Knowledge - Artificial Reefs

A reef is a shallow strip or ridge in the sea, ocean or other water body that rises to or near the water surface. This strip can consist of rocks, sands, corals or non-natural materials. Many reefs have emerged naturally, but others have not. The last type is called artificial reef (AR); a human-made underwater structure, typically built for the purpose of increasing marine life, but more reasons are known.

Reefs are important factors in water bodies. As the majority of sea beds and the ocean floor are empty and seem featureless, reefs are the exceptions. Reefs are structures containing hard substrate on which plants and coral larvea can find surfaces to root and which create shelter for fish life and crustaceans. Reef structures also affect the water movement, as they can reduce the energy level, which forms calmwater and thus good shelter. It also creates extra turbulence at some spots and may increase concentrations of small animals such as plankton. Subsequently, fish and other marine animals find shelter and food on the reefs. So, a healthy reef forms a complex habitat for marine flora and fauna and usually showing great biodiversity.
A second effect that reefs have is on hydrodynamics. A reef breaks the wave energy and movement of water currents. So, the waves that crash onshore will be affected by the reef. Interrelated, a reef affects the transport of sediments between the reef and the coast.

Thus, reefs are an important factor in the eco-system. They are known for their biodiversity and productivity and are, as such, popular spots for divers and fishers, both recreational and commercial. However, the extensive use of reefs has had its impact on the existing natural reefs. Many of them are struggling, especially with the sea water temperature rising, which kills coral and related species. Humans have always used the reefs, for commercial and recreational reasons and to the enhance of their advantage, they have created artificial reefs for many years.

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Types of Reefs

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ARs have been created for different reasons; the following types can be identified:

Ecological development

The first advantage of reefs is the biodiversity and productivity. The dense population of fish is ideal for fishing, recreationally and commercially. Because of this, fishers have created ARs for many years. This advantage has been used to revive some parts of water bodies as many of the natural reefs are deteriorating. The ARs created new (compensating) ecological values and increased the biomass in an area in and around the reef. Moreover, the flora and fauna on reefs can have a strong purifying effect to the water. However, there is debate on how effective these reefs are; this will be discussed under 'ecological aspects'.

Fisheries

As mentioned, reefs attract fish; therefore the fishery industry can use ARs to create fish spots. Also species as mussels do well on certain type of reefs. Reefs in favor of the fishery industry are especially used in South-East Asia.
On the other hand ARs can be used to protect the seabed from (trawling) fishing. By placing reefs accurately fishers can be kept out of certain areas. At the same time the positive effect of the ARs can benefit the fishers as well.

Coast protection

Another reason for an AR is coastal protection. At some coasts the waves just crash directly onshore, causing heavy detriment to the coast by sedimentation. By constructing a reef a couple of 100 meters offshore, the waves are breaking earlier, the wave energy dissipates, so less forceful waves enter the coast. This has effect on coastal erosion, swimming safety and surfing circumstances.

Recreation

Fourthly, reefs are very popular for marine recreation like surfing, diving and fishing. ARs can enhance the recreational value of an area greatly and related also add to the economical benefits. Moreover, ARs situated near natural reefs can spread the recreational activities between the natural and artificial reefs. In such way, less weight is put on the natural reefs and they get the possibility to regain their strengths.
Surfing does, however, ask for a different type of reef than diving and fishing. By placing an AR properly, a reef can improve the quality and the occurrence of surfable waves. Reefs can increase the wave height at breakpoint; they can influence the breaker type and promote a progressively breaking rideable wave.

Multipurpose

A last type of reef is a multipurpose reef. As the name indicates, the multipurpose reef services more functions. Mostly a multipurpose reef indicates a reef that is both created for surfing as for coastal protection. The dissipation of the wave energy and the prolonging of the wave length improves the surf quality and coastal protection.
Especially in Australia a number of multipurpose reefs are constructed. Bournemouth, UK, is the first one in Europe to be used as surfing and coastal protection reef.

Design of Reefs

Design of Reefs

ARs are constructed using many different materials.

