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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.

It is paradoxical, however, that ecology, the discipline that contributed the most to the construction of the theory of evolution by natural selection, did not contribute to the Modern Synthesis of the Thirties and Forties and stayed almost completely out of the evolutionary arena. Darwin did not use the word ecology, he used “the economy of nature” instead. With the advent of genetics and molecular biology, evolution became eminently genetic, whereas ecology followed another path, becoming increasingly reductionistic and focusing on proximate causes. Ecology, however, is far from reductionistic, being the science of interactions, and reductionism deliberately avoids interactions, disassembling complex systems into simpler ones (so reducing their complexity) to make them amenable to relatively simple statistical treatment. This was done in the hope of being able to later translate these individual analyses into a broader insight of the system under investigation. But the whole is more than the sum of the parts, so this approach has severe limitations. It is also not timely since in the age of anthropogenic climate change, ecology is far more than a topic of scientific interest. Ecologists are increasingly asked to interface with policymakers and thus to answer very practical questions related to the impact of climate change on human populations. As such the reductionist approach does not support the crucial question of how to address the changes we are facing in the Anthropocene (Glaser et al., 2012). What does it mean to be human in this geological period (Crutzen, 2002) and what are the implications of environmental insights to address the challenges of global environmental change?

In summary then, all epistemological analyses show that ecology cannot be ahistorical, reductionistic, linear, or predictable. It, instead, deals with historical, non-linear, holistic and unpredictable matters. This does not mean that current ways of conducting ecological observations are wrong, they simply are not sufficient. The mistake is not to pursue them, but to pursue ONLY them. It is fine to detect regularities or patterns, if these occur. But it is wrong to presume that only regularities (i.e. constraints, laws) govern the natural Earth system. This presumption will lead to misunderstanding and mismanagement of natural systems. The economic and environmental crisis we are currently facing is a product of just this attitude, pervading not only ecology but also economics.

5. And now: back to history!

To understand and interpret complex, historical events long-term observations are strictly necessary. The past can be reconstructed with paleoecology and paleontology but, if possible, it is preferable to study events while they occur. Natural historians did this in the past, but with the advent of more detailed ecological analyses the focus turned from mere observation to empirical and mathematical investigations sometimes losing sight of the importance of long-term observations as an important means of validating these experiments. In addition through the events of the second world war where being a naturalist was also inextricably associated with fascism, the population moved away from observing and noting nature in general — being a naturalist simple was no longer fashionable on mainland Europe. The English speaking world had less problems with this.

Now we are realizing that things are changing: we are experiencing global change. The first question is: how different is today's situation with respect to yesterday's? We need long-term observations but are (slowly) realizing that they are lacking for many areas. Often we collect data for just a few variables and for many different reasons. The abundance of fish and fish larvae is often not recorded for ecological but economic reasons. Many time series do not record species abundances or biomass at all, for instance, although we are so concerned about biodiversity. We are warned that species are becoming extinct at a very fast pace but, then, if asked: tell me three marine species that became extinct in the last decade… we do not know. We usually know very little about the history of whole communities and ecosystems, and we just have impressions, often of iconic species.

The Marine Strategy of the European Union rightly introduced many ecological variables in the descriptors of a good environmental status, but the conceptual and factual tools to measure them are lacking (McQuatters-Gollop, 2012; Mee et al., 2008). How to measure biodiversity? How to measure ecosystem functioning? Recognizing that these variables are important is a first step in the right direction, but now we must start to act wisely, correcting the mistakes of the past.

Indeed, an issue which is often overlooked in this dabate is, that environmental performance indicators (such as number of species in a given area) are often presented within already established frameworks that are generally built in a given societal context (Olsen, 2003). Thus, the application of certain descriptors and their respective judgment may need to differ between countries and between regions due to differences in demands, traditions, cultures or management systems. To take account of this array of complexity in the context of decision-making, a number of research supported approaches to indicator and monitoring systems have been developed and advanced to better understand the current and future interactions of various driving forces (Carpenter and Brock, 2006). However, these are somewhat determined by administrative and policy-driven scientific processes, resulting more often than not in a policy statement which mirrors what is socially acceptable (Cranford et al., 2012). Therefore it is important to be clear on whether the descriptor of Good Environmental Status is determined by policy decisions or by changes in ecosystems.

