RESOURCE-CULTIVATION FISHERIES BY ARTIFICIAL REEFS

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■ RESOURCE-CULTIVATION FISHERIES

Maritime countries make special effort to promote resource-cultivation fisheries. Figure 1 shows the resource cultivation fisheries based on biology and environmental engineering. Fisheries engineering deals with various techniques such as mass production of artificial seeding, formation and improvement of spawning and nursery grounds, development of fishing grounds, and the promotion of resource-cultivation technique.

■ FISHERIES ENGINEERING

Fisheries engineering technique aims to promote the resource-cultivation fisheries. It achieves this goal by means of environmental engineering, but it is not merely a study of dynamics. Rather, it is an academic field which encompasses a wide range of studies and activities such as (1) the study on the behavior of marine life, their response to environments (2) the identification, formation and control of environments in which marine life proliferates (3) hydraulics designs to enhance accident prevention and required function, after identifying optimum propagation conditions.

Example

If a certain type of fish tends to avoid a water mass with mixed water temperature and salinity (i.e. at certain density), the movement of water mass can be calculated and we can analyze fishways by applying the laws of physics.

Although the dynamic design of fisheries facilities is an area covered by marine engineering, little practical experience has been obtained so far in water depth of 200

meters or more. In some cases, we do not even have the knowledge of the basic design conditions.

The fourth subject the fisheries engineering deals with is (4) construction technology for marine structures. Here again, however, adequate technology has not been developed and we are faced with a new challenge such as the use of the continental shelf and shallow areas for aquaculture and fish farming.

■ FORMATIONAND CARE OF FISHING GROUNDS

Development of fishing grounds involves the engineering works listed below:

1. Formation and care of productive fishing grounds.
2. Formation and care of aquaculture.
3. Formation and care of fisheries propagation grounds.

