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RESOURCE BASED DREDGING

Dredging for large scale regeneration of arid landscapes

RESOURCE BASED DREDGING - DREDGING FOR LARGE SCALE REGENERATION OF ARID LANDSCAPES

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Abstract- *This article presents Resource Based Dredging (RBD), a novel regeneration methodology that utilizes locally available coastal sediments and seawater for large-scale regeneration of arid landscapes. The technique addresses the problem of firstly, acquiring the vast quantity of required resources and secondly, the fundamental challenge of vegetation establishment in arid environments, because of water scarcity, nutrient deficiency, and poor soil quality. By using fertile sediments as a soil amendment, the success rate of out planting seedlings, and thereby the success of any regeneration effort, is thought to be greatly improved. Together with large amounts of fertile soils, large scale regeneration requires a considerable volume of fresh water and many seedlings.*

Coastal sediments often contain high concentrations of silt, clay and organic materials as resources for fertile soils, but also contain salt and little to no active soil life. After dredging and segregating the coastal sediments, the sediments will be treated in a multi-stage bioremediation process where they undergo a desalinization process through leaching by flushing. This process is aided by sequential planting of diverse plant species, suited to salinity levels of the sediments, that aid the establishment of rich soil life. The plants in the final stage will serve as the seedlings for the regeneration efforts. An aquaponic-type system recovers nutrients from leaching effluent, creating natural fertilizers while managing water salinity. The bioremediation process requires about 1-1.5 years to produce seedlings with high-quality soil amendments suitable for planting.

Index Terms- Resource Based Dredging, Eco Oasis, arid land restoration, large-scale regeneration, bioremediation, coastal sediments, desalinization, ecosystem restoration, water cycle restoration

I. INTRODUCTION

This article aims to explain the working of Resource Based Dredging (RBD) in general and through the case study of the proposed works for the Sinai Peninsula. RBD is a novel technique that brings together the building blocks that allow for large scale regeneration of arid environments. These environments are characterized by low precipitation rates and sparse vegetation, and therefore, requires a thorough system understanding to accomplish the regeneration. At the core of these works lies the coupling between biosphere and hydrosphere, which has a large influence on the local climate.

Several studies document the impact of evapotranspiration and temperature on the hydrological (Makarieva & Gorshkov, 2007; Millán, 2014). Evapotranspiration refers to the combination of soil evaporation and plant transpiration processes. These exchanges and interactions between the biosphere and atmosphere regulate the hydrological cycle, govern the heat dynamics of the Earth and together produce the climate patterns we know today (te Wierik et al., 2021).

Based on these studies, one can state that when large parts of a landscape are regenerated, the evapotranspiration significantly increases and the air temperatures will be lower. This enhances condensation and thereby cloud formation and rain. This creates a positive feedback loop. Eventually the landscape will see increased precipitation. A larger biosphere will enable a more stable hydrological cycle, as discussed in other articles on the website of The Weather Makers Foundation.

A restored hydrological cycle, in combination with large scale lands, provides large benefits to the region. Functional biosphere increases social value and security. Many jobs can be created on healthy functioning ecosystems. Food can be produced in abundance of rich soils and clean waters. Once desertification is turned around and regeneration takes place, people can sustain a healthy life on the lands they live on (Mosier et al., 2021; Nielsen-Pincus & Moseley, 2013; Ullah, 2024).

II. REGENERATION STRATEGY

The goal of biosphere and water cycle restoration in arid environments requires large scale regeneration efforts. The majority of this restoration work will involve extensive planting activities, which are essential to address the fundamental challenges of these degraded ecosystems.

A. Key Challenges

While ecological restoration can be achieved solely by biological manipulation, the generally harsh abiotic conditions of arid landscapes require also abiotic interventions (Walker et al., 2007). Vegetation growth in arid environments is primarily constraint by I) low water availability, II) low nutrient availability, and III) poor soil quality, of which the latter can further be characterized by i) low soil organic carbon, ii) poor soil structure, iii) reduced soil biodiversity, and iv) a high rate of soil erosion (Ayangbenro & Babalola, 2021; Naorem et al., 2023). Solutions to these challenges will have to be incorporated into the strategy.

