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Published in:
Habitat

Publication date:
2024

Document Version
Publisher's PDF, also known as Version of record

habitat

#28

for en vild verden

Dansk Zoologisk Selskabs magasin

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BUILDING REEFS TO SUPPORT COD IN DENMARK

- Designing concrete reefs for research projects in the Baltic Sea

Only humans need shelter? Not really! Many fish rely, at least in part of their lives, on physical places where they rest, feed, and find shelter.

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„

Atlantic cod (*Gadus morhua*), and many other fish species, find shelter in underwater structures."

DO FISH NEED A PLACE FOR PROTECTION?

During early life stages, Atlantic cod (*Gadus morhua*), and many other fish species, find shelter in underwater structures (Figure 1) which provide shelter from predators and other stressors that can threaten their survival [1].

These structures, named reefs, have been sitting for years and even millennia on top of the seabed in Danish waters. Reefs are broadly classified in three categories based on their origin: geogenic reefs which are mainly composed of rocks e.g., boulder reefs, biogenic reefs which are created by living organisms e.g., coral reefs or mussel reefs [2], and lastly artificial reefs, which are human-made structures added to marine environments, such as concrete and iron structures, that may be used by fish and other organisms as reefs [3].

Cod benefit from reefs when they are juveniles, as they are small and face elevated risks of being eaten by larger fish or birds, such as cormorants [4]. Especially small cod are therefore associated with areas with vegetation or rocky environments where the fish find refuge and grow, but other fish species also benefit from reefs by finding food, shelter, or using the reefs as spawning grounds.

WHY SHOULD WE PROTECT JUVENILE COD?

The North Sea stock used to be one of the largest Atlantic cod stocks in the North Atlantic [5], but it has been under pressure in most areas, mainly due to overfishing and low recruitment rates [6, 7].

A similar development is observed in areas of the Baltic Sea [1, 8]. Low recruitment rates are largely caused by poor food availability, previous and ongoing fishing activities, and high predation risks by birds and mammals [8, 9].

The marine environment is affected by both physical and chemical processes. Eutrophication, the ingress of nutrients into the water, often leads to oxygen depletion, and it has been one of the major threats to Danish waters for the last 30 years [10]. Artificial reefs may not eliminate chemical threats, but by establishing reefs, we can provide a valuable environment [11] as hard-bottom habitats often increase cod biomass [12].

WHY DO WE NEED TO ESTABLISH MORE REEFS?

Habitats known as reefs are reported at least in 22 EU member states with more than one thousand Natura 2000 areas designated to protect reefs [13]. Nevertheless, there is no complete mapping of stone reefs across Europe or Denmark.

In Danish waters, boulder reefs, formed naturally during the ice ages, were more abundant decades ago. Unfortunately, many boulder reefs were removed by human practices, also called stone fishing [3] which resulted in the removal of more than 80 million rocks from shallow waters throughout the 20th century alone.

In biology, 'recruitment' levels refer to the process of adding individuals to its population, either by birth or immigration.

↑ *Figure 1: One Atlantic cod and two other fishes swimming around a boulder reef with vegetation. Photo: Tim Wilms*

"Stone fishing" consisted of removing boulders from shallow waters to use them in construction and coastal protection projects. Stone fishing was prohibited in 2010 in Denmark [3].

Boulder reefs can be reestablished. However, the boulders were transported to Denmark during the ice ages from Norway and Sweden and are not a common part of Danish geology. A few collections of stones to be used in future boulder reefs, called "stone banks", are being organized [14] where citizens and businesses can donate stones from their gardens or work with soil for boulder reef projects. To restore hard substrate habitats nowadays, transportation from Norway or Sweden is necessary or man-made alternatives could be investigated to document their potential to replace imported boulders.

Artificial reefs are man-made structures built to mimic natural reefs, and they have been used for many years and different applications, such as diving sites, to enhance tourism, and fisheries restoration [15]. Many materials are being used, such as ships, tires, wood, recycled materials, and most often reported: concrete.

Nowadays, concrete is widely used, as its chemistry can be adjusted, and its shape and surface texture can be easily designed and controlled in the manufacturing process.