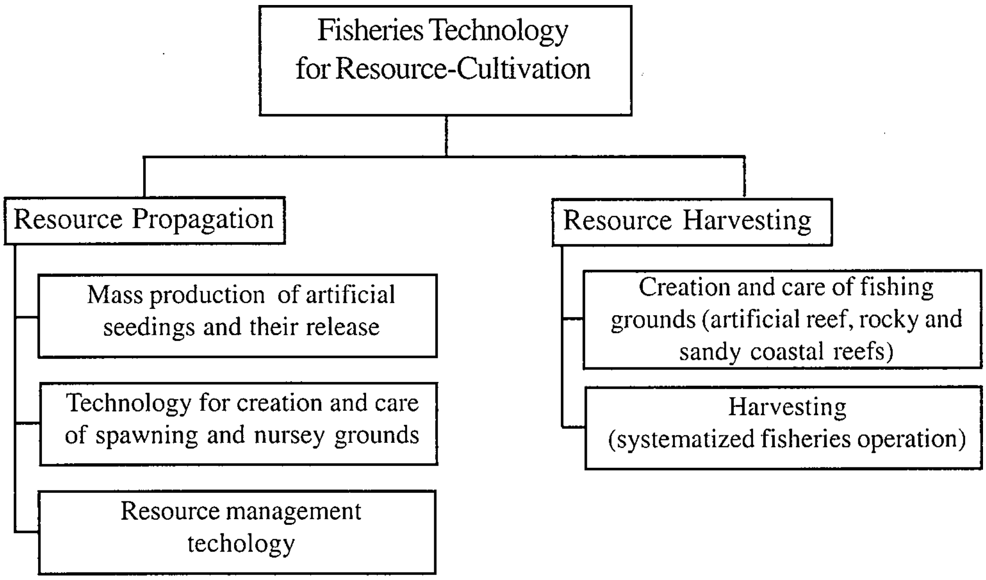


Fig. 1 Resource-Cultivation Fisheries

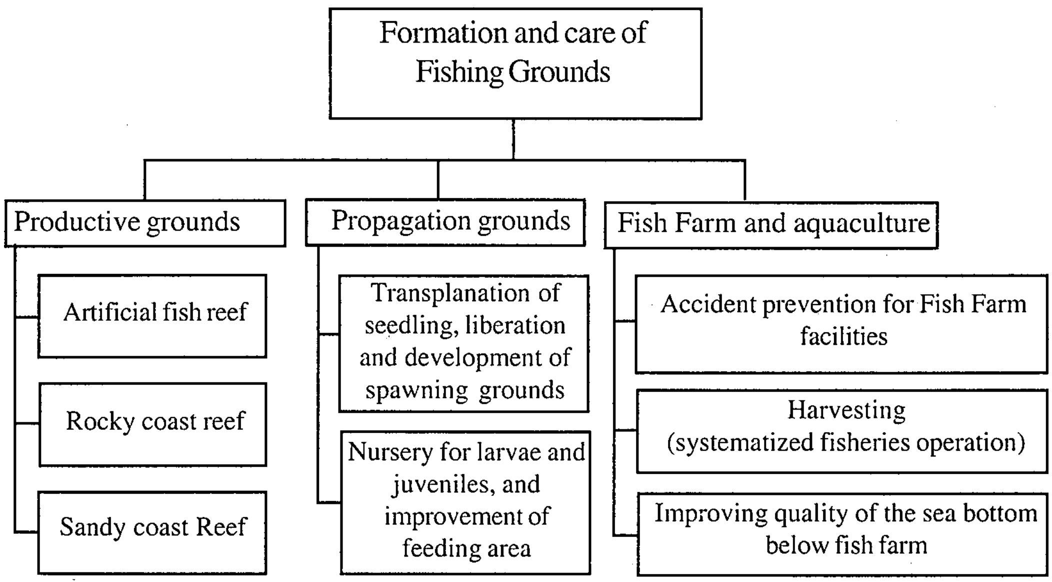


Fig. 2 Type of artificial habitats

Formation and care of productive fishing grounds

A "productive fishing ground" is an efficiently managed area, created for the purpose of increasing the harvest. It is also an area which allows us to cultivate resources and some example of productive habitats are artificial fish reefs, rocky and sandy coast reefs. Detailed descriptions of these structures will be made in the nex t section.

We can create productive fishing grounds by artificial means which emulate natural ones. It is one area that fisheries engineering address and it has trememdous potential for future development. It is likely that fisheries engineering in the future will evolve by incorporating new equipment and functions and by promoting "maring ranching" and systematiazed fisheries.

Formation and care of aquaculture

The term "aquaculture" includes sea surfaces as well as inland waters. Both artificial and natural feeding are practiced at these man-made habitats. Sea-surface aquaculture needs protective facilities to fend off waves. It is also important to secure a good flow of seawater in these habitats in order to keep the culture environments clean.

When culturing fish and shellfish in pond, leaks or other inland waters, the control of water quality and bottom grounds is quite an important subject. Accident prevention and improvement of facilities are also necessary, but these aspects are not discussed in this paper.

Formation and care of fisheries propagation

In essence, fisheries propagation technology is the application of artificial means to natural life history of target fish and shellfish species to enhance their propagation, and thus increase their catch. Most aquatic organisms spawn millions of eggs, but only a fraction of hatched spawn grows to aulthood. The highest mortality occurs immediately following birth. It is know that larvae and juveniles which survive the initial "high risk" periods usually grow into adult fish.

It is know from the existence of the "dominant year class" that a generation which has show an exceptionally high spawning rate wil later from a very large population. this shows the importance of early care in the very begining stage of larval growth.

Fig. 3 shows various methods used to increase larval propagation. The technique employed for mann production of artificl seding comes from biological engineering.

Resource-management technology is based on accurate resource forecasts and technology that allows efficent harvesting. Environmental control technology is equivalent to "artificial propagation ground formation technology", illustrated in Fig. 2, and involves such civil engineering works as the formation of artificial tidal basin, water ways, development of sand coast and rock reef seaweed beds, and the formation of propagation reefs and artificial inlet.

