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ORIGINAL PAPER

Alfred Russel Wallace's world of final causes

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Abstract Alfred Russel Wallace (1823–1913) is an important figure in the history of science, but there remain many questions about the nature of his world view, and how it developed. Here, Wallace's appreciation of the role of final causes in evolution is linked to some of its probable origins, with an emphasis on the influence of Alexander von Humboldt (1769–1859). The question is then asked whether a final causes-based scientific agenda might be possible, and answered by drawing attention to two current efforts in that direction by Adrian Bejan, and by the author. A sketch of the latter approach, adapted from Spinozian thinking, is given, with an empirical example involving drainage basin morphology that suggests structural influences of a final causes sort.

Keywords Alfred Russel Wallace · Final causes · Alexander von Humboldt · Evolution · Entropy maximization

Introduction

Alfred Russel Wallace (1823–1913) is arguably one of the most interesting figures in the history of science. Apart from his prominence in the development of evolutionary biology and biogeography studies, and significant involvement in several other fields of science, he was also known in his time as a scathing social critic and imaginative land reform theorist—and, not least, as one of the most vocal supporters of spiritualism. Over the years, an array of workers—historians, biologists, geographers, anthropologists, economists and geologists—has been trying to sort all this out, and they have found the going rough. Wallace was not a conventional thinker, and those who try to pigeonhole his thoughts are bound for failure.

There have been many past failures. In his own time and since, a good number of sources have looked down on his spiritualism as a simple delusion calling into question the rest of his more conventional contributions to science and social science. More recently, the attitude sometimes has been that there were "two Wallaces": the first a brilliant field investigator and theorist, the other a gullible pawn (Kutschera 2003). Others have looked upon him as a man whose positions on critical issues flip-flopped on several occasions, making his overall views suspect. Even within his own primary field of biogeography, many workers in the late twentieth century came to view him as a dinosaur whose ideas had held back the development of that field (despite the fact that his initial work within that realm directly laid the groundwork for their own!). Still others, with varying agendas, have claimed he was the real originator of the theory of natural selection, and that Darwin stole from him—an accusation made more to the ends of vilifying Darwin than gaining any insight into Wallace's thought. A small present contingent seems to view him as a bloodthirsty murderer who wantonly silenced hundreds of thousands of defenseless animals. Further, there is a selfish effort by today's Intelligent Design (ID) community to portray him as a proto-creationist or ID-er. And to top it off, there is an ongoing questioning of his basically English

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background by Welsh nationalists who claim him as one of theirs, despite his own referrals to himself as otherwise.

I am confident that all of these problems will be resolved as we become more and more familiar with the man and his writings. But it will not be easy. As Wallace himself noted on several occasions, minds are not easily changed; he saw the matter quite clearly, I think, when he opined in an 1861 letter to his brother-in-law that belief is not voluntary: "…Can you really change your opinion and belief, for the hope of reward or the fear of punishment? Will you not say, 'As the matter stands I can't change my belief. You must give me proofs that I am wrong or show that the evidence I have heard is false, and then I may change my belief?' It may be that you do get more and do change your belief. But this change is not voluntary on your part. It depends upon the force of evidence upon your individual mind, and the evidence remaining the same and your mental faculties remaining unimpaired—you cannot believe otherwise any more than you can fly…" (Marchant 1916/1975, p. 66). On this basis (and there are plenty of other examples in his writings as well) Wallace's "intelligent conviction" approach may be viewed as a significant step in the development of pragmatic thinking: "…To the mass of mankind religion of some kind is a necessity. But whether there be a God and whatever be His nature; whether we have an immortal soul or not, or whatever may be our state after death, I can have no fear of having to suffer for the study of nature and the search for truth, or believe that those will be better off in a future state who have lived in the belief of doctrines inculcated from childhood, and which are to them rather a matter of blind faith than intelligent conviction." (Marchant 1916/1975, p. 67).

In this paper, I intend to take a look at what I believe is the most fundamental element of Wallace's thought: a belief in final causes. This remained with him his entire adult life, under various guises, and served to unify his thoughts on science, the social environment, and the world of spirit.

What Are "Final Causes"?

Wallace has often been referred to as a teleologist, or theist, or both. Certainly through most of his life he believed that "current events" (such as the execution of natural selection) were ultimately related to larger-scale influences, but it seems to me that neither of these terms describes what he viewed as the processes involved. The "theist" label is mainly directed at his spiritualism beliefs, but here we must be careful, as many or most spiritualists do not adopt a view of reality quite like that of the followers of the great religions. Instead, the "world of spirit" is seen as an extension of the natural world, an extension that is causally linked to the latter, but different from it in not being spatially extended. This, as is plain from all of Wallace's more than one hundred writings on spiritualism, is exactly how he viewed the matter.