Primary succession of vegetation in arid landscapes can take decades, if it even takes place at all (Coradini et al., 2022; Hou et al., 2024; Huebner et al., 2022). However, several restoration studies have showed positive results of restoring land after addition of organic materials such as wood pellets, straw and compost and thereby speeding up succession (Bonet, 2004; Dietterich & Casper, 2017; Hueso-González et al., 2018). Some studies further comment on the importance of introducing soil life (Hou et al., 2024). These findings underscore the importance of soil amendments in regeneration efforts in arid landscapes.

B. A Multi-Scale Strategy

To address these interlinked challenges of water scarcity and low soil quality for vegetation growth, a multi-scale approach to restoration is proposed.

At the largest scale, the watershed level, strategic locations will be identified and prioritized where enhanced evapotranspiration will likely have the largest positive effect on the hydrological cycle. At the intermediate landscape scale, various water management techniques to catch, store, and slow down water movement will be implemented, including fog nets, contour bunds, check dams, and infiltration trenches (Whisenant, 1995). Additional steps techniques can be implemented to combat erosion (Huebner et al., 2022).

Finally, at the smallest scale, specialized planting techniques will be implemented that ensure long term survival of the plants, where facilitation between plants is larger than competition (Bonet, 2004). A diverse array of species, focusing on functional diversity, vegetation cover, density and soil improvement processes, will be planted according to the needs of the site to enhance the ecological resilience of the restored system over time (Eviner & Hawkes, 2008; Mussery et al., 2013; Sharafatmandrad & Khosravi Mashizi, 2021; Whisenant, 1995). An initial water reservoir can be added around the plant to improve water availability.[1] Additionally, soil quality will be addressed where needed through targeted amendments around the seedlings that provide essential nutrients, improve the water holding capacity of the soil, and introduce beneficial soil microorganisms. These soil improvements are critical for creating favourable conditions that support seedlings establishment and ensure their long-term survival. By planting whole plant communities with high quality soil amendments, the succession process can be greatly sped up. Ultimately, the success of the project will depend on the speed of growth and long-term survival of the vegetation.

The scale of the project requires consideration to resource management. A significant number of seedlings is necessary, along with substantial amounts soil amendments. These amendments must serve multiple functions: increasing soil water holding capacity, providing nutrients to support future ecosystem development, and harbouring essential soil microorganisms. Although synthetic soil amendments exist, they typically do not satisfy all these criteria simultaneously (Liiv et al., 2025). Therefore, high-quality organic soil represents the most appropriate option. As extracting quality soil from elsewhere would cause ecological damage to donor sites, it follows that suitable soil substrate will need to be produced specifically for this restoration project.

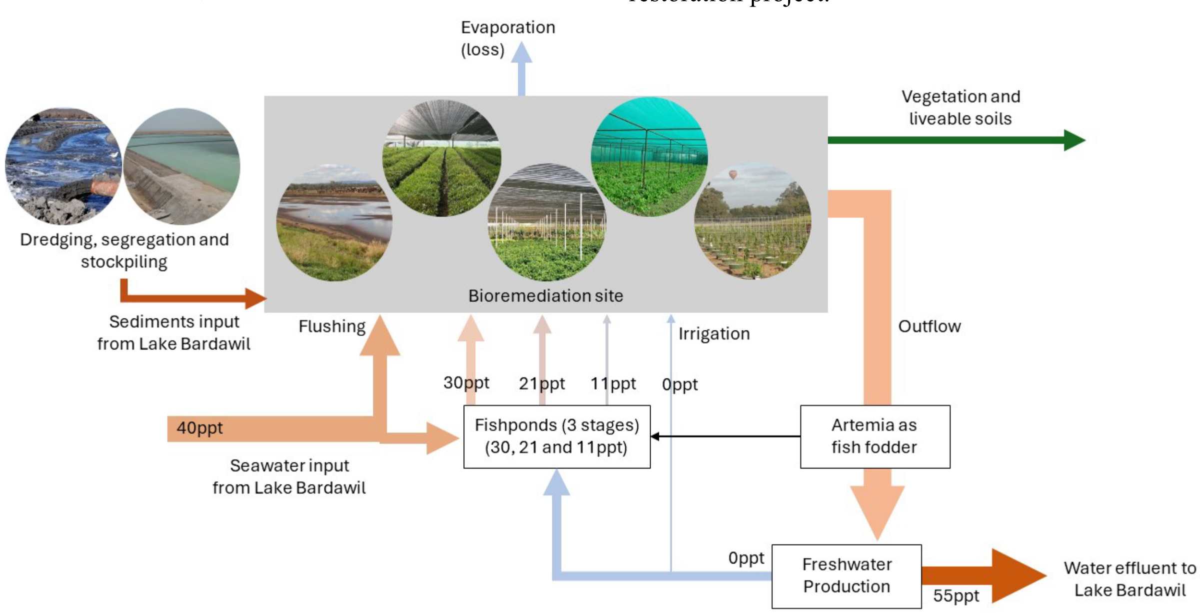

Figure 1. Scheme of the production of fertile soils and vegetation by Resource Based Dredging (bioremediation of soils, using coastal sediments and seawater)

