COASTBUSTERS: INVESTIGATION OF ECOSYSTEM BASED COASTAL STABILISATION SOLUTIONS

T. Sterckx[1], E. Lemey[2], M. Huygens[1], J. Fordeyn[2], B. Groenendaal[3], D. Delbare[4], T. Vanagt[5], B. Pycke[3], A. Semeraro[4] and T. Mascart[1]

ABSTRACT

Conventional coastal protection solutions such as dykes and embankments are increasingly being challenged by changes in sea level rise, more aggressive climatic conditions, land subsidence, erosion of beaches and altered sediment flow. Maintenance of these conventional structures will become unsustainable; hence, innovative alternatives are necessary to guarantee coastal resilience.

The Coastbusters project aims to develop three nature-based solutions for sustainable coastal protection. These solutions will create new habitats based on known 'biobuilder species' in the form of biogenic coastal reefs. The purpose of the reefs is to induce natural accretion of sand, attenuate storm waves and reinforce the foreshore against coastal erosion, thus, adding to coastal protection. Three key biobuilding concepts were identified to be tested to strengthen conventional coastal engineering: (1) Tube-building polychaete worm reefs (*Lanice conchilega*), (2) Marine flora fields (seaweed and seagrass) and (3) Bivalve reefs (mussels and oysters).

Based on a critical assessment of the actual state of the art, adapted innovative designs are evaluated in an integrated feasibility analysis prior to further step up pilot projects in the field. The created biostabilisation power of the biogenic reefs is tested in both laboratory experiments and in-situ pilot projects in front of the Belgian Coast. For each of the three concepts, the following generic goals were identified: (1) The organism survives the dynamic conditions of the foreshore and maintains its ecological functions - environmental survivability status. (2) The reef, built as a specific biogenic structure, is stable and creates ecological added value within the local coastal ecosystem - ecological added value (ecosystem services). (3) The natural reef develops in such a way that local sedimentation and natural stabilisation of the foreshore occurs - technical valorisation value (adding to coastal protection). As for each of the three concepts the same "success" criteria are formulated, a uniform monitoring and evaluation approach is set up in an integrated way.

The project was awarded an innovation grant from the Flemish government in March 2017 and runs for 3 years. This paper describes the selection process of the concepts including their design, development (from laboratory tests into a pilot scale setup in front of the Belgian coast), deployment and monitoring.

Keywords: Nature based solutions, Sustainable coastal protection, Ecosystem based design, Environmental & ecological dredging, ecosystem services, biogenic reefs.

[1] Dredging International DEME Group, Scheldedijk 30, B-2070 Zwijndrecht, Belgium; +322505211; sterckx.tomas@deme-group.com

[2] Jan De Nul, Tragel 60, B-9308 Aalst, Belgium; +3253737641; emile.lemey@jandenul.com

[3] Sioen Industries nv, Fabriekstraat 23, B-8850 Ardooie; +3251740900; bert.groenendaal@sioen.be

[4] EV-ILVO, Institute for Agricultural and Fisheries Research, Ankerstraat 1, B-8400 Oostende, Belgium; +3292722604; daan.delbare@ilvo.vlaanderen.be

[5] eCOAST Research Centre Ostend BVBA; Esplanadestraat 1, B-8400 Oostende, Belgium; +3259270400; thomas.vanagt@ecoast.be

INTRODUCTION

Adverse effects of global changing conditions associated with natural disasters and climate change are currently indisputably present. Under current climate change scenarios, it has been estimated that along low coastlines, almost 30% of residences, if sited within 200 m from the sea, may be severely affected by erosion-related property losses over at least the next 50 years (UN-habitat, 2009). Societies across the world are facing the need to adapt to safeguard valuable resources and to reduce the vulnerability of communities to an increasingly uncertain future. To this extent, classical engineering solutions, such as, redesigning water supplies management to deal with droughts and floods, altering crops and agricultural methods to deal with changing rainfall and rising temperature, placing conventional hard coastal protection solutions (e.g. dykes, breakwaters and embankments) to attenuate waves and reduce erosion, have been applied. Regarding coastal protection, these hard stabilization structures are currently severely challenged in many locations and are becoming unsustainable due to their costly and continual maintenance requirements, as well as, their rigidity to any widening and height increase to keep in step with the increasing coastal erosion risk. Additionally, such structures significantly alter the natural adaptive capacity of any coastline (see Figure 1 and Temmerman et al. 2013).

