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自然解方於荷蘭海岸沙丘應用之評析與台灣本土適用之課題

Evaluation of Nature-based Solutions Application in Dutch Coastal Dunes and Lessons Learned for Local Adaptation in Taiwan

安薇娜 [a]　　林宗儀 [b]

Viola Marcia van Onselen　　Tsung-Yi Lin

摘　要

全球海岸環境因人為活動和自然變遷的壓力而逐漸惡化，土地利用變遷、海岸侵蝕、海水面上升、污染等等因素，都使這些退化的環境變得相對脆弱，也提高了災難發生的風險。在面對這些挑戰的各種對策中，「自然解方」因為它的高度適用性及諸多好處而受到全球越來越多的關注。海岸沙丘是海岸防護的天然屏障，在思考對應海水面上升及海岸侵蝕的挑戰時，常比傳統的硬性工程措施，更加適合應用「自然解方」來減輕災害風險。本研究評析幾個在荷蘭海岸沙丘應用「自然解方」的實作案例，收集其相關的環境管理策略，討論其過程與成效，並將這些經驗教訓提供臺灣海岸本土適用之參考。雖然荷蘭海岸線在過去大部分已受到沙丘與不同軟性工法的保護，現今則更重視與自然協作。在這些應用「自然解方」的專案計畫中，減少人為的介入，明顯地促進了生物多樣性的發展，也加快了環境的恢復。臺灣和荷蘭一樣，相當倚賴海洋資源，海岸環境的多樣性高，並擁有許多獨特的棲地環境，但海岸地區同樣也面臨許多如海岸侵蝕的威脅。過去針對海岸侵蝕的對應策略以硬性工法為主，較少從生態面向來思考，而海岸管理也因事權分散而導致缺乏綜合管理，所以臺灣迄今尚無任何地區以自然生態系統管理面向，來研究軟性工法或探究如何降低災害風險。但以 2020 年 6 月新成立的桃園草漯沙丘地質公園為例，可以發現人們對於以設置地質公園方式來保育沙丘、降低災害風險，或透過可持續管理來加強沙丘生態系統等作為，已愈感興趣。現在這個地方級地質公園仍保存著脆弱的沙丘環境和大約八公里的活動海岸線，應該是一個可以適用「自然解方」的地區。

關鍵詞：臺灣－荷蘭、海岸管理、海岸沙丘、自然解方

[a] 國立臺灣師範大學地理學系博士候選人
Ph.D. candidate, Department of Geography, National Taiwan Normal University
[b] 國立臺灣師範大學地理學系教授，通訊作者（email: aeolin@ntnu.edu.tw）
Corresponding author, Professor, Department of Geography, National Taiwan Normal University

Abstract

Coastal environments are deteriorating worldwide due to a combination of human activities and natural stressors, such as land-use change, coastal erosion, sea level rise, pollution, etc. These degraded environments are vulnerable and can become a driver for disaster risk. As a countermeasure to these challenges, Nature-based Solutions (NbS) gain more awareness on a global scale due to their high applicability and many co-benefits. Additionally, NbS have a high rate of long-term benefits compared to traditional (hard) adaptation measures, which have been used frequently as a solution to sea level rise and coastal erosion. Coastal sand dune environments are well suited areas to implement NbS because they already act as a barrier to sea level rise or coastal erosion. Building upon this knowledge, it is important to compare coastal dune sites among different localities and learn from best practices. This study will contribute to gaining more knowledge on NbS and management strategies in sand dune areas in the Netherlands and provide lessons learned for Taiwan. For a large part, the Dutch coastline is protected by sand dunes, and different soft engineering approaches have been established over time, recently focussing more on working with nature. During the implementation of these projects, it became evident that less human involvement stimulates biodiversity and speeds up environmental recovery. Like the Netherlands, Taiwan also relies on marine sources and has a high diversity of coastal environments with unique habitats, but the coastal zone also faces many threats. Strategies to deal with coastal erosion are more focused on hard engineering methods and fragmentation in sectoral management represents different interests, leading to lack of integrated management in Taiwan. So far, not many areas in Taiwan are studied in terms of soft engineering approaches or disaster risk reduction through natural ecosystem management. This paper will outline different management approaches and experiments that are conducted in Dutch dune areas, discuss the evaluation of these projects, and explore possible implications for Taiwan. More specifically, there is a growing global interest in the use of geoparks for disaster risk reduction through NbS, by conservation or enhancement of ecosystems through sustainable management. A new geopark in Taiwan, called Caota Sand Dunes, now conserves a fragile dune environment and 8 km of living shoreline and might be a well-suited area to implement NbS strategies.