[1] https://www.groasis.com/

III. RESOURCE BASED DREDGING

We propose the concept of Resource Based Dredging (RBD), a restoration methodology where locally available resources are being used for large scale regeneration . The methodology aims to use local coastal sediments, in combination with a bioremediation process to transform the sediments into terrestrial soils, to improve the soil quality for the planted seedlings. Marine sediments are abundantly available and generally have high organic matter, high nutrient availability and generally smaller grain size. The downside of using marine sediments is that they contain salt ions and have no active soil life. The designed bioremediation process aims to tackle both these problems.

The general concept of Resource Based Dredging is presented in Figure 1 and described below.

- Coastal sediments are dredged and disposed in a segregation basin, where sediment particles are graded on size. The basin can be near the actual dredging site to minimize transport distance.
- Segregated fine sediments (<125µm), rich with organic matter, are pumped hydraulically to a stockpiling basin which remains underwater to avoid oxidation, close to the planting site.
- The sediments from the stockpile are mixed with local sands so that the desired soil structure is created to serve as future soil amendment. After this soil engineering process, the sediments are hydraulically placed into the 'bioremediation site' for the first stage of bioremediation. Hydraulic placement by means of continuous flushing of the land, such that sediments have time to settle.
- Bioremediation takes in five separate stages. In each stage a specific plant species or plant community is planted on the sediment to improve the soil structure and soil life. At. the last stage, the sediments have been turned into rich non-saline soils for the purpose of being a soil amendment for future planting.
- During the bioremediation process of the sediments, leaching by flushing takes place with water of different salinities to slowly remove the salt ions from the sediments. Freshwater is produced in the process and mixed with the seawater to obtain the correct salinity for each stage.
- When leaching salt ions from soils, other nutrients are also lost. Therefore, nutrients are recovered from the effluent water using an aquaponic inspired process. Algae are grown in the effluent water, which become feed for Artemia, an aquatic crustacean which in turn is feed for fish. Water from the fish tanks is used as new flushing water, with the potential of mixing in freshwater to reach desired salinity. The flushing water is rich with fish faeces, forming a natural fertilizer for the soils.
- The bioremediation process takes 1-1.5 years and in the final stage. The seedlings can be replanted to a regeneration site, including its clod around the roots of bioremediated soil.
- The whole setup required for the bioremediation process is called the 'Eco Oasis'. See Figure 4 for a full schematic overview at a relative small testing scale.

Figure 2 Activities contributing to large scale ecosystem regeneration. From top left in a clockwise matter: coastal dredging, segregation basin, pumping station and terrace structures.

Figure 3 Roots penetrate a clay marine sediment, allowing for better water infiltration.

