# Redefining ecological engineering to promote its integration with sustainable development and tighten its links with the whole of ecology

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Abstract

Ecological engineering was defined several decades ago, both in the academic field and in management. However, ecological engineering seems to be re-emerging as an academic field and as a cornerstone concept in French ecologists' writings. I first summarize Barbault, R. and A. Pavé, 2003. Territoire de l'écologie et écologie des territoires. In: P. Caseau (Ed), Etudes sur l'environnement: de l'échelle du territoire à celle du continent, Tec et Doc Lavoisier, Paris, pp. 1-49)'s point of view on why ecological engineering now seems rehabilitated in France. I next propose a definition of ecological engineering, in accordance with the two reasons for its French re-emergence, i.e. the prevalence of the concept of sustainable development and the development of applied ecological sub-disciplines. This leads us to suggest that ecological engineering should be ecological in the broad sense, and not only targeted to the ecosystem level. I end the paper by discussing some problems and characteristics of ecological engineering that stem from this definition.

Keywords: ecological engineering; ecology; values; sustainable development; expertise; experimentation; monitoring; ecological hierarchy

## 1. Introduction

As with many modern concepts, the concept of ecological engineering is one that at first appears attractive, consensual and intuitive, marrying engineering methods with the expertise of the ecological scientist under the banner of increasing respect for nature. Furthermore, it is a concept that is gaining force, both as an international academic discipline, and among scientific discourse in France. Although the term is becoming increasingly common, “ecological engineering” is not always used in the same sense. My aim in this text is to provide a definition of ecological engineering by reflecting upon existing definitions and analyses. The relationship between this concept and the current forms of natural systems management, ecological science and the notion of sustainable development leads me to propose a wider definition than is normally used, and one which is more consistent with the reasons behind the reappearance of the term ecological engineering in France. In terms of the ecological element of the discipline, I believe that it is particularly important not to restrict ecological engineering solely to ecosystem-level engineering. Our final discussion will centre on some of the consequences of this definition.

## 2. How can the current popularity of the notion of ecological engineering in the scientific community be explained? A brief history

Whilst its principal aim was present in the spirit of the founding fathers of ecology (Barbault and Pavé, 2003), the term ecological engineering was first coined in the 1960’s by H.T.Odum (Mitsch 2003, Mitsch and Jorgensen, 2003, Odum and Odum, 2003). Closely linked with ecosystem ecology (or ecosystemics), it was first used to describe energy flows: it corresponds to "those cases in which the energy supplied by man is small relative to the natural sources, but sufficient to produce large effects in the resulting patterns and processes" (Odum,1962).

Then, 1992 saw the appearance of the international journal *Ecological Engineering*. On the basis of this journal, the International Ecological Engineering Society (IEES) was formed in 1993 (see http://www.iees.ch/iees.html), and the American Ecological Engineering Society (AEES) in 1999 (see http://swamp.ag.ohio-state.edu/ecoeng/AEES_a.html). The *Ecological Engineering* journal uses the following definition of ecological engineering: "Ecological engineering is the design of ecosystems for the mutual benefit of humans and nature". It is an adaptation of first definitions by Mitsch and Jorgensen (1989), later refined by Mitsch (1993, 1996) and re-emphasized in Mitsch and Jorgensen (2004): « Ecological engineering is the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both ». This journal took a relatively open-minded approach to developments in ecological engineering across the world, and was notable for bringing Chinese achievements in the field to the West (Mitsch 1991, Mitsch and Jorgensen, 2003). It is finally worth noting that, as was the case with Odum, the current trend in ecological engineering focuses on "designing ecosystems" and therefore on ecosystem ecology, such as the use of natural or artificial ecosystems to treat toxic pollutant effluent by studying the flow of matter in the ecosystem. By contrast, there appears to be little link between this version of ecological engineering and population biology or community ecology – evidence for this can be found through a simple keyword search in the articles published in *Ecological Engineering*.

