(COMMUNIQUÉ) Disruptions in environmental sciences: tracking changes in scientific priorities and concepts (1970-2014)

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A U T H O R ' S I N F O

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A B S T R A C T

The paper presents data and criteria on the potential application of the concept of "disruption" within the trajectory of Ecology and its applications in the broader environmental science (-s) realm. Disruption is considered as a phenomenon that transforms drastically academic practice in the sense of the re-organization of research priorities followed by the creation of new academic aggregates and/or value networks. Two exemplary cases, distinctive but indicative, are examined in this perspective: "biodiversity" and "Information & Communication Technology" (ICT) applications in SMART transportation in urban setups". Data are extracted from the *Web of Knowledge* data bank on research publications. Criteria are differentiated regarding publication series of academic activity, i.e. *ISI* publications, on the respective fields. Both indicate that a sharp conceptual transformation has occurred after 2000 in environmental science *sensu lato*. The question of forecasting is set regarding the research production of scientific research in environmental fields.

K E Y W O R D S (in alphabetical order): *Biodiversity; Big data; Disruption; Information & Communication Technology (ICT); Transportation*

Introduction

What makes "progress in science" constitutes a longstanding problem in epistemology and philosophy of science (Polanyi 1969; Kuhn 1970; Lakatos 1978; Popper 2002). Ultimately, the questions of the very essence of a "scientific theory", the process of its construction and/or the process of its verification remain more or less unresolved. In scientific domains such as Ecology and applied environmental science(-s), these questions predominate because of their implications in addressing higher level ecological complexity, statistical strategies in experimental design (e.g. Peters 1991; Hilborn and Mangel 1997) and/or bridging and transfer of knowledge between "science" and "policy" (e.g. Pielke 2004).

In Ecology, for instance, the epistemic question on the "theory making" problem remains still open regarding environmental-problem solving issues, following Kitcher's distinction (1985): is it "bottom-up" approaches, i.e. accumulation of statistical evidence over a large number of individual cases, that lead to theoretical explanation of ecological/environmental phenomena -and therefore underwrite talk about practical environmental problem-solving- or, in the contrary, is it "top-down", exceptionless general laws that are required to be used in specific phenomena (e.g. Shrader-Frechette and McCoy 1993)? Within the realm of environmental "meta"-science (-s), the above complicates further given the answers that are provided by positivists, realists and relativists in a discourse-dependent narration insofar as Ecology is an applied endeavor - e.g. conservation biology and planning - that moves from singularity to explanation than one that proceeds in the opposite direction.

In simple or simplified words, this question is translated into how long time information on specific cases, empirical or conceptual, could be translated into useful knowledge. And, how many or long back steps might be recorded if we are not careful in the knowledge acquisition processes of the so-called "information or computer age" (Silver 2012)? In the era of "big data", the prediction by Anderson (2008) that the volume of data would obviate the need for theory, and even the scientific method, overcomes the usual epistemic discussion or controversy on "theory".

The present paper attempts to examine progress in Ecology and environmental science (-s) as disruptions in the incremental path of incumbent scientific production. I use the term "disruption" in the sense proposed by Christensen (1997) regarding "innovation" in "technology": in other words, I propose disruption as a sharp contrast between concepts or research priorities that help create new academic aggregates or value networks displacing older discourses, entities or practices. In this sense, disruptions differ from sustaining scientific progress in that they are neither usual transformations or revolutionary ideas in Ecology nor evolutionary extensions of it as functions of evolving knowledge itself but rather abrupt changing applications of it.

Instead of using typical historical scrutiny of the trajectory of sequences of concepts and theories in Ecology in order to identify and evaluate their impact in shaping environmental science (-s), I propose quantitative methods/criteria in an attempt to identify disruptions. The concept of "biodiversity" in Ecology and the strategy of "green" applications of ICTs (Information and Communication Technologies) to reduce carbon emissions within the framework of sustainable economic growth are used as exemplary cases hereafter.

