INTERNATIONAL REVIEW OF EMERGING TECHNOLOGIES TO MANAGE BEACH EROSION: DO THEY REALLY WORK?

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Abstract

The use of the coastal zone in Australia has radically changed over past centuries, from military and transportation of the early colonial settlements, through trade and fishing via minor ports to residential and recreational today. Nowadays, coastal planning is caught in a complex balance between high value beachfront properties and increasing risks from beach erosion and inundation, with future changes in mean sea level and wave climate predicted to exacerbate both hazards.

This paper presents the findings of the lead author's Churchill Fellowship which involved in 2012, an international study tour of innovative coastal protection structures and contributions to the recent Engineers Australia guidelines on coastal adaptation.

While traditional coastal protection structures such as groynes and seawalls have been widely applied, changes in the use of the coastal zone and stakeholder expectations have generated a demand for alternative solutions. In the last two decades, innovative coastal protection methods have been widely marketed in Australia as having lower environmental impacts and costs, and easier constructability. However, despite the growing interest, documented information regarding the design criteria, applicability and success (or failure) in the field remains scarce.

This paper presents an overview of the most recent innovations in coastal protection measures. Artificial reefs, beach dewatering systems, natural defences and artificial dunes are described by discussing the underlying concept, applicability, advantages and disadvantages associated with each technology. Twenty years of national and international experience in the field are reported with the focus on the performance of the innovative technologies in successfully reducing beach erosion. Rational guidance is provided to coastal managers and planners to assist in the evaluation of intervention options marketed as innovative.

A Changing Coastal Zone

The use and significance of the coastal zone has radically changed through history: from the transportation and strategic military uses of the early human settlements, to the industrial and commercial uses of the industrial revolution, to the residential and recreational usage. Today, especially in Australia, people turn to the coast for contact with a natural environment and for the quality of life that is associated with living "on the edge of land and sea". Presently, nearly 90% of Australians live within the narrow and dynamic coastal fringe (NCCOE 2nd ed., 2012).

In turn, sandy beaches worldwide are increasingly subject to pressures from growing population, urbanisation of the inland and receding shorelines. In Europe, it was estimated that 20,000 km, corresponding to approximately 20% of the coast faced serious impacts from coastal erosion (EUROSION, 2004). In Japan, beaches have receded since the 1970's with average annual rates of 0.3 m (Kuriyama, 2005). In the USA, 1,500 homes would be impacted by erosion every year if no intervention was undertaken to protect them (Dare, 2003). At present, the challenge of managing the erosion of our beaches is a worldwide challenge and one that is set to become even more important with the projected eventuation of climate change, sea level rise and shifts in wave climate.

Figure 1: Recreational use of the beach in Rena Bianca, Sardinia Italy (Source Alessio Mariani)

Innovative Solutions

With changes in use of the coastal zone, the development of novel solutions to address beach erosion as an alternative to traditional coastal protection structures (seawalls, groynes and breakwaters) has become more important. In the last decade, alternative approaches to manage beach erosion have been formulated and implemented both internationally and within Australia. These novel approaches are typically marketed as being characterised by lower environmental impacts, lower costs and easier implementation.

Numerous manuals and guidelines for the design and application of traditional interventions on the coast exist. However, despite the growing interest towards novel methods, publications and documented information about the design and performance of innovative approaches are not readily available. The purpose of this paper is to provide a concise review of innovative solutions to the management of beach erosion. This review is addressed to coastal managers and practitioners as a general guide in evaluating alternative options for coastal management. The innovative approaches assessed were: artificial reefs, beach dewatering, artificial dunes and natural defences (Figure 2).

