3.1 Environmental intelligence : publication under review

Environmental Intelligence: we need a new generation of scientists, policymakers, managers

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Abstract

Despite ample evidence that human activity endangers the Earth's future, political action to protect the environment in the Anthropocene seems uncoordinated and inadequate. From local to global scales, sustainable practices lack political support or face technical challenges. To identify and address complex environmental problems, a new dimension of collective intelligence is needed, which integrates ecological, engineering, economic, and cultural understanding. We describe here a collaborative-scientific process called *environmental intelligence*, E.I., which requires a continuous co-construction process fueled by multi-disciplinary data about the response of the natural and human systems to proposals and interventions. It starts with the definition of a common desirable horizon that will guide the shared decisions in a sustainable trajectory with the help of models and scenarios developed during co-construction.

Environmental intelligence requires a reimagining of the relationships among researchers, policymakers, and managers, as well as data and decision-making. New skills and perspectives are needed such as the capacity to integrate non-academic knowledge to allow specialized experts to effectively collaborate as interdisciplinary mediators. They have to become transdisciplinary, managing both social construction and numeric modeling. This new training governance mobilizes non-academic information and stakeholders in a collective research process towards ecological and inclusive solutions.

1. Introduction

Over the past 500 years, human activity has become the driving force behind many of Earth's great systems, including the climate, biogeochemical cycles, biosphere integrity, and the water cycle (Steffen et al., 2004, 2015; Brondizio et al., 2016; Koch et al., 2019). Socioecological interactions are characterized by unanticipated connections and crossings of tipping points and planetary boundaries (Rockström et al., 2009; Steffen et al., 2015; "The Global Risks Report 2018," 2018). These changes are accompanied by social repercussions, including a loss of common goals and a rejection of political or scientific "expert"-legitimized points of view. Scientific evidence and science-based solutions are often not easily accepted by the public (Levin et al., 2012; McCormick and Kåberger, 2007), while knowledge co-generation involving local citizens has proven more successful at increasing understanding and influencing policy (Abbott et al., 2018; Magnani, 2012; Rogers et al., 2008; Rumore et al., 2016; Soland et al., 2013). The "Yellow Jackets" crisis in France is an example of the tensions that complex environmental problems and proposed solutions may generate. Such social changes modify the traditional position of scientific knowledge and solutions, and call for a paradigm change in the way scientists understand and address environmental questions.

The Anthropocene (Crutzen and Stoermer, 2000) integrative concept (Brondizio et al., 2016; Steffen et al., 2011) offers a holistic framework, with a strong epistemological potential for integrating disciplines, levels and scales, including retrospective and prospective approaches (Biermann et al., 2016; Bleischwitz et al., 2018; Brondizio et al., 2016; Cudennec et al., 2018; Liu et al., 2018). This accompanies the paradigm shift from "development" to "sustainable development," which builds on global assessments (Future Earth, 2014; Millennium Ecosystem Assessment, 2005; Masson-Delmotte et al., 2018) and materializes in the Agenda 2030 organized through Sustainable Development Goals, targets, indicators and an associated monitoring process towards the 2030 horizon (United Nations General Assembly, 2015).

Intelligence, in its most accepted sense, means linking, interpreting and understanding information in order to develop innovation. Sustainable Development Goals (SDGs), ambitious, holistic and global mechanism is a form of intelligence, through *i*) the translation of the immense cognitive complexity and strategic challenge into elementary actions, and *ii*) a nested architecture referring to international and national geopolitics. However, progress towards the SDGs is too slow and lacks subnational implementation of transformative ambitions (United Nations, 2018). This corresponds to the challenge of downscaling the Anthropocene/Agenda 2030 intelligence at all the relevant socioecological levels by all the corresponding stakeholders. This requires the emergence and development of an *environmental intelligence*, which will elaborate a contextualized understanding of socioecological territories towards translation into coherent action plans. This environmental intelligence must be co-constructed by scientists, educators, and trainers (ICSU, 2017; Etzion, 2018; Lemos et al., 2018; Nat. Sustain. Editorial, 2018). In this paper, we develop the concept of environmental intelligence, E.I., and identify how this perspective would be adopted by a new generation of scientists and managers.