Keywords: Taiwan-Netherlands, coastal management, coastal dunes, nature-based solutions (NbS)

Introduction

Coastal environments are deteriorating worldwide due to a combination of human activities and natural stressors, such as land-use change, coastal erosion, sea level rise, pollution, etc. On a global scale, there is a growing awareness for the use of sustainable management strategies and many global platforms (Intergovernmental Panel on Climate Change [IPCC], Biodiversity platform, UN SDNS or UN SDG's) call for action to both mitigate and adapt to climate change through Nature-based Solutions (NbS). Many initiatives around the world have already pointed out the success of NbS approaches to address a wide range

of environmental and societal challenges (Pontee *et al*., 2016; IPCC, 2019).

There is a high potential for the use of geoparks in disaster risk reduction through NbS by conserving and/or restoring ecosystem values in these protected areas (Pavlova, 2019). This study explores NbS possibilities for implementation in a new Geopark, the Caota Sand Dunes local Geopark at the coast of Taoyuan, Taiwan. The aim of this study is to find more information on the current status and effectiveness of NbS in coastal sand dune areas in the Netherlands and learn from best practices for local implementation in Taiwan. The dunes are the first line of coastal defence as they can buffer against rapid erosion, sea level rise or storms, and they provide a habitat for unique flora and fauna and can have an added value for leisure activities (Lin *et al*., 2011). The Caota Sand Dunes currently is the most complete sand dune system at the coast of Taiwan and turned into a local geopark in 2020 (Cheng and Hetherington, 2020). This natural dune area is one of the few remaining natural barriers in Taiwan and is threatened by human interventions. By turning this area into a local geopark, it is protected from further development and deterioration, but the dunes need to be well-managed in the future to keep the natural values and protection function high while providing space for tourism in a responsible way.

NbS in coastal management is relatively new to Taiwan but has already been applied on a larger scale in other countries, such as the Netherlands. For this study, an in-depth research of Dutch dune management has been conducted, as the Dutch coastline mainly is protected by sand dunes, and long-term projects regarding different types of NbS have been implemented. Significant evaluation data needed for future implementations in other areas can be provided through these projects and experiments. Therefore, questions for this study entail 'What has the Netherlands learnt so far on coastal NbS and are there any insinuations for coastal management strategies in Taiwan?'. An overview is provided of several implemented projects in the Netherlands where NbS approaches are integrated in coastal dune management. By exploring the effectiveness of various coastal NbS, future implications can be considered for the new local dune Geopark in Taiwan, for the sustainable development of the coastal environment in Taiwan. The available data is selected based on long term experiments in the dunes, focused on Nature-based Solutions that promote dune recovery and that enhance the protection function of the dunes, as these are the major targets for the newly established Geopark in Taiwan. To acquire data for this review, a literature study is conducted on coastal management strategies in Taiwan and the Netherlands and public data of Dutch projects are obtained and evaluated form different kinds of sources (papers, educative websites, news articles and reports).

NbS and Coastal Management in the Netherlands

Defining Nature-based Solutions (NbS)

NbS is a relatively new concept and can be seen as an umbrella term for different natural management approaches that address multiple benefits. The most commonly used definition of NbS is formulated by International Union for Conservation of Nature as "actions to protect, sustainably manage and restore natural

or modified ecosystems, which address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits" (Walters *et al.*, 2016). Some approaches might focus slightly more on human benefits by helping prevent and reduce disasters using ecosystems, such as Ecosystem-based Disaster Risk Reduction (Eco-DRR), while other approaches are more focussed on biodiversity benefits, such as implementation of Green Infrastructure. For this study, NbS is defined as solutions to coastal hazards and environmental challenges through sustainable actions that enhance and work with nature and should have benefits for both society and nature (enhance the resilience of ecosystems through ecosystem services). Framed like this, healthy ecosystems that are well- managed and monitored are the foundation for successful NbS. Nature-based approaches are well suited as long-term solutions, but they usually require more space than artificial engineering structures. Even though, NbS entail a lower standard of services and are more cost-effective than hard engineering structures (Eggermont *et al*., 2015).

Concerning NbS, three main types have been defined by BiodivERsA, a European network promoting research on Biodiversity, Ecosystem Services and Nature-based Solutions. This framework is based on the degree of intervention in ecosystems and on the number of ecosystem services and stakeholders that are targeted by a certain NbS (see Figure1). These types are:

- Type 1 – Minimal interventions in ecosystems: mainly conserving/protecting natural areas and minimal management of the ecosystem. This holds up for ecosystems that have not yet been strongly degraded.
- Type 2 – Some interventions in ecosystems: improving the ecosystem, enhancement of ecosystem services. Examples are agroforestry, forest planting, dune vegetation control, etc.
- Type 3 – Active management of ecosystems: restoration efforts by changing landscapes, or creating new ecosystems, mainly in urban environments.

Coastal sand dune environments are well suited for the implementation of NbS, since sand dunes already act as a barrier to slow onset disasters like sea-level rise or to sudden environmental changes like storm floods or intense periods of coastal erosion (Koningsveld *et al*., 2007). Vegetation in and behind the dunes also plays an important role in blocking waves, blocking wind or salt spray and sand further inland. Dune habitats house many different unique species and the vegetation is specially adapted to withstand strong wind or high salt levels. Factors that are needed for coastal sand dunes to form are a large supply of sand, space, large tidal range for sand to dry and an obstacle to accumulate the sand and start the dune formation (De Jong, 2014). The first row of dunes (foredunes) in a typical coastal sand dune system are more dynamic and older dunes rows are more stabilized by vegetation, when there have been no human interventions. However, in many cases human actions have destroyed natural dune landscapes, and NbS can help restoring or strengthening dune habitats.