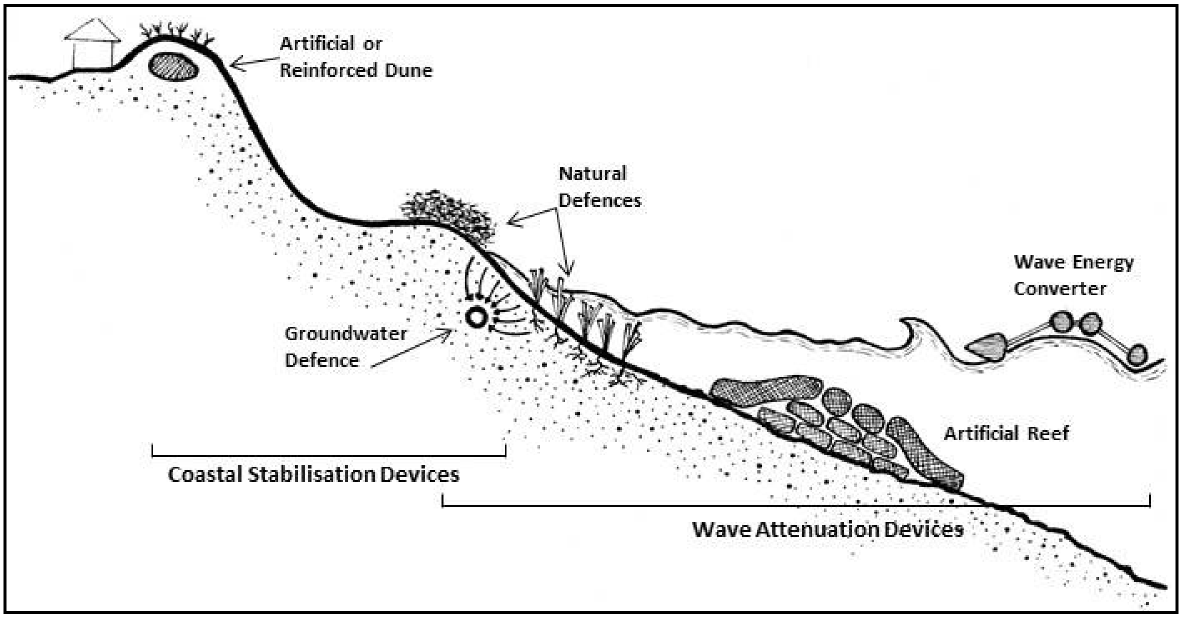


Figure 2: Innovative approaches based on wave Attenuation and coastal stabilisation (Courtesy of Sonia Beato)

Sir Winston Churchill Memorial Trust

The Churchill Memorial Trust was funded in 1965 to perpetuate and honour the memory of Sir Winston Churchill through the promotion of knowledge and international experience. Since its inception, the Trust has awarded more than 3,700 "Churchill Fellowships" allowing Australians to travel overseas to conduct research in their field of expertise.

In 2011, a Churchill Fellowship was awarded to Alessio Mariani, lead author of this paper, for the *"Investigation of International Innovative Coastal Engineering Solutions to Manage Beach Erosion"*. The Fellowship allowed him to travel during two months in 2012 to Japan, USA, Spain, France, The Netherlands and Italy to meet leading coastal engineering experts and to visit laboratories and field sites where innovative solutions to beach erosion were implemented. The findings of this research are presented in this paper and in the recent guidelines published by Engineers Australia National Committee on Coastal and Ocean Engineering *"Climate Change Adaptation Guidelines in Coastal Management and Planning"* (NCCOE, 2012).

Artificial Reefs

An artificial reef is a manmade submerged breakwater typically located nearshore in depths ranging from 2 to 10 metres. The structure's crest level is at Mean Low Water (MLW) or below to minimise visual impacts. The primary function of artificial reefs is to induce the incoming waves to break thus reducing the wave energy reaching the beach leeward of the structure. This generates alongshore gradients in wave height and longshore currents, altering sediment transport and (in some cases) promoting shoreline accretion.

Secondary objectives are the enhancement of the surf amenity and/or ecology in which case the structures are commonly referred to as multipurpose reefs. The main advantage of artificial reefs compared to traditional emergent structures is that the structure is not visible from the beach at most stages of the tide and therefore does not impact the aesthetics of the location. Pros and cons related to the use of artificial reefs are summarised in Table 1.