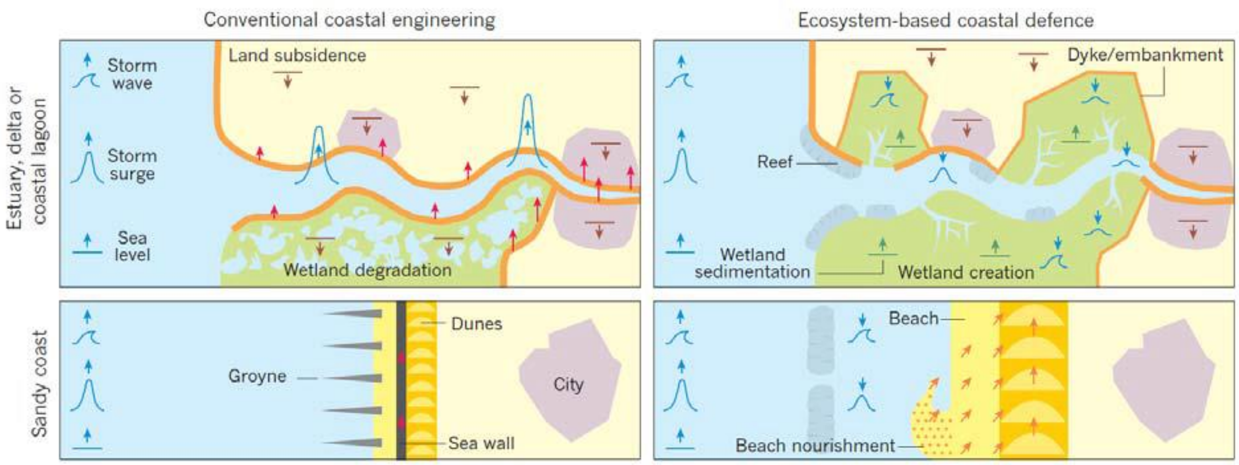

Figure 1. Conventional coastal engineering vs. ecosystem-based coastal defence measures. Blue arrows indicate the increase/decrease of storm waves, storm surge and sea level (as specified); red arrows indicate the need for maintenance and heightening of dykes/embankments/sea walls with sea-level rise; and brown arrows indicate land subsidence. Extracted from Temmerman et al. 2013.

Under present and future environmental conditions, the world requires smart coastal protection strategies that are, sustainable, multi-functional and economically viable to help solve immediate and predicted coastal erosion and inundation problems. Coastal lowlands such as Belgium are considered the most vulnerable to sea level rise and related inundations. In this respect, Belgium, together with the Netherlands, where more than 85% of the coastal zone is located below 5 metres elevation, is highly vulnerable. Moreover, sea level rise and the increased likelihood of severe storm surges are projected to be the highest in the tidal North Sea region, where both countries lay. These climate change effects may also aggravate coastal erosion, a problem which already affects a large part of the Belgian coastline. In addition to these morphological aspects, the socio-economic characteristics of the Belgian coastal zone make the area vulnerable to flooding due to the increasing numbers of people and economic assets near the coast.

The Belgian coast until the late 1960's has been protected by hard coastal defence schemes (sea walls, groynes, breakwaters). Since then, awareness has grown that these hard structures have a negative effect on the stability of the dynamic coastal system and can induce erosion of the foreshore. Gradually, soft engineering solutions, such as beach nourishments have been adopted to safeguard the natural dynamics of the coast giving the beach a typical profile prone to dune erosion and subtidal beach accretion during storms events (Figure 2).