The "teleologist" label is a bit more complicated to deal with. The *Dictionary of Philosophy* (Angeles 1981) defines the term "teleology" generally as: "the study of phenomena exhibiting order, design, purposes, ends, goals, tendencies, aims, direction, and how they are achieved in the process of development," but then is more explicit under its entry for "explanation, teleological": "1. Explanation in terms of some purpose (end, goal) for which something is done. 2. Explanation in terms of goal-directed or purpose-directed activity. Usually the goal or purpose is preset or planned. 3. Explaining the present and past with reference to something in the future (a goal, purpose, end, result) that is being striven for or for the sake of which the process takes place. Opposite to mechanistic explanation, which explains the present, and any future event, in terms of conditions prior to it. 4. Explanation in terms of the structures and activities of the parts of a whole being adapted (coordinated, adjusted, fitted, suited) to each other toward the fulfillment of the purposes or needs of that whole." Under the entry "causes, Aristotle's four" it defines "final cause" as "*that for the sake of which* an activity takes place; that end (purpose, goal, state of completion) *for which* the change is produced, or for which the change aims (strives, seeks). Its *telos* or *raison d'être*." Other dictionaries and encyclopedias provide similar definitions.

From these definitions, it becomes apparent that there is considerable overlap between the more purpose- or will-controlled concept of "teleology" and the "completion" orientation of "final cause." Teleological explanations are often or usually connected to an assumed first cause, especially the will of God. Wallace would have nothing of first causes, though his position on the possible existence of God was that if He did exist His powers were limited to influencing "lower" beings through natural chains of causality *only*. Any creationist or ID proponent, if wishing to admit Wallace into their camps, needs to come to grips with the fact that he did not recognize the classic Christian model of a God controlling destinies through direct, miraculous intervention, or for that matter any of the other trappings of institutional Christianity such as Heaven and Hell. Wallace did not believe in first causes-based miracles, for example: not because he did not feel there was adequate evidence for actual events of this sort having occurred throughout history, but instead because he believed such "miracles" devolved from natural causes of which we were still ignorant.

But in the definitions given above there is another "out" on this subject. In the classic Aristotelian setting of the "final cause" idea, the relationship between a sculptor planning out his work, and its actual achievement, is emphasized. The same portrayal could be given for almost anything that is thought out beforehand according to some plan or ideal, but this notion quickly runs into problems when one considers purely physical or biological processes. Even here, however, tolerable examples can be suggested. For instance, there is the case of the DNA molecule, which not only guides an individual organism through its full development into an adult being, but in so doing generates an element of the larger ecosystem which serves to help keep that system operating among its many impinging forces. It may be argued that DNA is not much more than a well worked-out and continuously operating program, but the fact remains that it is a program that only functions properly within a context clearly greater than itself, a role suggestive of higher levels of control yet.

It is my contention that Wallace was thinking in these general terms throughout his adult life, and that this format permeated his beliefs on evolution, including the evolution of consciousness and social systems. He is possibly the only significant figure ever to have done this, and even for this reason alone his approach is worthy of analysis, even instruction. It should be understood, of course, that he never actually came up with a specific model of how these "final causes" might be operating, but that is not to say that currently we can prove him wrong in his suspicions, or cannot actually extend the agenda to applicable science.

The development of Wallace's world view: A model

Wallace's development as a thinker has been treated by a fair number of historians and biographers (see Smith 1998 for a thorough review) most of whom, while getting the basic facts straight, have generally been less successful at putting the pieces together into coherent models of his overall world view. As a result, there have been frequent allegations of supposed inconsistencies in his writings. I feel these complaints are grossly overstated. For example, most observers have concluded that Wallace "changed his mind" between 1858 (the "Ternate" essay on natural selection) and 1865/1869, the period of his adoption of spiritualism, on the matter of the applicability of natural selection to human evolution. The conclusion has been, however, that he not only "changed his mind," but also actually *reversed* himself on the subject. Built into this observation is the assumption that as of 1858 he already felt that there was no difference between animal/plant evolution and the evolution of higher consciousness, but: (1) there is nothing in the 1858 essay that suggests he thought this at that time, (2) he never directly admitted to thinking this in his many later writings on the subject, (3) there is nothing in any of his other writings that suggest this. A better conclusion based on the facts available is that there was no reversal, and that instead his "opinions on the subject" had merely been "modified." (Marchant 1916/1975, p. 200; Smith 2006a).

So too there have been observations that Wallace's thoughts on biogeography vacillated over the years, especially to the degree he adopted extensionist principles (e.g., Fichman 1977; Bueno Hernández and Llorente Bousquets 2005). I am not sure I see any real progression in his thoughts in this area over the length of his career; instead, he seems simply to have investigated particular questions as they came up, using lines of thinking appropriate to the issue at the time. But it would take a good deal more space than is available here to defend this assertion in detail.

Wallace's intellectual development was complex, and affected significantly both by the varied events of his life, and the writings of a number of important literary figures. He grew up in a family with little money, and things finally got so bad that he was forced to leave school in his early teens. He became an apprentice, first briefly to a builder in London, and then to an older brother, William, who was forging a successful career as a land surveyor. In his mid-teens, he began to take an interest in geology and vegetation and other science subjects, and some years later when his brother moved his operation to South Wales became involved with some of the intellectual groups there, acting as a curator and lecturer in his spare time. In late 1843, during a work slowdown, he moved to Leicester, England, to take a job as an instructor at a private school. He lived there for about 15 months, during which period he met Henry Walter Bates (1825–1892), whose immersion in entomology caught his attention. It was also during this time he first witnessed demonstrations of mesmerism, and soon found that he himself was able to induce trances in subjects of his choosing. But in early 1845 William died suddenly and, left with tidying up his business obligations, Wallace was forced to return to Wales. He soon soured on the work, and concocted a scheme to support himself as a travelling natural history collector. The chosen locale was the Amazon, and in the spring of 1848 he and Bates, who he had enlisted (probably without much difficulty) to accompany him, set out for that location. The rest, as they say, is history.