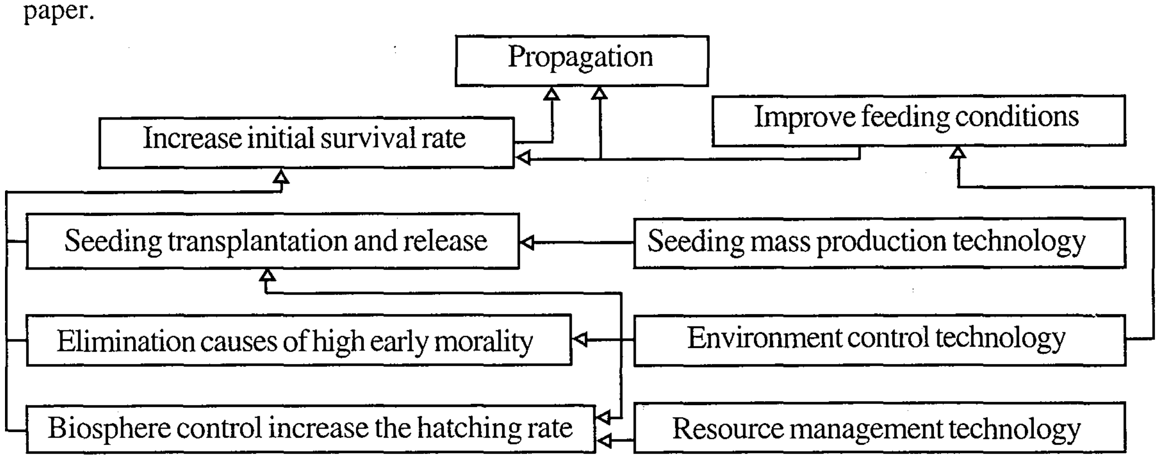


Fig. 3 Larval propagation and Required Technology

■ ARTIFICIAL FISH REEFS

Function

Artificial fish reefs protect and propagate fish populations and thus, contribute to increasing catch and efficiency in fisheries operations. In forming artificial fish reefs, we take advantage of behavioral characteristics of fish such as their tendency to aggregate in and around natural fish reefs and sunken ships.

Reef with widely varied topography are attractive habitats for various species of fish. When we look at the behavior of fish, they show certain taxis, or natural guided movements in response to a stimulus. Examples of various forms of taxis are listed in Fig. 4.

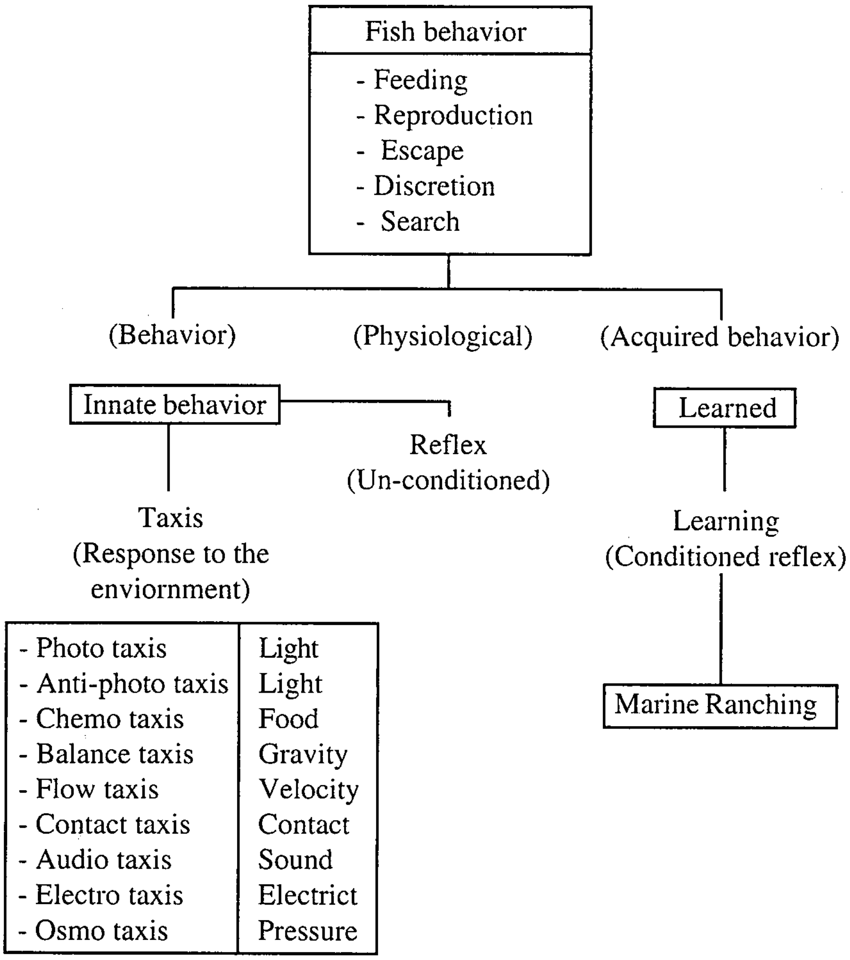


Fig. 4 Environmental stimuli and fish behavior

Animal behavior is triggered by natural intuitive impulses and displayed when its sense organs are stimulated. There are various froms of taxis, e.g. photo taxis caused by fish's sensitivity to light, chemo taxis triggered by the small of chemical components in the feed, balance taxis a fish intuitively keeps its abdomen down, but this may be interpreted as its anti photo taxis, and flow taxis cause by animal sense of action. Animals determine their body position in relation to the direction of surrounding objects or thier line in reference to the position or movement of the other objects), audio taxis, in which animals respond to certain sounds. (This behavior characteristic can be used in acoustic conditioning of fishes).

Intuitive behavior is a set of inborn behavioral patterns triggered by inner and outer conditions and including such activities as feeding, reproduction, escape, imitation and research. Reflexes are quick, either innate or learned reactions. An innate reaction to any stimulus is known as an unconditional reflex. The learned reactions are called conditional reflexes.