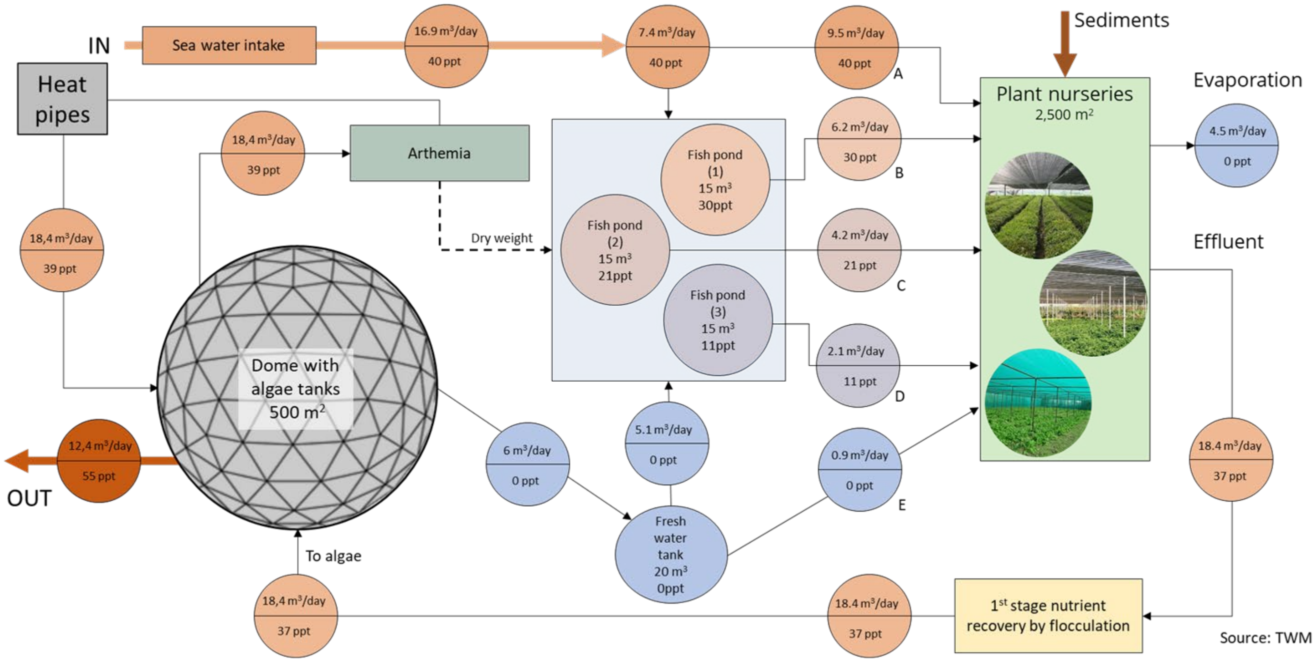

Figure 4 The Eco Oasis setup. Water and salinity balance within the bioremediation process for nursery plots of 2,500 m2. The input is sea water with a salinity of 40ppt and the output is water with a salinity of 55ppt. The latter value naturally occurs in Lake Bardawil during summer.

The plant communities in the nursery plots are delineated by three separate stages, while the desalinization will take place in 5 stages, A to E in Figure 4, each stage with a different salinity of flushing water relative to target soil salinity. Using more desalinization stages than planting stages allows for a more efficient use of freshwater.

Sediments placed inside the nursery is expected to be of 40 ppm salinity, aligning with sea water (mixing in sand will allow for lower saline sediments). During the first stage, the halophyte stage, the sediments can be flushed with sea water until halophytes have grown substantially. The roots of the plants permeate through the soil, allowing for deeper penetration of the flushing water. At that stage, flushing water can be used with a salinity of 30 ppt, originating from a pond with fish species that thrive in 30 ppt salinity. Once the sediments reach 30 ppt salinity, then they will be flushed with flushing water at 21 ppt. The process of using flushing water with different salinities continues until the sediments turn to approximately 0 ppt.

The three stages of plants growth on the sediments in the nursery plots correspond to salinity of the sediments. Halophytes can grow in saline environments of 40 to 21 ppt, their roots penetrate the soil, and they build up soil life. Grasses correspond to a brackish stage of approximately 21 to 11 ppt. Inhouse experiments have shown that plant roots significantly increase leaching speed as their roots create more pathways for the flushing water to go through the soil (see Figure 3). In the freshwater stage of 11 to 0 ppt, trees or grasses are grown, further turning the sediments to soil by benefiting soil life. The plants, including their clout, in this last stage will be the seedlings and soil that will be planted in the regeneration efforts.

The whole system uses sea water as its main source of water, by mixing in freshwater the target salinities in the basins and flushing water can be created. The required fresh water for the process is produced in the dome by natural evaporation of the seawater input. Due to the leaching of salt ions from the sediments and evaporation of the water the process yields a net growth surplus of salinity in the whole system. Therefore, a return stream with too saline water will have to be established. This return stream will be maximally 55 ppt, corresponding to salinity levels of sea water in coastal lagoons during summer.

A. Benefits of Resource Based Dredging

The process of RBD had been designed to use locally abundant resources, sea water and coastal sediments, to create the building blocks necessary for large scale biosphere restoration. These building blocks (seedlings, soil amendments and freshwater) provide the basis for the millions of the seedlings and required soil amendments that will have to be planted for the regeneration works. These resources are not likely to be taken from other sites without damaging those sites.