Wallace's early years were impacted by some other associations as well. On originally moving to London, he fell in with some Owenists—utopian socialists—and soon was attracted to their ideas on labor organization and morality. He abandoned conventional religion and became something of an agnostic. A few years later, he took part with his brother in surveying work under the Enclosures

Act. This experience also left a mark, as he saw first-hand the kinds of miseries it produced among small land-holders.

Meanwhile, he was beginning to read the writings of a number of significant figures across a wide range of subjects. Early on he digested some of the works of Thomas Paine and Robert Dale Owen (son of Robert Owen), eventually coming to the conclusion that self-improvement was closely tied to intelligent conviction (a Spinozian point of view, it should be noted). From then on he would put much emphasis on gathering "the facts" before coming to conclusions, a routine that would later make him celebrated for his ability to marshal evidence in favor of particular theories.

By the mid-1840s and his time at Leicester, natural science subjects had begun to dominate Wallace's attention. In 1843, he sent a short essay on telescope optics to a famous early photographer, Fox Talbot, demonstrating the advanced level of his knowledge even at that point (Smith 2006b). Sometime around then he also encountered and absorbed the writings of Charles Lyell (1797–1875) on uniformitarian geology, and at once adopted Lyell's view of a natural reality maintained by slow, inexorable, processes—as distinct from cataclysmic revolutions. In late 1844 or 1845, he read the sensational new book by Robert Chambers (1802–1871), *Vestiges of the Natural History of Creation*, originally published anonymously, which espoused a doctrine not only of slow change, but also of transmutation (as it was then called) of species. Wallace was an instant convert, apparently, though he recognized in *Vestiges* only the announcement of a theory, and not an exposition of underlying causes. One of the main reasons for the Amazon trip was to collect evidence that, hopefully, would lead to such an understanding.

Other names (Malthus, for example) have also been connected to Wallace's early education, but there are three further ones that may deserve more attention than they have so far received: Alexander von Humboldt (Fig. 1), Franz Julius Ferdinand Meyen (1804–1840), and Justus von Liebig (1803–1873). It is well known that Wallace was inspired to travel by the writings of three men in particular: Charles Darwin, W. H. Edwards, and Humboldt, and perhaps most by the last of these. But Humboldt's influence may have extended to well beyond this, into the realm of natural philosophy. It must be remembered that during these years, the 1840s, Humboldt was the most famous and respected naturalist in Europe. Wallace had undoubtedly read Humboldt's *Personal Narrative*, an account of his travels in South America at the beginning of the nineteenth century, but it has been overlooked that Wallace's interest in Humboldt likely included an attraction to his philosophy of nature in general.

Late in life Wallace reported: "I had been greatly influenced in selecting this work by reading tales of travel, particularly Humboldt's 'Cosmos,' and stories of that great explorer's personal travels" (Wallace 1911). Though it cannot be certain Wallace is remembering the right Humboldt book here, in a 28 December 1845 letter to Bates Wallace writes he has a "great desire" to read the book, only then recently made available in an English version. Further, an 1852 library catalogue at the Neath Philosophical and Antiquarian Society indicated a copy of the book was purchased for it sometime before that, quite possibly by Wallace himself, who was a part-time curator and librarian for the institution (Hughes 1989). Beyond these clues, we know that Wallace at some point read the book, as he quoted words from it in 1871: that "a presumptuous skepticism, which rejects facts without examination of their truth, is, in some respects, more injurious than an unquestioning incredulity" (Wallace 1871, p. 30). This exact sentiment is also to be found in the 1861 letter to his brother-in-law quoted earlier. In all, there seems a very good chance that Wallace got to read the work before he left for South America.

Fig. 1 Alexander von Humboldt (1769–1859) exerted a large influence on the thinking of Alfred Russel Wallace, notably through his monograph *Cosmos* (adapted from a painting of Joseph Karl Stieler 1781–1858)

How Humboldt's thought might have influenced Wallace not long after he read *Vestiges* becomes clearer through some quotations from *Cosmos*:

> "If the study of physical phenomena be regarded in its bearings, not on the material wants of man, but on his general intellectual progress, its highest result is found in the knowledge of those mutual relations which link together the various powers of nature. It is the intuitive and intimate persuasion of the existence of these relations which at once enlarges and elevates our views, and enhances our enjoyment." (Humboldt 1846/2010, p. 4)

> "The aspect of external nature, as it presents itself in its generality to thoughtful contemplation, is that of

unity in diversity, and of connection, resemblance and order, among created things most dissimilar in their form;—one fair harmonious whole. To seize this unity and this harmony, amid such an immense assemblage of objects and forces,—to embrace alike the discoveries of the earliest ages and those of our own time,—and to analyse the details of phenomena without sinking under their mass, are efforts of human reason in the path wherein it is given to man to press towards the full comprehension of nature." (ibid., pp. 5–6)

"That which is grave and solemn in these impressions is derived from the presentiment of order and of law, unconsciously awakened by the simple contact with external nature; it is derived from the contrast of the narrow limits of our being with that image of infinity, which every where reveals itself in the starry heavens, in the boundless plain, or in the indistinct horizon of the ocean." (ibid., p. 6)

