Title: Has 'natural' become nonsensical in ecology?

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Summary Paragraph:

The biosphere of the earth is inextricably connected, and virtually every ecological system, no matter how remote has been and is being altered by human influence. Ecologists apply categorizations to habitats and zones for comparison, for controls, for delineation of areas for protection and development and increasingly, for modelling predictions based on the effects of human activities. A problem is that the language used to make those categorizations is not standardized, not precise between authors and often undefined in text, leading the reader to assume the meaning of words and state of study areas. Lack of precision gives an avenue for criticism or obfuscation about the validity of findings. Here we show that the term 'natural', although ubiquitously used in ecology writing, is rarely defined, and when defined has a broad range of definitions between authors. We also found that the two most common definitions, "non-anthropogenic" and "without human influence", are applied almost universally to habitats with human influence. We argue that the term natural has become nonsensical and should be abandoned for ecology writing, and that more precise terminology is always available in the authors' lexicon.

Introduction

The biosphere of the earth is inextricably interconnected so that no system or organism can be said to be completely isolated from the rest. Now, in the Anthropocene era, there is evidence from virtually every ecological system on earth, no matter how remote, that human activity has and continues to affect it. The debate around human influence is no longer about whether it is happening, only its scale. There is strong evidence that we dominate most of the largest of the planetary dynamics: atmospheric composition[1], nutrient fluxes[2,3,4], global rainfall patterns[5,6], oceanic ecology through fishing[7,8,9], terrestrial ecology through farming, and as a vector for the transport of invasive species from all taxonomic groups[10,11,12,13]. Currently, we are the greatest cause of extinctions[14], and are driving changes in physiology in many organisms[15,16,17]. We are also creating novel habitats such as the "plastisphere" through the introduction of persistent waste[14,18]. It's arguable that humans are now even the largest driver of phenotypic expression[16,17,19]. We truly, indisputably, are in the Anthropocene era.

Human alterations of ecosystems are now so ubiquitous that it would be very difficult to find and study those that have not been influenced by human actions. However, for a very few ecosystems, their unique isolating boundaries may have kept them more resistant to alteration by human activities, or some may not have been altered due to the time scales at which they interact with other parts of the biosphere. An example could be in areas of the deep ocean, not trawled or drilled, to where no rubbish has been dumped or sunk, and where circulation patterns take thousands of years to bring the dissolved gasses of the current atmosphere. Likewise, sub-glacial or subterranean lakes and water deposits may have been sealed off from the current atmosphere, and their microbial biota will most likely be unaffected by humans. It may be that ecologies such as extremophiles in hot water pools or those surrounding fumaroles may not have been altered by anthropogenic activities, as the positive pressure of their inputs coming from deep subterranean sources effectively keeps the surrounding environment at bay. Interestingly, there springs a dilemma for those who wish to study these systems, in terms of the ethics of potential introductions and alterations due to sampling. Is it reasonable to go looking for those few places that have not been altered with the potential to fundamentally change them? If they are changed, then they no longer exist in the same state, so by studying them with direct sampling we may cause them to cease to exist. This philosophical dilemma has led to guidelines for potential sampling of Antarctic subglacial lakes developed by both the U.S. National Academy of Sciences and the Scientific Committee on Antarctic Research[20].

Otherwise all ecosystems exist on a continuum of human influence from potentially unmeasurable to completely novel. We may be able to measure the accumulation of anthropogenic compounds in Tundra melt pond sediments, but may never be able to ascertain whether they are affecting the biota within that environment. That is not to say that effects are, or are not occurring, just that we may not able to be measure them. At the opposite extreme, mine tailings laced with cyanide, floating plastics in the ocean, or radioactive waste water deposits from Fukushima have unique functioning microbial ecologies that can be studied. These are completely novel environments that could not have existed without human activities to create them, and yet, without humans intentionally introducing the organisms that live within them, these ecologies now exist. Nylon metabolizing bacteria were discovered in factory wastewater ponds in 1975[21], yet nylon was only synthesized in the 20th century. These bacteria evolved to take advantage of a novel energy source, they definitely were not engineered to do so by humans. In these human derived ecosystems, all ecological processes need to be understood relative to human influences.

