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Enhancing eco-engineering of coastal infrastructure with eco-design: Moving from mitigation to integration

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ABSTRACT

Eco-design aims to enhance eco-engineering practices of coastal infrastructure projects in support of ecological functions before these projects are developed and implemented. The principle is to integrate eco-engineering concepts in the early phases of project design. Although ecological losses are inherent in any construction project, the goal of eco-design is to introduce environmental considerations upfront during technical design choices, and not just afterwards when evaluating the need for reduction or compensatory mitigation. It seeks to reduce the negative impacts of marine infrastructure by introducing a new reflexive civil engineering approach. It requires a valuation of nature with the aim of reducing impacts by incorporating intelligent design and habitat-centered construction. The principle advocated in this paper is to design coastal infrastructures, at micro- to macro-biological scales, using a combination of fine and large scale physical and chemical modifications to hard substrates, within the scope of civil engineering requirements. To this end, we provide a brief introduction to the factors involved in concrete-biota interactions and propose several recommendations as a basis to integrate ecology into civil engineering projects, specifically addressed to concrete.

1. Introduction

Approximately 60% of the world's human population live within 100 km of a sea coast (e.g., Vitousek et al., 1997). On the public coast of France human occupation rate of the coastal zone doubled between 1965 and 1980 (MEDAM, 2015). Between 2000 and 2006, no less than 6.809 ha were destroyed for coastal parking, harbor construction, seawall protections and other human facilities (Ibid). For instance, in the Languedoc Roussillon Region of southern France close to the Mediterranean Sea, the urbanization level within a 15 km length of coastline is close to 70%. The phenomenon of increasing shoreline development is growing worldwide. In recent literature, this is often referred to as 'coastal squeeze', a term introduced by Doody (2004) in recognition of the threat to the existence of coastal habitats caused by the compound impacts of sea-level rise and human activities. The phenomenon is very prominent in developed countries (INSEE, 2013) such as Spain, Italy, Belgium, Japan, China, and the USA, but it is also becoming more prominent in the developing world (e.g., Vietnam, Thailand, Philippines, Myanmar, India and Indonesia) (Phan et al., 2014). It develops rapidly, especially in a context of emergency poverty alleviation and economic development where environmental governance is weak. Around the Mediterranean, urbanization increased from 54% to 66% between 1970 and 2006 (Halpern et al., 2008). Furthermore, the situation is likely to worsen; the world's population is forecast to

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approach 7.5 billion people living within 100 km of a coast by 2050 (Lussault, 2013), and this will necessarily coincide with a growing need for increased coastal development and associated disturbance of essential coastal habitats.

The consequences of coastal urbanization are synergistic with other anthropogenic impacts on the nearshore environment, i.e., climate change, rising sea level (including subsidence), recurrent pollution, habitat degradation and overfishing. Faced with these escalating impacts, it is critical to develop sustainable long-term management of our coasts based on well-informed decision making and public education. But it is clear that the driving issues are global: social, economic, and ecological, and moreover deeply linked with our model of society based on perpetual growth. Obviously, there is no "magic" solution. However, in the short term, pragmatic approaches are required to avoid or reduce destruction of natural capital (Kiesecker et al., 2010) by a better integration of Coastal Infrastructure (CI) projects with natural ecosystems. Ecological design of infrastructure is a way to reconcile urbanization with protection of the natural environment from which essential goods and services are drawn.

Eco-design is a new approach developed in response to the cumulative impacts of CI on the ecology, biodiversity, and natural resources of coastal areas. It involves introducing ecological considerations in new CI construction based on eco-engineering solutions. It is similar to the classic eco-engineering concept, rooted in both ecological theory and knowledge and engineering practices. In defining ecological engineering, Mitsch and Jørgensen (2004) remind us that its goal is to design, create, or restore "ecosystems that integrate human society with the natural environment that will be of benefit to both". As used today in the field of work design, eco-engineering is primarily a corrective approach to address problems that require mitigation. It tries to incorporate understanding of ecological phenomena to simultaneously repair and enhance biodiversity and ecosystem function. But, its insights are in general only poorly applied by civil engineers, especially during the early phases of work, such as the design and planning processes, where avoiding and reducing ecological impacts should be prioritized. In most cases, ecological engineering knowledge and know-how are restricted to applications at the latter phase of work, and are intended to offset negative environmental ecological impact from the CI construction through compensatory mitigation. In contrast, eco-design by definition aims to better associate and reconcile ecology and design, from the onset of the work design process, when the basic size and shape of a structure are defined (Fig. 1). It is a mix between eco-engineering design and work design processes, begun in the earliest stages of construction planning. Furthermore, if we consider that, in current use, civil engineers are working in the early phase of work design planning (preliminary design, detail scheme design, and general design), and eco-engineering at the end, when the general design is approved by financial and technical trustees, the only way to associate them is to incorporate an eco-design approach. Thus, a modernization of both construction and ecological approaches in civil work processes starts with marrying the two words "ecology" and "design". The hesitations of civil engineers to apply ecological concepts and solutions during initial phases of design should be eliminated, or at least reduced. Eco-design requires a full collaboration of civil and ecological engineers working together during the same planning phases; this should ensure a better environmental integration for the project (Fig. 1).