Table 1: Artificial reefs pros and cons

Artificial Reefs	
Pros	**Cons**
Not visible from the beach Marine habitat enhancement Coastal protection* Surfing enhancement* Recreational amenity (diving, fishing etc.) Simplicity of constructability* Removability*	Only suitable for small tidal range Sensitivity to sea level rise Limited design criteria Limited protection during storm Subject to scouring of base Subject to settlement Swimmer and navigational safety

Notes: *in some cases and if appropriately designed and constructed

Whether artificial reefs are effective as coastal protection and as surfing and ecology enhancement is still subject of debate. Figure 3 presents a list of major international projects involving artificial reefs. Their performance was reviewed in terms of successfully achieving the primary design criteria i.e. coastal protection, ecological or surfing enhancement. The list was based on field cases well documented in published scientific literature. Based on the documented field experience, the key findings are:

- Of the 26 artificial reefs reviewed, 19 were intended to provide coastal protection as a primary objective. Approximately half of these structures had no significant accretionary impact on shoreline alignment compared to the predicted morphological response.
- Six artificial reefs were constructed with the primary objective of improving surfability and at least half of these were considered unsuccessful.
- Where monitored, enhancement of marine colonisation and biodiversity was reported at all structures.
- Settlement and local scouring was observed at most artificial reefs. This affected the structure stability and intended performance, which often led to maintenance works and top up costs.

Figure 3: Artificial reef locations

Beach Dewatering

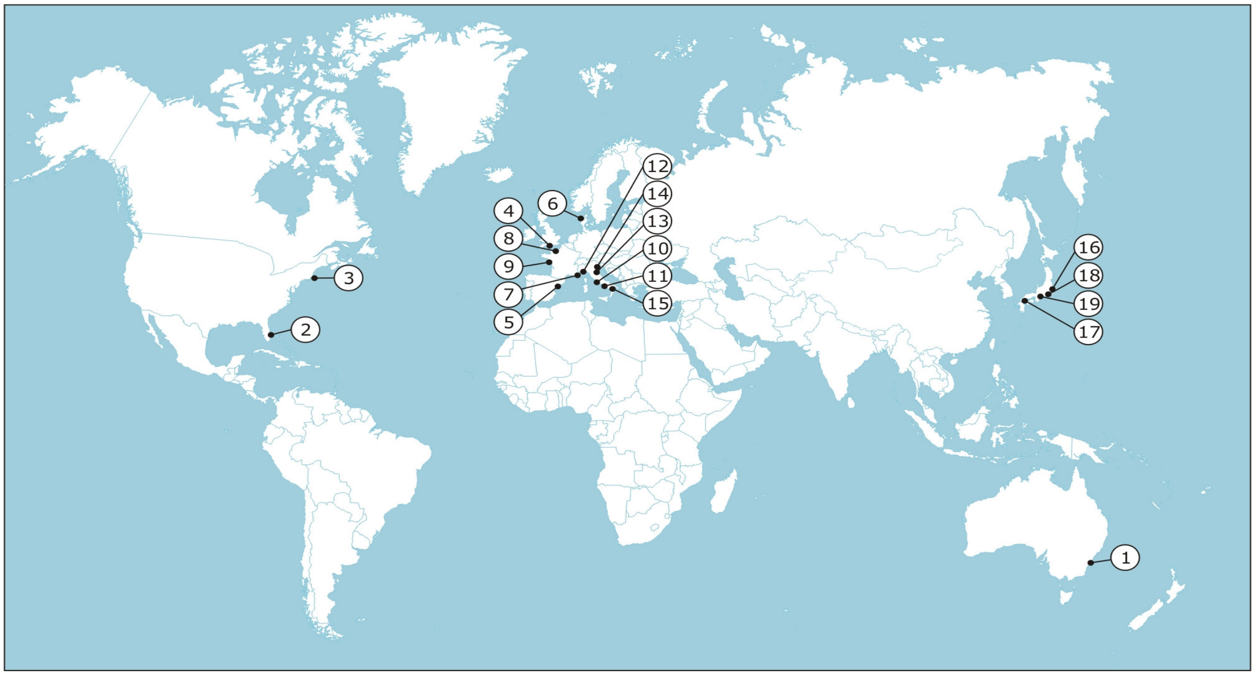
While dewatering is a well-established practice on construction sites, it is only in the last two decades or so that the dewatering concept has been commercially proposed and applied as an alternative to more traditional coastal stabilisation methods. Beach dewatering (also referred to as beach drainage) consists in the artificial lowering of the groundwater table on the beach, with its proponents suggesting that this results in enhanced infiltration losses during wave uprush/backwash cycles while promoting sediment deposition at the beach face. Pros and cons related to this approach are shown in Table 1.