Should humans suddenly be wiped off the face of the earth, the equilibrium state to which most of Earth's ecosystems would return, would not be like what it was before humans started to alter it. It is obvious in the short term that we have already elevated levels of methane and CO2 in the atmosphere enough to change the current and near future climate. If humanity disappeared tomorrow, the earth's climatological rhythms would most likely return to patterns in keeping with what would be considered normal for the last billion years, within a few dozen millennia, but for the near future it is has been changed at a rate faster than ever before measured, or visible in the geological record other than from catastrophic events. The great number of species that have been driven extinct, as well as those invasive hoards transported to new areas of the globe mean that new ecological balances, competitors and predator/prey interactions have been created in nearly every environment on the planet. The ability of systems to recover to pre-alteration states is lost with the extirpation of key species of either flora or fauna, and although this has always been occurring, the pace of change has undoubtedly been on the increase over the last three centuries. In New Zealand for example, the only land mammals as recently as 800-1,000 years ago were bats. Humans have introduced at least 32 mammalian species now considered part of current New Zealand fauna, not including livestock[22]. Whereas birds, many flightless, once filled the various niches of large land animals; without humans, the extinct birds would not return and the introduced mammals would not vanish. New Zealand then is a perfect example of how all future ecological systems will have been altered by human activities of the last few hundred years.

The term 'natural', although used ubiquitously in ecological literature, is most often left undefined and when it is, the definition is not consistent. This paper is not the first to address the ambiguity. Margules and Usher[23] noted the difficulty of defining naturalness yet used it as criteria for assigning conservation values. Machado[24] proposed a framework for naturalness with 11 categories along a gradient, and a table for the diagnosis of naturalness. Anderson[25] aptly asked whether natural is a scientific concept, and proposed a definition that a natural system is one that would, "continue to function in essentially the same way if humans were removed." If we accept Anderson's definition, a mowed lawn or a planted field would not then be natural as it would soon get overgrown by shrubs, competing grasses, and eventually trees; very little of it would remain within a few years to decades if humans were removed. The counter definition, an 'unnatural system', would be one that would collapse if humans were removed. Attempting to be precise in using Anderson's definition, we go into extreme chain pedantism of terms trying to determine what is meant by "in the same way" without humans. We have to define whether a different assemblage of species will continue to function in the same way according to mechanisms of competition, selection and reproduction. If there is even one change in the assemblage or balance of species it could be an endless reductionist argument about at what point the criteria of a system "functioning in the same way" is met. Therefore, Anderson’s definition lacks a degree of precision and also eliminates the possibility of humans being considered a component of a natural system. But there are probably no systems that would continue to function in exactly the same way without humans, or few enough to make the term irrelevant.

Do systems then have to be without anthropogenic influence to be considered natural? If so, there are very few that could be considered wholly natural. We as a species, have caused changes to our environments on large scales since pre-history, not solely since the agricultural revolution of 10,000 years ago or the industrial age. Pickett and McDowell[26] edited an excellent review of subtle but large area effects by humans on the scale of biomes, while also pointing out that ecological study and management often fails to account for them. For example, elk (*Cervus canadensis*) are a keystone species in and around Yellowstone park in Wyoming; their browsing can denude river margins causing changes to canopy height, vegetation composition, stream hydrogeography, density of beaver populations and whitetail deer. The reintroduction of wolves is expected to cause a drop in the elk population within the park, but not to pre-European levels. This suggests that Native American hunting of elk was just another predatory pressure shaping the ecology of the area, one which would have been relatively stable for thousands of years, but human predation was left out of initial management that closed the park to modern hunting. A central theme of their book is that the science of ecology must now shift to consider humans as a component of, rather than outside of the system, and that there is no fundamental understanding of any ecology without understanding the anthropogenic role. Alberti et al.[27] draw the same conclusion that humans are conspicuously excluded as subjects of much ecological thinking and experimentation and should be incorporated into all aspects of ecological thought, yet still define 'natural' as "nonhuman".