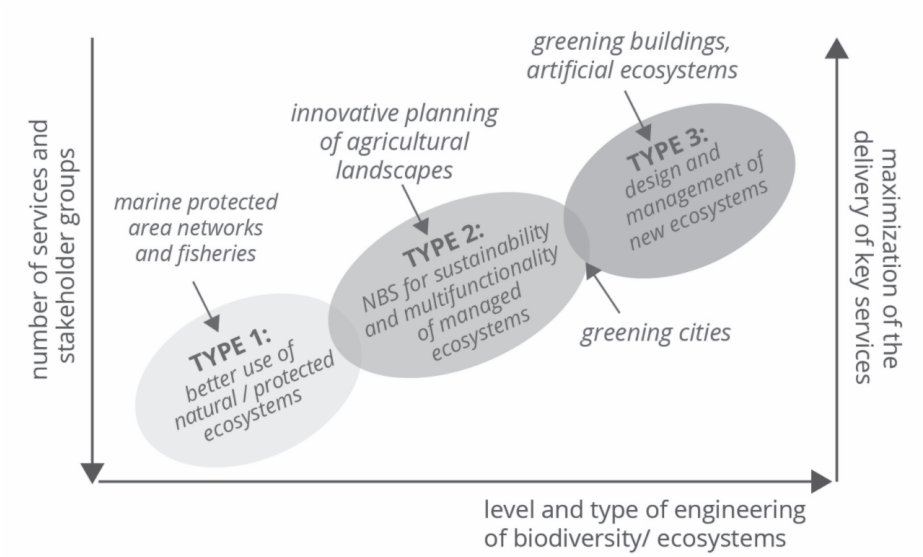

Figure 1 The three types of NbS explained by level of intervention and number of involved stakeholders. Retrieved from: Eggermont et al. (2015)

Collaboration and co-development of strategies with local communities is also essential for successful NbS and optimizing the delivery of multiple benefits on all levels (Seddon *et al*., 2021). Besides artificial engineering and NbS approaches, so called 'green-grey' or 'hybrid' approaches are actions that combine artificial and nature-based solutions. It is not always possible to implement NbS in every area, but to restore degraded ecosystems, this approach might be a useful alternative by introducing more natural adaptation measures in artificially engineered areas (Powell *et al*., 2019).

Nature-based Solutions in Dutch coastal management

The coastal landscape in the Netherlands stretches from north to south along the western coastline and includes sandy beaches and coastal dunes. The coastal areas and sand dunes originated naturally under the influence of wind and water dynamics. The central coast of the Netherlands (also called the Holland coast) is a 120 km long sandy shore with coastal dunes and protects some major cities. Huge parts of the Holland coast have been eroding for centuries, resulting in retreating coastlines up to a few kilometres at some places. Sea-level rise and land subsidence are major causes of coastal erosion in the Netherlands, in combination with human effects like the construction of hard coastal defences that disturb the natural dynamics or loss of sediment input from rivers due to activities upstream (Mulder, 2003). Past strategies to deal with coastal erosion mostly included ad hoc measures, when the safety of the polders was at risk or when valuable places in the dunes, such as drinking water areas or nature reserves, were threatened (Mulder, 2003). Thus, beach erosion was also accepted to a certain extent, and the coast was managed with more 'hard' engineering strategies such as dams and reinforcements, or by stabilizing dunes. In 1990, the policy strategy changed, stating that the entire coastline should be maintained at its 1990 position, meaning further erosion will be

counteracted by measures like sand nourishment, thus switching towards a softer engineering approach and introducing Nature-based Solutions.

Until today, the coast is maintained by sand nourishment and replenishment; sand is excavated outside the -20 m depth contour from the bottom of the North Sea and sprayed onto the beaches or added to the foreshore. By adding to the sediment budget, beaches will be widened and more material is available for new dune formation. Taking into account the sustainability of the deeper shore, a higher amount of sand is needed for these nourishments (Mulder, 2003). This can lead to an oversteepening of coastal profiles, and have harmful effects on benthic ecosystems (Van Slobbe *et al.*, 2013; De Ruig and Hillen, 1997). Alternatives for this strategy are being developed under the Delta Program (a program to make the Netherlands climate proof before 2050). New measures should include flexible responses and new insights are stimulated (Werners *et al.*, 2009). In line with the ICZM approach, the Delta Program also focuses on innovative collaborations with residents, businesses, knowledge institutes, and NGOs. Under this program, many projects and experiments are conducted to enhance or rehabilitate dune environments on both small and large scales. Additionally, at several sites, dune vegetation has been removed to make dune areas more dynamic and leave a more active role for nature in coastal zone management (Meyer, 2016). Soil acidification is a major issue in the coastal areas of the Netherlands, ammonium from agriculture plays a large role in soil acidification and it is anticipated that through management strategies which increase dune dynamics, the soils will become less acid. Ongoing projects to restore dune environments or increase biodiversity are actively monitored and evaluated. The acquired evaluation data can be useful for other countries such as Taiwan, also dealing with coastal erosion and land subsidence, to explore sustainable approaches for the protection and enhancement of coastal sand dune environments.