In parallel, the end of the 1970's saw the emergence of the ecological engineer profession in France as a response to the range of laws requiring engineers to use ecological results, tools and concepts. This refers particularly to the 1976 law and its decrees, which deals with the protection of nature, and circulars (1977, 1978…) concerning impact studies.  In response, the French Association of Ecological Engineers (AFIE) was founded in 1979 with the aim of ensuring or requiring a minimum level of training for ecological engineers, and of proposing a set of professional standards for ecological engineering (see http://www.afie.net).

More recently, French ecological scientists, Robert Barbault and Alain Pavé among others, have promised renewed development in the field of ecological engineering, with the aim of reconciling the scientific discipline of "ecology" with the demands of society. Ecology has indeed become an increasingly academic, conceptual and theoretical science, focusing more on populations and communities than on ecosystems – at least in France.  Ecology has moved far away from the applied science envisioned by its founding fathers.  This is what di Castri (2000) called the failure of ecological science (Barbault and Pavé, 2003). Today, the course of ecology is defined by society, especially given the emergence of the concept of sustainable development, with its strong relationship with ecology, and the underlying questions about the harm caused by human beings to their environment. At the same time, ecology has seen the development of sub-disciplines, fields of research and concepts, which are beneficial to society in this approach.  This applies in particular to conservation biology and landscape ecology (Barbault and Pavé, 2003), as well as spatial population biology and the study of post-disturbance dynamics. As Barbault and Pavé (2003) explain, it is because of this combination of society's expectations, socially beneficial ecological research, and well-established concepts and disciplines of applied ecology that the notion of ecological engineering is today so popular among the scientific community.

The re-emergence of ecological engineering in France might also be explained by a weaker development of applied ecology in France in the last decades as compared to other western countries.

## 3. Defining ecological engineering

What is understood by ecological engineering? The “traditional” definition of ecological engineering (that used by Odum) is associated with the idea of implementing natural cycles for the benefits of humanity and the ecosystems themselves – an approach which focuses on ecosystems within the framework of a partnership between man and nature. The definition of Mitsch and of the journal *Ecological Engineering* is further restricted to the "design of ecosystems". However, below this apparent consensus, lies an heterogeneity of definitions that has been well traced by Mitsch and Jorgensen (2003, section 3). For instance, in another book, Odum (1971) defined ecological engineering as the much more general "management of nature" while Straskraba (1993) proposed to prefer the broader term "ecotechnology" to ecological engineering, not limited in scope to "the creation and restoration of ecosystems". Here, I propose to widen the classical definition by defining a number of adjectives or qualifiers that, depending on the context, will help to clarify the type of ecological engineering in question.

### 3.1. Distinguishing between practical and “scientific” engineering

To begin with, we shall take a logical approach to this problem, and look at the definitions of the two terms themselves: “engineering” and “ecological”.

As highlighted by Barbault and Pavé (2003), there are two possible definitions of the term *engineering*: “the conception and global study of all aspects of a specific specialist research coordination project (technical, economic, financial, social…)”; or: “an applied scientific discipline”. These two definitions are not, of course, mutually exclusive, but they refer to quite different realities. This is why – if I have understood them correctly – Barbault and Pavé (2003) (respectively Painter 2003) propose that *ecological engineering* (resp. *engineering ecology*) should be used to describe the applied discipline of ecology, and *ecological systems engineering* (resp. *ecological engineering*) should refer to the area of field projects. Mitsch (1996, p.112) makes a somewhat different distinction, contrasting *applied ecology*, restricted to the monitoring of ecosystems and the exploitation of natural resources, and *ecological engineering*, described as the process of proposing solutions to the problems posed by society. Personally, I make the distinction between these two forms of ecological engineering using the qualifiers “*practical*” (i.e. *practical ecological engineering*) and “*scientific*” (i.e. *scientific ecological engineering*). The former refers to practical engineering in the field (it may also have been possible to use “prescriptive” here, to take Mitsch’s (1996) approach, or "applied"). The latter is used for the applied discipline of ecology (the adjectives “technological” or “academic” were also options here, but I prefer to use the term “scientific” in a wide sense).