Table 1: Beach dewatering pros and cons

Beach Dewatering	
Pros	**Cons**
No visual impacts (once installed) Beach stabilisation (in some cases) Simplicity of constructability Removability Relatively low cost Drying effect on beach for increased recreational use	Only suitable for low energy wave areas No protection during storms Susceptible to damage during storms Durability Maintenance costs for pumps Lack of design criteria

Although several beach dewatering experimental and commercial installations have been implemented around the world (including in Dee Why and Durras Beach NSW Australia) few were established in combination with an independent scientific review of the effects on shoreline stabilisation and fewer incorporated a monitoring period of the shoreline response over longer than 5 years.

The prototype system implemented in Dee Why Beach, NSW (Davis et al., 1991) consisted in an array of shore normal strip drains occupying about 160 m of beach with no pumping system added. Monitoring of the site concluded that no discernible reduction of beach erosion could be attributed to the gravity drainage system.



1. Dee Why, Australia
2. Sailfish Point, USA
3. Nantucket Island, USA
4. Branksome Chine, UK
5. Riumar, Ebro Delta, Spain
6. Thorsminde, Denmark
7. Saint Raphaël, France
8. Villers-sur-Mer, France
9. Les Sables d'Olonne, France
10. Lido di Ostia, Italy
11. Isola di Procida, Italy
12. Alassio, Italy
13. Lido Adriano, Italy
14. Bibione, Italy
15. Metaponto, Italy
16. Hazaki-HORS, Japan
17. Nijigahama, Japan
18. Matsuzaki, Japan
19. Tsu-Matsuzaka, Japan

Figure 4: Beach dewatering locations

A total of 19 installations (shown in Figure 4) were reviewed in terms of achieving the predicted coastal stabilisation. The main findings from the review of the documented field experience are:

- Of the 19 beach dewatering systems reviewed, approximately half had either negligible effects on shoreline stabilisation or monitoring results were inconclusive.
- Field and laboratory experiments showed that the watertable below the beach face can be successfully lowered through dewatering systems with morphological response ranging from negligible effects to possibly effective beach stabilisation.
- Beach dewatering systems are susceptible to storm damage and do not provide adequate protection from storm erosion. Hence their use for protection is limited to low wave energy environments.

- Established engineering design criteria and durability in the field remain to be proven.

Artificial Dunes

Coastal sand dunes are complex ecosystems generated through wind transport and located at the interface between terrestrial and marine environments. Sand dunes play an important and well recognised dual role in coastline and beach stabilisation:

i. they provide natural protection to sea-front properties and assets against wave impact and storm surge inundation; and
ii. they constitute an erodible sand supply for beaches (Dare, 2003).

Dunes also provide a natural "trap" for wind-driven sand which settles and contributes to the growth of the dune system while reducing potential clogging of stormwater drains.

The (re)construction of dunes is common practice in beach restoration projects and involves the use of compatible sand transported to the beach (e.g. via trucks or a sand bypassing system) and reshaped mechanically as a natural dune. Alternatively, sand can be mechanically moved from the lower part of the littoral beach system to the dune (beach scraping).

Another common practice used to promote dune stability is to place a resistant body within the constructed dune to provide a second line defence during storm events. In fact, this dune "artificial armouring" remains completely buried and not visible during normal conditions, becoming exposed and acting as a hard revetment in the case of beach erosion. Buried rock or concrete seawalls have been utilised for the dune core while a variety of patented systems such as stone-filled matrixes, grids, mats and sand-filled geotextiles are being used as buried dune armouring. The use of sand-filled geocontainers (bags or tubes) to form the core of artificially constructed dunes is an emerging practice which may provide an alternative to other techniques.

Figure 5: Dune reconstruction in Cadiz Spain (left) and Delfland Coast The Netherlands (right) (Source: Ron Cox and Alessio Mariani)

Several documented methods are available for dune reconstruction and rehabilitation including the use of wind fences, re-vegetation and management of beach access points (Figure 5). These methodologies are well described in specialty literature such as the Coastal Dune Management Manual (NSW, 2001) and the Coastal Engineering Manual (CEM, 2003). Table 2 summarises pros and cons associated with artificial dunes.