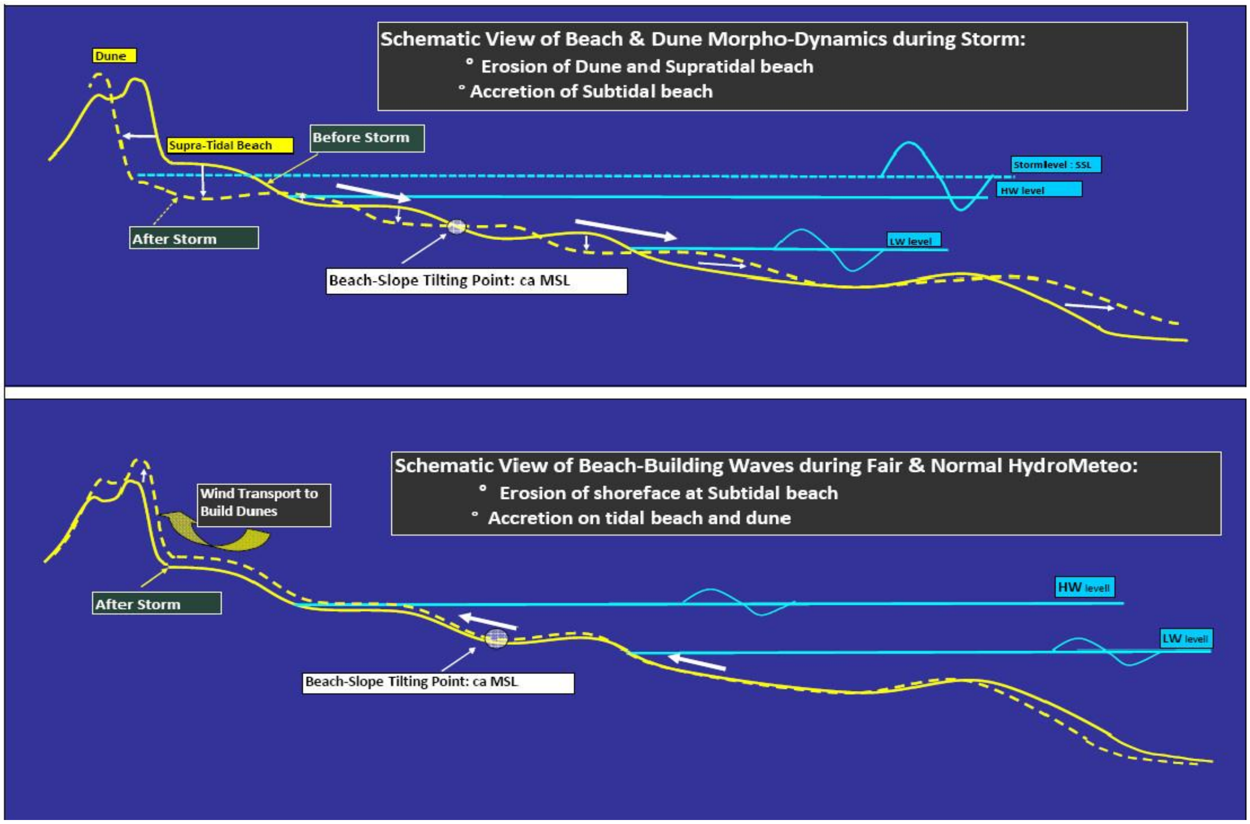

Figure 2. Typical Belgian coast beach profile with specific dune-morpho dynamic during storm events (top) and normal weather conditions (bottom). Adapted from consortium's internal communication.

So far, these coastal protection measures such as soft beach nourishments and the maintenance of hard coastal defence infrastructures are carried out on an incessant yearly basis. As example, between 2004 and 2007, the Belgian coast was replenished with 2.7 million m³ of sand to secure a safety level of at least 100 years (Lebbe et al. 2008). From data gathered by the European Policy research corporation 10 years ago, Belgium spend about € 18 million annually on coastal maintenance. In addition, specific measures to protect the harbour city of Ostend against flooding and erosion amounted to € 9 million in 2008. The indirect expenditure to protect against flooding and erosion amounted to € 1.3 million in the same year. Over the period 1998-2015, Belgium invested at least € 419 million in coastal protection and climate adaptation. In 2011, the Flemish Coastal Division initiated an Integrated Master Plan for Coastal Safety (Flemish Government Maritime and Coastal Services Agency, 2011) to protect Flanders against extreme flooding events in the present and in the future (2050). Extreme flooding events were defined as those associated with storms with a 1 on 1000-year return period. The Master Plan aims to ensure the same level of protection under current conditions and in the case of a 30 cm sea level rise by 2050. Moreover, in 2013, the European Commission launched a joint initiative implementing Integrated Coastal Zone Management (ICZM) strategy and maritime spatial planning (MSP) to promote holistic consideration of coastal marine ecosystems by encompassing all ecosystem services aspects.

Ecosystem services – an anthropocentric notion, which aims at highlighting the benefits humans receive from living organisms in fully functioning ecosystems or as the well-being benefits derived from nature to people (MEA, 2005) – have an economic valuation. Such services became central for all stakeholders to collaboratively decide on the best policies to protect and use multiple ecosystems in a sustainable way. In recent policies and regulations (EU Biodiversity Strategy, Flood Directive) it has been clearly stated, the need for inclusion of Ecosystem Services assessments in socio-economic analysis such as cost-benefits appraisals and risk reduction programmes are necessary. One of the benefits from coastal and marine ecosystems are particularly linked to the coastal protection service, namely the natural defence of the coastal zone against inundation, erosion from waves, storms and sea level rise.