### 3.2. Considering the vast field of ecology

Secondly, what is understood by the term "*ecological*" in ecological engineering? First of all, a reminder of the definition of ecology: it is the scientific study of the relationships between living beings and between them and their environment. It is worth adding that there are several different organisational levels in the study of relationships between living beings: the study of communities or populations; the study of local ecosystems; study on a landscape (ecocomplex) level… Mitsch (1996) and *Ecological Engineering* place varying degrees of emphasis on the importance of "ecosystems" in ecological engineering. The thinking behind this is that high quality ecological engineering analysis requires the consideration of entire ecosystems, the adoption of tools reflecting a systematic and modelling approach, especially targeting energy and matter flows. This approach therefore does not consider older forms of ecosystem-level engineering and planning, such as agriculture, silviculture and fishing, as "ecological". This same belief applies to some sub-disciplines too, such as pest control and yield optimisation.

Following the example of Berryman et al. (1992), I propose to widen the ecological field covered by ecological engineering for several reasons:

(i) firstly, to ensure rigorousness on a semantic level: autoecology and community ecology are just as "ecological" as ecosystem ecology;

(ii) secondly, to maintain the link with "applied" ecological disciplines other than ecosystem ecology – for example, conservation biology and landscape ecology –, and to favor the links between these disciplines. Gawlik (2006) illustrates the interest of the interaction of ecological disciplines by gauging the role of wildlife science in wetland ecosystem restoration;

(iii) thirdly, to signify the continuity between this approach and past practices (agronomics, sylviculture, pest control…), as well as practices normally defined as part of ecological engineering (for example, stabilising fields and river banks through revegetation; biological control, Berryman et al, 1992). Such practices were also ecological, although under a form of ecology with rather restricted aims, and which today may be prone to causing environmental problems;

(iv) fourthly, to revisit Blandin's (1993) arguments, to allow ecological engineering to respond to the different management objectives demanded by society – an ability without which the importance of ecology to sustainable development would be reduced (see below). However, these objectives may not always involve the smooth running of an ecosystem or an ecosystem fulfilling a certain role, but sometimes to the destruction or artificialisation of certain ecosystems. An example of this can be seen in the practice of impact study;

(v) finally, to incorporate the two main schools of ecological philosophy identified by Callicott et al. (1999): "compositionalism" – very much related to evolutionary ecology, to the conservation of ecological entities and thus to biodiversity questions–, and "functionalism" – primarily linked to ecosystem ecology, thermodynamics and the study of processes. Ecological engineering has probably mostly developed at the ecosystem and functionalist level because of the greater facility to generalize at this level of analysis (Callicott et al. 1999); however, some questions asked by society to ecological engineers are closer to compositionalism than to functionalism (cf. 5.2).

### 3.3.

### 3.3. Towards a more anthropocentric value judgement

Finally, before arriving at a definition of ecological engineering, we must make a *value judgement* (see Berryman et al, 1992, p.268). Do we want to emphasis the alliance or partnership between humanity and nature, their inseparable nature (like the Odum school of ecological engineering), or do we have a more asymmetric view in which humanity has an increasing interest in Nature conservation ? Berryman et al (1992) were astonished how easily the Odum way of thinking became the prevailing consideration in ecological engineering, despite its contradiction with western inclinations and its similarity to eastern value systems. In terms of defining the objectives of ecological engineering, I would prefer to maintain a humanist or anthropocentric approach, encompassing the widest possible range of management processes, including artificial ecosystem management (see Blandin, 1993). There are four essential reasons for this, the first two of which are reformulations of arguments made previously:

- if we accept Barbault and Pavé’s (2003) proposal that ecological engineering should find its justification within the framework of the concept of sustainable development then, in certain cases, it must prioritise economic and social considerations above environmental ones (see point (iv) above);

- also, we must not forget that the most naturally-functioning ecosystems are not necessarily the best ones for all aspects of the ecosystem; for instance, there are some cases where human activity has generally promoted biodiversity (Blandin, 1993; see also point (iv) above);

- making “Nature” or its elements the subject of law poses problems both in terms of practicality and in terms of coherence. From a philosophical point of view, this approach leads us to ask whether non-human entities can be subjects of law outside of any human value judgements or standards (see Bourg, 1992, Bourgeois, 1993, Comte-Sponville, 1995, Bourg, 1996);

- finally, assigning itself the objective of “benefiting Nature” requires an official “translator” to define exactly what is beneficial to “Nature”, with the risk that this “translator” (ecological engineer, naturalist, environmentalist NGO) will be given decision-making powers. In my opinion, it is healthier to assign this power to the normal operating procedures of society.