Methods and theory

This approach assumes the use of large sets of data on published research during a sufficiently long period of time. It is not a review *sensu stricto* that compiles published results and inferences - i.e. the *content* of publications - in order to propose a new "story" on a theme, e.g. as it is the case with the recent analysis by Low-Décarie et al. (2014) on the falling explanatory power in Ecology. Rather, it uses the *context* of publications - i.e. the existence of publications responding to thematic keywords or identifiers during a certain period of time. Such data sets became possible with the development of web resources and the Internet economy and services, e.g. the *Web of Knowledge*/ISI or *Google Scholar* and *Trends* or *Sets*.

I use the *Web of Knowledge* data bank in order to retrieve secondary information on the number publications/year responding to specific queries on keywords, domains and scientific areas covering the period 1970-2014. It is assumed that the publications reported therein correspond or encapsulate the ensemble of criteria regarding scientific quality, peer reviewing, prestige and/or accessibility to the international academic community as well as its evolving values and biases through time.

"*Case Study*" 1: disruption in Ecology as a lower attack of established concepts.

The history of "biodiversity" as a scientific neologism, political construction and boundary object is repeatedly reported (e.g. Takacs 1996, Oksanen and Pietarinen 2004, Loreau 2010). "Biodiversity" was never studied before as a disruption to our best knowledge. A "lower attack" is a narrative description of a situation where the trajectory of a "new" technology or concept crosses the trajectory in time of incumbent technology or concept and establishes itself as the dominant configuration of them.

Data sets were selected on queries responding to the following keywords: "nature", "environment", "diversity", "ecosystem", "goods AND services", "biodiversity" and "biodiversity AND goods AND services". Research domains and areas were restricted/refined to "Environmental Sciences" AND "Ecology" in order to avoid semantic and linguistic biases and redundancy. The disruption criterion was set as the condition where a lower attack by "biodiversity" crosses the trajectory in time of incumbent, i.e. pre-existing and established, "nature" or "environment" concepts. This criterion could be represented either in absolute values of #publications/year or as relative values, ratios, of "biodiversity" over comparative "concepts" on a logarithmic scale. When ratio values become higher to 1, it is assumed that disruption occurs.

"*Case Study*" 2: disruption in environmental science (-s) as a reversed algebraic sign.

In that case, the selected query focused on the the keyword combination "green OR SMART AND vehicl* AND ICT" referring to SMART 2020 environmental targets on cities and transportations. The final search procedure consisted in a sequential elimination of redundant and/or semantically "noisy" keywords, domains and areas. The refined query areas comprised Computer science, Engineering, Transportation, Operations research, Telecommunications, Environmental sciences, Automation control, Mechanics, Geography, Construction building technology, and Public environmental health.

In this "case-study", it is assumed that the trend of cumulative number of publications, during 1970-2014, should follow some monotonically increasing function, e.g. linear or exponential. A "linear" increase should be interpreted as a persistent but entrenched/steady effort in this research area - i.e. an enhanced BAU operation of a well defined community of scholars - whereas an "exponential" one could be interpreted as a diversification of both research issues and identities of interested scholars. However, given the nature and time length of data, it is almost impossible to test directly the hypothesis that "SMART-target" issues are disruptive or not - i.e. an "attack" from the bottom of incumbent literature.

