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A Design Method For Determining the Optimal Distance between Artificial Reefs

Since the mid-twentieth century, fisheries resources in most of the world's coastal countries have been threatened by overfishing, which have all shown signs of deteriorating year by year,[1] as well as the deterioration of the environment in coastal waters, and global climate change. Many species are now on the verge of extinction. According to a FAO report, at present, nearly 90 percent of the world's fish stocks are subject to overfishing or have reached their catch limit. How to ensure the sustainable development of marine fisheries, and how to provide high-quality marine animal protein for human consumption on a continuous and steady basis, have become urgent problems faced by scientists and marine fisheries workers.

In 1971, the term "marine ranching" first appeared at a conference organised by the Japanese Department of Aquaculture, suggesting a concept for a system of sustainable food production from marine biological resources. In recent years, with the continual development of science and technology, marine ranching has received considerable attention as a new form of modern marine fishery production, and has so far achieved good results where it has been carried out.[2]

In Europe and America, marine ranching (also called ocean ranching) is most often referred to as stock enhancement. It involves mass releases of juveniles which feed and grow on natural prey in the marine environment and which are subsequently recaptured and add biomass to the fishery.

Releases of captive-bred individuals are common responses when critically low levels of fish populations occur due either to abrupt changes in habitat, overfishing or recruitment failure from other causes. Captive-bred individuals are also introduced both inside and outside the natural geographical range of the species concerned in order to build up new fishing stocks.[3]

However, in Asia, and especially in China, marine ranching is often regarded as a novel mode of marine fisheries production. Because providing stable and high-quality marine animal protein for humans is its main purpose, marine ranching is also referred to in Asia as the "blue granary." It stands to reason that, in order to produce a continuous supply of high-quality seafood, we need to repair and even transform the marine environment.

Alluding to the grazing of cattle and sheep on grassland, on a basic level marine ranching can be interpreted as grazing animals such as fish, shrimp and shellfish in the sea. Reef fishing offers a salient example. While reefs readily attract fish, in recent years natural reefs have declined as a result of marine engineering practices and destructive fishing methods. In response, artificial reefs are springing up.

In terms of marine ranching, the formation of artificial reefs is a fundamental ecological project. By forming artificial reefs, we are reconstructing the habitat of fish destroyed by bottom trawling. This practice, especially the scraping of nets across reef areas and seaweed beds, causes major damage to the sea floor. These compromised places are often habitat and spawning grounds for fish. There is an obvious parallel with grazing sheep: if the grasslands that sustain them are destroyed through desertification, then the stock will have nowhere to feed.

Thus it is important to support the restoration – and proliferation – of fish habitat. We can consider artificial reefs as apartments or houses for fish, offering habitat and shelter. Because this is analogous to building homes for people on the land, artificial reefs are often referred to as artificial habitats.[4] Many fish spend their lives on and around reefs. As they do not migrate long distances like species such as salmon, if shelter is provided for them these kinds of fish can be attracted to make their homes there. As man-made structures in the sea, artificial reefs have the function of restoring and optimising the marine environment for food production.[5]

Following the construction of an artificial reef with a particular size and configuration in a suitable area of the ocean, the ecological environment of the reef will be modified. First, factors such as the flow field around the reef, the light field created by the light layer, the sound field and the bottom type form a variety of environments – including places where animals can attach themselves, hide, avoid harm, lay eggs, lure prey, make homes, and so on – which will provide artificial habitats for different marine organisms.

Second, after construction, various organisms can be introduced to artificial reefs. Because aquatic plants absorb nitrogen and phosphorus, they enhance the water quality and improve the marine environment. Large numbers of fish will begin to gather in the reef area, leading to a steep increase in fishery resources. The artificial habitat for the accretion of marine life thus provided will improve both the quality and quantity of marine biological production and fishery production in the area.
The construction of artificial reefs is a vast marine project. The United States has formed them by placing decommissioned aircraft carriers on the sea floor, Turkey has used airplanes, and other countries have chosen reinforced concrete, steel, stone and other materials to make reefs of various forms, experimenting with particular structures and layouts.

As with building a house on land, structure and design needed to be considered when constructing bodies in the sea. If houses are built too close, lighting may spill over. If they are spaced too far apart, land will be wasted, so it is important to consider the distance between houses. The same is true for artificial reefs. Although the design of artificial reefs is usually based on previous experience, it often fails to achieve the best results. If the reefs are too close, the number of reefs per unit area means that construction costs will be maximised. If the distance between the reefs is too large and they are effectively scattered, fish will be vulnerable to predation due to their inability to form large protective schools.