"It is the special object of this work to combat these errors, which, originating in vicious empiricism and defective induction, have survived even amongst the higher classes of society (often by the side of much literary cultivation), and thus to augment and ennoble the enjoyments which nature affords, by imparting a deeper view into her inner being. Such enjoyment (as our Carl Ritter has well shewn) is highest, when the whole mass of facts collected from different regions of the earth is comprehended in one glance, and placed under the dominion of intellectual combination." (ibid., p. 18)

"General views lead us habitually to regard each organic form as a definite part of the entire creation, and to recognise, in the particular plant or animal, not an isolated species, but a form linked in the chain of being to other forms living or extinct. They assist us in comprehending the relations which exist between the most recent discoveries, and those which have prepared the way for them." (ibid., p. 23)

"Who will venture to affirm, that we yet know with precision that part of the atmosphere which is not oxygen, or that thousands of gaseous substances affecting our organs may not be mixed with the nitrogen? or who will say that we already know even the whole number of the forces which pervade the universe?" (ibid., p. 32)

"I take pleasure in persuading myself that it is possible for scientific subjects to be presented in language, grave, dignified, and yet animated; and that those who are able to escape occasionally from the restricted circle of the ordinary duties of civil life, and regret to find that they have so long remained strangers to nature, may thus have opened to them access to one of the noblest enjoyments which the activity of the rational faculties can afford to man. The study of general natural knowledge awakens in us as it were new perceptions which had long lain dormant…" (ibid., pp. 35–36)

"…the final aim of physical geography is to recognise unity in the vast variety of phenomena, and by the exercise of thought and the combination of observations, to discern that which is constant through apparent change. In the exposition of the terrestrial portion of the Cosmos, we may sometimes find occasion to descend to very special facts, but it will only be for the purpose of recalling the connection existing between the laws of the actual distribution of organic beings over the surface of the globe, and the laws of the ideal classification by natural families, analogy of internal organisation, and progressive evolution." (ibid., p. 48)

These remarks—and a good deal more like them scattered throughout the Introduction to the work alone—expose Humboldt as a believer in general principles; of organization coming first, and detail later. Wallace would have been delighted to hear words such as these, and coming from a leading light at that. This was the kind of thinking that would expose the workings of great natural processes such as transmutation; at the very least it suggested that change might be related to overarching, but yet unknown, characteristics of the environment related to climate and landscape. For Wallace, it was the first major step toward geography, a study indebted to Humboldt as a founding father. Wallace had already come to similar conclusions regarding the advantages of acquiring "varied forms of knowledge," as is apparent from the content of two of his earliest writings, from around 1843 and 1845 (Wallace 1845, 1905). The resemblance of sympathies is so great that one wonders whether Wallace might already have read some of Humboldt's earlier writings—for example his *Personal Narrative* or *Views of Nature* in the original French, perhaps with the aid of his sister, who was fluent.

It is worth noting that Wallace cites Humboldt 19 times (in five works) in his pre-1857 writings, but Lyell only twice (in two works). It may well be that Wallace embraced Lyell's views on geology, but it seems more likely that when it came to ecological processes, Humboldt, the geographer, was the model.

The degree to which Wallace was fascinated by Humboldt is suggested by the presence of Wallace's name on the list of subscribers to the 1846 English language edition of Franz Julius Ferdinand Meyen's *Outlines of the Geography of Plants* (Meyen 1846). Meyen (1804–1840) was among the most prominent of Humboldt's protégés, and his book contains more than 75 referrals to the older naturalist's works. Although Wallace may have had some trouble obtaining his copy of the book (Wallace 1846), judging from period advertisements it became available around May 1846, and by 1848 it was probably widespread in major British libraries. It seems very likely that Wallace was able to read it before leaving for South America.

On examining *Outlines*, Wallace would have found sections titled "On the Conditions of Climate Which Determine the Presence and Distribution of Plants," "On the Conditions by Which the Soil Influences the Station and Distribution of Plants," and "The Distribution of Plants Over the Surface of the Earth." The initial pages mention Humboldt's observations on the latitudinal gradients in plant species numbers, and the final section introduces several themes and challenges that Wallace would later take up in his own work. For example:

> "The physiognomics of vegetation teach us, that nature, at the creation of plants, has distributed them over the surface of the earth according to certain laws, which are quite unknown to us. We have now learned some of the external causes which place the more developed and nobler forms of vegetation in the hot zones; but we know no cause, why the same species of plants are not always produced in the same conditions of climate." (Meyen 1846, p. 99)

Here was a research question worthy of an industrious naturalist!

Justus von Liebig (1803–1873) was a chemist, and a very good one. In one of his later writings, Wallace notes: "Living thus almost constantly on the land and among farmers and country people, I soon took a great interest in agriculture. I studied the works of Sir Humphrey Davy and Baron Liebeg [*sic*], at that time the great authorities on agricultural chemistry…. I really believe that at that period of my life I could have passed a very fair examination in theoretical and practical agriculture" (Wallace 1885a, p. 15). Wallace probably knew Liebig's *Organic Chemistry in its Applications to Agriculture and Physiology*, which had reached English translation from the original German in 1840. Liebig is most remembered for his "law of the minimum," the observation that agricultural yield is directly dependent on the least available critical nutrient, whatever that may happen to be in a particular instance. This "limiting factor" concept was a central element in the development of ecological theory over the next 100 years, and it was likely at the back of Wallace's mind all those years before he hit upon the natural selection concept, which shifted his focus from large-scale environmental controls on evolution to the individual-focused process of selection for adaptive suites. A possible role for the "law of the minimum" in Wallace's thoughts in the 1840s and 1850s should not be dismissed, as it is but a short step from the principle to natural selection itself: how might organisms change in a manner allowing them to exploit environments short on particular "critical nutrients"?