At the same time humans have evolved and are living animals, so how is it that we call an anthropogenic modified system 'non-natural', when all organisms modify their environment to some extent? If we do say that an anthropogenic system is 'non-natural' then we must decide at what extent of modification it changes from 'natural'. There is a circa 200,000-year history of *Homo sapiens* existing on the planet, and at some point in that continuum we must have to have been considered part of the natural environment. Either, when the first individual that we would call fully genetically human was born then the first non-natural environment was born with it, or we must pick an arbitrary point at which human modification was severe enough to be called non-natural. Was it when weapons such as spears appeared, or deliberate fires were used for hunting? Was it when humans begin to build houses and if so, what level of size and materials separates these from the 'naturally' built nests of hominid apes? Was it at the agricultural revolution when humans begin to transport and modify plants and create small monocultures? Perhaps it was the industrial revolution and the beginning of the use of fossil fuels? In any case, if a point is picked, then it is arbitrary and subject to debate.

There is a third possibility, which is that all systems, even those modified by modern humans such as mine tailings or radioactive ponds, could be considered natural as they exist on earth and are due to a population of living animals. And a fourth possibility, that almost no systems on earth could be called natural due to human influence. But if all systems, or no systems can be considered ‘natural’, then what use is the term as a distinction?

We thought that a start to answering that question was to determine how the term ‘natural’ is most often used by ecologists, whether there is consistency in its use and whether it is defined or assumed in current ecology literature.

Results

We found that there is not consistency in how different authors' studies of ecology conceptualize and use 'natural', and each of the definitions used can be problematic. Although the following section shows many examples of logical or semantic contradictions, the goal of this paper is not to criticise individual authors. Each has a mental concept of what is natural, and each concept is personal and unique. Confusion arises in that when left undefined, the author is assuming the reader understands the same concept.

Natural as "non-anthropogenic"

Most commonly, one third of the reviewed articles either directly defined or implied that natural meant non-anthropogenic, yet nearly half of those referred to natural systems that have humans as a component (figure 1). Yousafzai, et al.[28] refer to "non-anthropogenic or non-controlled systems" as natural, but then say that, "Natural aquatic systems are extensively contaminated with heavy metals released from domestic, industrial and other anthropogenic activities", and were also subject to extractive fishing and other human uses. Thrippleton, et al.[29] in discussing the main over-storey disturbances in European forests contrasts the natural disturbances of windfall, to anthropogenic disturbances and browsing as a biogenic disturbance. It can be argued then, that browsing or anything biogenic is a non-natural occurrence. We know of course that the hydrological cycle is hugely influenced by biogenic transpiration, and that in this case, the biogenic cannot be separated from the natural. Sheppard-Brennand, et al.[30] call variations in urchin populations "natural" if they are not anthropogenically caused. Yet natural predator densities are inferred to be that which co-exists in the survey sites, even if those predators are fished species.

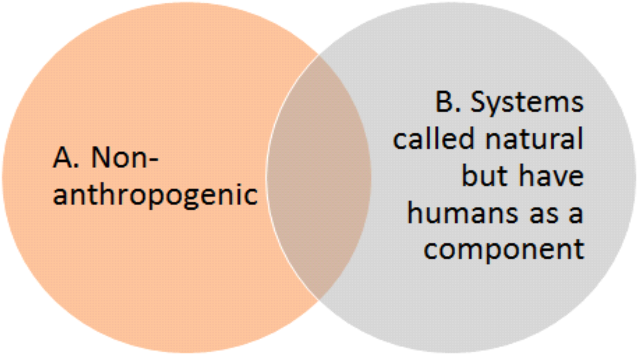

Figure 1 – Venn diagram illustrating the overlap of A. articles defining natural as 'non-anthropogenic', and B. articles with study sites defined as 'natural' that have humans as direct components or ecological actors within those systems. Given that A by definition excludes B, there should be no overlap, yet 46 articles within this study did overlap. The area falling within the circles represents articles in which the authors' definition of natural excludes their own natural study site.

