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# Ecoengineering with Ecohydrology: Successes and failures in estuarine restoration

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ABSTRACT

Ecological Engineering (or Ecoengineering) is increasingly used in estuaries to re-create and restore ecosystems degraded by human activities, including reduced water flow or land poldered for agricultural use. Here we focus on ecosystem recolonization by the biota and their functioning and we separate *Type A Ecoengineering* where the physico-chemical structure is modified on the basis that ecological structure and functioning will then follow, and *Type B Ecoengineering* where the biota are engineered directly such as through restocking or replanting. Modifying the physical system to create and restore natural processes and habitats relies on successfully applying Ecohydrology, where suitable physical conditions, especially hydrography and sedimentology, are created to recover estuarine ecology by natural or human-mediated colonisation of primary producers and consumers, or habitat creation. This successional process then allows wading birds and fish to reoccupy the rehabilitated areas, thus restoring the natural food web and recreating nursery areas for aquatic biota. We describe Ecohydrology principles applied during Ecoengineering restoration projects in Europe, Australia, Asia, South Africa and North America. These show some successful and sustainable approaches but also others that were less than successful and not sustainable despite the best of intentions (and which may even have harmed the ecology). Some schemes may be ‘good for the ecologists’, as conservationists consider it successful that at least some habitat was created, albeit in the short-term, but arguably did little for the overall ecology of the area in space or time. We indicate the trade-offs between the short- and long-term value of restored and created ecosystems, the success at developing natural structure and functioning in disturbed estuaries, the role of this in estuarine and wetland management, and the costs and benefits of Ecoengineering to the socio-ecological system. These global case studies provide important lessons for both the science and management of estuaries, including that successful estuarine restoration is a complex and often difficult process, and that Ecoengineering with Ecohydrology aims to control and/or simulate natural ecosystem processes.



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## 1. Introduction

### 1.1. Background and definitions

Environmental management aims to fulfil the 'big idea', i.e. 'to protect and enhance the natural structure and functioning of the ecosystem while at the same time ensuring the processes which deliver ecosystem services from which we then obtain societal goods and benefits' (Elliott, 2014). This is also the raison d'être of ecological engineering which aims to restore the desired ecosystem functioning but, as we emphasise here, using Ecohydrology. The main physical processes behind the restoration, recovery or maintenance of the ecology of systems based on management actions is Ecohydrology (Wolanski and Elliott, 2015), and may be regarded as the means of achieving these end-points (Box 1). Ecological engineering (or Ecoengineering) is widely regarded as engineering the physico-chemical processes, including water quality and quantity, to improve the ecology (what we term Type A) but it also includes engineering the ecology (e.g. by replanting, restocking, etc) (Type B). This review emphasises Type A Ecoengineering initiatives which lead to the recolonization of biota and their food web relationships but, because of space restrictions, gives less attention to Type B ones involving the active introductions of organisms.

Bergen et al. (2001) considered that there are five design principles which inform ecological engineering. Modifying the first two of these slightly: (1) ecohydrological principles should be used to ensure an appropriate, natural suitable and sustainable physico-chemical system, and (2) the design should encompass local features and so be site-specific. The remaining principles are that the design parameters and features should (3) be kept simple in order to deliver the functioning required but with the simplest design; (4) use energy inside the system or, if coming from outside then work with nature, such as existing flow conditions, and lastly (5) aid the natural system and help achieve social goals and thus have an ethical dimension; this may involve 'over-engineering' the design in order to further protect human safety and property. These principles therefore aim to produce at least a 'win-win' for economy and ecology or even 'triple wins' by including human safety.

**Box 1**
Estuarine Ecohydrology

*The science and understanding of the links between the physical functioning and the means by which it creates the appropriate ecological functioning of an estuary. It assumes that the ecology is primarily driven by the physics, which in turn affects the biological processes operating within a system. It includes changing the physiography and manipulating the freshwater flows from the catchment and it is also influenced by the anthropogenic users and uses of the estuary, some of which will have modified and impacted both the physics and the ecology. It is that knowledge which guides the management of the entire river basin from the headwaters down to the coastal zone, which Ecohydrology views as an ecosystem.*

Ecoengineering may involve 'hard' or 'soft' engineering solutions to rehabilitate estuarine systems. The former encompasses permanent physical features (e.g., concrete groynes) whereas the latter involves temporary or 'soft' features (e.g., substratum modification, such as by dredging or beach nourishment) in rehabilitation. As we aim to show, these always involve trade-offs, often the underlying conundrum of Ecoengineering, i.e. benefits to safety and economy may only produce a 'feel good' benefit for society in general and ecologists in particular without fully restoring the ecology of the natural environment.

Ecoengineering is therefore regarded here as manipulating the estuarine or coastal system either to restore it from past degradation or to improve its delivery of nature conservation and natural structure and functioning to increase ecosystem goods, services and societal benefits (Box 2). This may include recovery from the excesses of development designed to achieve societal benefits but often at the expense of the natural system, e.g. poldering for agriculture which removes coastal and estuarine wetlands. While there is the aim for Ecoengineering to achieve wins for ecology and the economy, and management measures are often carried out with the best intentions, this is not always the case. The aims and objectives of the management measures may be poorly defined, thus making it difficult to determine success. Furthermore, a misdiagnosis about how we should attempt to restore nature is often caused by uncertainty in what constitutes a win-win solution using science and engineering (Rodgers, 2000).

Ecoengineering often involves continuous intervention or maintaining management actions, with Ecohydrology providing the underlying principles for Ecoengineering (Box 3). Here we take the view that Ecohydrology often establishes the dynamic processes necessary to meet the aims, while Ecoengineering often aims to produce a required status (such as a restored seagrass bed) rather than restoring all natural dynamic processes (unimpeded water movement, salinity balance, sediment erosion-deposition cycles, etc.).

Following the conceptual model of Elliott et al. (2007), giving ecosystem improvement options from degradation (Fig. 1), habitats