It appears Wallace encountered *Vestiges* before he read *Cosmos*, and as I state elsewhere:

> "the dynamic created by this order is an interesting one to consider… Both works feature a review of natural phenomena, but *Vestiges* has a more restricted purpose, arguing for the existence of a process of organic evolution. But, even from… the quotations given… [earlier] one can see that *Cosmos* preaches, at the very least, the existence of 'connections' between natural forms. *Vestiges*, moreover, ultimately is unable to project a process model that could result in organic evolution. Wallace (and just about everyone else) recognized this weakness right away. The author's train of thought was interesting, but on the other hand the book's anonymous publication made it suspect. Humboldt, by contrast, was a world-famous figure as a man of science, and Wallace would have found his words, even if not directly supporting an evolutionary reality, appealing for their visionary worth. The result… was a Wallace who in his initial view of cosmology, favored an evolutionary process that worked more from the top down, than from the details of adaptation, up." (Smith 2013, in press)

The only other models available to Wallace at that time, moreover, must have been unappealing to him from the start. Creationist logic, whether of an institutional religion type or involving the geological catastrophism some were still espousing, did not interest Wallace. On becoming an agnostic some years earlier, he looked disdainfully on the prospect of first causes; beyond this, he had adopted the uniformitarian views of Lyell unreservedly and was not willing to think in terms of major revolutions having taken place in nature (though it is interesting that at that point Lyell himself looked upon biogeographical similarities as possibly being the result of multiple creations). Then, there was Lamarckism, in which changes to an animal's body during its lifetime were posed to be transmitted on to the next generation. Wallace probably learned of Larmarck's ideas through his reading of Lyell, who was one of the few English writers to take much notice of the Frenchman's ideas. But, like many others, Wallace was not impressed with these views, as there seemed to be little if any evidence to back them up.

Later in life Wallace unfortunately had just about nothing to say about his working model of evolution circa

1845–1858; neither do his few letters to Bates and others from that period reveal very much. There are, however, a few published writings of his that give us some idea of his leanings at that point. The first comes from his *Travels on the Amazon and Rio Negro*, in 1853, and seemingly harkens back to his reading of Meyen:

> "It must strike every one, that the numbers of birds and insects of different groups, having scarcely any resemblance to each other, which yet feed on the same food and inhabit the same localities, cannot have been so differently constructed and adorned for that purpose alone. Thus the goat-suckers, the swallows, the tyrant flycatchers, and the jacamars, all use the same kind of food, and procure it in the same manner: they all capture insects on the wing, yet how entirely different is the structure and the whole appearance of these birds!… What birds can have their bills more peculiarly formed than the ibis, the spoonbill, and the heron? Yet they may be seen side by side, picking up the same food from the shallow water on the beach; and on opening their stomachs, we find the same little crustacea and shell-fish in them all. Then among the fruit-eating birds, there are pigeons, parrots, toucans, and chatterers,—families as distinct and widely separated as possible,—which yet may be often seen feeding all together on the same tree; for in the forests of South America, certain fruits are favourites with almost every kind of fruit-eating bird. It has been assumed by some writers on Natural History, that every wild fruit is the food of some bird or animal, and that the varied forms and structure of their mouths may be necessitated by the peculiar character of the fruits they are to feed on; but there is more of imagination than fact in this statement: the number of wild fruits furnishing food for birds is very limited, and the birds of the most varied structure and of every size will be found visiting the same tree." (Wallace 1889, pp. 58–59)

Then, 3 years later, in a treatment of the habits of the orangutan, he states:

> "Do you mean to assert, then, some of my readers will indignantly ask, that this animal, or any animal, is provided with organs which are of no use to it? Yes, we reply, we do mean to assert that many animals are provided with organs and appendages which serve no material or physical purpose. The extraordinary excrescences of many insects, the fantastic and many-coloured plumes which adorn certain birds, the excessively developed horns in some of the antelopes, the colours and infinitely modified forms of many flower-petals, are all cases, for an explanation of which we must look to some general principle far more recondite than a simple relation to the necessities of the individual. We conceive it to be a most erroneous, a most contracted view of the organic world, to believe that every part of an animal or of a plant exists solely for some material and physical use to the individual,—to believe that all the beauty, all the infinite combinations and changes of form and structure should have the sole purpose and end of enabling each animal to support its existence,—to believe, in fact, that we know the one sole end and purpose of every modification that exists in organic beings, and to refuse to recognize the possibility of there being any other. Naturalists are too apt to *imagine*, when they cannot *discover*, a use for everything in nature." (Wallace 1856, p. 30)

Wallace's continuing nod to more "recondite" natural forces may in the more general sense be ascribed to, perhaps surprisingly, a certain conservatism on his part as to just how much was really known about natural causation during his life (recall the Humboldt quote given earlier). Over his career, he returned time and time again to the notion that a particular theory should not be expected to explain everything (e.g., Wallace 1864, 1870a, b, 1885b, 1908). And, although he recognized natural selection as a universal "filter" through which all organic change passed, he was keenly aware that little was known about the sources of variation upon which the process acted. As he aged he became more and more fascinated with this matter, despite the fact that he himself largely remained outside the science on the debate. Still, there seemed to be various kinds of clues available as to the overarching causalities involved.