Evaluation of NbS in Dutch coastal dunes

NbS in coastal sand dunes for DRR

Coastal dunes protect a large part of the Dutch coast from erosion and sea level rise. A large part of dune environments in the Netherlands is off-limits for visitors. The approach of dune maintenance (keeping them in a fixed position) has been abandoned in most cases, and higher mobility of sand dunes is promoted to better cope with future disasters. Still, there are different types of NbS approaches in the Dutch coastal dunes, and many projects have been carried out over the past few decades to enhance or restore dune environments. Central to these projects is the question of how the dune landscape develops after interventions. In general, four types of approaches can be described, in which the degree of human interaction in the natural system varies (for locations of the different approaches described below, see Figure 2 and Table 1).

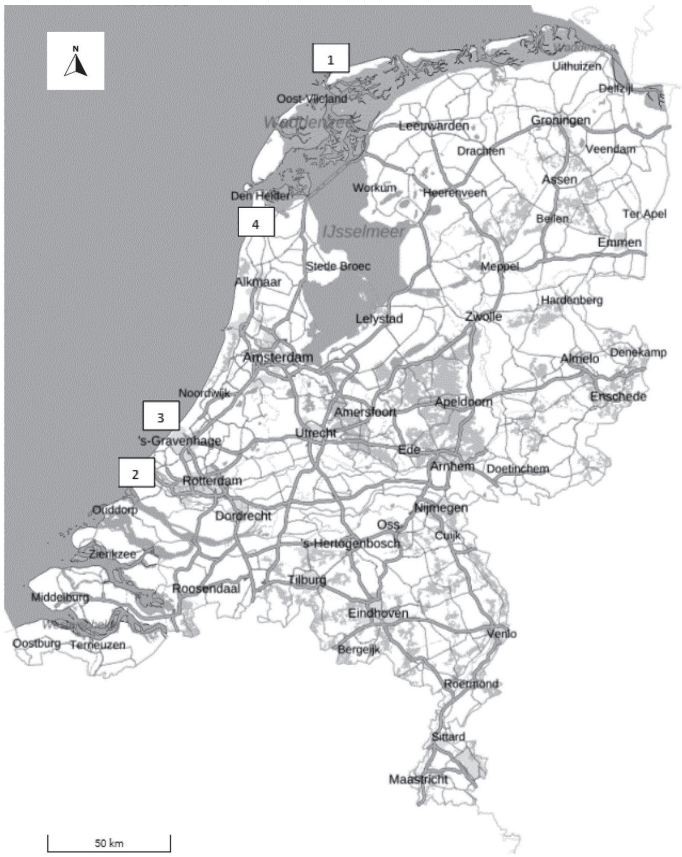

Figure 2 Coastal dune environments are present along the entire Dutch coastline examples of projects discussed in section 3.1: 1: dynamic dune management on the Wadden Islands, 2: Dune restoration at Voornes Duin, 3: sand nourishment, Sand Engine and 4: creation of new dune environment at Hondsbossche dunes. Adapted from: nationaalgeoregister.nl

1. Reintroduce dynamics (increase foredune dynamics)

From several centuries ago, marram grass had been planted to fix the dunes. This deep-rooted plant fixates the sand, causing the dunes to erode less when attacked by waves. However, marram grass inhibits the natural growth of dunes and the transported sand will remain in the front dunes, where it is transported back and forth into sea after storm events. Along the Dutch coast, some dunes can grow in a more natural way when the marram grasses are removed. In this case, the sand is not only transported to the foredunes, but is also transported further behind the first dune row. As a result, a wider and stronger row of dunes will emerge to protect against sea-level rise and coastal erosion. The land behind the dunes is elevated if the sand can blow further inland. Moreover, additional sand and less marram grass seems to have a positive effect on biodiversity in the dune areas in the longer term. Several projects have been carried out to reintroduce dune dynamics, by actively removing vegetation (see Table 1). This technique can be implemented both on small

and large scales. The large-scale implementations are aiming at a continuous rejuvenation and dynamic dune landscape, but there is no guarantee of permanent durability. Rainfall can have a large impact on the sand drifts since moist surfaces tend to stabilize quicker, so a succession of wet years could mean the end of the dynamics (Arens and Slings, 2017). On the other hand, a small-scale implementation in most cases leads to stabilization without maintenance (Arens *et al*., 2007).