Nonetheless, concrete interacts with seawater which alters the material where dissolved CO_2 and other ions are taken up while other elements such as calcium are being washed out. Calcium carbonate forms on the concrete surface which has the same chemical composition as mussel shells. The interaction of ions with concrete can lead to cracking and disintegration, especially when embedded reinforcement steel is corroding through rust formation which causes cracking. The removal of artificial reefs is required in Danish waters today, as they are typically only allowed as temporary research reefs. This should be considered when designing a research reef.

Concrete is a composite material made from 3 main ingredients: Cement, water, and aggregates (sand & gravel).

Figure 2: Stone fishing conducted with a mechanical crane.

All hard substrates are covered by organic matter in a biofilm when exposed to the marine environment. The defining species become more complex over time, from bacteria and algae to seaweed and mussels, this evolution is called succession. The period during which increasingly complex organisms establish themselves can be several years or even approach a decade. Therefore, the success of an artificial reef could vary with the exposure time. An example of concrete exposed for 18 months in the Øresund is shown in Figure 3. Several studies have investigated concrete to identify attractive compositions and surfaces in terms of roughness and cavities where organisms can settle and grow quickly [16, 17]. The succession on boulder and artificial reefs might differ in time, hence the success of the deployment might depend on the monitoring time. This exact relationship is yet unknown.

WHICH ARE THE MAIN PARAMETERS TO DESIGN A REEF?

For every material and structure that is being introduced into the ocean, different aspects may be considered to ensure efficient and sustainable habitat creation, such as (not exclusively):

- Bio-colonization rates.
- Amount of shelter produced.
- Deployment methods.
- Environmental impact such as CO_2 emissions.
- Production process and costs.

Concrete structures present similar bio-colonization rates, fish abundances and community composition as rocky reefs [16, 18], making concrete a good candidate material in terms of biological compatibility.

Nevertheless, when producing cement, extracting stones, transporting the materials, transporting the final product etc., CO_2 emissions should be considered, and they should be addressed as a design parameter. Based on these assessments, we suggest using recycled materials after screening for possible toxins, to create low-density units that contain voids (Figure 4), and that are produced as close to the deployment site as possible to reduce the CO_2 emissions [19]. A comparison between emissions of artificial reef's production and those of transporting boulders from Norway should be considered for a more complete environmental impact assessment.

As a Master thesis project [20], concrete reef units were designed (Figure 4) which would build an artificial reef by stacking several reef units together. This was explored in a small scale in the thesis where the units were produced on a scale of 1:10 of the proposed size, being approximately 10x10x10 cm^3.

To be able to compare boulder reefs and concrete reefs, stones and single concrete units had similar outer volume, in average between 570 and 600 cm^3 with a weight of ca 1.2 kg for concrete and ca 1.5 kg for natural stones. Volume was measured by Archimedes' principle, measuring the volume of water displaced when the unit was submerged.

As a result, a reef that uses less material per volume was designed by creating in-between spaces to provide a valuable reef with a more efficient use of material, thus, less CO_2 emissions.

Artificial reefs can be constructed in different ways from design to manufacturing and deployment. Hence, deployment options should also be investigated to produce a reef that is quickly established and thus economically viable. Both concrete reef units and natural stones can be deployed from the sea surface in two ways: by releasing them close to the sea surface or placing them directly on the seabed. The latter would be expected to be more labor intensive. Reduction of deployment time may lead to lower CO_2 emissions through reduced resource consumption.

By having several designs, the sensitivity towards design changes can be analyzed, and the best performing reef can be selected.