This is not the place to try to do full justice to the range and depth of Wallace's appreciations on this matter, but some of these connections, at least, may be mentioned briefly. One well known one is his initial view that vestigial organs were incipient structures; this speaks to his impression that ambient influences on change were in operation. But he did not stop there, also suggesting throughout his later career that the incipient emergence of mathematical, moral, and paranormal abilities (of spiritualistic mediums, mesmerists and witches) reflected ambient forces extending beyond mere natural selection. So too he treated the connection between beauty and its perception as being relatable to transcendental inertias. As a lesson in these directions, he pointed to domestication, and how we would not recognize it if we ourselves were experiencing analogous influences; as further evidence of same he pointed to what he interpreted as examples of selective forces being imposed by other higher animals on lower ones (Wallace 1910). And one must not forget the "balance in nature generated by feedbacks" element introduced in his Ternate essay of 1858 through the steam engine analogy:

> "We have also here an acting cause to account for that balance so often observed in nature,—a deficiency in one set of organs always being compensated by an increased development of some others—powerful wings accompanying weak feet, or great velocity making up for the absence of defensive weapons; for it has been shown that all varieties in which an unbalanced deficiency occurred could not long continue their existence. The action of this principle is exactly like that of the centrifugal governor of the steam engine, which checks and corrects any irregularities almost before they become evident; and in like manner no unbalanced deficiency in the animal kingdom can ever reach any conspicuous magnitude, because it would make itself felt at the very first step, by rendering existence difficult and extinction almost sure soon to follow." (Wallace 1858, pp. 53–62)

All of these thoughts bear strong traces of the intellectual imprint of von Humboldt: the leaning toward a philosophy supporting what might be termed a "natural systems Bauplan."

Can scientifically acceptable final causes be identified?

Wallace's enthusiasm for "remote final causes" notwithstanding, it is fair to ask whether this kind of thinking, focused in the right direction, could actually produce scientific understandings of a useful nature. I do not see why not; nevertheless, there would seem to be some constraints on how to proceed.

In the 1950s and 1960s, a largely new kind of approach to the study of natural and social processes emerged; this became known as "General Systems Theory." Its goal was to identify characteristics of complex systems that might pertain to most or all of them. The movement produced some interesting ideas and a few classic papers (e.g., Maruyama 1963) and books, but by the 1970s was fading—not necessarily because investigators had entirely lost interest in trying to answer big questions, but because steady progress was being made answering smaller systems-related questions in studies such as bioengineering, artificial intelligence, and robotics. In short, investigators retreated to more conventional, reductionist approaches to answer more particular questions. Yet in recent years, attempts to answer the "big questions" seem to be on the ascendancy again. A brief description of a couple of these may be useful here.

In the 1990s, an engineer named Adrian Bejan began to promote a model of organizational tendencies he termed "constructal theory" (Bejan 1997; Bejan and Zane 2012). The essence of this theory is that all things in nature that arise spontaneously evolve internally in such a manner as to facilitate flows of energy—more particularly, to improve the ratio of mass moved within the system to the amount of energy needed to move it. Bejan has devised ways of looking at structures undergoing such organization, and provided many examples. From one perspective, this might be regarded as a model of final causes, because all systems are supposed to undergo such developments as a simple matter of physics that makes their directional development inevitable.

Nevertheless, Bejan's model has found limited support, not because it seems unreasonable a priori, but instead because its formulation is rather vague. Many of its most crucial elements have not been reduced to first principles, with the result that its key concepts related to flow and access remain poorly defined. I believe one of its most severe problems is its lack of integration of the notion of constraints into the model; i.e., it embraces a self-organization model that does not recognize a place for *restrictions* on complexification, and especially the relationship of system function to the fact of existing as a spatially extended reality.

The standard reductionist model begins with a spatial setting "within which" things happen. The reality of space itself, and how spatial extension might be fundamental to the organization and interactions of all things, is usually ignored or assumed. However, it is entirely possible that space itself is emergent in the things we usually merely think of as "being in it." A true final cause may lie lurking in the rules of emergence, and how this affects the evolution of any complex system.

In the 1980s, I began to investigate this concept, and soon came upon the writings of Benedict de Spinoza (1632–1677), the great Rationalist philosopher. In his *Ethics,* he deduces the plan of nature, a plan which recognizes an essential similarity of organization up and down the natural hierarchy through the operation of two fundamental attributes, "thought," and "spatial extension." These "attributes," however, are not of the kind we now associate with particular aspects of natural systems, but instead are what might be termed "rules of order" that apply to the organization of all of them. After some years of considering the matter, I came to a model I have been trying to develop ever since.

The key to this model is the notion that all natural systems might *subsystemize* in a manner common to them all, and do so in a way that *itself* constitutes physical, extended space. Thus within every natural system, large and small, there might be an exchange of energy and information that satisfies a working integrity within the system, and generates space as it does (Smith 2007; Smith and Derr 2012).