### *3.4. Proposal of definitions for ecological engineering*

In these bases, it is possible to propose the following two definitions of ecological engineering:

- that for "practical ecological engineering":

"the conception, implementation and monitoring of the ecological component of a planning and/or management project, for the benefit of human society, including its environmental expectations. The ecological components of ecological engineering projects can target various ecological levels or units (sensu Jax, 2006; e.g. populations, communities, ecosystems, landscapes...) , and should be linked to the development of knowledge and methods in the field of ecology";

- that for "scientific ecological engineering", directly linked to the first one:

"the scientifically based development of tools, methods and concepts for direct use in practical ecological engineering".

I hesitated for a long time over the explicit inclusion of the term sustainable development in these definitions, and finally decided not to include it in order give some flexibility to the other definitions. It would perhaps be necessary to rethink this choice if the inter-generational component of sustainable development were to figure here explicitly.  However, for the other major component of sustainable development – the consideration of economic, social and environmental factors together – which, in my opinion, is linked with a humanist or anthropocentric vision of environmental issues, the meaning is inherent in the expression "the benefit of human society, including its environmental expectations", as well as in the value judgements explained above.

## 4. A few examples

The definition used here is a wide one. It does not, in itself, demand reconsideration of age-old practices (agronomics, sylviculture…), nor of more recent practices (impact studies…). Ecological engineering being broadened, it will often be useful to qualify it more precisely:

- according to the level of organisation: *ecosystem-level; community-level; population-level*;

- according to its aims and the risk it poses to the environment concerned: *impact* ecological engineering to artificialise or destroy…; *conservation* ecological engineering to…; *restoration* ecological engineering to…The following represent some of the major types of objectives associated with ecological engineering (cf. also Mitsch and Jorgensen 2004):

(i) using natural ecosystems or ideas based upon them to reduce or eliminate pollution problems (e.g. waste treatment (composting), waste water treatment…) (Jorgensen and Mitsch, 1989);

(ii) restoration: restoring ecosystems following significant disruption as a result of human activity (rehabilitation or restoration of quarries, mines…; restoration of rivers and lakes…) (Jorgensen and Mitsch, 1989; Barbault and Pavé, 2003);

(iii) "ordinary" management: using the resources of certain ecosystems whilst preserving the smooth ecological running of the ecosystem (in agriculture, fishing, sylviculture…) (Jorgensen and Mitsch, 1989, Barbault and Pavé, 2003) and the populations it contains;

(iv) preservation and conservation: managing ecosystems with the aim of maintaining or improving parts of biodiversity (similar to the objective of conservation biology) (Jorgensen and Mitsch, 1989, Barbault and Pavé, 2003) or functions and characteristics of ecosystems (Shields et al., 2003);

(v) impact assessment and mitigation: evaluating the impact of planning or management on the surrounding ecosystems (Blandin, 1993, Barbault and Pavé, 2003), with the potential definition of mitigation measures (e.g. Shields et al., 2003).

As a result, ecological engineering – especially of the scientific type – is highly likely to include such varied activities as the following:

- proposing indicators for the characterisation of an ecological system and, more generally, devising diagnostic and surveillance procedures and techniques;
- predicting the possible effects of alternative human activities on ecological systems in different scenarios;
- specifying action plans to steer an ecosystem towards its desired state;
- initiating the development of specific scientific research in response to both observed and resulting problems.