School of fish congregate in and around fish reefs because of their taxis and intuition. In designing the structure of a fish reef, it is important to know the functions of the sense organs of fish. In an effort to create environments attractive to fish, fisheries engineering takes advantage of these behavioral patterns of fish.

Reaction to fish reefs differs from fish to fish. Although there are no quantitative definitions, the tendency of fish to gather around a fish reef is well-known and is called "reef affinity".

By means of the relative positions that fishes maintain within the reef, they are classified into 3 to 5 categories. But is should be noted that such relative positions, and therefore, fish classification based on them, change with different stage of growth.

Type I : The fish keeps a part or most of its body in close contact with the reef.

Type II The fish does not directly come in contact with the reef, but the school swims around a reef or positions itself in the sea bottom around reef. (example: Red sea-bream, parrot bass, flounder, sole, blanquillo)

Type III : The fish swims close to the sea surface or in the intermediary waters far and away from fish reefs. (example: Yellow tails, skipjack, mackerels).

Structure

The most important issue in artificial reef design is how to make the best use of the target fish's taxis. For fish that gather around a reef, spacing is an important concern because they select habitats according to their body size. For example, Type I fishes such as hata and rockfish, which show contact-taxis, will need space and clearance of all sizes.

As for the Type II fishs, their photo taxis behavior is stimulted line by vision and their audiotaxis is activated by the lateral line. For them, the best clearance size is between 1.5 to 2 meters, then the fish can continuosly keep objects in view. Fish eye are true spheres and can see quite a wide range, as far as 150 degrees around the eye, but due to very poor resolution, their depth of vision is only about 1 m.

Therefore, an ideal fish reef for Type I and II in other words, bottom fishes, must have space and clearance of various size, all preferably under 2 m. Many fish leave the reef at night when their vision deteriorates. Those remaining in the reef area position themselves by sensing the differences in water pressure caused by turbulence in the flow, which in turn, is cause by physical structures of the reef. The minimum requirements for driving fish way from turbulence caused by the members of the reef are shown in the following equation.

$$Bu > 100 \text{ (Unit : cm, sec)} \qquad (1)$$

where, B is the width of the member and u is the flow rate. If the flow rate is $u = 5$ cm/s, then the width of the member, B, must be 20 cm. When the flow rate increases, for example during the tidal flow, fish with small swimming capacity move to the downstream of the reef. If down stream flow velocity is shown by u', and the upstream velocity by u, then the following equation holds true:

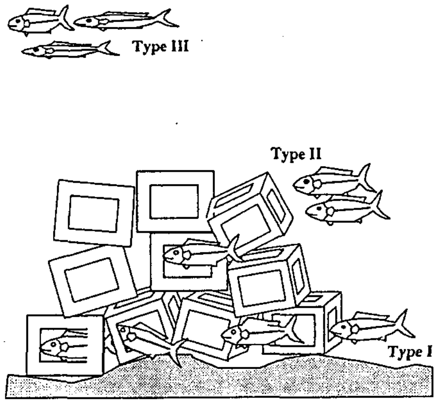


Fig. 5 Structure of fish reefs and fish types

$$u' = u\,(1 - C_D A/2S) \quad (2)$$

where, C_D is the drag coefficient of the fish reef and A is the actual projected area where fluid pressure is applied, S is the area of the upstream flow tube that corresponds to the flow line of the hind-steam formed by the entire reef. S is about the same as the nominal projected area of the entrie fish reef, and this area includes all the internal areas including space (see Fig. 6)

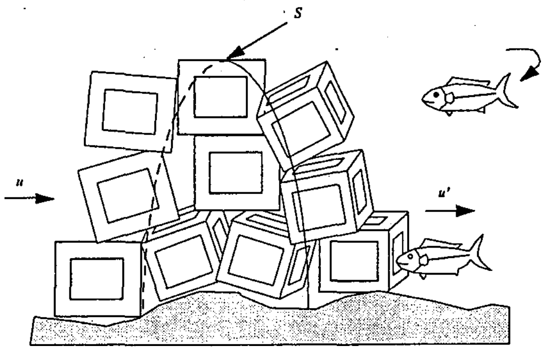


Fig. 6 Flow velocity behind a fish reefs

Exercise 1: As shown in Fig. 7, an artificial reef has been made by stacking 13 cubic reef units 1.5 m. in dimension. If the upstream flow rate is u = 1.0 m/s, what is the downstream flow rate, u'? The drag coefficient CP is 2.0 when the total fluid pressure is expressed by the projected area.