To investigate this idea, I have employed both simulation techniques and empirical analyses of actual systems. The simulations were aimed at determining whether the input–output relations of a mathematical system might correspond to a spatial projection of same. Many thousands of matrices with dimensions of $n = 3,3$ through 7,7 were filled with random numbers, then entropy-maximized (through an operation known as double standardization, or bistochastization, which yields iteratively standardized rows and columns of z scores) to investigate whether the output corresponded to a three-dimensional, spatial, output. It turned out that only matrices of dimension 4,4 could produce such output, and at a rate of less than two percent (depending on the exact details of the constitution of the matrix) of the configurations tested. So, for example, a 4×4 matrix containing some set of random numbers might double-standardize to a result of:

$$\begin{array}{rrrr} 1.2344 & -1.0426 & -0.9238 & 0.7320 \\ -0.9238 & 1.2344 & 0.7320 & -1.0426 \\ -1.0426 & 0.7320 & 1.2344 & -0.9238 \\ 0.7320 & -0.9238 & -1.0426 & 1.2344 \end{array}$$

Another set might double-standardize to:

$$\begin{array}{rrrr} 1.2344 & -0.9238 & -1.0426 & 0.7320 \\ -0.9238 & 1.2344 & 0.7320 & -1.0426 \\ -1.0426 & 0.7320 & 1.2344 & -0.9238 \\ 0.7320 & -1.0426 & -0.9238 & 1.2344 \end{array}$$

It turns out that only the second set of results, involving symmetric output, projects a scores matrix corresponding to an unambiguously Euclidean three-dimensional space. This approach was extended to simulations of (grouped) random patterns on two-dimensional and three-dimensional surfaces (which were then investigated through the use of spatial autocorrelation techniques). Generally speaking, successful three-dimensional projections were more frequently produced for these than for inputs consisting of unconstrained random numbers.

I then began to apply the same method to study group spatial patterns in some real world structures. In a study of topographic patterns within 31 stream basins in the Commonwealth of Kentucky (Smith and Derr 2012), 30 of the basins passed the spatial projection test (with the last one only narrowly missing). Just as importantly, a secondary statistic used to describe the degree of redundancy of structure within each matrix representation of the basins showed a clear affinity with the four-subsystem model, as shown in the figures below (reproduced from Smith and Derr 2012).

Figure 2 summarizes the random numbers-based simulations mentioned above for dimensions (number of classes) 3×3, 4×4, 5×5, and 6×6. Two different structural redundancy measures (mean correlations derived from each input matrix's derivative correlation matrix) were applied to the input data, as were two conditions of randomness (see Smith and Derr 2012 for details). The values plotted are means derived from the number of simulations indicated to the right of the graph; values 17 through 20 represent the means connected to the matrices that actually passed the spatial projection test. Regardless of the details, there is a smooth decrease in the mean

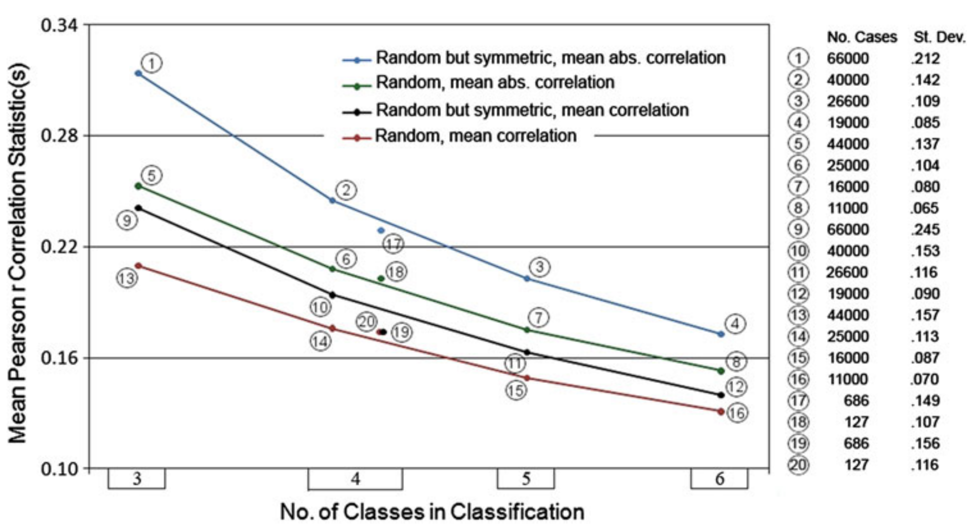

Fig. 2 Summary of spatial projection simulations for matrix configurations of dimension 3×3 through 6×6. *Circled numbers* refer to data at the right margin giving the number of simulations in each test and the standard deviations accompanying the mean values plotted. The plotted numbers are the two *mmr* and two *mamr* values obtained at each dimensionality (="no. of classes in classification"). *Colored line* coding connecting points is for readability purposes only. Point values 17 through 20 are compiled from subsets of the data leading to point values 2, 6, 10, and 14, respectively. (After Smith and Derr 2012, Fig. 1; see text for further explanation.)

