive filter. See also the one-sided interpretation of E. Mayr (2005), 'Teleology', in *What Makes Biology Unique?*, cit., p. 58: 'Darwin has taught us that seemingly teleological evolutionary changes and the production of adapted features are simply the result of variational evolution, consisting of the production of large amounts of variation in every generation, and the probabilistic survival in every generation, and the probabilistic survival of those individuals remaining after the elimination of the least-fit phenotypes. Adaptedness thus is an a posteriori result rather than an a priori goal seeking. For this reason, the word teleological is misleading when applied to adapted features.'
25. C. R. Darwin *Origin of Species*, cit., chapter 4, p. 63; *The Variation of Animals and Plants under Domestication*, cit., vol. 1, pp. 6–7.
26. C. R. Darwin *Origin of Species*, cit., chapter 6, p. 162–3; see also C. R. Darwin *The Autobiography*, cit., p. 87: 'The old argument of design in nature, as given by Paley, which formerly seemed to me so conclusive, fails, now that the law of natural selection has been discovered. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by man. There seems to be no more design in the variability of organic beings and in the action of natural selection, than in the course which the wind blows. Everything in nature is the result of fixed laws.'
27. See C. R. Darwin *Origin of Species*, cit., especially chapter 4, pp. 85–105.
28. C. R. Darwin *Origin of Species*, cit., chapter 7, p. 178.
29. See for example C. R. Darwin *Origin of Species*, cit., chapter 15, p. 417: 'old forms are supplanted by new and improved forms'; recent forms 'have conquered the older and less improved forms in the struggle for life'.
30. C. R. Darwin *Origin of Species*, cit., chapter 15, p. 428.
31. See for example C. R. Darwin *Origin of Species*, cit., chapter 4, p. 103: 'If species had been independently created, no explanation would have been possible of this kind of classification; but it is explained through inheritance and the complex action of natural selection, entailing extinction and divergence of character'.
32. See S. J. Gould and E. S. Vrba (1982) 'Exaptation – a missing term in the science of form', *Paleobiology*, 8 (1), 4–15, especially pp. 6 ff.
33. See for example, the criticism of the concept of *exaptation* by D. C. Dennett (1998) 'Preston on Exaptation: Herons, Apples, and Eggs', *The Journal of Philosophy*, 95, n. 11, 576–80, and D. C. Dennett (1995) *Darwin's Dangerous Idea. Evolution and the Meanings of Life* (New York: Penguin), especially pp. 280 ff.

34. See in this sense, N. Eldredge (1995) *Reinventing Darwin*, cit., especially chapter 2, 'The Hearth of the Matter: Adaptation and Natural selection', § 'Dr. Pangloss'.
35. See R. C. Lewontin (1998) *Gene, Organismo e ambiente* (Roma-Bari: Laterza), p. 79.
36. R. C. Lewontin (1991) 'Facts and the Factitious in Natural Sciences', *Critical Inquiry*, 18, n. 1, 140–153, 143 f.; see in the same sense S. J. Gould (1994) 'The Evolution of Life on the Earth', *Scientific American*, 271/4, 85–91, especially pp. 85 ff.
37. See A. Gotthelf (1999) 'Darwin on Aristotle', cit., especially pp. 22–3, which refers especially to J. G. Lennox (1993), 'Darwin was a Teleologist', cit.; in the same sense, see also A. Gotthelf (1999) 'From Aristotle to Darwin. Closing Words', in C. Steel *et al.* (eds) *Aristotle's Animals in the Middle Ages and Renaissance*, cit., p. 399. A. Ariew (2007) 'Teleology', in D. L. Hull and M. Ruse (eds) *The Cambridge Companion to Philosophy of Biology* (Cambridge: Cambridge University Press), p. 179, has taken an intermediary position, however, in my opinion still with a finalistic slant.
38. See M. T. Ghiselin (1994) 'Darwin's Language may Seem Teleological, but his Thinking is Another Matter', *Biology and Philosophy*, 9, 489–92, p. 489, who immediately makes it clear: 'Before turning to Darwin studies I did my doctoral research on evolutionary physiological anatomy and was well prepared to understand the conceptual difficulties that attend the study of function. As a result of my work on Darwin I realized that teleological thinking was still exercising a pernicious influence, and the application of a non-teleological approach led me to make quite a number of discoveries, including the size advantage model for sequential hermaphroditism. My book on the evolution of sex is mainly devoted to showing what is wrong with teleological thinking (Ghiselin, 1974)'; if it is true, as suggests Lennox (1994) 'Teleology by Another Name: A Replay to Ghiselin', *Biology and Philosophy*, 9, 493–5, that from the texts as well as the correspondence of Darwin the adoption of a teleological approach to natural selection emerges; on the contrary, this does not remove the possibility of developing a critique of this teleological concept: it suggests developing such a critique.
39. See A. Gotthelf, *From Aristotle to Darwin*, cit., p. 399: 'Scholarly discussion continues today on the relationship – both the deep similarities and the fundamental differences – between the theoretical structures of the Aristotelian and the modern Darwinian biological world-views, and on what we, in our time, may yet have to learn from Aristotle's biological and philosophical work'.
40. C. R. Darwin *Origin of Species*, cit., chapter 7, p. 168.
41. See for example N. Eldredge (1999) *The Pattern of Evolution* (New York: Freeman), pp. 153 ff.
42. C. R. Darwin *Notebook B*, cit., 25.
43. C. R. Darwin *Origin of Species*, cit., chapter 4, pp. 104–5.
44. S. J. Gould (1989) *Wonderful Life. The Burgess Shale and the Nature of History* (New York: Northon & Co.), p. 32.
45. S. J. Gould and R. C. Lewontin (1979) 'The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme', *Proc. R. Soc. London B*, vol. 205, n. 1161, 581–98; on 'Panglossian' circularity among

observations and theory within the adaptationist context, see also R. C. Lewontin (1991) 'Facts and the Factitious in Natural Sciences', cit., especially pp. 144–6.