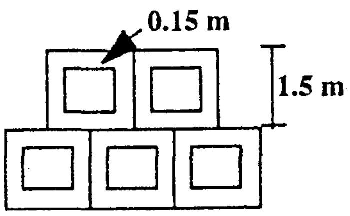


Fig. 7 Flow rates around cubic reef units

Answer : From equation (2)

$$u' = 1.0\left[1 - \frac{2 \times 5(1.5^2 - 1.2^2)}{2 \times 5 \times 1.5^2}\right] = 0.64 m/s$$

Active fish, e.g. those looking for food, usually locate themselves in the upstream tide around the reef. Therefore, artificial reefs must have a structure which ensures good tidal flos through them.

In summary, artificial fish reefs targeted at bottom fishes (Type I, II) must have various spaces no larger than 2m apart, having the width of the member obtained by equation (1), and intermediate sea areas. The reef must have sufficient height, and must be able to interrupt the water flow and create fluid noises. Interruption of flow and fluid noise can be calculated from equations (1) and (2).

In the case of pelagic fish (Type III), it is important to place artificial reefs in the surface and intermediate sea areas. The reef must have sufficient height, and must be able to interrupt the water flow and create fluid noises. Interruption of flow and fluid noise can be calculated from equations (1) and (2).

Fig. 8 shows the height of a turbulent flow in reference to the reef height/water depth ratio. The graph has been prepared by estimating the heights of turblent flows from the records of fish sounders. In this figure, we can see that turbulent flows develop rapidly to about 80% of the water depth if the height of the reef is about one tenth (10%) of the water depth. Turbulent flows do not develop as readily when the reef height exceeds 10% of the depth.

From Fig. 8, we can conclude that the optimal height of an artifical reef for Type III fishes is about one tenth of the depth of water. Sometimes the flow conditions at the bottom of the sea reach upper layers. One example is shown by the topographic wave. When density gradually increases from the surface to the bottom, and if there is only a mild flow, artificial reefs located at the sea bottom create topographic waves, a type of internal wave, as shown in Fig. 9. Topographic waves frequently develop when the reef height/water depth ratio is 1/10, and when the Froude number F = 0.09. The Froude number is defined by the following equation.

$$\left.\begin{array}{l} F_r = \dfrac{u}{\sqrt{\varepsilon g h'}} \\ \varepsilon = \dfrac{\rho_2 - \rho_1}{\rho^2} \end{array}\right\} \qquad (3)$$

where, u is the flow rate, g is the acceleration of gravity, h is the water depth and are the density of sea water depth, ρ is water density of sea water at the top and bottom.

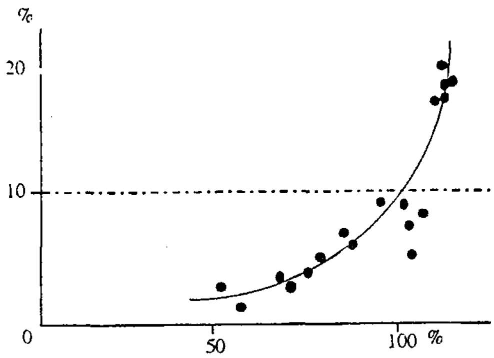


Fig. 8 Correlation bet when height of reef and height of turbulent flow.

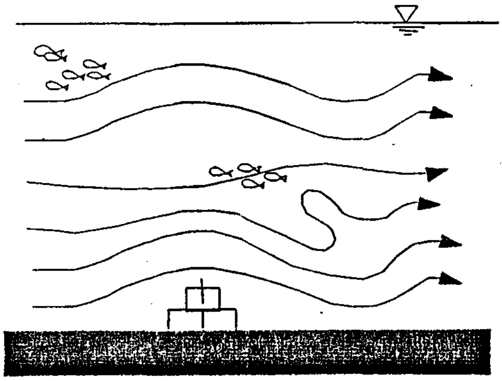
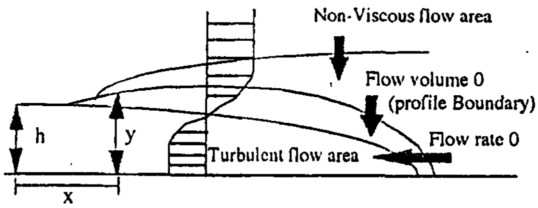


Fig. 9 Formation of topographic waves by an artificial reef.

At a maximum flow rate, Fr > 0.32 (=1/π), the topographic wave will be pushed back and the area behind the reef will have flows as shown in Fig. 10. This is proved by the movement of pelagic fish to deeper waters during bad weather.



The correspondence between topographic wave and type III fishes has been assumed by this writer and has not yet been proven. But obtaining data from research in the sea itself is quite difficult. By applying my assumptions, we can use the following criteria to determine reef location:

If Fr < 0.31, a submerged reef is better

If Fr > 0.31, a suspended reef is more desirable.