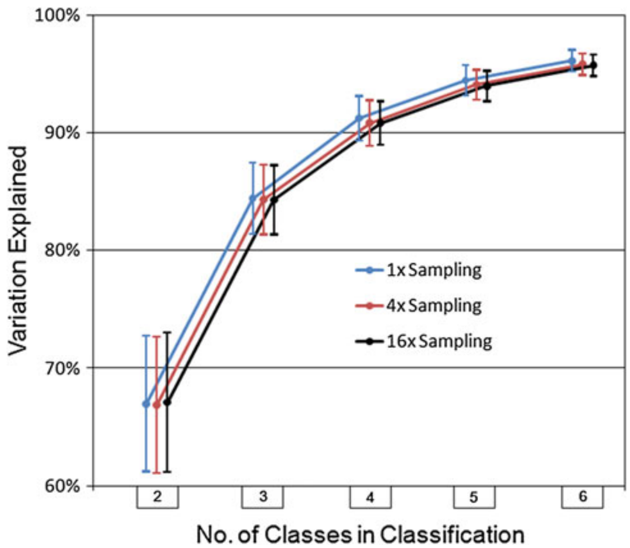

Fig. 3 Summary of variation explained statistics obtained for the clustering of the stream basins data (vectors) into two through six classes. The plotted points are the mean ($n = 31$) variations-explained for each classification, at three fineness levels of sampling. *Colored line* coding connecting points is for readability purposes only. (After Smith and Derr 2012, Fig. 2; see text for further explanation.)

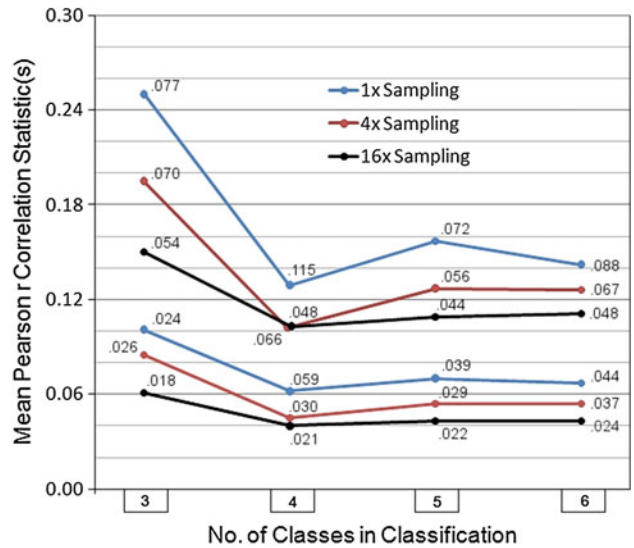

Fig. 4 Summary of spatial subsystemization properties of topography in 31 Kentucky stream basins, based on three fineness levels of sampling. The *plotted values* in the *top* three sets of four points are the *mamr* values; those in the *bottom three* are the *mmr* values. The associated standard deviations are written out next to each plotted value. *Colored line* coding connecting points is for readability purposes only. The results as displayed here are in marked contrast to the simulation results shown in Fig. 2, suggesting that the spatial expression of the basins is related to a functional (not just statistically described) subsystemization process. (After Smith and Derr 2012, Fig. 3; see text for further explanation.)

redundancy statistic with increase in numbers of dimensions (i.e., number of classes in classification). In all three figures, connecting lines are inserted for sake of readability only.

Figure 3 shows the increase in variation explained in the nonhierarchical clustering operations on sampled elevations in the 31 Kentucky stream basins. Again, the plotted values are means across the 31 systems, and in this instance show the results for three different areal sampling densities (1×, nearest neighbor 860 ft away, 4×, n.n. 430 ft, 16×, n.n. 215 ft), and five different classification models. A smooth increase in variation explained is readily apparent.

The results displayed in Figs. 3 and 4 are not surprising, as it is typically the case that variation explained totals will increase with number of partitions of the data. Figure 4, however, relays an entirely different story. This summarizes the results of the internal redundancy analysis of the 31 Kentucky streams, once spatial relations among the classes (ranges) of elevation are taken into account. (In this instance spatial autocorrelation statistics were again the values that were double-standardized; see Smith and Derr 2012 for details.) The values plotted are means (across the 31 streams); two sets of three results are shown because two different spatial autocorrelation measures were applied as a check. Importantly, it can be seen that once spatial relationships are taken into account, there is no longer a smooth function of change as the number of partitions increases. In fact, and across all the models, redundancy minimizes at the four-class partitions. A previous pilot study on twenty-five other stream basins produced similar (though not quite so clear) results. There is thus something about the four-class solution that is special; that is, that may be related to an actual organizational influence, and not some statistical artefact. What could it be?

In Smith and Derr (2012), some suggestions are offered. First, if the subsystemization structure is fundamentally related to spatial extension, it makes sense that the energy/information flows/cascades among specifically four subsystems would be involved, as it takes the relations among a minimum of four origins to specify Euclidean three-dimensionality. Secondly, equations with more than four roots can only rarely be solved; thus an equilibrial balance among four subsystems would be easier to achieve purely as probabilities. Lastly, because the posed equilibrial balance is not restricted to a single set of measured interrelations, changes across the overall system may be measured and evaluated, and related to various outcomes. For example, the onset of disease in a human organ might be identified through such forms of second-order pattern analysis long before overt symptoms are noticed, even through imaging attempts. In the case of stream basins, variations in the energy and topographical conditions within systems could be better analyzed and understood.

Concluding remarks

The stream basins example given here is not a biological one, but is offered in an effort to show that scientific models invoking final causes might not be so difficult to imagine as is usually thought. The suggestion here is that such systems might be self-organizing as a function of a sharing of information at the *subsystem* level. It is not necessary to invoke teleology or intelligent design to think in such terms. Would Wallace be surprised?

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