2. Environmental intelligence concept

2.1. Environment can have a positive effect on a collective Intelligence

Although there is no definite definition, Intelligence first refers to a set of processes including understanding, learning, creativity and problem solving and allows developing a knowledge to be applied towards adaptive behaviors within an environment or context (*Wikipedia, itself considered as resulting from a collective intelligence process*). The initial dimension is the neurocognitive one in life science which refers to processes that empower responsiveness and adaption. Intelligence concepts classically refer to "intelligence activities" within the framework of defense or military activities. Economics is a second field which has linked activities to intelligence. Economic intelligence refers to information acquisition, treatment and security to understand consumption behaviors and promote a firm or a product (Gbosbal and Kim, 1986). Artificial Intelligence, A.I., is defined as "the science of making machines capable of performing tasks that would require intelligence if done by [humans]" (Minsky, 1968). A.I. may be applied to all other fields defined here. A specific subdiscipline is land-based economic intelligence which uses all means to develop economic growth in a specific geographic location. Territorial intelligence is also a concept which can be defined as a systemic approach towards the sustainable development of territory attractiveness and quality of life. More recently ecological intelligence (Sterling, 2009) has focused on the relationships between humans and nature as a guide for sustainable system definition.

Artificial, economic, and territorial intelligences, although potentially necessary to developing sustainable solutions, do not address all aspects of environmental problems. Indeed, the capability to adapt to the environment, which defines intelligence, does not integrate intrinsically the interests or wellbeing of the environment. Additionally, participative functioning could have a more important place in intelligence definition as an intrinsic pathway.

Environmental intelligence aims at integrating the components of the environment as contributors of the collective thinking as well as all human sensibilities, even those poorly organized and represented. The participative functioning which is not specified in current intelligence definition could constitute an intrinsic part of our collective intelligence. In a certain way, it connects to the noosphere concept introduced by Vernadsky and Teilhard de Chardin, as this concept includes all intelligences, biological and human (Vernadsky, 1945; De Chardin, 1959).

2.2. Definition of environmental intelligence, E.I.

The concept of environmental intelligence, E.I., we propose is a territorial co-construction process of sustainable trajectories. Trajectories are understood as a time-wise implementation of truly sustainable practices which progressively enhance societal and environmental wellbeing. It is based on the capacity to link knowledge, cognitive interactions, collective information (thus including aspects of A.I.), actor's networks, and collaborative processes for innovations and co-decisions. **It implicates the involved stakeholders and mobilizes creative fields focused on the environment, including natural sciences, mathematics, social sciences, and the humanities.**

