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Time is an affliction: Why ecology cannot be as predictive as physics and why it needs time series

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ABSTRACT

Ecological systems depend on both constraints and historical contingencies, both of which shape their present observable system state. In contrast to ahistorical systems, which are governed solely by constraints (i.e. laws), historical systems and their dynamics can be understood only if properly described, in the course of time. Describing these dynamics and understanding long-term variability can be seen as the mission of long time series measuring not only simple abiotic features but also complex biological variables, such as species diversity and abundances, allowing deep insights in the functioning of food webs and ecosystems in general. Long time-series are irreplaceable for understanding change, and crucially inherent system variability and thus envisaging future scenarios. This notwithstanding current policies in funding and evaluating scientific research discourage the maintenance of long term series, despite a clear need for long-term strategies to cope with climate change. Time series are crucial for a pursuit of the much invoked *Ecosystem Approach* and to the passage from simple monitoring programs of large-scale and long-term Earth observatories — thus promoting a better understanding of the causes and effects of change in ecosystems. The few ongoing long time series in European waters must be integrated and networked so as to facilitate the formation of nodes of a series of observatories which, together, should allow the long-term management of the features and characteristics of European waters. Human capacity building in this region of expertise and a stronger societal involvement are also urgently needed, since the expertise in recognizing and describing species and therefore recording them reliably in the context of time series is rapidly vanishing from the European Scientific community.

1. Introduction

The observation of regularities and variability in the way some natural phenomena occur led to the formulation of laws (e.g. Newton's law of gravitation or Liebig's law of the minimum) that, when applied, can lead to predictions. The transition from description to prediction, then, is considered as the ultimate objective of any "mature" science, and this is invariably achieved through mathematics, whose use, indeed, is considered as the basic sign of the solidity and exactness of science. This stems from Kant's claim that "*in any special doctrine of nature there can be only as much proper science as there is mathematics therein*" (Kant, 1786, p 6). Since physics is the most mathematized science, epistemologists tended to consider it as the most mature of all sciences, this being supported by a famous statement by Ernest Rutherford: "all science is either physics or stamp collecting" (as cited in Birks, 1962). Such statements have led the practitioners of other sciences, from ecology (Egler, 1986) to economics (Bennis and O'Toole, 2005), to develop the so-called physic's envy syndrome. This inferiority complex of non-physicists, however, is ill-based, as explained by Darwin (1859) in the "handful of feathers" argument: "*Throw up a handful of feathers, and all must fall to the ground according to definite laws. But how simple is this problem compared to the action and reaction of the innumerable plants and animals which have determined, in the course of centuries, the proportional number and the kinds of trees now growing on the old Indian ruins*".

What Darwin's example implies is that, in many systems, particularly ecological ones, processes cannot be explained by the application of fundamental physical laws alone. A system governed solely by physical laws is essentially ahistoric, governed by constraints (i.e. natural laws), and nothing could be gained by long-term observation of this system, as variability would be very low. While observations are still necessary for the formulation of laws, once these laws are defined, however, the behavior of ahistorical systems would be predictable in a mathematical fashion.

Ecological systems on the other hand can be described as historical systems as they are governed by both constraints and contingencies, and are inherently unpredictable, since the occurrence of contingencies cannot be predicted with certainty. The future behavior of historical

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systems, thus, can be assessed only in a probabilistic fashion, stemming from the analysis of both the history of the system including the processes that determined them. Rather than leading to firm predictions the end result of such endeavors is the production of scenarios for future developments.

The response of biological systems to physical changes in the environment can serve as an example. While these responses are ultimately governed by laws of physics described by mathematical relationships, the relevant processes are difficult to quantify and less easily intuitively predictable due to the great number of variables involved. Critically, interactions or feedbacks between these variables, might cause a system response to parameter x to deviate from what is predicted. It is easy to predict, for instance, that temperature increases will result in distress for cold-water species (as this is governed 'simply' by the physiology of the organisms involved), and will favor the establishment of warm-water species where they may previously have been absent. However, it is seemingly impossible to predict which species will become dominant, after ending up in regions affected by global warming. An example might be simple systems e.g. in the intertidal zone where interactions between a limited number of species have been well characterized by experimental studies backed up by extensive time series coupled with modeling (Hawkins et al., 2008; Hawkins et al., 2009; Poloczanska et al., 2008). It is thus important, to define the nature of the systems under study, achieving a level of awareness as to what is possible and what is impossible when carrying out analyses.