On the surface at least (see next section), the notion of ecological engineering is not too distant from some management concepts. The notion of ecosystem management (see Meffe and Carroll, 1997, Samson and Knopf, 1996, Kaufman et al, 1994), which focuses on the management of natural processes (especially disruptions), on management at the landscape level, and on the simultaneous management of several species, is one that can provide solutions for the ecological engineer (again, see next section). The same goes for organic agriculture, which focuses on allowing natural processes to operate with as little intervention as possible (at least in terms of composting). On a more institutional level, the *Parcs Naturels Régionaux français* (French Regional Nature Parks) and the UNESCO Biosphere Reserves (Barbault and Pavé, 2003) seem to adopt a vision similar to that of ecological engineering in a broad sense, applied in this case to land use planning.

# 5. Discussion

In view of the examples cited above, it appears that ecological engineering does not significantly change our ecosystem management practices: it can encapsulate the way in which ecosystems have been managed and, in certain cases, permit the destruction of some ecosystems… What, therefore, is the contribution of the definition of ecological engineering proposed here? Furthermore, what are the difficulties that it will need to overcome?

## *5.1. The ecological engineer at the heart of sustainable development*

Ecological engineers, as a result of their in-depth ecological training (as well as training in other disciplines and natural sciences), and their involvement in the politics of sustainable development (which underlies the current concept of “the benefit of human society”), will often look to take the same position as Odum and Mitsch, placing as much emphasis as possible on "natural" processes – an approach founded on the autonomy of ecosystems, and the importance of solar energy. However, they are also prepared to devise less "ecological" solutions if the socio-economic reasons are satisfactorily justifiable, responsible and consistent with the notion of sustainability. In terms of their responsibilities, they can also help to explain the reasons behind these choices and their possible consequences for society, ecosystems and living organisms. Given the immense pressures in play and the tendency to explain away individual interests as genuine socio-economic reasons, the profession requires a code of ethics (Jax, 1993; such as that proposed by the AFIE, http://www.afie.net), and solutions which are both anti-economic and anti-ecological must be rejected.

### *5.2. Developing the monitoring and experimentation culture*

From the ecological engineer's point of view, the usefulness of the recent trend for academic ecology is not necessarily evident, since this discipline has focused more on general concepts than on more practical approaches resembling the reality of ecological management (Barbault and Pavé, 2003, Bunnell and Huggard, 1999, Gosselin, Submitted), and since it has great difficulties to make predictions simultaneously about the dynamics of particular populations and the functioning of the ecosystem (Jax, 1993). However, we must also rely on contributions that are not necessarily scientific in nature (empirical expert knowledge) to solve problems (see Gosselin, Submitted) and, on a more log-term basis, on the development of the operational character of ecology, following a possible future link between ecology and ecological engineering. Meanwhile, ecological engineers will have to rely on empirical knowledge to propose solutions and on experimentation and monitoring to evaluate their action (Simberloff, 1999, Gosselin, Submitted). If there is an area in which modern ecology can drive the development of the conservation management of natural ecosystems, it is in the culture of experimentation – an area that is well developed in agronomics and sylviculture, but which is still woefully lacking in the conservation management of ecosystems (Simberloff, 1999; see Gosselin, Submitted). This point has a direct impact on the training of ecological engineers, for they must not only have excellent knowledge in the field of ecology, but must also possess a certain experimental culture and, more generally, the ability to organise their arguments and pose themselves questions.

### *5.3. Bringing together the wide range of ecological issues*

A second, underlying advantage of my definition in comparison to the traditional (ecosystemic) definition of ecological engineering is that it emphasises the wide range of issues at stake. I think that the development of ecological engineering based mainly or entirely on its ecosystemic level and on a functionalist philosophy (cf. 3.2) – excluding ecological levels such as populations, communities, landscape and a compositionalist perspective – would be a dangerous approach in scientific terms. More specifically, concepts of ecological engineering that focus on ecosystems (ecosystem management or organic agriculture, for example; see above) often evoke notions of natural equilibrium, and of the health or integrity of natural ecosystems, with the corollary that a properly functioning ecosystem benefits the component parts of an ecosystem – e.g. the species living there (Simberloff, 1999). From the point of view of populations and communities, this approach is a problematic one. On the one hand, these notions may be too vague to be verified or quantified (Simberloff, 1999). On the other hand, there exist some properly functioning ecosystems that support species-impoverished communities (Simberloff, 1999). This is why the systematic replacement of endangered species management with ecosystem management seems an especially dangerous approach (Jax, 1993, Gutiérrez, 1994, Simberloff, 1999). To give another example, the artificial seeding experiments of many plant species, described in Mitsch (1993) and Mitsch and Jorgensen (2003), would be considered positively within a functionalist perspective based on the principle of self-design, but would be judged with considerable care with a compositionalist eye – especially if some of the seeded species are exotic species that could become invasive.