Traditional

Traditionally, especially the South East Asian fishers would put bundles of brushwood, boxes of leaves or coconut palm fronds in the water to attract fishes.

Recycling

In modern times, people started using recycled materials to create reefs. Over the years many concrete and steel structures are dumped in seas and oceans. Examples of these materials are ship wrecks, oil & gas platforms, subway wagons, army gear and tires etc which were purposely sunk in the water to form a new reef. These structures give a good foundation for water plants and coral. Moreover, fish and other mammals find the protection needed to house.
Dismantling of the constructions is necessary to remove all possible harming parts; parts that could get loose, toxic materials or other harmful materials. The cleaned construction would be sunk at selected location at sea. Many of these ARs have locally increased the flora and fauna population. However, these structures can have some adverse effects on the environment. For example, the tires that have been dumped in the sea appear to be toxic. Also corrosion is an issue with some type of steel structures. And the sea gets filled with structures that are slowly deteriorating the water quality.

Special designs

Recently, new specially developed materials are preferred for ARs over recycling old materials. Reasons are that some of the recycled materials had a negative impact on the environment; environmental laws have become stricter on rules to sink old waste and new, special designs appear to have a better effect on the diversity and productivity of a reef.
New materials are specifically designed to increase the effectivity of the reefs use. They are mostly made of concrete, steel and geo-textile. Examples are:

Reef balls

Reef balls are concrete structures in the shape of a half a ball with holes. These structures have been placed on the bottom of seas and oceans to create new eco-systems. The concrete shape forms good habitat for plants and coral and the hollow structure provides shelter for fish and mammals. Experience with artificial reef balls in New South Wales, Australia, has shown that after 2 years the richness of the AR exceeded the natural one close to the AR. This can probably be explained by the increased physical complexity of the reef balls compared to the relatively low profile natural reef.

Top view breakwater from reef balls

Reef balls

Reef havens

Similar to reef balls but a different design.

Eco reefs

Eco-reefs are constructions of ceramic. They are designed as a snowflake with multiple branches and therefore increasing suitable hard substrate surface. The structures are smaller (covering a surface of approx 1m2) and lighter (60kg) compared to the reef balls. The structures are anchored in the seabed with a rod and easy to install.

Geo-textile

Geo-textile is used in tubes or containers which are filled with sand. Those tubes can be used as beach strengthening, groynes, berms and also as ARs. These 'soft' structures appear to have environmental and technical advantages over 'hard structures' as rocks. The durability and survivability is high, although somewhat sensitive for vandalism, the structure itself is very durable. Moreover, the flexibility of the materials prevents the negative impact on the sediment dynamics hard structures do have.
Monitoring has shown that geo-textile structures form an excellent foundation for a broad diversity of marine species. Furthermore, it is a safe and user-friendly material.
Geo-textile structures have been used in a number of ARs, best known the Narrowneck Reef, which will be discussed later.

Bio Rock

Bio Rock refers to a method of using steel and electricity to speed up growth of coral reefs. First they place steel structures on the ocean floor. Through those structures electric currents are run, which crystallize the minerals dissolved in the water on the structure and form limestone. This type of limestone is similar to the structures created by coral reefs. Next to this limestone, the electricity also accelerates the growth of coral plants and other shell-bearing organisms. By placing broken pieces of the natural coral onto the construction, a new coral reef can develop fast.
The production of this method is fairly simple and the shape of the construction can be adjusted to the specific needs of that area.
This mechanism can be used to restore destroyed coral reefs, and next to ecological advantages, the diving industry can also benefit. Moreover, the Bio Rock reefs appeared to increase the resilience of the coral, so, it survives better after any damage.
Next to beneficially shaping coral reef, the structures provide solid shore protection as well. The open but solid structure is ideal to form a physical wave barrier. Disadvantage is that you always need a power source.

3D printing

A very new technique in development is 3D printing. 3D printing makes it possible to create very complex habitats. However, this is still under construction.