The question of how to configure fish reefs and set the optimal distance between them needs to be carefully considered. The simplest way is to determine the productivity and density of a single fish reef based on its size and the production costs involved, but this is difficult due to the absence of information relating to the environment and the biological reactions involved. Some researchers seek to solve this problem through hydrodynamics – the distance between the reefs can be set by simulating and measuring current flows.[6] However, this method fails to consider the reaction of fish to modified flow fields in the area and their distribution. Because we form artificial reefs to create fish habitat and optimise reproduction, we should first consider the behavioural responses of various fish species to the configuration of reefs.

We have adopted a new method to determine the distance between reefs based on the behaviour of fish. We selected two common species found in the northern coastal areas of China, *Sebastes schlegelii* and *Hexagrammos otakii*, two of the most typical reef fishes in this area. They spend their entire life cycle in the rock reef zone. Following the creation of artificial reefs, these species can be attracted to live, feed and reproduce there, allowing us to easily protect and restock them. The proliferation of fish resources in such areas has great potential.

Based on the living habits of fish, as well as previous research findings, we have designed a method for calculating the escape distance of fish according to their burst swimming speed, or the speed of fish eruption.

According to this method, having calculated the escape distance of the fish at full speed when they encounter a threat, the optimal distance between individual reefs is determined by this distance. Following the construction of reefs according to this method, when the fish in the reef area are threatened by predators, they can escape by swimming at full speed to nearby reefs.

The burst swimming speed is the fastest speed of which fish are capable. Lasting less than 20 seconds, a fish uses its burst swimming speed to catch prey, escape from predators or scare them off, and swim in strong currents.

The specific experimental methods deployed were as follows. A trial fish, which had been fasted for 24 hours, was introduced to the swimming channel and allowed to acclimatise for 20 minutes. Then the fish was provoked into swimming by tapping the swimming channel and prodding its back. When the test fish stopped swimming, stimulation was re-applied until the fish tired. The performance of ten individuals was measured in this way. Experimental video was used to analyse distance and swimming time and calculate the speed of the experimental fish. The results showed that the burst swimming speed of *Sebastes schlegelii* specimens with a body length of 10-22cm was 76.68–118.18 cm/sec, and the burst swimming speed of *Hexagrammos otakii* individuals (10-22cm in length) was 81.69–121.25 cm/sec.

The maximum escape distance for the two species was estimated based on the burst swimming speed and the maximum swimming time at this speed (20 seconds). The burst swimming speed of *Sebastes schlegelii* individuals with a body length of 10-22cm is 76.68–118.18cm/sec, with an average value of 96.11 cm/s; the maximum escape distance is 15.33–23.64 m, and the average value is 19.22m. The instantaneous burst swimming speed of *Hexagrammos otakii* individuals with a body length of 10-22 cm is 81.69–121.25cm/sec, and the average value is 96.75 cm/sec; the maximum escape distance is 16.34–24.25 m, and the average value is 19.35 m.

According to these results, we estimated that if the flow velocity around the reef exceeds the burst swimming speed of the fish found there, and lasts for more than 20 seconds, it will directly affect the life chances of these two species in reef areas.

In addition, according to the results, the escape distance of the two species was estimated at 15-25m. The space between the individual reefs that form artificial reef systems can thus be set at this distance. In addition, if we want fish to thrive in reef habitats in the future, this study will inform those seeking to fish between reefs using movable nets. The methodology used here also offers potential for future research on artificial reefs through the study of the swimming behaviour of fish. Our results require verification through future experiments and field investigations involving existing artificial reefs.

As an area involving multidisciplinary study, artificial reefs cover many fields, including material science, spatial structure and resource assessment; many related studies have been carried out in recent years, including evaluations of different configurations of artificial reef.

The design of artificial reefs should also be adapted to local conditions. This process should take full consideration of environmental conditions, especially ocean currents, and consider the ecological habits of the species under investigation. It is only through such an approach that artificial reef construction can deliver the greatest benefits. Future research would do well to concentrate on the development of artificial reefs focused on ecotypes and multi-trophic-level combination reefs, as well as new design models, so that people can grasp the ecological and economic benefits of marine ranching more intuitively.

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