2. **Habitat restoration (rejuvenating vegetation/reducing soil acidification)**

EU protocols determined that the Netherlands has the responsibility to preserve and protect the so-called "Gray Dunes," since this is a scarce biotope in Europe (Natuurmonumenten, 2016). Gray dunes are older bare dune tops without vegetation that are located further inland. These grey dunes are disappearing because of changes in soil acidity and because they are overgrown by invasive species. Through a project called Dutch Dune Revival, habitat restoration of dune environments is implemented with the aim to set back dune succession and create beneficial conditions for the development of more diverse habitats with unique species and increase biodiversity. Even though strategies for increasing foredune dynamics and habitat restoration and vegetation rejuvenation can also be combined, removal of this vegetation, including exotic invasive species, is the most prominent part of the project, and it is not targeted on the foredunes but on environments in the secondary or older dune rows. The main cause for the implementation of these strategies leads back to the reduced dune dynamics, planting of trees and decline in number of small grazers, resulting in an increased speed of succession. Due to this rapid succession, the older dunes are overgrown by shrubs and trees and the biodiversity decreases. Another issue in the Netherlands is a huge amount of nitrogen deposition, leading to acidification of soils and reducing the biodiversity and soil quality. By creating openings, calcareous sand can be blown in and the soils will become less acidic (De Jong, *et al*., 2014).

In most dune areas, large grazers, such as horses or highland cows (Figure 3f), maintain the shrubbery and prevent the vegetation from growing too dense. In this way, the dunes can be more dynamic and unique habitats originate in the older dune rows. The disadvantage of highland cows is that in warm weather they gather in small ponds, which has a negative impact on the water quality and the underwater life; they fertilize the water, which is detrimental to life in the ponds. Other types of vegetation management to restore dune areas concern actively controlling invasive alien species, promoting the growth of endemic species, 'rewilding' nature and minimizing human influence (Krol and Löffler, 2013).

3. **Sand nourishment (replenishment)**

This method is based on sediment supply from other sources to strengthen the dunes (Figure 3d). Sand is constantly exchanged between the shallow sea, the beach, and the dunes. However, there no longer is a constant sediment supply along the Dutch coastline due to human interventions, and this leads to an imbalanced sand budget and overall coastal erosion. To solve this problem, sand nourishment on the beach or foreshore can (temporarily) maintain the balance in the sand flows. The sand is excavated outside the -20 m depth contour from the bottom of the North Sea. Along the Dutch coastline, most sand replenishment takes place in the shallow sea (foreshore), where new sand is deposited like a sandbank off the coast to ensure that

more sand will end up at the beach. When the wind blows this sand into the dunes, they grow stronger and can protect the land behind it. This procedure must be repeated depending on the speed at which the supplemented sand erodes and is carried away, which might vary for different areas. This technique can also be applied on small and large scales; the Sand Engine is an example of a large-scale sand nourishment in front of the coastline (Van Slobbe *et al*., 2013). This is an ongoing project, which will not be maintained, and the sand will be distributed by waves, currents and winds along the coastline. When the sand is spread along the shoreline it will produce a buffer of sand to protect the coast against sea level rise, assuring long-term safety for the coastal zone (but it is still not evident for how long).

Sand nourishment and replenishment have been standardized in Dutch coastal dune management, but even though this technique uses nature as part of the solution, more and more disadvantages are brought forward. For example, this method can have a huge impact on the natural environment where the sand is being dredged. Moreover, the fact that it is a recurrent process can lead to an oversteepening of coastal profiles.

4. Development of new dune habitats

When creating 'new dunes', natural principles are applied as much as possible, using wind and vegetation to build up the dunes. Examples of seaward broadening by creating new dune landscapes can be found at the Hondbossche dunes or the Prins Hendrik dune-dike. In both cases, the existing sea dike no longer met current safety standards. Therefore, the dikes were reinforced with a soft, natural barrier of sand on the seaside of the dike. This resulted in seaward reinforcement of dunes, and in the case of the Hendrik dune-dike, sandbanks and a new bird island were also developed (fitting type 3 NbS; creation of a new ecosystem). At the Hondsbossche dunes. more than 35 million cubic meters of sand was deposited in front of the dike in one year. In a short time, a completely new dune landscape had been created, shaped by the wind, and the dunes can easily grow with rising sea levels. In both cases, safety measures were integrated with nature in a flexible solution to create a more robust multifunctional sea defence. A disadvantage is that these are very costly projects requiring a huge amount of sand, which has to be extracted from the bottom of the North Sea (Kanning and Kok, 2010).

3.2 Evaluation

The effectiveness of coastal NbS on adaptation and mitigation to climate change and related hazards is still relatively less studied but can be quantified by measuring the biodiversity (is nature becoming more diverse?), dune height measurement (does the morphology of the foredunes change?), soil quality (does the soil become less acid?), erosion measurements (can the dunes cope with coastal erosion and sea-level rise?). Moreover, the scale of NbS implementation should be taken into account (Hutchins *et al.,* 2021), and it should be assessed if there are any safety problems or negative effects for the surrounding residents (like increasing sand drift). The benefits for humans can be measured on an economic level or based on health, well-being, safety etc. The evaluation data for this review are mainly focussed on the natural outcomes of measurements for NbS performance, like biodiversity increase or structural improvements.