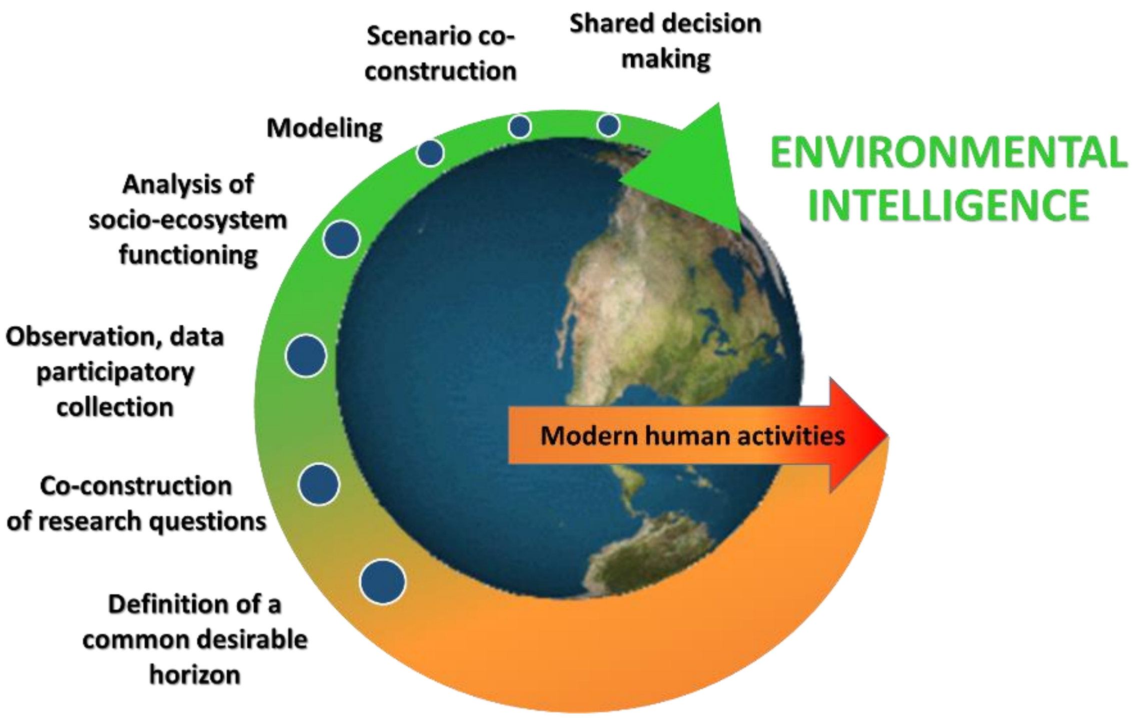

Figure 1: Definition of environmental intelligence E.I.
The whole process is seen as a co-constructed process that requires the definition of a "desirable" horizon that corresponds to a common sustainable vision, and several steps defined in the figure. The process is iterative, with the shared solution emerging from positive compromise and negotiation at a given moment in a given context which must evolve towards the desirable horizon.

The whole process (Fig. 1) is seen as an iterative co-constructed process towards shared knowledge and values.

First step – Stakeholder's mobilization:

The stakeholders' capacity and motivation to act have been widely debated (Freeman, 1984; Freeman and Reed, 1983; Goodpaster, 1991; Mitchell et al., 1997; Rowley and Moldoveanu, 2003). The modern definition of stakeholder is "a person or organization that has a legitimate interest in a project or entity"(Boatright, 2001). E.I. process is based on a group including all the stakeholders. The rule for the stakeholder's group definition is that all the trends of thought of the social groups susceptible to affect or be affected by the referred project are represented. In a globalized world, this could effectively include the entire Earth's population. Within the various social groups, one can list informal collectives of individuals (residents, consumers, voters, non-voting, concerned), economic and social interest groups, and traditional stakeholders including officials, unions, and administrations (central and decentralized). Some stakeholders, i.e. "nature", "the environment", or "future generations", cannot be directly engaged in the dialogue. For this reason, the stakeholders of a territory must communicate directly with various environmental or human-rights non-governmental organizations or governmental agencies in charge of environment.

In an ethical approach, each stakeholder benefits from the same weight, and the discussion procedures help priorities to emerge. The groups of stakeholders concerned are not identified *a priori*, their configurations depend on the questions that are asked and the way they are asked. Moreover, following the evolution of the reflections, the groups of stakeholders can transform, some stakeholders being no more concerned while others begin to be concerned.

Second step – Desirable horizon and defining issues:

This horizon must be seen not as an individual desire but as a fundamental necessity which also includes the environment (ecosystem) and is framed by the integration of planetary boundaries (Bai et al., 2016). It is thus complex and allows numerous interpretations and sub objectives that will in turn allow consideration of all points of view. It is not only a matter of environmental preservation but also economic activity and a way to create social bonds. The desirable horizon also refers to the continuous construction/reconstruction of the public interest through a process of cooperative inquiry (Minteer, 2005). This is also a question of establishing shared values, such as what is worth addressing as a community through cooperative inquiry and action (Afeissa, 2008).

A key point of the process is that the priorities and values integrated into the horizon of each stakeholder cannot be denied by one group. This rule is particularly important because it improves integration of the environment, i.e. non-human interests. The objective of the co-construction at this stage is to allow the different points of view to be reconciled around a vision of the desirable with consideration of current constraints. The concrete shared solutions that will result will be applied to different spatiotemporal scales. For example, the discussions around green lanes in Montreal were initially guided by the definition of a desirable future to avoid climate change while also containing a more central objective for some mobilized stakeholders of reinforcement of the social bonds in some neighborhoods (Audet et al., 2019).

Once the desirable horizon has been defined, the objectives of the research have to be co-constructed with the stakeholders involved without *a priori* selection. This step corresponds to the co-construction of a shared problematic which is essential for the progress of the project. While the values of the horizon cannot be denied, the solutions must be discussed in a context of change. The iterative functioning of the project is thus extremely important.

<u>Third step - Research methodology:</u> The data/observation collection procedure might be co-constructed to integrate the stakeholder's perceptions, priorities, and their ways of approaching the research questions. It may also provide the opportunity to develop participatory collection processes for some of the data with a goal of sharing research with a larger portion of the stakeholders (Gigone and Hastie, 1993; Hogg and Tindale, 2001; Wallach and Kogan, 1965).

The data collection co-construction might be extended by the sharing of numerical modeling. This may take place in the definition of the model: which parameters do stakeholders think have an impact on their community? What are, in their opinion, the driving variables directly related to climate change? Then the use of the models must be simplified so that stakeholders can adopt and reuse them. Data collection, management, and modeling approaches as defined here require the development of new numeric tools that mobilize numeric scientific fields (Voinov *et al.*, 2018).