Construction

An artificial reef must be laid out as shown in Fig. 11. The terms used in artificial reef construction are defined as follows:

Fish reef unit : The single, smallest unit structure used for constructing an artificial fish reef.

Unit fish reef: The smallest fish reef created by placing one of more fish reef units together.

Fish reef group: An artificial reef created more than two interrelated fish reef units.

Fish reef zone: An expansive area containing more than two fish reef groups.

Unit fish reef

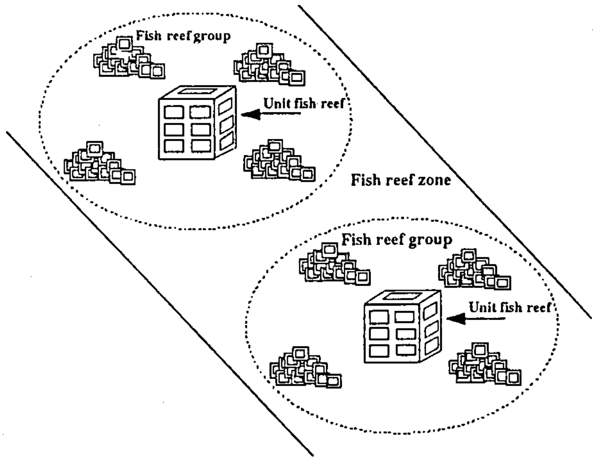
When we make an artificial fish reef, sometimes a single reef unit suffices to supplement the naturally existing ones. But on other occasions, several reef units are used. The purpose decides the functions of an articial reef.

A standard fishing ground size is approx. 400 m^3 and this criteria is used for determining the size of an artificial reef. But actually, the size varies with the construction accuracy at different depths, purpose of the reef, location, characteriestics of target fishes, sea area environments, the operating efficiency of fishermen and other factors.

For Type I fish, the nominal volume (m^3) is an important factor, while enveloped surface area and height are important, respectively, for Type II and Type III fishes. For reefs targeted at Type II and Type III, we can obtain a maximum enveloped surface area if the reefs are scattered. But if they are placed too far apart, fish gathering efficiency will drop because of decreased stimulus.

A distribution area within 20 times the projected area is considered desirable. Even in this case, however, it is not necessary to make the reef any higher than 5 m. When Type III fish are targeted, the reef height should be about one tenth of depth of water, but here again, the features of the particular sea area and the ease of construction method must be taken into consideration.

A fishing ground created by a unit fishing reef is about 200 meters wide from the edge of the reef, for Type I and II fishes and 300 meters in the case of Type III fish. Past research has shown that the distance between adjacent reefs, in which fishes can detect and migrate back and forth, is about 1 km.



Here is a partical example in determining the distribution of a fish reef, which ideally, should be within 20 times the projected area of the reef.

Exercise 1

Suppose a unit fish reef J is formed with cubic reef units with dimensions of **a**. The distribution radius *r* can be obtained from the following equation, when the unit reef surface area is *S*:

$$\left.\begin{aligned} s &= \frac{J}{a^3} \times a^2 \times 20 = \frac{2J}{a} \\ r &= \sqrt{\frac{20J}{\pi a}} \end{aligned}\right\} \quad (5)$$

For example is a cubic reef of $J = 400$ m^3. $a = 1.5$ m. is used then S=5333 m^2. and $r = 41$ m. This is the maximum size of an efficient reef, so a good fishing ground cannot be created by any distribution area greater than this. In other words, a good artificial reef can be obtainaed if $J = 400$ m^3, or by an accumulation of 119 cubic reefs in an area of 82 m. in diameter.

When you look at the size of unit fish reef from a construction viewpoint, the size of a unit reef *Ju*, and a arequired number of *Nu*, then the possible distribution range *Rc* can be obtained as follows:

$$\left.\begin{aligned} Ju &= \frac{\pi a r_c^2}{20} \geq 400m^3 \\ Nu &= \frac{\pi a r_c^2}{20a^2} \geq \frac{400m^3}{a^3} \end{aligned}\right\} \quad (6)$$

Exercise 2.

When you are given a cubic reef of a = 1.5 m., and asked to construct with an accuracy of rc = 50 m, then what is the required size of the unit fish reef?

$$Ju = \frac{\pi 1.5 \times 50^2}{20} \geq 600 m^3$$

$$Nu = \frac{3.14 \times 50^2}{20 \times 1.5^2} \geq 175$$

By using the above equations, you will need 175 cubic reefs. However, construction accuracy usually deteriorates with depth, therefore, the size of the unit reef usually become larger with increasing water depth.