Example cases

Example cases

Geotextile: Narrowneck surfing reef

Introduction: Located on the Gold Coast in Queensland, Australia, a surfing reef enhances both coastal defense and the surfing qualities. This Narrowneck reef is part of Northern Gold Coast Beach protection strategy which aims at a sustainable long-term coastal management solution. As the Gold coast experiences high wave energy and heavy sand transport, it is necessary to protect the northern Gold Coast beaches from erosion. Moreover, the Gold coast is considered a popular surf spot, so, improving surf quality is seen as secondary objective.

Objective: The site of Narrowneck reef was heavily influenced by beach erosion. Plus, the site is surrounded with many popular surf sports. The objectives of the reef were therefore to enhance beach protection and the surfing conditions.

Solution: The AR is designed to have a flared V-shape and is constructed using more than 400 Geo-textile containers. The design is created to have two twin reefs with a stream for peddling in between.
The geo-textile containers are filled with sand and dropped on the right location by a hopper dredger. The first construction took place in 1999/2000, but over the next ten years an extra 50 containers and some minor rearrangement was needed, mostly in response to severe storms.

Performance: The performance of Narrowneck reef is closely monitored, including the shoreline erosion and accretion trends. In general, the reef has proven to be effective in stabilizing the beach and creating a salient. Because of adjusted sediment transport the beach is widened in direction of the ocean between the coast and the sea, forming a so-called salient. The reef has also proven to be able to resist storms and bad weather.
Next to the direct effects, the reef also seems to have a positive indirect effect as it interacts with the surrounding sand bar formations. This interaction creates even more favorable conditions for beach protection and surfing.

The surfing conditions at the Narrowneck site have improved significantly. At first, before settlement of the reef, the reef created some hazardous waves which were very hollow and sucked dry at breakpoint. However, after first settlement the surfing conditions improved, especially when weather conditions are suitable for surfing. However, the reef has not gained a good reputation as surf spot and is rarely surfed. Reason for this is the location of Narrowneck between some of the world's best surfing breaks, which work in similar conditions as the AR. Moreover, a media-hype at the start of the project has led to unrealistic expectations that the reef would be surfable all year round and under all circumstances.

Next to beach protection and surfing, the reef also became a diverse ecosystem; the geo-textile containers provided an excellent substrate for marine flora and the development of a diverse ecosystem. Initially, only some fishes were expected to settle on the reef, but soon new extensive flora and fauna appeared on the reef. The reef is mainly covered with macro-algae and pelagic fish, but also by a wide variety of benthos, fish and other marine fauna. As an unexpected result of this is that the reef has become popular with locals for fishing, diving, snorkeling and spear-fishing.

Ecological aspects: In the ecological discussion on the question whether the reef works to relocate fish or increase the productivity of the area; the answer is said to be both. It is found that the reef acts as a fish attraction device. However, on top of that, many juvenile species and species are found, that are not observed on nearby natural reefs. This indicates that the reef also increases the productivity of the area.

Lessons learned:

Surf reef projects	Date constructed	Country	Vol (m³) approx	Type	Total (A$)	Per m³ (A$/m³)	Construction method	Tide Range (approx)	Average Wave climate (Hs)
Completed projects									
Bargara	1997	Australia	300	Rock	$18,000	[illegible]	[illegible]	3.7m	<1m
Cables	1998-99	Australia	5,000	Rock	$1,400,000	[illegible]	Rock placed with excavator from barge	0.6m	Summer 1-2m winter 1.5 – 2.5m
Narrowneck	1999-2000	Australia	70,000	SFGC non-woven	$2,100,000	$30	150-450t mega sand filled containers filled in hopper barge and placed	2m	1m
Pratte's	1999-01	USA	1,350	SFGC woven	$385,000	[illegible]	14t sand filled containers filled onshore, loaded on barge and placed by crane from barge	1.6m	< 1m
Partially constructed									
Mount Maunganui	2005 - ??	NZ	6,000	SFGC non-woven	$1,545,545	$242	Mega sand filled containers attached to vessel, anchored and filled in situ (20% construction outstanding)	<2.5m	< 1m
Opunake	2006 - ??	NZ	?	SFGC non-woven	$700,000	?	Mega and sand filled containers attached to vessel, anchored and filled in situ (construction stalled?)	<3m	