There is further inconsistency within articles using non-anthropogenic, as to whether indirect human influence, or only direct human influence limits a system from being 'natural'. In 42 out of the 107 articles using non-anthropogenic as a definition for natural (table 1), our reading of their criteria was that only direct effects were included. Bhardwaj, et al.[31] call the suite of fungi sampled from the rhizosphere, "natural", but from what they called a “natural ecosystem” of agricultural monocultures in cropped fields, There is no distinction about how those fungi appeared, they could have been native to that area, or introduced as passengers with the latest plantings. The implication is that only intentionally introduced fungi would be ‘un-natural’. In discussing behavioural changes as adaptations to a changing climate, Beever, et al.[32] calls unpredictable food shortages caused by droughts, “natural”. Some droughts will be due to indirect anthropogenic climate change though, meaning only direct anthropogenic effects can be unnatural. David, et al.[33] has the same dilemma studying storm disturbances in dune communities, and indirect effects are excluded in several other articles in which non-anthropogenic is the meaning of 'natural'[34,35,36,37,38,39,40].

The next step in the continuum of papers using a definition of non-anthropogenic is in which it is ambiguous whether indirect anthropogenic effects are part of the natural world. Parasites play a "natural part" in marine food webs but should be viewed separately from outbreaks in stressed host populations[41]. Effects on hosts from the same species of parasites then, can be natural or unnatural depending on the state of human influence.

Finally, for 20 articles, the 'natural, non-anthropogenic' sites explicitly exclude even indirect effects of humans. For example, Fedriani, et al.[42] states "Seed dispersal by vertebrate frugivores is an important element for successful woody recolonization of both natural and human-altered landscapes." So, any human-altered landscape then is not natural. Confusingly this article includes a second definition of natural, meaning 'not human directed' (seed dispersal) and has study sites within systems where humans are a component. The contradiction in excluding any human influence in the definition of natural, yet having a study site with humans as a component can be found in other articles within this study[43,44], and it would not be surprising if pressing the authors in the articles in which no definition was supplied or implied.

Natural areas outside of a model, microcosm or lab

Many ecology experiments are carried out by comparing manipulated conditions, such as in a lab, to non-manipulated conditions either in situ, or increasingly through computer modelling. Of the articles included in this analysis, 49, or 15% of them referred to the natural world or natural environment as that which was not in a manipulated site. Their natural systems ranged from: at one extreme, those with no anthropogenic activities[45,46], intermedials with some human activities such as secondary regenerating forests[47], fished marine ecosystems[48], currently grazed pastoral land[49,50], ponds in Hungary and Minnesota near human settlements[51,52]; and at the other extreme, acetate panels hung within a marina in Queensland[53], coking sludge from bio-activated treatment tanks[54], anywhere that a symbiotic mycorrhizal fungus occurs outside of laboratory[55] or even any non-laboratory site[56].

Natural areas previously or currently grazed, logged or cropped

There are huge areas of the terrestrial world that are in some stage of recovery from past human disturbance[57,58,59]. At least 15% of the articles reviewed here considered study sites within areas previously or currently grazed, logged or cropped to be natural. Some of these include full canopy recovering forests[47,60,61,62,63]. Others refer to shrubland or grasslands unmanaged, but grazed[49,64,65,66]. Currently used paddock, forestry and cropland is considered natural by other authors[50,67,68], even if a monoculture[31].

Natural populations that are subject to fishing or hunting pressure

Many of the most studied species in ecology are those with the most economic or recreational value, and when studying these populations, natural mortality is often distinguished from fishing mortality or hunting mortality. Extractive use at even minimal levels alters population densities and community structures, though especially with selective harvesting such as trophy heads or larger individuals[69,70], and considering the wider impacts of non-extractive human activities[71,72,73,74] and the fishing induced alterations to the wider community[73,75], any ecological study of an exploited system needs to acknowledge human effects greater than only direct mortality. It is probable that any extrapolated direct cause of natural mortality in an exploited population will be different from the rate in an unexploited population, suggesting that at the least, a temporal component be added such as instantaneous natural mortality. The 24 articles or 7.4% of the total in our analysis with exploited populations included fish[76,77,78], birds[79,80], rodents[81,82,83], elk[84], zebra[85] and invertebrates[30].