In the light of the holistic approach of marine ecosystem services, newly developed policy frameworks on innovative engineering solutions supplementing existing conventional coastal protection solutions are being promoted. Amongst others, this has led to recommendations to create or restore natural habitats, providing coastal protection in place of (or complementing) artificial structures (Davis et al. 2015). Such ecosystem inspired approaches are based on the creation and restoration of existing coastal ecosystems, such as natural vegetation (e.g. mangroves, salt marshes, seagrass beds and dune vegetation) and biogenic reef structures (e.g. corals, oysters, mussels and tube building worms). Natural coastal ecosystems have some resilience capacity for self-repair and recovery, and can provide significant advantages over traditional hard engineering approaches against coastal erosion (Gracia et al 2017).

This global need of novel ecosystem based coastal defence solutions to protect shore communities and associated infrastructure is inevitable (Resio & Westerinket 2008, Knutson et al. 2010). Above mentioned naturally occurring ecosystem engineering or biobuilding species have the capacity to reduce storm waves (Barbier et al. 2008, Shepard et al. 2011) and storm surges (Wamsley et al. 2010, Zhang et al. 2012, Temmerman et al. 2012), and can keep up with sea-level rise by natural accretion of mineral and biogenic sediments (Kirwan et al. 2010, Fahgerazzi et al. 2012). Henceforth, the Coastbusters project, presented in this paper will implement and investigate three ecosystem based coastal stabilisation solutions using biobuilder species, as they have the capacity to positively influence their surrounding environment through their own biogenic structure (Bouma et al. 2009).

This project fits within the vision for further development of the Belgian coastal zone is on its way aiming at the integration of safety, natural values, attractiveness, sustainability and economic development including navigation and sustainable energy.

NATURE BASED SOLUTION DESIGN

The Coastbusters consortium leading this 3-year project (2017-2019) consists of Dredging experts (Jan de Nul and Dredging International - DEME group), textile manufacturer (Sioen industries), marine consultant (eCoast) and research institution (Institute for Agricultural and Fisheries Research, ILVO). The Southern part of the North Sea at the Belgian Coast, nearby the Broersbank sandflat (ca. 51°07,11'N – 002°34,45') has been chosen to test the concepts of biogenic subtidal reefs using "biobuilder species". The dimensions of the installations within the testing zone will be approximately 100m² per concept.

The Coastbusters project will test the ecosystem resilience, survivability and reef building capacity of three biobuilder types: (1) Bivalve reefs (*Mytilus edulis*), (2) marine flora reefs (seaweed and seagrass) and (3) reefs of tube-dwelling sand mason worms (*Lanice conchilega*) (Figure 3).

Figure 3. Coastbusters' logo (l) and 3 conceptual reef building ecosystem engineers.

To test those nature-based solutions, suiting substrates or sockets are being used or specifically developed. Following innovative designs have been put in place to speed up/stabilize the formation of the respective biogenic reef:

(1) For the bivalve reef field test, we used specific socket method (based on aquaculture technique) in combination with a string of 40 shellfish bags (artificial structures) as a substrate for colonisation. For the in-field layout and deployment we refer to Figure 4 and Figure 7A.