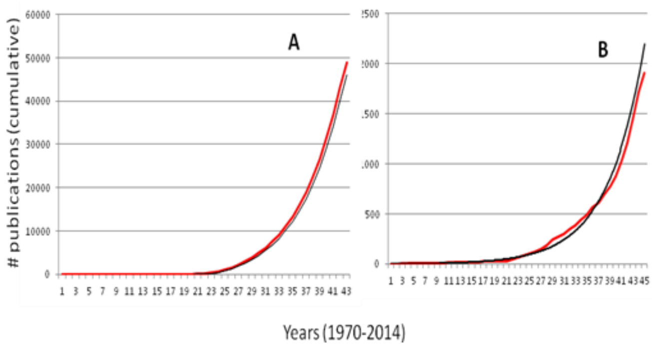
Thus, an inference on potential disruption could be approached through a simple transformation of raw data, according to a naive model accepting that the trajectory of the cumulative # publications is described by:

$$P_t^y = \mu + \varepsilon_t^y$$

where *P* is the number of publications on a yearly basis at year *t*, *y* is the annual accumulation of # publications, μ is a constant (hereafter, the average of #publications 1970-2014) and ε is a yearly variation, because of the structure of the search *WoK* query, $\varepsilon_t^y \sim N(\mu, SD)$.

Results

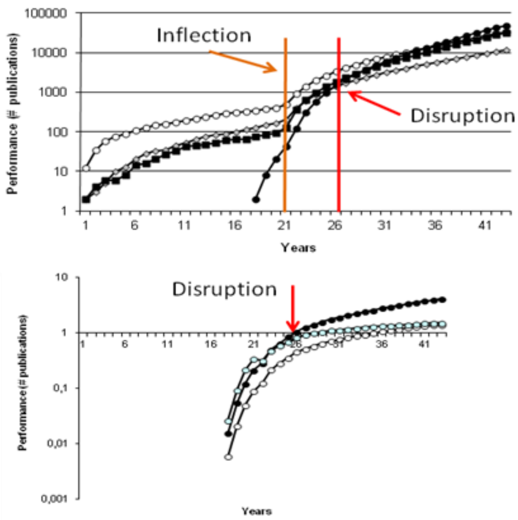
As expected, in both "case-studies" the cumulative #publications/year increased in an exponential way during the studied period: it is the growth rate *per se* that offers a perspective in the ever-growing interest regarding the concepts. Figures 1A and 1B present the respective trends. However, "disruption" following our criteria could be revealed in Figures 2A, B and 3.



Figures 1A and 1B. Trajectory of cumulative # publications/year reported in Web of Knowledge, according to the search query (combination of keywords and research areas) on **(A)** Biodiversity and **(B)** ICT applications on 'green OR SMART" urban transportation. **Red** curve: actual # of published research; black curve: best fit exponential equation on data (R^2 > 0.98 in both cases).

Figure 2A presents comparatively the trajectory of publications/year for the keywords "nature", "environment", "diversity" and "biodiversity": for all curves, a positive "inflection" or "jump point" - i.e. a revived scientific interest- is observed in year 1970+20 (±2) (refer to Conclusions section). It corresponds to late 80's/early 90's years after the eruption of mid-80's conceptual development in environmental issues with the construction of "terms" such as "sustainability" (1987), "biodiversity" (1986) and/or "global change" (1986). Logically, publications on "biodiversity" appear 2-3 years after the term was coined. Publications on "biodiversity" cross the trajectory of the comparable terms in year 1970+30 (± 2), i.e. in early 00's. The least resistant term proves to be "nature", indicating that "biodiversity" is a modern and more adapted scientifically term matching better the discursive needs of science and the academic community. The same conclusions are drawn from data in Figure 2B where ratios between compared terms are presented. Thus, the criterion of a ratio > 1 between publications on terms - i.e. concepts - could be used as indicating "disruption" in Ecology.

This statistical treatment is not applicable for emerging fields in environmental science (-s) because of their short time scale. Therefore, the alternative criterion proposed hereabove on the inversion/reversal of sign, appears more adequate or eligible in these cases. Figure 3 presents the trajectory of the cumulative #publications/year minus the overall average of publications over the studied period ± 1 SD.



Figures 2A and 2B. A (upper graph): trajectory of cumulative #publications/year, retrieved from Web of Knowledge, during the period 1970-2014 for the keywords "nature" (◊), "environment" (○), "diversity" (▪) and "biodiversity" (●); B (lower graph): trajectory of rations between publication on "biodiversity" over "nature" (●), "environment" (○) and "diversity" (●). Disruptions are identified when lower trajectories cross already established ones; inflections are identified when abrupt changes in a trajectory are observed without crossing other trajectories. See text for explanations.