Table 1 NbS approaches in Dutch dune environments, related strategies, and example projects plus the positive and negative points that came forward after evaluation of these projects

Type of NbS	Strategies	Projects and evaluation data
1. Dynamic coastal management (small scale or large scale)	o Remove vegetation o Remove sand fences o Remove sand to create openings in active dune rows	**Projects**: *Small scale:* Experiments with dynamic management on the Wadden Islands. *Large scale*: Noordwest Natuurkern, Kennemerduinen **Evaluation**: + Requires less management + Dunes grow higher and stronger and can grow naturally with rising sea level + Drifting sand increases biodiversity in older dune rows - Small scale harder to rejuvenate vegetation and needs to be maintained to prevent stabilization - Enough space and sediment supply are needed **References**: (De Jong, *et al*., 2014; Krol and Löffler, 2013)
2. Habitat restoration	o Remove shrubs and trees o Remove unwanted species o Introduce large grazers	**Projects**: Voornes Duins, Noordwest Natuurkern **Evaluation**: + Increase biodiversity + Improvement of soil quality - Constant control of unwanted species - Manure issues of large grazers **References**: (Arens *et al*., 2013; Kuipers *et al*., 2020; Natuurmonumenten, 2016)
3. Sand nourishment (small scale or large scale)	o Sand dredging o Foreshore nourishment o Beach nourishment + bulldozering across the beach	**Projects**: *Small scale*: many beaches and foreshore areas along the Dutch coastline *Large scale*: Sand Engine **Evaluation**: + Natural dune growth + Decrease coastal erosion (protective buffer zone) - Steepening of coastal profile - Harmful for marine habitats - Increase CO_2 emissions when dredging sand offshore

Type of NbS	Strategies	Projects and evaluation data
		References: (Van Slobbe *et al*., 2013; Stive *et al*., 2013; De Schipper *et al.,* 2016)
4. Development of new dunes	o Sand dredging o Strategic sand deposition o Planting vegetation o Seaward broadening	**Projects**: Hondsbossche dunes or the Prins Hendrik dune-dike **Evaluation**: + Successful dune formation + Dunes grow quickly and protect against erosion and sea-level rise + New natural habitat can be created, attracting more species - Expensive - Require a huge amount of sand (and dredging affects marine life) **References**: (Kanning and Kok, 2010; Koningsveld *et al.,* 2007)

Management strategies expressed in the field

Dune areas that need more protection or where restoration projects take place, are shielded from the public by both natural and manmade (barbed wire) barriers, to prevent people from wandering off the trails (Figure 3a). Natural barriers can consist of huge trunks that block the way to these more vulnerable areas, or by placement of thorny bushes along the trails, so visitors will stay on the designated paths (see Figure 3b). Footpaths protect dunes from trampling and the tracks and walking paths mostly consist of a mix of rustic paths. Information signs around the dune areas keep the visitors up to date on current projects or educate people about certain landscape features. Many natural dune parks in the Netherlands have informative visitors' centres with information about the biodiversity, routes you can walk, where to go to see certain things, information about the restricted areas, history etc. Regular guided tours in the areas are organised for interested visitors and interactive knowledge games for kids, like scavenger hunts or quizzes, for environmental education and entertainment. Behind the active dunes, you can often find cycling paths, which are actively used, but need to be well-maintained due to drifting sand. Volunteers started an initiative to keep the coastal areas clean, in collaboration with local coastal management bodies, such as municipalities and nature conservation organisations. They place wooden tubs ('Jutbakken') at beach entrances to collect waste that is found on the beach or in the dunes (Figure 3c). This initiative calls out to all visitors to pick up waste when hiking in these areas, to keep the beaches clean. Community involvement is an increasingly important part of Dutch dune management. Local communities and visitors are continually updated about ongoing projects in dune areas via different sources and through volunteering or citizen participation projects, they

can help collect data or contribute to dune restoration activities. (Natuurmonumenten, 2016).

a. Protected dune area in province of Zeeland

b. Vegetation as natural barrier (sea buckthorn)

c. Jutbak: waste bins at the beach entrance to collect trash

d. Sand nourishment at foreshore

e. Example of walking paths, away from the active dunes

f. Grazers (highland cows) in Voornes Duin

Figure 3 Examples of how management strategies to protect, enhance and revive dunes are visible in the Dutch dune landscape. Picture credits: Han Meerman and George de Vries

Suggestions for local adaptation in Taiwan

Coastal management in Taiwan

Taiwan is an island with a high diversity of coastal environments and unique habitats, but increasing pressure of coastal development and human activities has resulted in extensive and, in some cases,

irreplaceable damage along the coastline (Shih, 2016). Like in the Netherlands, coastal erosion is also a threat to coastal areas in Taiwan. Especially along the west coast, over the past few centuries the shoreline has generally retreated (Hsu *et al*, 2007). In combination with the high amount of artificial coastline, currently more than half of the Taiwanese coastline has been subject to hard or so-called grey engineering constructions, this has led to erosion and degradation of many coastal ecosystems. Hard engineering structures that are used as coastal defences, in general do not have a long life-span and often have high maintenance costs, while soft engineering or NbS solutions are more cost effective in the long run (Rooney, 2010). With increasing industrial developments along the coastline, there is not much effort to implement soft (green) approaches to deal with coastal erosion or sea level rise in Taiwan.