One way to address these difficulties, is that ecosystem managers increasingly use a monitoring endpoint, known as thresholds of potential concern (TPC), to decide when management intervention is needed (Biggs and Rogers, 2003). TPCs are a set of operational goals along a continuum of change in selected environmental indicators (Gillson and Duffin, 2007). TPCs are being continually adjusted in response to the emergence of new ecological information or changing management goals (Cranford et al., 2012). They provide a conceptual tool that enables ecosystem managers to apply variability concepts in their management plans, by distinguishing normal “background” variability from an important change or degradation (Gillson and Duffin, 2007).

6. Monitoring and observation

Marine scientists and particularly oceanographers are very good at gathering data or rather at monitoring. We have conceived many sensors that can measure abiotic variables in a very efficient manner, with drones, satellites, buoys, moorings, AUV and gliders and other instruments. Molecular tools can inform us as to which genotypes are present in a water sample. But this is not enough. Sure, we can monitor many things, but in the process and unless we take a holistic approach at the same time, we run the risk of losing contact with the sources of contingencies, particularly the intricacies of relationships among different variables (Wiltshire et al., 2010). Monitoring implies a predetermined set of variables that are measured at a regular pace and that are presumed to be good descriptors of the quality of the environment. With the new visions of the European Marine Strategy, however, monitoring is clearly not sufficient. It is very important, of course, but it is not sufficient. The shift from monitoring, usually with standardized instruments, to true holistic sustained observation implies the direct intervention of humans in the study of the marine environment. Humans observe and are able, if properly instructed, to detect changes, even in variables that are not covered by standardized protocols. A mass mortality event, for instance, is usually not part of a monitoring effort, just as a massive occurrence of a species that is usually rare or even absent. These events are the contingencies that might re-direct the path of history of a given system (Boero, 2013a).

Boero and Bonsdorff (2007), for instance, argued that the jellyfish blooms of the early Eighties determined, in the Adriatic, a series of phase shifts from an initial stage of fish abundance to a jellyfish phase, followed by a red tide phase and then a mucilage phase. These phase shifts were not perceived as such, while they were occurring, and were studied only in their proximate causes, without considering the ultimate ones, i.e. the influence of past events on current ones.

6.1. We need observatories!

Marine stations originated in Europe as sites to carry out experiments on organisms that are not easily kept in land-based laboratories (Franke et al., 2004). As such they were also ideally placed to become focal sites for the study of local biodiversity structure and function. This work could easily have led to the establishment of time series in many sites, if a coordinated policy had been enforced. Unfortunately it was not. Each station developed its own peculiarities, and became conditioned by the inclinations of the scientific community inhabiting it. Some stations started time series, usually of plankton, others did not. Some developed innovative tools to monitor plankton biodiversity, such as the Continuous Plankton Recorder (Reid et al., 2003), others simply used standard instruments, mostly plankton nets and bottles. Therefore the available time series suffer many problems. For example, instruments differ from station to station, the expertise is different, with different levels of taxonomic accuracy in the identification of species (and varying expertise for different subspecies of the resident communities), the sampling frequencies differ between species and the way information is stored is different from station to station. In other words, there is not a coherent system of observation of the features of our oceans. We have satellites and buoys, but they provide just a few, basic variables. There are cruises with oceanographic vessels, but, with few exceptions, they are linked to specific projects and do not allow for continuous measurement of environmental quality, although many research vessels do collect a number of basic oceanic parameters. The research icebreaker Polarstern for instance has collected 20 year time series (and older in some cases) of CTD profiles and other measurements (Nunez-Riboni and Fahrbach, 2009).