Fish reef group

A fish group is an artificially created fishing ground made of several interrelated fish reef unit which have been laid out to attain maximum effect. When designing a fish reef group, it is important to note that the type of fish reef must match the fishing methods, angling, line haul, or sill net fishing. Using data such as estimates on increase in resources and volume of fish attracted to the reef, we aim at increasing daily catch per boat.

Artificial fish reef habitats are expected to increase the population of Type I fish, while an increase in Type II fish resources is also likely because reefs will contribute to the proliferation of plankton and benthos. We can achieve betters results by tying reef formation to artificial seedling release and construction of propagation grounds.

For Type III fishes, we can design various combination of unit fish reefs based on the estimated volume of fish attracted to them. In determining the distance between adjacent reefs, in achieving an effective fishing ground.

An effective distance is 400 m. for Type I and II, and 600 m. for Type III. These figure are obtained by doubling the figure 200 m. and 300 m., which are known to be effective congregation ranges for Type I, II and III, respectively.

Before constructing fish reef unit, the correlation between fish movements and water mass in a particular area must be studied to maximize the effect. In addition, adequate space must be secured for fishing operations.

Fishways are determined by releasing tagged fish or by tracing fish equipped with Bingers sounders, movement of water mass by checking water temperature and salinity, thermographics created by remote sensing, water color graphic analysis, and by behavioral analysis of internal waves as well as checking existing fishing rounds. Artificial reef must be placed in a way that they will intercept presumed fishways. Fig. 12 shows example of fish reef unit layouts.

Fish reef zone

In a fish reef zone, reef Unit and reef groups are placed one after another for maximum effect. The most important factors in fish reef zone installation are such that 1) they do not cause a drastic decrease in fish population density, 2) Create a series of fishing grounds which can be used one after another in conjunction with seasonal migration of various fish species.

In terms of fish population density, fishing grounds must have sufficient space between them so that a drop in the population at one fishing ground will not effect other areas. In other words, they must be spaced far enough apart to prevent migration of fish from one area to another. It is desirable for two adjacent fish reefs to be separated by more than twice the fish's perceptible distance.

The range of fish perception varies with the fish type and with currents. In an investigation conducted in Niigata Prefecture, Japan, the perception range of flounder was about 100 m. According to other research conducted in Shimane, it was 600 m. for red sea-breams.

The direction in which these fish reef zones are oriented is decided by considering such factors as the movement of water mass, estimated through physical and chemical investigations, and the assumed movement of the target fish based on biological research.

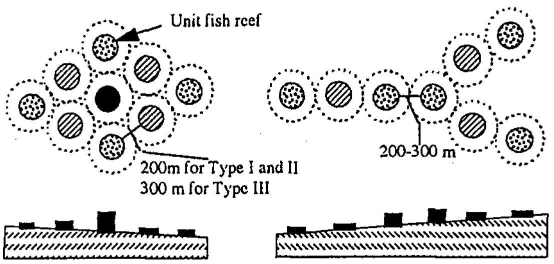


Fig. 12 Fish reef group creates by effective installation of unit fish reefs

Location of artificial fish reefs

When selecting a sea area suitable for farming artificial habitat, we must analyze the result of basic research and select areas assure can when fishing efficiency. It must be an area that enable fishermen to operate most effectively.

1) Target mrine life and location of fish reef

It is important to check the selected area for its suitability as a habitat for the target fish, and then, to check if it intercepts any fishway. An investigation of physical conditions such as water temperature, salinity and depth, is necessary to make sure that they are satisfactory for various stage areas which will benefit greatly from the installation of artificial reefs.

For Type I fish, since artificial reefs are most likely to enlarge their habitats, areas with good distribution and places which allow easy seedling release should be selected.

For Type II fish, area with good larvae distribution and those intercepting fishways of adult fish are more suitable.

For Type III fish, we must select sea areas which are part of fishways of adult fish.

In order to find the best location for installing artificial reef, we must know the distribution of the existing fishing grouds, conduct catch investigations as well as seedling release experiments. Needless to say, it is important to select an area which will easily allow future improvement or expansion.