However, on 2015, the Coastal Zone Management Act (CZMA) was enacted to preserve natural coastal environments, respond to climate change, prevent coastal disasters and environmental damage, protect and enhance coastal resources, and promote sustainable development in coastal areas (Chen and Shih, 2019). The CZMA involves local governments and states which are responsible for finding sustainable ways to protect the regional coast from erosion (Shih, 2016). Moreover, the plan promotes collaboration between different stakeholders through coastal integration management, based on Integrated Coastal Zone Management (ICZM), which is a framework to manage the coastal zone in a sustainable way while also leaving room for coastal development (Sekhar, 2005). These new plans and management strategies need to be actively endorsed or enforced and supervised and evaluated in a constructive way in order to work towards these intended results. However, due to fragmentation in sectoral management that represents different interests, integrated management is still lacking (Shih, 2016; Chen *et al.*, 2019). This leads to the issue of over- or undermanagement in different coastal areas. Likewise, the vision and attitude of residents and other stakeholders towards coastal environments and sand dunes play an important role in the efficacy of coastal planning strategies.

Coastal geoparks along the Taiwanese coastline can play an important role in education and awareness rising, especially since in Taiwan geoparks need to meet four core values; landscape conservation, environmental education, landscape recreation and community development (Lin and Su, 2019). Therefore, geoparks help promote coastal ecosystems, nature conservation, education about sustainable approaches to coastal hazards and get the public involved in multiple ways. This is discussed further in section 5.2.

Implications for local geopark 'Caota Sand Dunes'

Caota Sand Dunes currently is the most complete sand dune system at the coast of Taiwan and turned into a local geopark in 2020. This geopark conserves a unique coastal environment and the height of the dunes can reach up to 20m, making the area well suited for the function of coastal protection based on the NbS approach. The dunes can be a buffer zone against coastal erosion and sea-level rise. One of the core values of this geopark would be the function of protecting the coast, and the area can become more resilient to natural hazards when NbS are implemented. The city government of Taoyuan promotes the area for coastal tourism and plans to train local coastal eco-narrators, and strives to engage the public and educate people

about the dune landscape (Anon, 2020). To work towards a more natural landscape, management strategies should also address human influences by reducing the amount of artificial engineering structures, waste, pollution, etc. The geopark is divided in 3 different zones (see Figure 4) the core section, with the most complete sand dune ecology, would be accessible only for research and environmental education (by application) to preserve the dunes and nature, while the general section would be opened for the public and be accessible for recreation purposes. There is also a rehabilitation area in the park, not open to the public, that is currently the location of huge landfills, where nature can be restored only after removal of the landfills.

Figure 4 The Caota Sand Dunes Geopark is located in North-West Taiwan and is divided in three sections: I = general section, II = rehabilitation area and III = core section

The dunes at Caota have been manually built up by stacking sand fences, and trees are planted on the sand dunes in attempts to stabilize the sand bodies. However, these bamboo fences result in steeper dune built up, which leads to increased erosion (Figure 5a). Different case studies along the west coast have shown show that human interventions have contributed significantly to coastal erosion, as activities such as sand mining or coastal defence structures disturb natural dynamics along the shoreline, or upstream mining or construction of reservoirs causes reduction of sediment supply from rivers (Hsu *et al.*, 2007). Other human activities in this area that specifically led to dune degradation are sand mining, constructing roads in the dune landscape, building wind turbines on top of the dynamic foredunes, and landfills and waste disposal in the dunes (Figures 5b, 5c, 5d). Natural pressures in this environment are sea level rise, storm surge, heavy rains or typhoons, which increase the risk of flooding, erosion and retreat of the coastline (Hsu *et al*., 2007).