This is not to say that everything about these stations' sampling programs has to or even can be made equal. Indeed it is important that individual stations follow their own approaches adapted to the needs of local stakeholders. Some differences will always remain due to local funding and research programs but differences need to be better documented, understood and, hence, managed so as to make programs in different stations more comparable. Incidentally this also makes economic sense as better co-operation such as equipment and sample sharing will also save money and facilitate more intensive analyses. A particular problem, at least for stations hosting plankton time-series, is that different time series have very different approaches in general. Many of the oldest stations producing time series data adhere to traditional sampling and analysis methods and have to do so, to maintain internal consistency (Wiltshire and Dürselen, 2004). Often these stations integrate new technologies. These are not usually designed to replace existing measurements and counts (at least for the foreseeable future). These provide valuable additional data but also data archival challenges. Many of the younger time-series, on the other hand, have adopted automated or semi-automated measuring devices, producing high frequency measurements of oceanographic parameters but increasingly also plankton biodiversity data (Olson et al., 2003; Sosik and Olson, 2007). While traditional time series are usually run by taxonomists or professional phytoplankton analysts the expertise employed for "innovative" time-series is IT and engineering centric. However, taxonomic expertise is needed for training and validating the automatic image recognition system. The situation is made even more complex by the inclusion of molecular methods, which by now are also being developed to run automatically or at least semi-automatically (Dierck et al., 2008; Metfies and Huljic, 2005) and can, at least in theory, detect organisms without anybody ever having seen the organism, essentially creating a new kind of 'taxonomic' science that cannot be judged yet with respect to how well it matches to traditional taxonomic science. Therefore, while there are still many areas for which data are lacking, we are at the same time facing a shifting paradigm since, in some areas, we face an unmanageable data deluge rather than data gaps (Borgman et al., 2007). What we are really facing then is a growing data diversity (within time-series) and a potentially greater inequality in what is being measured (between time-series) and we need new collaborative concepts for dealing with this type of diversity (Kraberg and Schäfer, 2014). Several large organizations are already in place that could facilitate a better co-ordination of our observational efforts e.g. the Partnership of the Global Ocean (POGO) and the Group on Earth Observations (GEO) who seek to provide an element of governance and reduce fragmentation globally. The newly emerging EUROMARINE has similar goals at the European level having emerged from the three large EU networks of excellence Eurocean, Marine Genomics and MarBEF (Marine biodiversity and ecosystem function, see http://www.euromarineconsortium.eu/).

Marine stations are the perfect tool for observatories. Nothing need be invented anew, and rarely does a new station need to be set up — we just have to use and better co-ordinate the available resources. This involves not only both the management of sampling and analysis but also the making available of existing data to the scientific community, and most importantly, appropriately targeted long-term funding.

6.2. Observations do not pay!

Contrary to any logic, many marine stations are in a financial crisis and are running the risk of being closed. Helgoland Roads is one of the few marine observing stations where its use was recognized, its data is placed in an institutional frame work (Wiltshire et al., 2010) and the monitoring is secure. Importantly in contrast to other marine stations this was achieved without intermittent closure or a reduction in monitoring intensity (see Hawkins et al., 2013).

Some stations have been closed already, including the Port Erin Marine Laboratory and the Wellcome Laboratory in Robin Hood's Bay in the UK; others are being re-addressed in their priorities, even though Arnaud et al. (2013) recognize their important role in evaluating the state of the environment with the collection of long-term time-series data. In spite of these recognitions, traditional knowledge on biodiversity (i.e. taxonomy) is being lost. Knowledgeable experts retire and are not replaced by trained personnel, hoping that automatic measuring devices can replace them. The reason for all these is very simple. Observation over the long term is, by definition, a long term investment. Current practices, instead, require short term results. Projects cover from three to four years and chances are that, once finished, they will not be renewed, since new topics will be present in the respective funding calls. Scientists work in the short term and are forced to produce quickly, so as to foster their own curricula with many publications. Once triggered, this mechanism is very difficult to stop and only a top-down impulse can have some effect. Scientists with overly inflated curricula tend to perpetuate their approach and, due to their publication scores, ridicule natural historians while praising their own accomplishments. It is not by chance that, in the era of biodiversity, the basic science of biodiversity, i.e. taxonomy, is running toward extinction in spite of the enormous funds made available to discover new species (Boero, 2010). It has to be noted however, that much of this funding is devoted to molecular taxonomy, which in theory does not even rely on the description of classic morphological characteristics, not to speak about what species do to make ecosystems function. Paradoxically, the morphology and ecology of many "new" species detected with molecular methods are unknown, the new taxonomy being even more typological than the old one.