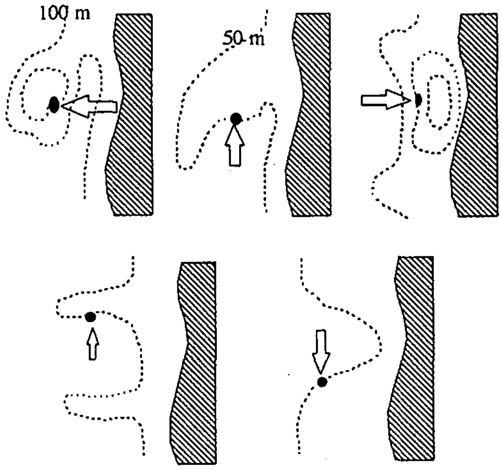


Fig. 13 Geographical features suited for reef installation

2) Physical and chemical conditions and location of fish reefs

Sea bottom features that are most suitable for artificial reef installation are those with good distribution and a wide variety of banks, seahills, basins, depressions, ridges, sea valleys and the like. In other words, they are areas which contain geographical features resembling islands, capes, bays and inlet on the water surface. Areas rich in geographical indentations support tremedous variety, for example, in terms of current flow rates, current direction, internal tides, internal waves, upwellings, etc. Artificial reefs must enhance these natural features and contribute to the propagation or congregation of fish.

When building artificial reefs along expansive sandy coasts, you must select a depth that would satisfy all biological conditions. Generally speaking, a good location is a semiflat area on the sloping side of a shelf. Whe building an artificial reef, it is desirable to select an area provided with many kinds of sea currents. For Type I fish, an area close to upwells with good supply of plankton and benthos is naturally suitable for purpose. For Type II fish, the movement of water masses must be considered, in addition to the volume of available feed, areas with little fluctuation in water temperature, salinity and tidal difference is considered better. For example, an area where internal tides and waves merge makes a a good fishing ground.

Since Type III fish are sensitive to water mass movement, and hardly leave a water mass unless to feed or reproduce, it is only natural that larger water masses are better suited for artificial reefs aimed at Type III fish.

Isothermal variation lines indicate how long a certain water mass will remain in a aparticular sea area. They can be obtained by continuously measuring water temperature, for example, for two weeks or a month, and ascertaining difference in temperature. If line are far apart, the water mass is supposed to be large with stable water temperature and quality. Therefore, it is ideal for building an artificial ree. On the other hand, closely packed lines are an indication of rapid and violent changes in water masses, so in such areas, we can expect that Type III fish will not stay for a a long time.

In terms of the quality of the sea bottom, the volume of organic feed, such as benthos and detritus, the currents and flow dynamics need to be considered. The feed condition is of particular important for Type I and Type II fish.

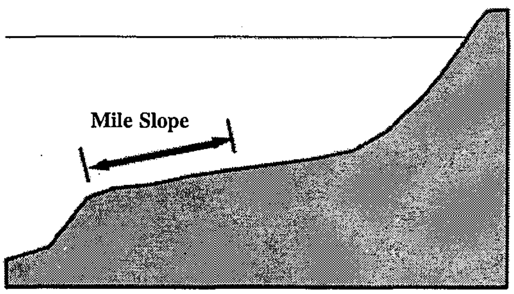


Fig. 14 Semi-flat sedimentation area suited for reef installation.

Estimate of effect on the catch

Potential increases in catch can be estimated by the amount of seedling released, farming conditions, actual catch and volume of uncaught fish, mortality and fish gathering effects of fish reefs. For particular purposes, fish catch effect is estimated by using the data of earlier, similar works, experimentally submerged reefs, of the catch volume in similar sea areas.

The reef's effect in attracting fish differs with the type of fish that are dealt with, e.g. Type I, II or III. Potential catch is estimate in the following manner, if the area developed by building artificial reefs is considerably larger than the measurable area (in which the catch is already known and can easily be measured.)

For Type I fish, an increase in the habitat leads to an increase in catch, so potential catch grows in proportion to the overall size of the the artificially created reef. The catch effect of Type III fish will increase in proportion to the area of the newly created reef, if the size of their schools passing that particular area is sufficiently large. In the case of Type II fish, the amount of plankton, benthos and other feed supply conditions are an important factor.

Fig. 15 show the time required for a fish reef to become operative. For Type I, the required time is equal to the time period needed for natural growth of larvae into adulthood, while Type III will show immediate results. Type II requires a time period womewhere between Type I and Type III.

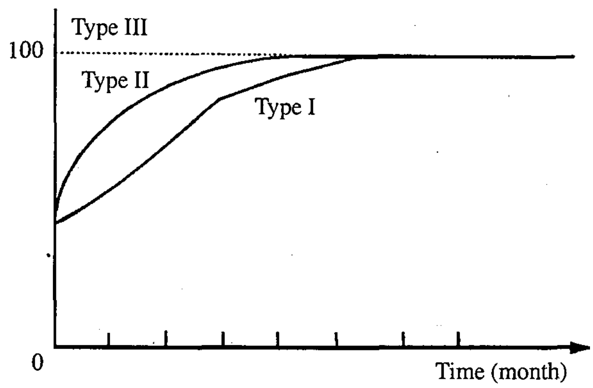


Fig. 15 Shows the time required for a fish reef to become operative.