<u>Fourth step – Scenario co-construction and decision making:</u> Model results must be shared within the stakeholder's group who has to make its own of the results and diffuse them. From this step, the group must define the new steps, adapt the original questions, and define future scenarios to be tested (Berkhout and Hertin, 2002). Each step is an experience with an effectiveness that relies on the iterative process. Along with the resolution of some questions, the shared choices and decisions, which rely on the model results and shared knowledge of the group, progressively appear.

2.3. Example of the environmental intelligence approach

In this section, we present an example of how E.I. was developed in Brittany-France, an intensive agricultural region, which is further described in the Sup. Info. Figure 2 presents an example of what we have learned from these experiences and how they conducted us towards the environmental intelligence approach. The **blue** part of the figure corresponds to the usual scientific approach regarding mainly quantitative dimensions of groundwater resources. Taking into account ecosystem characteristics through the protection of ecosystem services necessitates an enlarging of the boundaries of the investigated system, for example coupling groundwater aquifers to surface wetland functioning represented in the **green** part of the figure. In a second step, shared projects with stakeholders (farmers, ecological NGO, public managers…) led us to integrate their priorities and values within the scope of our research, to co-construct scenarios and finally to promote shared decisions (**purple** part of the figure).

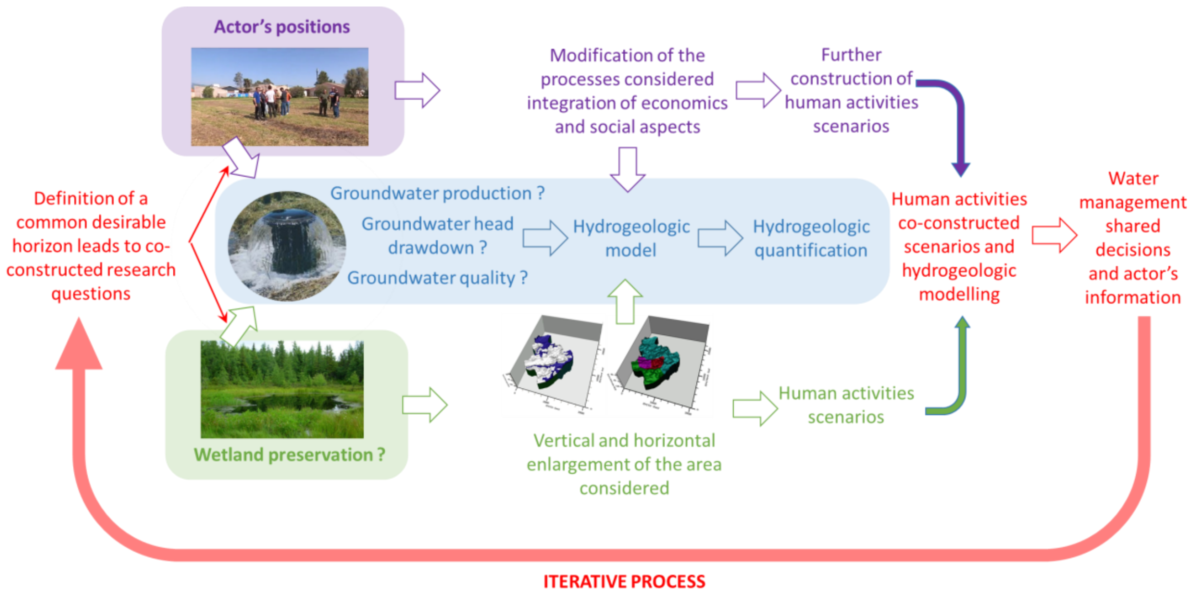

Figure 2: Example of the environmental intelligence E.I. approach

For instance, people in charge of ecosystem protection raised the issue of groundwater uptake impact on surface wetlands while this issue that was previously not accounted for by water managers. Moreover, discussions with inhabitants and farmers allowed common actions and commitment from both parties to encompass previous conflicts on water uses and quality.