This approach is close to "building with nature" in the EU (De Vriend and Van Koningsveld, 2012) and in the win-win insight proposed by "reconciliation ecology" between humans and nature (Rosenzweig, 2003). It finds its roots at the end of the 19th century with the famous "re-culturation of nature and re-naturation of culture" of K. Marx as a concept to link the future of humans with the fate of the natural world (Berque, 2014). In addition, there is an increasing perception that nature can help provide viable solutions to problems of CI by taking into account the properties of natural ecosystems (Coombes et al., 2015). Moreover, concept of nature-based solutions (NBS) has been developing in recent years. The IUCN defines this as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". "It can also help to create new jobs and economic growth, through the manufacture and delivery of new products and services, which enhance the natural capital rather than deplete it" (EU Horizon H2020 Policy).

As Aronson et al. (2016) reminded us, "Engineers and ecologists must work together and learn from each other if our work is to generate significant societal benefits", and Mitsch (2014) asked "When will ecologists learn engineering and engineers learn ecology?" The current lack of integration between these two professions is one of the reasons why the creation of new infrastructures that successfully integrate both ecological and technical concerns is so challenging. Based on our experience, although some engineering schools or training programs are developing courses and research programs on marine ecology, currently, most civil engineers are not fully aware or attuned to relevant ecological concerns when they are tasked to develop projects or when asked specifically to try to "build with nature". This is not simply due to a lack of knowledge of ecological issues and lack of proper training, but also due to the current philosophy of building in natural areas. Consideration of technical, economic, or social concerns have high precedence over environmental (bio-physical) ones during the design of infrastructure.

In this paper, we try to review some of the most important marine biological phenomena, to be take in account at the early phase of project of CI, to try to bring together civil and ecological engineers in a process of eco-design.

Historically in ecology (cf. Table 1), research about coastal colonization or settlement phenomena reflected mainstream literature about the use of artificial substrates during the 1970's through the 1990's (*e.g.* Zobell, 1972; Relini, 1993). However, since the 2000's, traditional coastal infrastructures have been implicated as major risk factors in reducing local biodiversity in comparison with surrounding natural ecosystems (Bulleri and Chapman, 2004; Bulleri et al., 2005; Jackson et al., 2008; Bulleri and Chapman, 2010). There have been multiple reports about the toxicity of concrete infrastructures, problems with using smooth surfaces in the marine environment, landscape disruption, and indirect impacts due to the carbon dioxide production in concrete fabrication and habitat destruction due to rock or sand extraction (Hillier et al., 1999; Wilding and Sayer, 2002; Moschella et al., 2005; Terlizzi and Faimali, 2010). Further, novel habitat (artificial hard substrata) can influence and even alter local and regional biodiversity by modifying natural patterns of species dispersal or by facilitating the

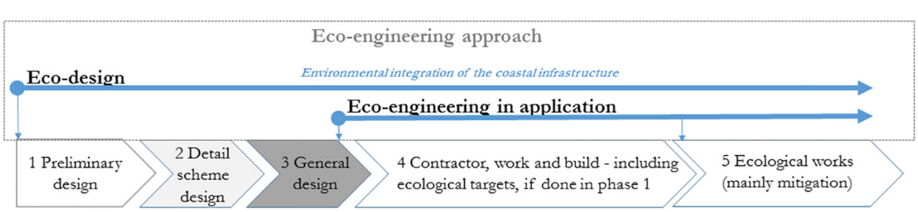

Fig. 1. Eco-design application within civil engineering projects in comparison to present eco-engineering application. The eco-design approach begins in the early phase of the work design planning. In comparison with usual eco-engineering treatments, which are based on compensatory mitigation resulting from environmental impact assessments or ecosystem damage. They are mainly considered after the design of coastal infrastructure to reduce or offset negative impacts, reducing environmental integration of CI.