Publication effort regarding "green OR SMART" transportation in urban setups shows an inversion of sign in year 1970+30 (±1): this turning point, identified in 2000-2001/2, coincides with major political/academic events such as Rio+10, the UNEP 2002 commitment of World leaders on abatement of environmental degradation, etc - i.e. a change in political priorities, goals and funding. The fact that as years progress the cumulative #publications overpasses by two or three times the limits of variation $\varepsilon_t^y \sim N(\mu, SD)$ is considered as a validation of the hypothesis of disruption of incumbent research interest and methods.

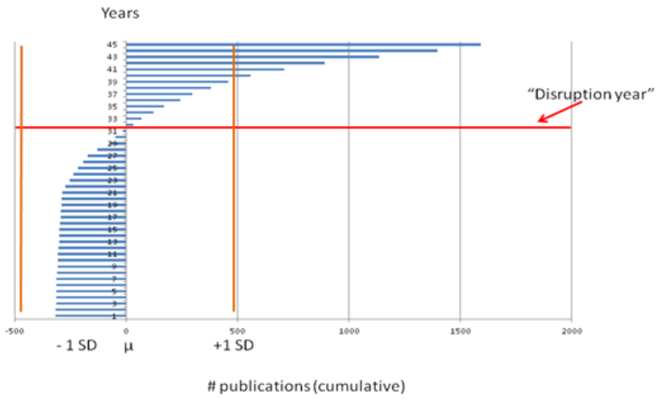


Figure 3: A hypothetical presentation of "disruption" in research interest regarding the "greening" or SMART targets in transportation in ICT-related scientific literature. Data are retrieved from Web of Knowledge (1970-2014). μ: average of #publications/year and SD: Standard Deviation.

Conclusions and extensions

There are two classes of questions that arise succinctly hereabove: (1) technicalities on the criteria proposed; (2) epistemic issues on the concept of disruption in environmental sciences. "Disruption" and "inflection or jump point" in thematic publications trajectory are neither synonymous nor extensions or shifts in terminology. For they describe different conditions and they are generated by fundamentally different mechanisms of theory-making.

In strict mathematical terms, there is no inflection in a continuous concave curve. Therefore, the term inflection as used herein has sense "between brackets" or as a short-cut for the alternative "jump point" which actually means points where the trend in the rate of change of the variable is accelerated. Technically, this corresponds to a situation where the annual absolute increments (i.e. the absolute differences between annual values of the variable # publications) are divided by the value of the year before forming thus an index: "jump points" are identified in years in which the second derivative of the index differs significantly from zero.

More important is, however, to notice that an "inflection" refers to the trajectory of a concept taken alone, e.g. #publications on biodiversity, whereas "disruption" refers to the replacement of a concept by another in time; therefore, for a disruption to be identified there is a need for comparison of the trajectories of two concepts that eventually compete narratively, conceptually and/or practically. That's exactly what the proposed criterion tries to identify in "case study" 1, e.g. concerning biodiversity vs nature.

However, this strict comparison is not always feasible, especially for emerging fields of scientific interest which are not sufficiently long time present in the literature in order to examine the trajectory of publications curve in comparison to an incumbent concept, as it the case for the ICT example presented hereabove. Strictly speaking, the only search possible in that case is search for "inflections" or "jump points"; to define approximatively a disruption there are mainly two options. Either an alternative criterion, i.e. the inversion of algebraic sign as proposed, or the use of the first criterion upon forecasted data for compared concepts. For the second option, the arsenal of time-series analysis and forecasting could eventually be used: there are several examples of such approaches available in various fields such as GDP growth applied on annual or quarterly data or *Google's* big data *Trends* on a weekly basis searches.