Otherwise ecological systems will be treated as if they were governed just by laws (i.e. constraints) leading us to study historical systems that are governed both by constraints and contingencies, solely with tools appropriate for ahistorical systems. Such approach is simply wrong. The success of 'predictive' ecology occurs when "nothing strange" happens, that is when there are no contingencies. However, as stated above, exceptions from a general rule are common in complex ecological systems with many abiotic and biotic interactions leading to unexpected long-term changes (and short-term variability). In fact without change there would be no evolution. These concepts are very clear in Darwin's Origin of Species, as argued by Boero (2010) but are being ignored by most ecologists who desperately try to transform a historical discipline into an ahistorical one.

The objective of this contribution is therefore to highlight the role of Ecology as historical discipline, which is governed by both constraints (i.e. natural laws) and contingencies leading to a complexity that can only be described using a range of approaches including but are not restricted to mathematical/modeling approaches. An acceptance then of the importance of history as a driving factor is what makes long-term data so important as they are the only means of judging possible probability ranges for future predictions on the basis of historic knowledge of the regularity of events.

2. The complexity of ecosystems

Constraints lead to a regular sequence of events, thus if a given set of conditions occurs, this will lead to another set of conditions and as long as the initial state of a system is known, then possible future states can be predicted.

The set of initial conditions can, however, be very difficult to determine in physical and chemical as well as biological processes. Chaos theory already showed that many systems, including ecological ones can be extremely sensitive to initial conditions (Huisman and Weissing, 1999; Levin, 2000; Levins, 1979; Norberg et al., 2012; Passarge and Huisman, 2002). The introduction of disturbances (at particular temporal or spatial scales) for instance can suppress the previous complex behavior in a community (as observed by Huisman and Weissing, 1999) and transition it into a deterministic system (Roelke et al., 2003). This means that an apparently irrelevant condition can have a relevant influence on the behavior of a system. Even chaotic systems, however, are constrained into the orbit of attractors. They can vary freely but within their bounds. Summers are warmer than winters, but we cannot predict the weather of next summer with mathematical precision. The seasons follow each other in a more or less regular fashion, but they are subjected to great irregularities within their "limits".

In the short term, the weather determines the functioning of ecosystems, whereas over the long term, climate is the regulating driver (Helmuth et al., 2006). The natural variability of the weather determines the yearly success of reproductive phenomena, then interacting with such biotic factors as predation and competition. The match or mismatch of weather conditions with phenological events can determine the success or the failure of recruitment of a given set of species, changing the composition of communities and thus also cause mismatches in the interactions between individual species e.g. competitors or predator and prey (Durant et al., 2005; Edwards and Richardson, 2004; Greve et al., 2005; Hays et al., 2005). This is particularly true in rapidly evolving systems, like the planktonic one (Durant et al., 2005; Stenseth and Mysterud, 2002). Since the water column is the most widespread type of environment of the planet, such events are far from rare. Climate changes can influence the distribution of species (Burrows et al., 2014), with long term changes that are not explained by simple seasonal variations. Change, in this framework, is the advent of irregularities in a presumably regular landscape.

Resistance and resilience account for the possibility that systems can withstand irregularities, resisting them or going back to the initial state after a disturbance (i.e. an irregularity) (Folke et al., 2002). However, most current predictions state that global climate change will alter biological diversity and the ecosystems we rely upon; but there is a general weakness in most of these predictions because they omit important, fundamental ecological processes such as species evolution and competition. Thus, the so-called "eco-evolutionary dynamics" occur frequently in nature and can influence responses to climate change (Norberg et al., 2012). Hence, without irregularities, the world would be monotonous. In fact Connell (1978), with the intermediate disturbance hypothesis, postulated that irregularities or contingencies (i.e. disturbance) prevent communities from being dominated by just a few species.

3. The role of history

In its recent publication 12 Compelling Cases for Policymakers, Science Europe highlighted marine environmental history for the relevance for future ocean management. It is argued therein that the research findings of marine historical ecology provide baselines of species abundance and distribution prior to modern fisheries. However, the implications of these findings for human history still need to be worked out. Paradoxically, in the example of fisheries history, much is still written with little or no reference to ecological theory (Holme et al., 2010). History studies the events of the past, reconstructing the patterns characterizing the system under study and identifying the processes that led to them. Human history aims to understand the past, but it does not aim at predicting the future.

In spite of this, historians can provide scenarios about the future, based on the experience they gathered by studying the past. The study of history, in fact, allows to detect regularities in the course of history, and the application of natural laws can allow for some weak predictions (von Storch and Zwiers, 2013; Weisse et al., 2012).

4. What should we do, then?

Naturalists, in the past, used to accumulate careful descriptions of natural events and, eventually, attempted to conceptionalize them in a logical framework. The theory of evolution by natural selection is an example of just this: Darwin, who defined himself a naturalist, accumulated an enormous amount of small facts, he carried out many experiments and very many observations and measurements, and then assembled them into a theory.