The above examples, ranging from environments with minimal measurable human influence to coking sludge all being called 'natural' validate that there is an extreme range of use, and most importantly, no consistency in the mental construct of the term, ‘natural’. Adding to the confusion, generally, the definitions given or implied are not affirmations of some attribute that makes up natural, but rather a description of what is not natural. For example, defining a natural system to be that which is not used for agriculture, means that any other system including an urban environment is included. Defining something only through the use of what that thing is not, leaves a lot of room for uncertainty. Further, 66 or 20% of these articles have no definition or even implied definition, which means the above percentages understate the actual level of inconsistency.

Should each author then be required to provide their own definition within each essay? For example, if an author uses 'the wild population' instead of 'natural' to describe a population of Atlantic salmon as opposed to caged salmon, there will be less ambiguity for the reader when they are trying to determine if what is meant is all free ranging salmon, or excludes escapees, or excludes populations interbred with escapees. Given the confusion and with respect to previous authors' attempts to categorize naturalness and define 'natural', it may be time to discard the term from use in ecology literature. In the Anthropocene era, only those ecosystems that are disconnected from the current atmosphere can remain without anthropological inputs, so our terminology of ecology must keep pace with this fact.

Conclusion

Ironically, the best term to describe that timeline of which we are on the cusp is 'natural history' and we truly are on the cusp of a period in 'natural history' in which humans are altering every part of the fundamental makeup of planetary ecology. We would argue then, that the term 'natural' belongs in the past era and should be discarded from use going forward in ecology writing. There is always a more precise term to use, such as 'previously logged' or 'non-laboratory', or 'urban greenspace' that takes away the need for the reader to assume the state of a site. Perhaps we are being overly pedantic in calling for authors to stop using the term 'natural' as it's such a ubiquitous word that is infused everywhere colloquially. An analogue would be the word 'significant', which has a different usage in science writing than in general speech. Machado[24], Anderson[25], Margules and Usher[23] and others took the first steps in describing the ambiguity that exists with the term, and they attempted to address it. The results of this study clearly show though that even amongst those most immersed in ecological study, there is an assumption of commonality of concept, but that no commonality exists.

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Table 1 – Usage of the term ‘natural’ from 324 recent articles in top rated journals of ecology.

Usage of 'Natural'	Criteria if definition provided or implied	number of articles	% of all articles
Implied		216	66.7
Not defined		66	20.4
Defined		42	13.0
	Systems called natural but have humans as a component	154	47.5
	Non - anthropogenic	107	33.0
	Without direct human influence	86	26.5
	Natural is outside of a model, microcosm or lab	49	15.1
	Natural within areas previously or currently grazed logged or farmed	49	15.1
	Multiple definitions or implied definitions	38	11.7
	Non - agricultural or aquacultural areas	33	10.2
	Natural populations subject to fishing or hunting exploitation	24	7.4
	No human influence at all	23	7.1
	Semi-natural or other term with 'natural' used	19	5.9
	Not built	19	5.9
	Not managed	18	5.6
	Natural systems even within sub/urban areas	17	5.2

Methods

A preliminary sample of peer reviewed articles was selected by searching for the keywords ‘natural’ and ‘ecosystem’ using Google Scholar. The first 40 studies of ecology with those terms were read to determine whether defining the term 'natural' is common practice, and we noticed that it was most often not defined. We then applied a systematic review protocol to the project by limiting our scope to the top 20 ranked journals of ecology by impact, taking the 20 most recent articles with the term 'natural' in the body of the article, yielding a sample size of 400 peer reviewed articles. This analysis was concerned with elucidating the usage of natural to describe ecological systems, interactions and conditions. Therefore, usages of the term 'natural' were disregarded as irrelevant if included in the phrases: "natural selection", "natural log", "natural history" or "natural resources". Remaining were 324 peer reviewed articles. Each was read to determine whether the authors had defined the term 'natural', implied a non-explicit definition, or left it undefined in relation to the ecology of that article's subject ecosystem. If the authors had provided or implied a definition of 'natural', it was characterized into 13 further criteria to highlight commonalities and differences of usage.