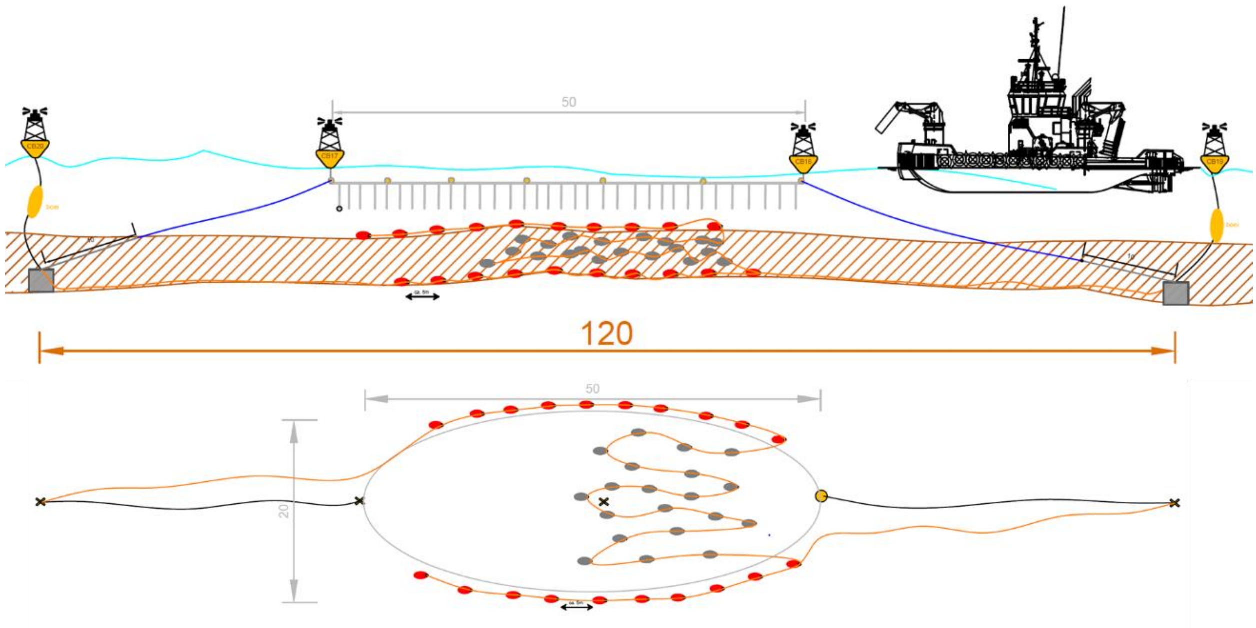

Figure 4. In-field installation of mussel *Mytilus edulis* socket and bivalve bags. Top: cross section of installation. Bottom: top view of in-field layout. Distance between both anchorage points is 120 m.

(2) For the flora reef field setup Coastbusters installed three reef concepts, parallel to the coastline, using bags and frames with innovative seeded textile bags (Algaetex ®Sioen) as a substrate. The in-field setup comprised four bags and two frames per reef as shown on Figure 5 and Figure 7B).

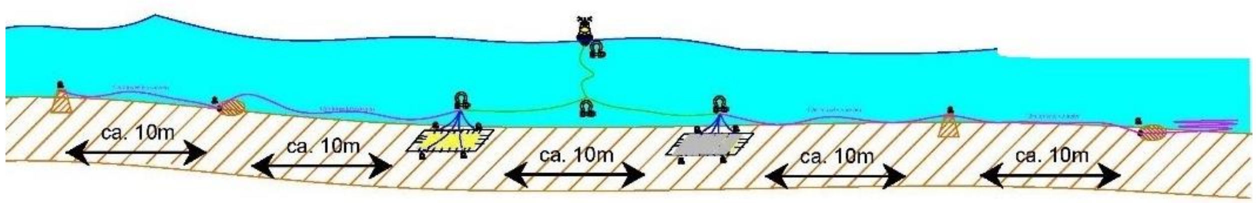

Figure 5. Flora Reef in-field test setup of impregnated seaweed *Saccharina latissima* seed bags and frames (m).

(3) For the *Lanice* reef concept we first perform ex-situ tests in laboratory conditions prior to in-situ tests. In the laboratory we cultivated *Lanice* juveniles to test several recruitment substrate prototypes in a Kreiseltank (see Figure 6). For the in-situ tests we used several artificial structures with protruding tubes, simulating a *Lanice* reef for efficient recruitment adding to coastal protection (See Figure 7C).

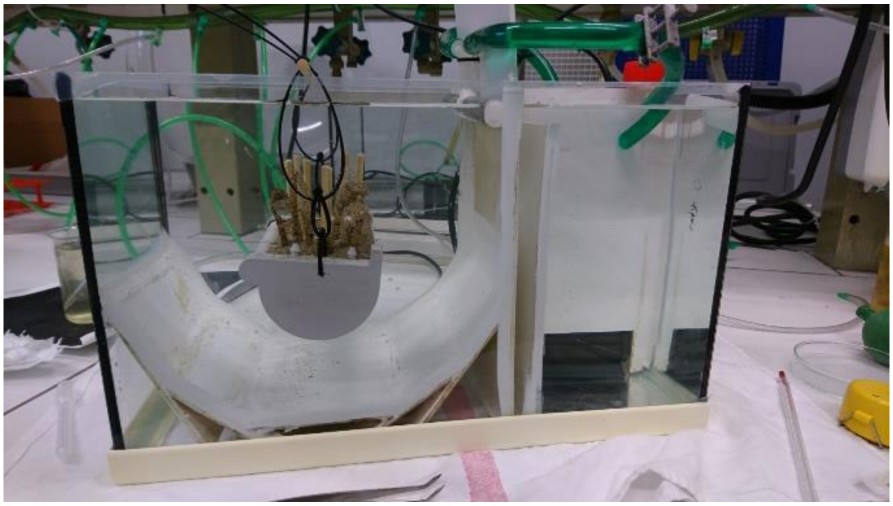

Figure 6. *Lanice* Reef laboratory set-up using *Lanice* juveniles in a Kreiseltank.