The Catch 22 situation then is that, if natural history is almost extinct, who will pledge to its continued support? Ricklefs (2012) did so with the American Society of Naturalists, but the result of his call for a revival of natural history is still to be seen, in the US scientific community!

7. A strategy for long term observation systems

Wiltshire et al. (2010) describing the 45 years of data collected at the Helgoland Roads time-series station is a good example of what a long-term series can accomplish in following the evolution of an environmental system through the continuous record of its features with standardized methods and detailed data archival that make the data interpretable (and reveal past mistakes). This time series, initiated in 1962, is one of the temporally most detailed time series in the world. It has been used to study long-term trends in species composition of the phytoplankton around Helgoland, and to closely monitor the impact of new species on the system, with the possibility, due to its high temporal resolution (work-daily samplings) to elucidate food web interactions (Hoppenrath et al., 2007; Loebl et al., 2009; Lohmann and Wiltshire, 2012; Schlüter et al., 2012).

Similar experiences are being made at other marine stations, such as those at Plymouth (Soutward et al., 2005; Widdicombe et al., 2010) and Naples (Zingone et al., 2010). A co-ordinated strategy is therefore necessary, especially in the present period of fast change of ecosystem structure and function. A common observation protocol, and its enforcement at strategic sites, is badly needed, to evaluate ecosystem features in the light of the definition of Good Environmental Status, as required by the Marine Strategy Framework Directive of the European Union, which could provide a common framework/strategy for the co-ordination of these observation programs. The usual project-oriented policy of research is inadequate to achieve this. Projects can be launched to define the protocol, with some experimental phase aimed at the tune up of the system. But, after the launch phase, the system of observatories must receive direct long-term support, with the training and the recruitment of specialized personnel, and with the construction of dedicated databases aimed at storing the information and at analyzing it as soon as it becomes available. This will provide the capability to answer urgent questions such as: what are the hot spots of change? What are the trends that can be observed at various geographical scales? Are these trends consistent, or are they linked to local conditions? What might be the adaptive measures to face such changes? These and many other questions that might arise in the future. A considerable problem in this respect is that funding is often much easier to obtain for setting up new projects and databases than for the provision of continued and long-term support, as the latter is not seen as innovative. Nevertheless many large database projects have now emerged, that between them can facilitate archival of most types of datasets: e.g. biogeographic diversity data in Ocean Biodiversity Information system (OBIS/EUROBIS), the Global Biodiversity Information Facility (GBIF) or the Pangaea repository (http://pangaea.de). Not all available database systems can deal with biodiversity data efficiently. However, they at least facilitate the long-term preservation and use of available time series data.

Observation systems must be adaptive, with a 'learning by doing' attitude that is often absent in rigid monitoring systems (this has to happen without jeopardizing the integrity of an individual time series — flexibility yes, but in the right places). Such enterprises must be linked to the observation of fisheries trends, also to enforce the ecosystem approach to fisheries (Fogarty, 2014; Sarto et al., 2014).