Further, besides technicalities, the mechanism generating an "inflection" vs a "disruption" is different. An "inflection" could be explained by a conjectural increase in publication effort by the concerned scholar community without any structural, operational or conceptual change within it. A "disruption" occurs when such changes are actually observed.

Although disruptions are observed in both exemplary cases according to our criteria, the question of "progress in science" is more challenging as an epistemic problem when emerging concepts/issues are addressed. It is the case for "biodiversity": through time biodiversity becomes an incumbent concept itself, after *ca* 35 years of intense research activity. "Biodiversity" - as well as other planetary change concepts - starts suffering the by-effects of its original missionary successes, as related to its disruptive character. An overwhelming part of biodiversity-related literature relates to non-pure Ecology or genetics issues: in fact, although biodiversity and ecosystem function research is a consistent part of the fundamentals of natural science-making, a very large extent of publications refers to applications within agronomy and forestry, economics, management and social sciences. This is more than obvious when predictions in scientific domains such as Environmental or Ecological Economics are reviewed or when social processes over decision-making regarding environmental issues, e.g. participatory processes, are addressed. Analyses and/or predictions in such domains are directly confronted to actual results in the real world of policy-making. For instance, the disruptive momentum of biodiversity met with success in the Institutional and public-discourse spheres as long as the ultimate goal of the academic community was -or still is- to drive decisions towards rational choices or, at least, to an informed political opportunism, in a perpetual confrontation between science and policy -or even politics. On the contrary, the flagrant failure of the "2010 Biodiversity goal" on slowing down or halting the biodiversity extinction rates (e.g. Butchart et al. 2010) underlines that there are narrow limits in the linear relationship between "good science" and "good policy" and in the performance of a discourse-dependent strategy no matter how disruptive could be the conceptual pillar of such endeavour.

However, sticking to Christensen's (1997) original definition of a disruption as a mechanism that helps create new academic aggregates or value networks displacing older discourses, entities or practices, biodiversity is indeed a disruptive concept since it has reshaped the operation of scholar ecology to a large extent, e.g. research priorities, funding, constitution of groups, publication platforms, etc.

For an, or any, emerging environmental field such as the exemplary research domain on ICT applications in SMARTer targets regarding e.g. urban/transport "command & control" issues is promising for further development as a disruption. There is not yet a clear/definite bridging between disparate research fields such as "transport" and "sustainability", *sensu* effects upon emissions and urban air quality (and several other related fields such as environmental friendly commuting, urban air quality and heat islands, optimization of traffic and public health, the economics of daily calendar of work force, etc.). In that sense, "progress" should be examined as to whether ICT could improve this bridging at the level of Urban decision-making, as an example. However, "progress" would not be evaluated in that case but if ICT applications are proved not as secondary elements of a "transport" policy in urban settings, but rather as promoters of established SMARTer solutions.

In an environmental "meta"-science field, where the questions of pure scientific method remain debatable - e.g. pluri-disciplinarity and/or trans-disciplinarity approaches *vs.* falsification experimentation - the core question is not the *a posteriori* confirmation/validation of hypotheses but rather the forecasting ability on trends of collections of elementary explanatory drivers. Therefore, it is genuinely requested that some kind of prediction of "early warning" signals of research priorities and methods for scientific policy-making from the point of view of international research institutions and funding agencies. This problem could potentially be viewed as a forecasting problem based on current trends of usual academic research production. Obviously, such forecasting methods cannot definitely predict disruptions, because by definition they are not predictable! But, they can provide for a solid understanding of science making and the performance of science policies.

Acknowledgements: *The paper is dedicated to the loving memory of Professors Nikos S. Margaris and Leonidas Louloudis. The author thanks Ioannis Troumbis for his help and support in examining and understanding the peculiarities of ICT applications in environmental science(-s) and SMART targets. Financial support from an anonymous source is greatly appreciated.*

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