By evaluating which factors contribute the most to the degradation of the dunes, management strategies can be adapted to increase local resilience to coastal hazards. Habitat restoration in the most vulnerable areas can increase the natural ecosystem services and enhance the protection function of the coastal sand dunes. Creating ecozones in a dune area, off-limit for visitors, has proven to stimulate natural development and increase biodiversity in the Netherlands. Introducing dune dynamics by removing sand fences might benefit

the natural process of dune development and sand drifting, if there is enough space for the dunes to move landward. According to the evaluation results in the Netherlands this action helped strengthen the sand dunes and make them a more suitable buffer to hazards (Van Slobbe *et al*., 2013). This process has also proven to reduce soil acidification, which is also a threat in Taiwan due to industrial pollution and heavy rainfall. Small scale experiments to stimulate dune dynamics in the area can further study the effect and the consequences for residential and agricultural zones behind the dunes. It is hoped that the visitors and local communities can increase their understanding and help in preserving or raising ideas to strengthen the protection of the dune geopark. Additionally, the local communities could benefit from the geopark's tourism and environmental education objectives. If they get involved, the local economies could benefit from these functions.

a. Beach and aesthetic pollution

b. Wind turbines on top of the dunes and seawalls

c. Washed up waste

d. Landfills with garbage

Figure 5　Current status of Caota sand dunes

Discussion

Like Taiwan, the Netherlands is densely populated and many other functions in the coastal zone, such as industries, housing, infrastructure and recreation, claim space. This acts as an extra barrier to implement green adaptation strategies, which favourably create more space for dynamic natural environments. To work towards a sustainable future, perhaps some of these occupied spaces need to be reconsidered. Evidently many co-benefits are involved in these greener options. As seen from the example projects in the Netherlands,

stabilization of dunes is not incorporated in most management strategies. Planting vegetation or placing wooden sand fences can help retain sand and reduce the impact of wind and water to help grow dunes naturally. But if dunes are more developed, stabilizing vegetation or structures might limit the dune growth and expansion. In the Netherlands, due to the space that is available, and the idea that dunes can grow with the rising sea level, dynamic dune management is gaining more support.

In Taiwan, dunes along the coastline have been removed by sand mining or for road constructions and industrial parks. Low dune slacks are reclaimed to construct fish or duck breeding ponds. The continuous and increased intensity of human actions has resulted in widespread and sometimes irreparable damage on the dunes ecologically and morphologically. To reduce the adverse effects of human activities, increasing data collection, creating more political awareness and downscaling of industries are options to consider. A shore act can be drawn that protects all coastal dunes to prevent their destruction, but for successful implementation more control and enforcement is needed. However, only with a good understanding of the environment, processes and issues, the dunes and the ecosystem are able to recover and function as NbS. Based on evaluation of NbS in the Netherlands, various types of strategies can be adopted in dune landscapes. Recommendations for further research entail the assessment of the dune vulnerability for the Caota dunes geopark, concerning geomorphological conditions of the dunes, human effects on the dune landscape and an ecological analysis, before fitting strategies can be proposed.

Since another important imperative in the Taiwan geopark approach is community participation, more research is needed on how local communities can contribute to management strategies for coastal dune areas and how they can participate in the management or benefit from the economic developments around the geopark. This can also address the overlap of different authorities and responsibilities in Taiwanese coastal management, as projects might fail when there is a lack of awareness, public participation, or collaboration between stakeholders. Interdisciplinary meetings between different stakeholders (local community, government officials, NGOs, companies, etc.) and bottom-up approaches, can be promoted for the development of integrated management strategies.

Conclusion

The effects of using artificial constructions to prevent coastal erosion remain unpredictable and will affect surrounding coastal habitats over long a period of time. Soft engineering methods are encouraged in the Netherlands and sand nourishment is a required technique to maintain the coastal safety, despite the negative impacts that come forward. Therefore, more flexible solutions to coastal erosion and sea-level rise are stimulated, taking into account Nature-based Solutions. In the dune environments, approaches to increase dune dynamics have proven to be valuable for dune strengthening and biodiversity. Still, in many cases active management to control unwanted species or open up spaces in the older dune rows, are required. With the implementation of large grazers and by reintroducing dune dynamics, human influences in dune management

are reduced.

For Taiwan, conserving dune ecosystems or restoring coastal ecosystems while managing them in a sustainable way can be a natural alternative to the hard engineering structures found at many places along the coastline. More integrated coastal management and supervision or enforcement of sustainable measures in the future can benefit the recovery of coastal ecosystems and the local geopark at Caota Sand Dunes can be a well-suited area to experiment with NbS strategies.

It needs to be recognised that natural management approaches need time; it takes several years to decades to see outcomes. Moreover, enough space is needed for more dynamic dune management. However, there is still a lack of awareness around the long-term effectiveness of nature-based solutions, mainly because there are not many documented case studies with evaluation data. To shift from hard structures to Nature-based Solutions, more awareness and engagement from involved stakeholders is needed around the risks and impact of climate change, concerning conventional methods and the value of ecosystems and biodiversity. By studying the impacts of NbS strategies, and maintaining collective databases, well-informed decisions for future coastal management strategies can be made. Naturally, each region and country will have different interests for the management of coastal regions, and the positive and negative effects must be considered for each area, but stimulating biodiversity and the introduction of natural dynamics have demonstrated positive effects to create more resilient environments. In this global crisis of climate change, countries can learn from each other, but more importantly help each other increase their knowledge and find new ways to adapt and mitigate the effects of climate change.

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