Table 2: Artificial dunes pros and cons

Artificial Dunes	
Pros	**Cons**
Buffer against wave impacts and inundation Sand supply for fronting beaches Creation of natural habitat Prevents sand from moving inland	Sensitivity to sea level rise Performance in the field of dune armouring Durability of reinforcement materials Stability of reinforcement materials

The rebuilding and reinforcing of dunes are widespread and recognised practices for coastal protection as such they have been implemented successfully at several sites both nationally and internationally. The Netherlands has at the heart of its national coastal defence policy massive sand nourishment with the intention of maintaining robust dune systems. In Australia, Gordon (1989) reports that the entire dune system (13 km) along the Sydney region open coast was completely reconstructed, fenced and stabilised throughout the late 1970's and early 1980's. Following the severe beach erosion of the late 1960s on the Gold Coast, ongoing beachfront development was conditional upon construction of an engineered seawall by landowners. Presently, a 32.2 km seawall is buried beneath the beach dune of the Gold Coast shoreline between Kirra and Southport.

Natural Defences

For sheltered, low wave energy areas such as estuaries and deep embayments, coastal vegetation can be effectively used as a non-structural protection against coastal erosion. Coastal vegetation typically includes seagrasses, salt marshes and mangroves.

Seagrasses are aquatic flowering plants that form meadows in near-shore brackish or marine waters, in temperate and tropical regions. Australia has the most diverse array of seagrass species in the world (Butler and Jernakoff, 1999). Most seagrasses colonise soft sandy substrates in quiescent shallow waters to depths of 90 metres, however, sometimes seagrasses (such as some Posidonia) are exposed to relatively high wave energy. A salt marsh is a community of plants and animals in the upper coastal intertidal zone. In Eastern Australia, their distribution overlaps with mangrove forests which are usually established in low elevation sites where inundation is more frequent. However, mangroves which comprise several species of trees and shrubs, typically extend in tropical and subtropical coastal waterways.

It is recognised that coastal vegetation can provide coastal protection through two mechanisms:

i. Wave attenuation; and
ii. Seabed/soil stabilisation (Gedan et al., 2011, Koch et al., 2006).

The above ground portion of the plants has a dampening effect through the structural presence of the plants which results in wave attenuation and wave energy dissipation. The consequent reduction in near-bed flow velocities promotes settling of sediment while the plants root system enhances soil cohesion and seabed stabilisation.

The most significant research is being conducted in laboratories around the world to characterise wave attenuation by a variety of coastal vegetation. Field and laboratory studies (Prinos *et al*., 2010, Brandley and Hauser, 2009, Thompson *et al*., 2003) identified as key variables water depth, height of the vegetation, density of the meadow and wave length. Field experience showed that the planting and growth of coastal vegetation can be an effective and non-structural way of mitigating erosive processes while enhancing the ecological habitat of areas characterised by low wave energy conditions. To increase its effectiveness, coastal vegetation can be combined with protective structures such as low crested breakwaters. However, the suitability of these defences is restricted to generally low energy estuarine and coastal locations and provides little opportunity for erosion protection on exposed open coasts. Pros and cons of using natural defences as coastal protection are summarised in Table 4.

Table 3: Natural defences pros and cons

Natural Defences	
Pros	**Cons**
Wave attenuation Soil stabilisation Enhancement of ecological habitat Natural non-structural protection	Only suitable for low wave energy areas Only suitable for shallow slopes Difficulties in planting and growth Ecological impacts Limited knowledge of wave attenuation characteristics

Conclusions

While traditional approaches to coastal protection rely on a long history of application and well established engineering design criteria, novel and emerging technologies, by definition, are still undergoing development through prototype and field trials. Field experience using innovative approaches showed that emerging methods have been applied with varying degrees of success. Results indicate that large uncertainty is associated with these interventions. This uncertainty needs to be considered in any feasibility analysis, as it presents a significantly higher risk in comparison with other forms of coastal protection. It is important to note however, that the success or failure of an approach at a site does not warrant its application or dismissal at other sites. Alternative approaches are always to be assessed in relation to specific beach erosion problems following in-depth site-specific investigations. Field trials and long-term (several years) monitoring are recommended when considering such approaches.

Where a method is not proven (including appropriate theoretical analysis and laboratory testing, where no monitored field trials have been undertaken) then the coastal manager is urged to exercise extreme caution. The old adage that *"If it seems too good to be true then it probably is!"* remains relevant.

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