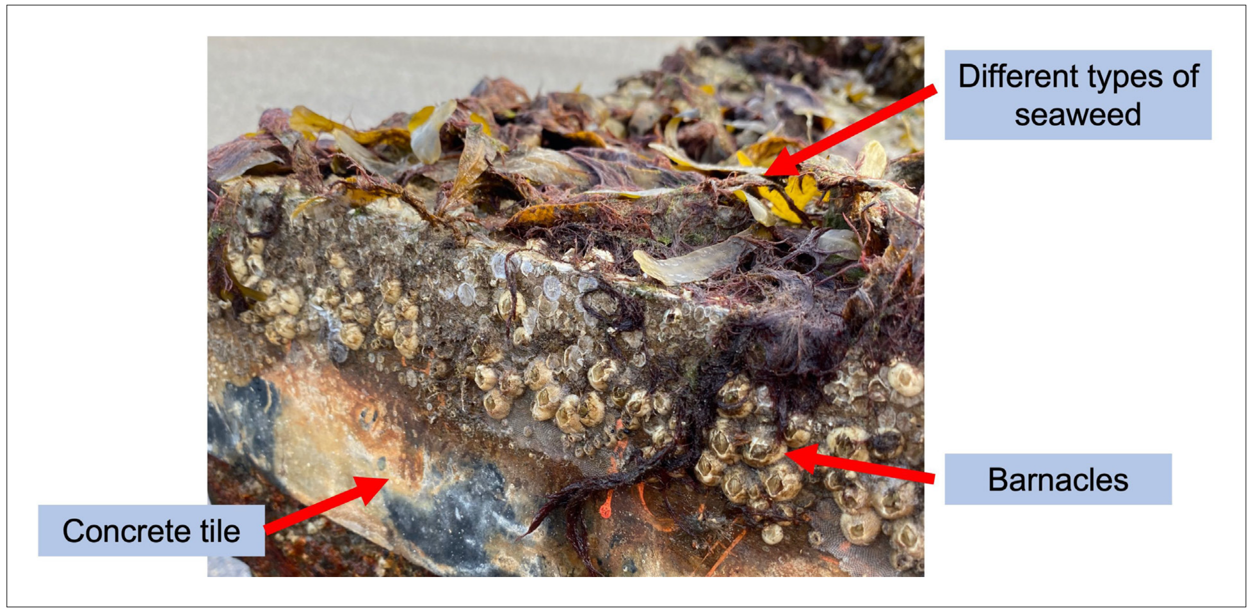


Figure 3: Biological colonization on concrete block. Extraction from a DTU project [21] within Øresund waters between Denmark and Sweden.

> **Building and implementing an artificial reef could be considered as an option to help the local cod populations.”**

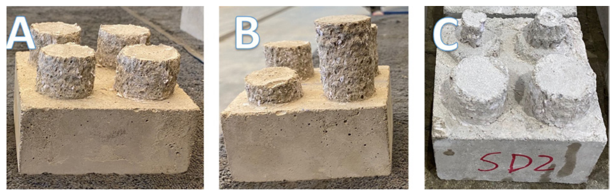
Therefore, one of the aims of the project was to compare the shape and positioning of the artificial reef units and stones when located randomly after sinking from the sea surface.

The concrete units produced taller reefs with double the height and covered smaller surface areas of the seabed, in comparison to natural stones (see for example Figure 5). Therefore, boulder reefs require extra labor to control the shape of the total reef consisting of several reef units or stones.

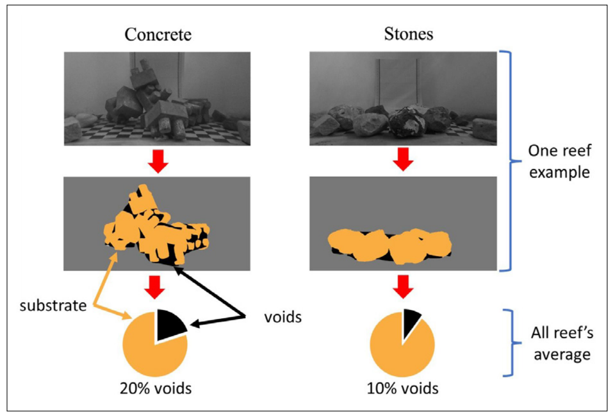
Lastly, the main aspect is to document how much shelter these types of reefs will produce, assuming more voids are desirable for juvenile cod, local fish, and other species that would benefit from the new habitat.

When deploying the designed reef units together, a big reef structure is going to be established, but due to the design of the units, the reef will present inside voids (Figure 5). By having a reef with more voids, juvenile cod and other species have more spaces to use as shelter from predators like cormorants, bigger fish, and seals [8].