For each of the three concepts, separate goals were identified: (1) the organism survives the dynamic conditions of the foreshore and maintains its ecological functions, (2) the reef, built as a specific biogenic structure, is stable and creates ecological added value within the local coastal ecosystem (ecosystem services), and (3) the natural reef develops in such a way that local sedimentation and natural stabilisation of the foreshore occurs (adding to coastal protection).

For each of the three concepts the same criteria are formulated, wherefore a uniform monitoring and evaluation approach is set up. All concepts will be monitored and evaluated in an integrated way: (1) environmental status (survivability, quality, etc.), (2) ecological value as ecosystem services provider for the coastal zone, and (3) technical efficacy as added value to coastal defence by way of stabilising the foreshore. The specific design objectives, proof of concept and feasibility analysis put forward are summarized in Table 1.

Table 1. Design, feasibility and proof of concept of 3 reefs.

Reef	Design phase	Feasibility analysis	Proof of Concept (PoC)
Bivalve	A submerged mussel longline combined with hard substrates on the bottom will be ecologically designed for optimal settlement of bivalves and other species (e.g. Crustacea, …). The biogenic reef growth, stabilization of the structures and position, is validated in design process.	A mussel longline of 50 meter length combined with 40 bottom structures (shellfish bags) spread out over a surface of approx. 500 m² will be tested during the feasibility analysis. This phase will be considered successful if there is a good settlement of reef critters on the artificial reef structures.	The PoC phase aims to produce a bivalve reef with mussel densities of 1500 mussels/m² or > 30% coverage.

Flora	Selection of marine plant species. Development of substrate with good cultivation properties for the selected species. The substrate will be functionalized for seeding, deployment and immobilization on the "foreshore".	The prototype will be tested during the feasibility analysis and considered successful if the algae/ seagrass grows under the local conditions.	The PoC phase aims to produce a natural marine flora reef and natural accretion of sand (or a min. of 100 shoots/m^2 for seagrass or up to 20-50 seaweed plants per m^2 depending on the species).
Lanice	Development of substrate with good cultivation properties with embedded vertical tubes or other *Lanice* settlement inducing properties. Furthermore, the substrate will be functionalized such that they can be easily seeded, deployed and immobilized on the "foreshore".	The prototype will be tested during the feasibility analysis and this phase will be considered successful if there is a good initial settlement of tubeworms on the artificial reef structures and a good secondary formation of biological substrates in the artificial reef area.	*Lanice* The PoC phase aims to produce a tubeworm reef with coverage densities of at least 5% coverage or a density of 2272 Lanice worms/m^2.

THREE ECOSYSTEM BASED COASTAL STABILISATION SOLUTIONS

Coastbusters tests three concepts of biogenic subtidal reefs using "biobuilder species" as an alternative to conventional coastal engineering in the field, where up to now theoretical concept-validation is lacking and where ecosystem services will be used to validate the tested field setup. The goal of this project is to find alternative, environmentally friendly ways to stabilize the shoreline and minimize local erosion by using an ecosystem approach. The use of biostabilisation – biological processes to increase sediment stability – or to reduce the potential for erosion by tidal currents and wave action can be a cost efficient and sustainable way to obtain a safe and resilient beach. This alternative or addition to recurrent sand nourishment will influence the natural ecosystem of the beach in a positive way. In 2018, all three reefs were successfully put in place (see Figure 7 illustrating the deployment) and monitored over the duration of the project.

Figure 7. In-field installation of mussel *Mytilus edulis* socket (A), impregnated seaweed *Saccharina latissima* seed bags (B) and sand-mason worms *Lanice conchilega* (C) for induction of biogenic reef formation, respectively, Bivalve, Flora and *Lanice* reef.