46. Aristotle *Parts of Animals*, cit., IV, 10, 687a 8 ff.
47. Aristotle *Parts of Animals*, cit., IV, 12, 694a.
48. Aristotle *Progression of Animals*, cit., 17, 714a–18, 714b.
49. See on the contrary J. Barnes (1982) *Introduction to Aristotle* (Oxford and New York: Oxford University Press), p. 77, who defends functionalist organs/aims thus: 'Aristotle express this by saying that one answer to the question "Why do ducks have webbed feet?" is "In order to swim." His "in order to" sounds odd to us only because *we* associate "in order to" primarily with intentional action. Aristotle associates it primarily with function, and he sees function in nature. He is surely right. Natural objects do contain functional parts and do exhibit functional behaviour; the scientist who is unaware of such functions is ignorant of a major part of his subject-matter.'
50. See C. R. Darwin, *The Descent of Man, and Selection in Relation to Sex*, 2nd edn (London: Murray, 1882), especially II, pp. 227, 500–33: having recognized that the horns of male deer can be 'injurious' and having proposed an explanation in terms of sexual selection, Darwin notes: 'With stags of many kinds the branches of the horns offer a curious case of difficulty; for certainly a single straight point would inflict a much more serious wound than several diverging ones', a difficulty which the utmost attention must be paid to, and the discussion of which remains definitely open.
51. S. J. Gould and R. C. Lewontin (1979) 'The spandrels of San Marco', cit., p. 152.
52. S. J. Gould and R. C. Lewontin (1979) 'The spandrels of San Marco', cit., p. 151.
53. Aristotle *Parts of Animals*, cit., I, 640a 20 ff. See on the contrary J. G. Lennox: besides a teleological character attributed to natural selection, he also maintains that 'Aristotle's essentialism is *not* typological, nor is it any obvious way "anti-evolutionary". Whatever it was that Darwin was up against, it was not Aristotelian essentialism', and he maintains that 'Like so many debates in the history of scientific methodology, the one over the limits and value of teleological explanation in biology is as alive today as it was when it began in the fourth century BC. And there is evidence that some of Aristotle's admirers, like some of Darwin's, had a tendency to throw the teleological baby out with the panglossian bathwater' – respectively in J. G. Lennox (2001) 'Kinds, Forms of Kinds, and the More and Less' and J. G. Lennox (2001) 'Theophrastus on the Limits of Teleology', both in *Aristotle's Philosophy of Biology. Studies on the Origins of Life Science* (Cambridge: Cambridge University Press), p. 162, note 11, and p. 276.
54. R. C. Lewontin, *Gene, organismo e ambiente*, cit., p. 73.
55. See for example C. R. Darwin *Origin of Species*, cit., chapter 4, p. 402: 'There remains, however, this difficulty. After an organ has ceased being used, and has become in consequence much reduced, how can it be still further reduced in size until the merest vestige is left; and how can it be finally quite obliterated? It is scarcely possible that disuse can go on producing any further effect after the organ has once been rendered functionless. Some additional explanation is here requisite which I cannot give.' On the question of non-use, also

in relation to moles' eyes, see for example E. Mayr (1991) *One long Argument. Charles Darwin and the Genesis of Modern Evolutionary Thinking* (Cambridge Mass. and London: Harvard University Press), pp. 109 ff.

56. C. R. Darwin *The Descent of Man*, cit., p. 61.
57. From this perspective, according to which DNA represents an eminently material element subject to random mutations, I find the parallel with Aristotle's *eidos* unjustified. Rather, it represents an immutable form; see on the contrary E. Mayr (2005), 'Teleology', in *What Makes Biology Unique?*, cit., pp. 54 ff. and *The Growth of Biological Thought*, cit., pp. 55–6; F. O'Rourke (2004), 'Aristotle and the Metaphysics of Evolution', *The Review of Metaphysics*, 58, n. 1, 3–59, especially pp. 10–2.
58. See A. Koyré (1956) 'Influence of Philosophical Trends on the Foundation of Scientific Theories', cit., p. 197, in French in the text.

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Index

Starting with Aristotle and moving on to Darwin, Marco Solinas outlines the basic steps from the birth, establishment and later rebirth of the traditional view of living beings and its overturning by evolutionary revolution. The classic framework devised by Aristotle was still dominant in the seventeenth-century world of Galileo, Harvey and Ray, and it remained hegemonic until the time of Lamarck and Cuvier in the nineteenth century. Darwin's breakthrough thus takes on the dimensions of an abandonment of the traditional finalistic theory. It was a transition exemplified in the morphological analysis of useless parts, such as the sightless eyes of moles, already discussed by Aristotle, which Darwin used as a crowbar to unhinge the systematic recourse to final causes. With many excerpts, a chronological sequence and an analytical approach, this book follows the course of the two conceptions that have shaped the destiny of the life sciences in Western culture.

Marco Solinas holds the national scientific qualification as Professor of Philosophy; he has studied and researched in Florence, Nottingham, Berlin, Frankfurt and Paris. He has written articles in important international reviews and is author of *Psiche: Platone e Freud* (2008), also published in German with the title *Via Platonica zum Unbewussten* (2012).

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