8. Citizen science

Krause and Welp (2012) stressed that in the Age of the Anthropocene, the application of systems thinking within broader social learning by whole societies as a common endeavor (Kates, 2001; Siebenhüner, 2004), is a central challenge. They argue that social learning for sustainability would benefit from a better understanding of systems thinking among ordinary citizens, as it is not sufficient only for experts to be knowledgeable (e.g. about marine ecosystems). The public needs systems thinking in order to understand processes that take place in our economies, environment and societies. This involves time lags, non-linear behavior and feedback loops, and other patterns of behavior that are typical of complex systems. If long-term political measures, for example to mitigate climate change, are to be legitimized in a democratic decision-making process, citizens need a level of systems understanding that is appropriate to the situation. What this appropriate level implies and what kind of approaches to learn systems thinking are useful in practice are two of the core issues yet to be discussed (Krause and Welp, 2012). But it seems obvious that interested scientists and other volunteer programs even with very limited means can make a contribution toward complementing much needed monitoring efforts of the marine coastal environment.

In spite of the wide geographical distribution of marine stations throughout European waters, many portions of the European territory

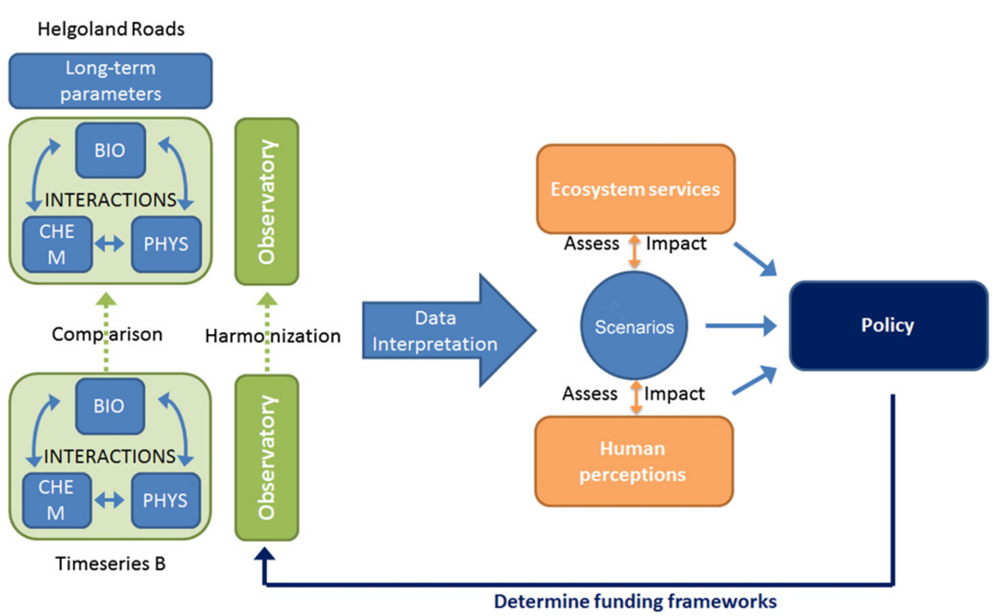

Fig. 1. Summary of the cycle from first generation of time series data toward addressing their societal relevance and recommending areas for policy action that will support. A sound interpretation of available data will require a considerable collaboration/harmonization between Time series stations and joint analyses of multiple datasets, here using Helgoland Roads and a hypothetical 'Time series B' as an example.

remain unstudied, due to the scant number of marine scientists. Citizen science is an approach which can be harnessed to cope with this problem, at least for some variables. Boero (2013b), for instance, showed how citizen science can accumulate valuable information about the occurrence of gelatinous plankton blooms, even leading to the discovery of new species and to new records of species previously unknown from a given geographical area (see also: Cheney et al., 2013; Hidalgo-Ruz and Thiel, 2013; Hsu et al., 2014). Similar projects also exist in the UK (see http://www.seasearch.org.uk/). Other variables that can be easily covered by citizen science are mass mortalities of conspicuous organisms, harmful algal blooms, concentrations of marine litter on the coast, occurrence of unusual abundances of any species, arrival of conspicuous non-indigenous species, etc. Many such projects are now emerging using a range of different tools to empower local citizens to partake in coastal/marine observation projects (Grant, 2010). An example using information technology is the Secchi disk project in which a person can download an app to report Secchi disk depths (http://www1.plymouth.ac.uk/marine/secchidisk/Pages/default.aspx).