Bivalve Reef

The on seabed present *Mytilus edulis* reef building socket and detached clumps of organisms are currently modifying the erosive character of the foreshore stabilizing the bed and attenuating hydrodynamic energy whilst accumulating sediment on the foreshore. In addition, mussel beds or other reef building species beds enhance biodiversity by providing shelter and nesting area for fish and crustacean species (e.g. crabs and shrimps). Further, mussels and, for instance, oysters are filter feeders filtering algae from the water column for food. By doing this they clarify the water by removing not only algae, but also silt and organic particles from the water column (Borsje et al. 2011). This additional ecosystem service makes the bivalve reef a worthy ecosystem based coastal stabilisation solution.

Flora Reef

Sugar kelp (*Saccharina latissimi)* supports high primary productivity, magnifies secondary productivity, and creates a three-dimensional habitat structure for a diverse array of marine organisms, many of which are commercially important. In addition, it has a bio-remediation potential through filtering dissolved nutrients from the water column. These ecosystem services make the flora reef a good bio-builder, however it exhibits pronounced spatiotemporal variability and does not consolidate sedimentation. Kelps (and in extension seaweeds) need a hard substrate (natural or artificial) to develop. Consequently, the ecosystem services from the kelp flora reef are not primarily coastal protection but in combination with other reefs, these reefs can increase the overall ecosystem services delivered. In contrast, other types of flora reefs, like seagrass-based reefs have an added value regarding enhancing sedimentation, hence, coastal protection. However, these require specific physical conditions, which might not currently be present at the Belgian coast.

Lanice Reef

The physical reef characteristics of *Lanice conchilega* have been proven to consolidate the sediment deposition within the biogenic reef and thus provide coastal protection. In addition, the biological community structure of associated fauna will presumably increase within the aggregations, thus showing a positive correlation and increase of macrobenthic fauna, which are feed for adults and/or juveniles of commercially fished fisheries. However, those biogenic aggregations are ephemeral in time if no yearly renewal of existing aggregations through juvenile settlement occur. Hence, the spatial extent and patchiness of the biogenic reefs might fluctuate over time, presenting oscillating ecosystem services over time. Therefore, site selection is primal to ensure continuous juvenile settlement to create large self-sustaining *Lanice* reefs with optimal densities to fulfil its ecosystem services.

CONCLUSION

This paper presents examples of three nature-based pilot projects aiming to enhance coastal protection by making use of bio-builder species. The drawback is that most suitable ecosystem engineering species depend on the specific site characteristics, for instance location, wave action, tidal height and sediment grain size, and other biological characteristics, such as species life-traits and ecology. Thereby, not all coastal locations will be suitable for each reef. In addition, extreme events such as storm surges, might be able to harm ecological systems to such an extent that returning to the state valuable for coastal protection can prove troublesome or not possible. Information on resilience of specific engineering functions of species is lacking (Groffman et al., 2006), meaning that use of engineering species for coastal protection will require systematic and continuous monitoring, to fuel and quantify claimed ecosystem services on longer spatial and temporal scale.

The main advantage to traditional (soft or hard) engineering is that the latter are generally over dimensioned and static, hence, not responding to fast changing conditions. Integration of nature-based solutions into coastal protection allows a dynamic interaction between organisms and the natural evolution of the coastal system. In case of sea-level rise, nature-based solutions may be used to postpone massive engineering measures for coastal protection. Thereby, organisms that trap sediment to keep up with long-term sea level rise may provide a long-term sustainable protection and might, at least locally, reverse or delay ongoing trends. Moreover, given the adaptive abilities of ecosystem engineering or bio-builder species, solutions could be less over-dimensioned compared to traditional engineering solutions, which reduces costs during deployment, monitoring and maintenance. Thorough knowledge of ecosystem functioning, and ecosystem-based management is needed to make this approach successful (Granek et al., 2010).

To conclude, all three ecosystem based coastal stabilization solutions put forward in Coastbusters are currently being tested and are still in a proof of concept phase to demonstrate their coastal protection efficiency and ecological added value on a large scale and long term. Nevertheless, Coastbusters is sharing best practices on design, development, deployment and monitoring adding pioneering knowledge in terms of emplacement, hydrodynamics and life-trait requirements of proposed nature-based solutions. In addition, Coastbusters aims to answer existing and future coastal protection challenges, with the main drive to promote nature-based engineering as the way forward to integrate multiple social, economic and environmental functions into innovative coastal resilience management.

REFERENCES

Barbier, E.B. et al. (2008). "Coastal ecosystem-based management with nonlinear ecological functions and values". Science 319, 321–323.

Borsje, B., van Wesenbeeck, B., Dekker, F., Paalvast, P., Bouma, T., van Katwijk, M. and de Vries, M. (2011). "How ecological engineering can serve in coastal protection." *Ecological Engineering*, 37-2.