2.4. A land-based localized process

There is generally a lack of individual as well as political concern regarding planetary changes, even when individuals realize they are or will be directly affected (Latour, 2017). This lack of political and social will could be a consequence of the loss of a common horizon (progress and equality) and soil to root (globalization effect). A new 'territorial localization', that would not be constructed against globalization or as an identity movement but as the recovery of a human and local meaning, needs to emerge (Latour, 2017). Indeed, environmental intelligence is specifically a place-based approach. It assumes that socioecological issues must be defined in a geographical context to identify the involved stakeholders and to integrate the environmental parameters at the scale of the locality. However, locality is often difficult to define, as it has various dimensions relating to data acquisition, social and political governance, historical context and finally identification, which more precisely relates to the relationships between a living territory and the inhabitants. Furthermore, localization in environmental intelligence not only refers to a geographical location which identifies a community ("common location") but also a value-based community of "common interests" (Licklider and Taylor, 1968).

3. What can we expect from the environmental intelligence concept?

3.1. Implications of the environmental intelligence concept for the scientists

From a scientific problem to a desirable horizon. In the E.I. concept, the scientific issue overlaps questions of the stakeholder's group. To prevent distraction and conflict, before this cross-over experiment, the group must engage in a common approach to define the desirable horizon. The scientists have thus to accept the interaction between scientific and field questions.

To provide a place for all stakeholders. The intelligence of the process is partly related to the stakeholder's group composition. One key point is that this group is not only a matter of social groups that are already organized and able to exert political pressure. Stakeholders that are not necessarily organized but who interact with the locality must also be represented. This is particularly important for the least favored groups such as those living in poverty, isolated families or indigenous communities. 'Non-human stakeholders' must also be represented (Hache, 2011). Ecosystems are usually represented through the interest conferred by some groups such as farmers, for example. However, ecosystems have to be taken into account for all the services they provide: economic services (pollination for example) but also cultural, patrimonial, and historical perspectives. E.I. relies on the capacity to fully integrate all the environmental components of a defined territory.

Science is not only a matter of experts. The inclusion of scientists in the stakeholder's group implies that the scientist is no more in a dominant or condescending position. This does not mean that the scientist loses her or his expert role, but that this expertise only corresponds to a part of the process, while perceptions, questions, understanding, and knowledge are all shared. Mobilization of stakeholders plays a central role in the E.I. process. However, the proximity of stakeholders to the scientific approach is not natural, which raises the need for a mediation between researchers and citizens. This mediation can be viewed as a new skill in the participatory method.

The intelligence of the process requires sharing of models, results, and scenarios for the future which is in itself a research domain both for numeric and social sciences. At a larger scale, it indicates that research process is not an isolated process but is fully included in a movement of the society which tries to evolve towards sustainable pathways (Norman, 2018).

Engaged scientists and managers. A consequence of the previous item is that scientists and managers are not isolated from social conflicts such as climate-skepticism or resource protection. They become actors of the local to global transition and advocate for political or social positions, on the basis of their scientific expertise and their values as human beings. This inclusion in the debate must become not only an individual position but an institutional position (Whistle Blower, 2007).

3.2. A new form of scientists and managers

We advocate that E.I. requires the emergence of new environmental scientists and managers who must master the following skills:

- Manage interdisciplinary projects and knowledge. Environmental scientists and managers can no more be considered only as experts in a specific domain. They have, in addition, to be aware of and value highly different approaches for generating knowledge such as social sciences for a bio-physicist and conversely.
- Develop integrated, land-based localized projects. Environmental scientists and managers must be trained to contextualize research problems in order to integrate territories' stakeholders.
- Integrate both modeling and social approaches in research projects. As seen above, modeling is a basis of the knowledge exchange and must be mastered as well as social aspects of the project.
- Becoming mediators: scientists or managers have to acquire specific skills to facilitate co-construction. Environmental scientists and managers must listen to all stakeholders, even if they have absolutely no scientific background. They also must integrate non-academic

knowledge. Involving stakeholders in the project group, including non-academic knowledge and integrating scientists and stakeholders in shared decisions, they become expert of mobilization.

New schools are needed that truly allow interdisciplinary tracks and allow for E.I. skills to be developed. Such schools need to be particularly opened to various non-academic teachers for the students to be faced with merging of knowledge. The Earth Institute in Columbia University is an example, established 20 years ago, of environmental basis (the Lamont-Doherty observatory) and now devoted to sustainability by including several institutes. Other places have also developed similar schemes with sustainability open-institutes transversal to disciplinary departments (e.g. USYS-TdLab in ETH Zurich). However, the number of schools interacting with stakeholders and promoting citizen science is too small given the magnitude of the socioecological issues we face today and the growing need for managers implementing new solutions at all levels of the society. There is thus a great need for new institutes, integrating sustainability as a goal, modifying their teaching methods and integrating stakeholders and civil society in their functioning.

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