The design and construction of this reef shows a number of (unexpected) advantages. The reef does improve the coastal protection and surfing conditions. Moreover, the reef positively affected the adjacent sand bars. This type of reef has also shown to be capable of surviving severe storms. It has to be noted that if a reef is constructed on a seabed, the fluctuations in the seabed can have significant impact on reef settlement and performance.
The surf conditions on the site of the reef have improved, however, only in weather conditions when surf conditions would have been decent anyhow. This has had a negative impact on the Narrowneck's reputation as surfing reef. However, this can be explained by the unrealistic expectations that existed before construction. The expectations that the surfing conditions would be good all year long were clearly not met.
The soft materials used to build the reef have both advantages and disadvantages. On one hand the geo-textile containers are sensitive for damaging by f.e. vessels, but on the other hand the soft materials promotes soft growths as algae, which are safer for surfers than hard materials as corals.
Narrowneck reef was a cost-effective project. Reasons are found in using efficient gear and experienced operators during the project.

In Australia, USA and New Zealand multiple surfing reefs have been created. A small comparison is in table: Reef comparison (Jackson & Corbett, 2007), see thumbnail.

Ship wreck: Spiegel Grove

Intro: The Spiegel Grove is an old US navy ship; this steam turbine-powered ship functioned as a dock landing ship, transporting landing crafts that carried combat troops to shore. During the Cold War, from 1956 till 1989, the Spiegel Grove served in several war missions over the world. After retirement, the ship was stored, till it was decided to sunk the ship and it became the world's largest AR ship of 155 by 26 by 24 meters in 1996.

Objective: The Spiegel Grove was planned to be sunk out off the Florida coast near Key Largo. It would create an AR that could function as new eco-system and a diving spot. Because of its size, the ship would provide diving experience for multi levels of divers. Before sinking, the ship needed to be cleaned from many loose and toxic materials.

Solution: While planning started in 1994, the ship was not sunk until 2002. A lot of commotion existed on financial and legal issues and the cleaning procedures.
In 2002 the ship was finally sunk, although not completely according to plan as the ship sank faster than intended and rolled over. It ended up with the stern on the seabed and the bow just above sea level. A large operation was needed to move the ship onto her starboard side, so it would not endanger passing vessels.
In 2005 the hurricane Dennis passed the Florida coast and surprisingly flipped over the ship into the position it was originally planned to be.

Performance: Over the years, the Spiegel Grove is become inhabited by different species of marine flora and fauna. The ship has become a

popular diving site for many different types of divers and snorkelers. Many sources point out the ship to be an extreme experience, mostly because of its size.
Already in the first month after sinking many different species were found on the reef; this number continued to grow over de following five years the monitoring was executed. It took three years for the species composition of the AR to become persistent and more similar to the surrounding natural reefs. The Spiegel Grove especially shows similarities with the deeper natural reefs in the neighborhood. And although similar to the natural reefs, also some rare fish species were documented on the AR. This counts as an indication that the AR does form a preferred habitat for some species unknown to the area.

Ecological aspects: The main ecological issues with the Spiegel Grove was the cleaning of a material called PCB, which was also the reason for the six year period between planning and sinking. PCB was regularly used in things such as paint, electrical transfer and hydraulic equipment. Because of its toxicity PCB was banned in the US in 1979. So, originally the Spiegel Grove needed to be cleaned completely from PCB. However, this appeared to give cost-effect issues in relation to the planned AR. In order for the Spiegel Grove to be allowed to be sunk, the legacy on PCB needed to be adjusted to an allowance level of PCB that was acceptable in the ocean.

Governance aspects:
From 1994, when the South Florida Community started the process of turning the Spiegel Grove into an AR, it took 4 years until the ship was moved to Florida. Many financial and legal issues delayed the process. Also the cleaning procedure of another four years, was a complex process as explained under ecological aspects.