Using image analysis to estimate the 3D spaces created, based on 2D images taken



↑ *Figure 4: Variants of concrete reef units were used with different design features. A. Standard unit. B. Randomized height unit. C. Variant with additional design variations to identify the most efficient geometrical design or shape.*



↑ *Figure 5: Identification of voids and reef substrate of both concrete and stone reefs with image analysis. Average void rates obtained per category. Orange area as reef substrate and black areas as voids.*

from two different angles (front and top), to quantify and compare the concrete results against those of boulder reefs, a clear difference in using concrete reefs rather than stone reefs emerges. Almost double the number of voids (possible shelter) were created with the concrete reef units (Figure 5).

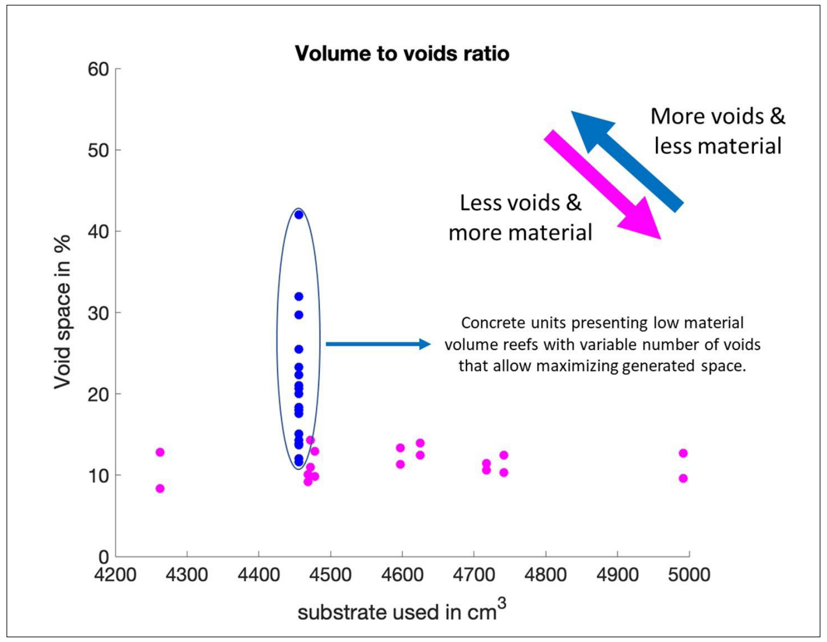
The concrete units have a defined material consumption and can create on average 20 % voids of the whole reef structure that is available for organisms to create a reef habitat with shelter (Figure 5). This is also visible in Figure 6 showing that natural stones (in pink dots) create on average only 10 % of inside spaces with a wide range of material volume used.

Building and implementing an artificial reef that presents minimal ecological downsides and creates suitable shelter spaces with similar biological compatibility as stone reefs, could be considered as an additional option to help the local cod populations to increase in numbers since many local boulder reefs have been removed.

Removal of the concrete reefs may be required by the coastal authorities as artificial reefs are not intended to be permanent reefs. The removal obligation lies with the applicant for the artificial reef. However, deployment of concrete reefs would provide a unique opportunity for long-term monitoring and on-site testing (more than 5 to 10 years) providing an insight into the link between habitat creation and reef design within the ecosystem.

Creating a protective environment for species like cod may help them to increase their population and by saving energy from predation risks, their production may also increase [11]. Nevertheless, other factors affecting cod, such as fishing and oxygen depletion, should also be addressed to help rebuild cod populations.

Stakeholders in interdisciplinary projects are diverse and have different knowledge and expectations which leads to debate. This includes suitable sizes of shelters for key species. Further analysis and monitoring should be conducted to identify the link between individual species, life stages and the optimal material, and design parameters to be able to use these technologies where appropriate.



← *Figure 6: Results of void space created against material volume of generated reefs. A clear majority of reefs having more voids with less volume of material used can be observed from the concrete standard units (blue dots) against stones (pink dots). The arrows point the direction in which the results will be more predominant.*

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