Furthermore, the distribution of these resources through large landscapes requires consideration. Sea water and coastal sediments can be hydraulically transported over hundreds of kilometres, thereby connecting the coastal dredging site with inland planting sites and their adjacent stockpiling basins. Pipelines have higher upfront costs but make more economic sense over time.

Another key element of RBD is the integration of ecological processes from the start. Growing seedlings together with their soil amendments creates a synergistic soil life in the nursery plots that will also remain after out planting (Singh & Kumar Gupta, 2018). While more ecological processes will have to be considered during the whole regeneration efforts, it shows strength to make a good start. Multiple projects afforestation projects have failed to deliver results because ecological processes were not taken (sufficiently) into account (Cao, 2008).

B. Required Innovation

RBD is an innovative way for large scale regeneration of arid landscapes, while it uses proven technologies from the dredging sector such as segregation, hydraulic transport, stock piling, and soil engineering. The novelties come from the bioremediation process where sediments are turned into healthy soil. This process incorporates i) desalinization of sediments through a step wise process involving different plant species, and ii) using an aquaponic type process to capture nutrients from the leaching effluent and convert them to fertilizer. The Weather Makers have run experiments on both these innovations.

The experimental set-up for sediments desalinization consisted of sediments where halophyte plants were growing, which were compared with control sediments with no vegetation. Sediments were sourced from a local salt marsh and 1:1 diluted with sand for improved permeability. They were flushed 4-5 times per week and water was reused every time, only to be refreshed by fresh water at the start of the week. Sediments with halophytes had 61 - 79% of salt removed, while control sediments had 48 – 58 % removed. While the experiments are not statistically viable, they indicate that halophytes improve leaching efficiency and that leaching with salt water is possible.

Experiments with aquatic trains has been built up by attaching translucent 2.1 m3 cylinder shaped tanks and several ponds (totalling ± 90 m3) to each other and allowing a continuous water flow through the system. By placing aquatic life inside the system consisting of algae, zooplankton, macrofauna, and several fish species, an aquatic freshwater ecosystem built itself up over time. Experiments were done on nutrient uptake rates by the system and using water from the aquatic trains as a water source for plots, inside and outside the dome planted with seedlings.

Results of these experiments showed: i) significant uptake rates of N and P by the aquatic trains, ii) a larger vegetation cover and standing biomass in plots watered with water from the tanks vs groundwater, and iii) high leaf area index of the seedlings grown inside the dome in 5 months of growth as much as natural forest would reach in 42 years. These results suggest that nutrients can be cycled through an aquatic train and be used for plant growth on terrestrial soils.

These experiments have touched the complete span of the RBD process but still need be further examined in an integrated environment, incorporating all components and processes.

Figure 5 A freshwater Eco Oasis system within a translucent 160 m2 dome, currently standing in the outskirts of 's Hertogenbosch in the Netherlands

IV. DISCUSSION

Large-scale regeneration is a significant undertaking that demands substantial resources, making efficient resource utilization essential. These resources encompass not only natural elements like soil, trees, and water, but also financial capital, workforce, and time.

RBD is designed to work with locally available resources using ecologically sound methods that support long-term ecosystem development and water cycle restoration. Unlike other approaches that simply add organic materials to soil as amendments, RBD recognizes that such methods may prove inadequate in arid or hyper-arid regions, where maximizing water availability for seedlings dramatically improves project success rates. In semi-arid regions with higher annual precipitation and better soil water retention, RBD may not be necessary. Ultimately, RBD serves as one valuable tool in the restoration designer's toolkit.

Additionally, enabling hydraulic transport likely offers economic advantages over trucking seedlings, soil, and water across hundreds of kilometres. However, this needs to be quantified with specific data once project details are finalized.

Before widespread implementation, conducting a thorough economic feasibility analysis is crucial to ensure the investment delivers meaningful returns, both environmentally and financially. Understanding the cost-benefit ratio will help determine where RBD provides the greatest value and guide strategic deployment decisions.

Finally, RBD requires validation through pilot projects. Research from TWM has demonstrated promising potential for the complete restoration process.

V. ACKNOWLEDGMENT

"The Weather Makers Foundation" has been established to set the plan for a regenerated Sinai in motion. This document has been created in a series with several other articles that detail the plan on Regenerating the Sinai. These documents are distributed freely.

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