Lessons learned: Large steel structures have proven to be suitable as AR, but due attention shall be given to cleaning of contaminations and to governance aspects.

Artificial Reefs Dubai:

Companies involved: Royal Haskoning and Van Oord

Intro: The sea near Dubai has very little flora and fauna and few places where fish populations exists. Due to construction of the Palms, many breakwaters were constructed in the sea. These breakwaters function as artificial reefs in the featureless sea. Although some valuable coral was destroyed, it appeared that the advantages of this hard rock underground outweigh the negative impact of the work.

Objective: The objective of ARs in Dubai is to create ARs on a large breakwater constructed for the artificial islands of The World. The aim is to create a barrier that looks like the islands of the Maledives, which are low reefs that are barely higher than sea level. The sea defense should therefore be made out of natural materials and be partly underwater to enhance the marine life.

Solution: A 25 kilometer World Barrier Reef will protect the artificial islands of The World against the sea. To meet all requirements an innovative design is made using material available in the surroundings.

Design: The design of the breakwater is 25 kilometer long AR with an innovative shape. First, it is a long stretched stairway, which shape creates a natural sea defense as the waves crashing onto the top of the reef is minimal. Therefore, the reef can remain lower than usual at only 2m above sea level. The major part, that is below sea level is especially designed to enhance settlement of species. Secondly, the design was affected by the lack of rock in the neighborhood. In the solution a large amount of sand was used that was covered under a small layer of rock. The stairway shape of the design also increased the possibility of using only a small layer of rock.

Artificial Reefs Noordzee

Intro: Legacy on water management within the Netherlands in the beginning of the 1990's aimed at optimally using the potential of the North Sea. Partly by increasing the habitat and biodiversity of the area. In order to do this an option is to create some ARs.

Objective: The objective was to install a foursome of ARs in the North Sea as an ecological experiment.

Solution: The location of the ARs was set at 8,5 kilometers out of the coast of Noordwijk. Four reefs were placed in 1992 in 18 meters deep water.

Design: The four reefs consisting of a circular shape of basalt rock. They are placed in line with each other, perpendicular on the flow direction.

Performance: Within the first hours after placement, fish was spotted on the reef. Twelve days later also the first cultivation is found on the rocks. It only took ten weeks till 80 percent of the reefs was covered; a percentage that remained stable over the following ten years. Monitoring campaigns are executed within the first five years of the reefs and once more in 2001 to see how the ARs had developed. Overall can be said that the reefs enhance the biodiversity and biomass of the area for a longer period of time. Over the first nine years this positive effect has remained the same, as did the amount and type of other species found around the reef as well.
What did change was the size. Only 40 percent of the reefs was left after 9 years; the rocks sank into the seabed. With what rate the reefs are sinking is unclear as dredged materials were placed in the neighborhood.
Evident is that the results of the ARs are in general similar to the results found on other ARs in the North Sea, such as ship wrecks. However, the biomass appeared to be less than elsewhere. The location is thought to be the main reason, as hydrodynamics influence the development on the rocks.

Ecological aspects: The question is whether the ARs attract species or cause relocation. It is proven, that the ARs in the North Sea do promote growth of new populations and attract new species. Species have been seen that have been extinguished in the North Sea for many years. Moreover, monitoring showed that the ecological status of the surrounding areas remained the same.
The level of biodiversity enhancement was as it was expected. The hard substrates of the reefs are not found on the sandy sea beds, so, placing those materials will attract species to the otherwise featureless sea. For that same reason ecologists were afraid that the ARs are too unnatural to the North Sea and would have a negative impact on the balance of the eco-system. However, it is argued that rocks, like the basalt rocks, could be found in the North Sea before, but most have disappeared because of trawling fishing. Therefore placement of the reefs can also be seen as restoring the original eco-system of the North Sea.