Bouma, T.J., Olenin, S., Reise, K. and Ysebaert, T. (2009). "Ecosystem engineering and biodiversity in coastal sediments: posing hypotheses." Helgoland Marine Research 63, 95–106.

Davis, M., Krüger, I. and Hinzmann, M. (2015). "Coastal Protection and SUDS - Nature Based Solutions." *Re-Create Policy brief 4.*

Fagherazzi, S. et al. (2012). "Numerical models of salt marsh evolution: ecological, geomorphic, and climatic factors." *Rev. Geophys. 50*, RG1002.

Flemish Government Maritime and Coastal Services Agency (2011). *Masterplan coastal safety, Masterplan Kustveiligheid*.

Flemish Government Department of Mobility and Public Works (2014). "Vlaamse Baaien, Flanders Bays 2100." *Masterplan Vlaamse Baaien: Toekomst van het kustsysteem in Vlaanderen.*

Gracia, A., Rangel-Buitrago, N., Oakley, J. and Williams, A. (2017) "Use of ecosystems in coastal erosion management." *Ocean and Coastal management.*

Granek, E., Polasky, S., Kappel, C., Reed, D., Stoms, D., Koch, E, Kennedy, C., Cramer, L., Hacker, S., Barbier, E., Aswani, S., Ruckelshaus, M., Perillo, G., Silliman, B., Muthiga, N., Bael, D. and Wolanski, E. (2010). "Ecosystem services as a common language for coastal ecosystem-based management." *Conserv. Biol. 24*, 204–217

Groffman, P, Baron, J., Blett, T., Gold, A., Goodman, I., Gunderson, L., Levinson, B., Palmer, M., Paerl, H., Peteron, G., Poff, N., Rejeski, D., Reynolds, J., Turner, M., Weathers, K. and Wiens, J. (2006). "Ecological thresholds: the key to successful environmental management or an important concept with no practical application?" *Ecosystems 9*, 1–13.

Kirwan, M.L. et al. (2010). "Limits on the adaptability of coastal marshes to rising sea level." *Geophys. Res. Lett. 37*, L23401.

Knutson, T.R. et al. (2010). "Tropical cyclones and climate change." *Nat. Geosci. 3*, 157–163.

Lebbe, L., Van Meir, N. and Viaene, P. (2008). "Potential implications of Sea Level Rise for Belgium." *Journal of Coastal research vol. 24* (2) p. 358-366, West palm beach, Florida

Millennium Ecosystem Assessment (2005). "Ecosystems and Human Well-being: Synthesis". Island Press, Washington, DC

Resio, D.T. and Westerink, J.J. (2008). "Modelling the physics of storm surges." *Phys. Today 61*, 33–38.

Shepard, C.C., Crain, C.M. and Beck, M.W. (2011). "The protective role of coastal marshes: a systematic review and meta-analysis." *PLoS ONE 6*, e27374.

Syvitski, J.P.M. et al. (2009). "Sinking deltas due to human activities." *Nat. Geosci. 2*, 681–686.

Temmerman, S., De Vries, M.B. and Bouma, T.J. (2012). “Coastal marsh die-off and reduced attenuation of coastal floods: a model analysis.” *Global Planet.* Change 92–93, 267–274 (2012).

Temmerman, S., Meire, P. et al. (2013). “Ecosystem-based coastal defence in the face of global change.” *Nature*, Vol. 504.

UN-Habitat (2009). *UN-habitat Annual Report*. United Nations, New York.

Wamsley, T.V., Cialone, M.A., Smith, J.M., Atkinson, J.H. and Rosati, J.D. (2010). “The potential of wetlands in reducing storm surge.” *Ocean Eng. 37*, 59–68.

Zhang, K.Q. et al. (2012). “The role of mangroves in attenuating storm surges.” *Estuar. Coast. Shelf Sci.* 102–103, 11–23.

CITATION

Sterckx, T., Lemey, E., Huygens, M., Fordeyn, J., Groenendaal, B., Delbare, D., Vanagt, T., Pycke, B., Semeraro, A., Mascart, T. “COASTBUSTERS: Investigation of ecosystem based coastal stabilisation solutions”, *Proceedings of the twenty-second world dredging congress, WODCON XXII*, Shangai, CHINA, April 25-29, 2019

ACKNOWLEDGEMENT

This project received funding from the Flemish innovation and entrepreneurship agency under agreement number HBC.2016.0637 Coastbusters: Development of ecosystem-based protection against coastal erosion.