The demands of society and the actual work of ecological engineers – at least in France – also call for a broader ecological perspective, as was acknoweldged by Callicott et al. (1999) for conservation biologists moving "back and forth in emphasis [between compositionalism and functionalism; cf. 3.2] depending on circumstances". Here, defining ecological engineering as only the design of systems is unnecessarily limiting the domains of intervention of ecological engineers who also face situations in which the need is not to re-design the whole system but instead to manage a particular aspect of the ecosystem or a particular species. In corollary, we think that all what society has to ask to ecological engineering cannot be formulated operationally in terms of energy, power, and so on ([Mitsch, 2003 #99897], [Odum, 2003 #80070]).

I therefore think that if ecological engineers wish to remain closely associated with ecology and linked to the variety of society's demands, they must pay attention both to the bigger picture – the longevity, sustainability or proper functioning of the ecosystem – and to the smaller parts – the longevity of species, genes, etc. This calls for an extension to more ecological levels – than just the ecosystem and energy levels – of the "sustainability ethos" (Painter, 2003) at the core of current ecological engineering. Of course, this aspect of ecological engineering has an impact both on the training of ecological engineers – ecology in its broad sense and not simply ecosystems ecology – and on the tools that these engineers will use – not just systematic approaches and modelling, but also tools frequently used in the rest of the field of ecology, e.g. taxonomy, genetics, multicriteria evaluation, statistics, monitoring, and experimentation (Berryman et al, 1992). For sure, the fact that ecological engineers must pay attention to both the whole and its component parts at once is a challenge, since not every planning project can organise the monitoring and evaluation of the whole ecosystem and its components. There are therefore choices to be made, for example in the interpretation of indicators, or in the willingness to approach some projects with a highly scientific methodology, whilst other projects may involve much less rigorous evaluation. Yet it is in the very nature of ecology to have to deal with a wide range of objectives at the same time, all of which are defined on different scales. And it is in the very nature of engineers to take decisions based on rational grounds, on their experience and on incomplete knowledge. Whilst the main objectives of ecological engineers in a given project are assigned by a third party, it is highly likely that their scientific questioning and reflection capabilities, as well as their intuitive ability to understand the situation on the ground, will lead them to consider the different levels of organisation of living beings and understand these different scales. In order to achieve this, ecological engineers will need to develop extensive personal experience in articulating these levels in their capacity as an engineer. Furthermore, on a more collective basis, and with the help of ecology, they will need to rationalise choices and strategies relating to the consideration of these different levels.

## 6. Conclusions

After a brief history of ecological engineering, I proposed a wide-ranging definition of ecological engineering, which is compatible with its role in the concept of sustainable development and with a broad range of ecological disciplines, especially applied disciplines. I deliberately excluded purely ecosystemic ecological engineering because society's demands can concern other ecological levels and because there is no use pretending that there is a “knock-on effect” from the smooth running of the whole – the ecosystem – on the longevity of its constituent parts – habitats and species. This definition may also seem rather demanding since it does not dismiss old ecosystem management practices. In fact, I believe that the notions of sustainable development and the bilateral demands of the marriage between engineering practice and a scientific, academic discipline breathe new life into these old practices. It remains to be seen whether ecological engineering can provide a bridge between applied disciplines (such as agronomics, sylviculture and conservational biology) and academic ecology, as Mitsch (1996, p.123) suggests.

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