Governance aspects: The 'Kunstriffen Noordzee' is a pilot project initiated by the Dutch government, Rijkswaterstaat. It is said that not enough attention is paid to creating public acceptation. As the project has been executed as a scientific research program, it was not thought valuable to promote public acceptation. In hindsight, it is recognized that it would have been important to get local public, fishers and divers to participate in the project.

Lessons learned:

- Monitoring has shown that species are seen on the ARs, even rare ones, or others that haven't been seen on the Dutch coast for long.
- The richness of the populations found on the reefs is poorer than expected, although the pilot was still successful as overall biodiversity and --mass did increase.
- The location of the reefs could have been better, as the dynamics and hydronamics in the area affected the reefs.
- The shape and construction appeared to be useful.
- Not enough public acceptation was created.

Lessons Learned

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Engineering/effect aspects

The concept of an AR has been used by humans for many centuries; therefore there are many different types and methods. It is stated that 'when properly designed, located and constructed with an adequate quantity of stable and durable substrate, man-made reefs can be equally as productive in theory as naturally occurring hard- bottom habitats, limited only by the life-span of the materials utilized.' Many materials do exist that are effective, durable but although rather inexpensive.

Governmental aspects

Decision makers have to deal with two important factors when deciding upon an AR; the economic and the ecologic value. ARs are supposed to affect both the ecological and the economical value, the latter mainly through recreational income and fishing opportunities. For a successful process it is important to clearly define the costs and incomes on these aspects.
In terms of resistance of the public, ecological and coastal protection reefs are easier accepted by the public, where surf reefs tend to get more opposition. When combining the opportunities in a multipurpose reef, most benefits can be achieved.

Environmental aspects

The environmental aspects of ARs are mainly positive. ARs can be used to create new habitat for marine flora and fauna and can have an accelerating effect on the biodiversity and productivity of the area. Research shows that the organisms that are attracted to the AR create new sources of food, which attracts other species. And mature ARs, around 3-5 years old, play a significant role in the increasing biodiversity.
However, also a number of remarks need to be made on the environmental effects of ARs.
Firstly, using recycling materials appeared to be cost and environmental effective, however, not all materials were completely risk-free. Tires would break loose and damage the natural reefs and certain types of steel cause corrosion that is very harmful for the environment. Also the effect of these structures in 100 or 200 years is unknown.
Secondly, although it is recognized that ARs attract fish, it needs to be questioned whether a reef really promotes new populations to grow or it only attracts existing populations to a richer location. Not in all cases it is proven that ARs enhance the fish population or just affect relocation.
Another negative effect of ARs can be intensification and over-fishing. Because reefs have a high density of fish, it makes a very good fishing spot. However, in some cases it has led to overfishing.

Concluding Remarks

Overall, from the different ARs it can be concluded that most ARs in seas and oceans do enhance biodiversity, -productivity and -mass as the hard substrates used are very different from the natural seabed and ideal for marine flora and fauna. However, the material chosen to use does make a difference on the type of species that can be found on the reef and how much the biomass will increase.
Public acceptation is a topic that returns in all projects, as it can be used to derive attention from natural reefs, it can prevent abuse of the reefs and is necessary for the success of ARs.

EDD Lessons learned

The EDD aspects of ARs can mostly be found in multifunctional reefs, when ARs are used incorporated in a project, such as the sea defense in Dubai or the surf and coastal defense reefs in Australia. Those reefs use natural dynamics to enhance safety, ecology, recreation and even the economy.

The most important lessons learned are:

- The type of material makes a difference on the type of reef and the success.
- Artificial reefs can potentially be used to increase and concentrate the population of fish in a certain area.
- ARs can benefit the natural ones as they move the interest and density of visitors.
- Ship wrecks as reefs can alter attention from natural ones, mostly when a ship has special features that are extra attractive to divers and fishers.
- ARs show large numbers of a diverse range of species. There appears to be significant differences in species richness, diversity and relative abundance between the artificial and natural reefs.
- There is a clear possibility to create multi-purpose reefs that benefit both people, planet and profit.

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