In this way the involvement of citizens as observers in marine research is also a good tool to improve Ocean Literacy, another stringent priority in EU policy (Adams and Matsumoto, 2009; Boubonari et al., 2013). The only way to foster ocean literacy, in fact, is to commit citizens to carry out scientific enterprises, making them feel important in the progress of scientific knowledge. Marine stations, but also public Aquaria and Marine Protected Areas, are the ideal centers for the spread of marine and maritime culture, linking the scientific community to the public at large.

8.1. Information is not knowledge, knowledge is not wisdom

Historians gather information and transform it into knowledge, but this important step is not enough. If we cannot predict the future with mathematical precision, we can, however, acquire the wisdom that will allow us to design future scenarios that are conducive to our well being. We cannot predict when something will happen, but we can predict that something will happen. The precise prediction indicating 2048 as the year in which the populations of the currently exploited fish species will collapse (Worm et al., 2006) has been disputed by several authors. However, even if we cannot predict with precision when the last fish will be caught, we can predict that if we continue to tap at this rate from fish populations, these will become exhausted. And we can predict that, if we culture carnivorous fish species, and feed them with smaller fish from natural populations, sooner or later even these populations will become exhausted. We can make mistakes in predicting “when” something will happen (e.g. the collapse of fish populations in 2048) but we can be quite sure about “what” will happen (if we continue to fish in this manner, fish populations will collapse). Indeed, it is more about the “what” and “how”.

The predictions are there anyway, they are not precise in a mathematical fashion, but they are sufficient to encourage us to change our attitude in interacting with the rest of the natural world. Natural history, observation, citizen science, ocean literacy, marine stations, long term series are key words that will have to be seriously considered in the future, if we want to achieve the result of keeping this planet a hospitable place for our species.

9. Summary and conclusions

It has been known from the early 19th century that long-term observations can be an important tool for understanding our environment (Roberts, 2009). Time series exist for a huge range of parameters from flowering periods of alpine plants to atmospheric time series and plankton or fisheries time series. However, with the growing importance of ecological studies time series were not seen as timely anymore and many were facing funding problems that led to gaps in data coverage or cessation of the entire time series. We are now coming full circle in that the long-term consequences of anthropogenic climate change require the analysis of historical data for the assessment of climate change impacts on the marine environment and importantly on the services it provides for coastal populations. Indeed, renewed interest in the early 21st Century led to restart of some time series (Hawkins et al., 2003; Soutward et al., 2005). However, the data coverage even for coastal areas is still rather patchy and strategies are therefore urgently needed to harmonize sustained observing and even analysis efforts. Importantly, while this is particularly true for biological data it is clear that these time series always need to be supported by a minimum of physical and chemical oceanographic data.

However, it is now vital that we take time to understand the processes and develop research strategies that are viable — harnessing human emotions about the environment and using novel technological tools (e.g. smart phone apps) to promote social collective discovery and learning. The emphasis must move from the need to simply ‘know more’ and deploying even more information to policy and expert circles toward the development of adaptive cross-sector capacities and new types of knowledge (Mahony, 2013). Especially since efficient communication at the Science–Policy interface might also influence the development of future funding frameworks and therefore also influence how long-term observing systems can develop in the North Sea (Fig. 1). Such knowledge in our view allows a more adequate response to the changing dynamics of ecological systems in the Age of the Anthropocene. This is timely, as the era of the industrial revolution removed people far from nature. However, a transition in perceptions has taken place ever since the reports of the Club of Rome in 1972, Brundtland Report 1987, the 1992 Earth Summit in Rio and its follow-up in 2002 in Johannesburg. Thus, awareness of the disconnection of man and nature is increasing and could be harnessed for long-term observations of nature.

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