FISH BEHAVIOUR APPROACH FOR IMPROVING TRAWL GEAR SELECTIVITY

by

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Abstract

Gear selectivity has been a gold-medal goal for research and development in Fishing Technology, for the purpose to increase the target catch and to decrease the bycatch. In case of trawl fisheries, the gear designing by mesh size or shape modifications were only the tools for improving the species/size selectivity. Another approach for the aimed trawl is also practical through the strategy in locating the best fishing ground by use of catch data bases and acoustic devices. The better understanding on fish behaviour can be useful not only for both of the conventional strategies, but also for developing the bycatch reduction devices(BRDs) as the modification of the present gear designs. The aim of gear selectivity in shrimp trawls is classified into 4 categories as Monster excluder, Trash Excluder, Shrimp/Fish Separator, and Species/Size Selection. Another approach to classify the selectivity function is according to the positions for exclusion/selection, as between warps, sweep lines or wings, around net mouth, and in front or rear part of codend. Up to now, varieties of BRDs are in practical use with ideas on size filtration and utilization of behaviour differences in species and sizes. For the size filtration purpose, the mesh size against the body circumference or the grid spacing against the body width inside the codend can be defined as the passive BRDs which may cause the stress and injury for escapees through the gear contact. The active BRDs ahead of the trawl mouth may be the best tool as the conservation strategy without the gear contact damage, by means of understanding for avoidance ability in gear recognition and swimming performance of target and bycatch species..

1. INTRODUCTION

The historical developments of the fish capture technology has been strongly related to the knowledge level on fish behaviour. In this point of view, it can be emphasized that the success of fishing technology relied upon the level how much knowledge of fish behaviour has been utilized for fishing gear designings and operations, as shown in Fig.1[1]). At the same stand point, the awareness on the environmental impact due to the fishing activities requires the new concept on the conservation harvesting technology, which can be also achieved through the fully understandings of fish response toward the gear during the capture process.[2]) Here, the behaviour approach for improving the trawl gear selectivity will be introduced with the special references to the use of artificial stimuli for fish harvesting and controlling purposes.

Three major fields of fishing technology research can be categorized as follows;

a) Fishing gear designing with underwater gear geometry and behaviour

b) Fish behaviour toward the gear, and its control for capture purpose

c) Fish detection by locating the fishing ground, and finding for capture purpose

All three are closely interrelated each other for the better fishing strategy both for increasing the catch and for improving the selectivity, hence the research activity in each field is also related each other. Among them, the understanding of fish behaviour can help the improvement of the catch efficiency as the traditional priority, then of the conservation aspects such as the selectivity or sustainability in the large ocean ecosystem.

2. STIMULI-RESPONSE SYSTEM AND SENSORY MODALITIES 3)

Fig.2 shows the stimuli-response system with some analogies on Input-Output mechanism. A certain stimulus can release a certain response. This can be done though the chain of three components; receptor, adjuster(or conductor) and effector. The sense organs given in Table 1 can act as the specific receiver for the certain stimuli of which intensity exceeds the threshold level to release the specific response as shown in Fig.3.

One of the major tasks of fish behaviour research is to identify the adequate stimulator to release the proper response of fish for capture purpose. The first step will be the study in Sensory Physiology for Input information. Another step will be the study of Muscle Physiology to determine the Output of locomotive performance. Between the Receptor and Effector, there is a nervous system which adjust or conduct as the Central Processing Unit. This 3-omponents system can be analogize as a Black-Box which is operated by input switch as TV monitor. The physiological approach may reduce the unknown factors of output performance of the black-box, while the complete explanation of the brain or the central nervous system will be remained toward the next century.

Table 1. **Sensory modalities of fish**
P.C.Withers(1992):Comparative Animal Physiology, Chpt.7
T.J.Pitcher (1993) :Behaviour of Teleost Fishes, Chpt. 3

Modality	Stimuli	Sense Organs
Chemo-reception	Chemicals Smell(Olfaction)	Nose:Olfactory rosette & Lamella
	Taste(Gestation)	Mouth, Barbs, Lips, Fins : Taste Bud
Temperature	Heat & Cold	Body surface : Temperature point
Mechano-reception	Vibration Water turbulence	Lateral line:Canal organ:Cupula & Hair cells
	Sound Hearing(Audition)	Ear, Inner ear
	Pressure Touch (Tactile)	Skin, tongue
	Rotation and Balance	Inner ear : Labyrinth and Otolith &Hair cells
Photo-reception	Light See(Vision) Polarized light	Eye: Retina : Visual Cell , Pineal body
Electro-reception		
Magneto-reception		
Nociception(pain)		Body surface : Pain point

3. BEHAVIOUR MODIFIERS BY USE OF THE ARTIFICIAL STIMULI

The present range of fishing gears and methods used for harvesting fish can be classified into four categories depending on the techniques for controlling target fish behaviour to assist the capture process. Stimuli resulting in the opposite reactions of Attractions and Repulsion elicit the directional locomotive responses, while Barriers and Trapping are used to prevent escape by restricting locomotion and/or confining them into a limited space, as shown in Fig.4.

The greatest significance of this idea with 4 controlling elements, any of the fishing gears and methods can be interpreted of the capture process as organized with the integration of some or all of the elements. The capture process of trawl gear 4) can be a good example for understanding the controlling elements as illustrated in Fig.5. In the beginning of capture process, the trawl gear has the herding effect for concentrating the fish toward the trawl mouth by means of the Repulsion of the towed otterboard and the sweep line with its created sand cloud. The fish can realize the approach of the visual and acoustic stimuli, and in the very close position the water turbulence by the lateral line sense. It is note worthy that the sand cloud can play a role of sensory Barrier for the purpose to herd fish toward the trawl mouth even with its harmless existence. The wing net also act as the sensory Barrier for confining them inside the wings, then herd and guide them toward the trawl mouth, even with the large mesh at the wing net which fish can swim through. After being inside of the body net, the fish are surrounded by the moving net panel of square, belly and bating, and side walls all of which have large meshes but can have a confining effects as the sensory barrier. Then, the fish are entrapped in the codend of smaller meshes which can assure the mechanical confining effect as the stage of Trapping. In case of the trawl gear, Attraction element is not involved in the capture function. The light fishing, or the baited hook angling can be a good example of Attraction to increase the density of fish for the capture purpose.

In Fig.4, the same artificial stimuli , for example, the light stimuli can have the different effects of Attraction and Repulsion. It depends on the stimuli pattern of the quality and quantity, or in other words the intensity level of certain colour or on-off interval and frequencies. Fig.3 is the simple schematic model on the response level according to the stimuli intensity. 5) No response can be expected under the threshold level of stimuli intensity. The threshold is defined as the minimum level to evoke the approach response in this case. By increasing the stimuli intensity, the response level is proportionally increasing until the maximum response level in which the upper limit of stimuli intensity. In the stronger intensity beyond the upper limit, the response is reached to be constant on the maximum value of saturation level. The further increase of stimuli intensity gives the drastic change of response of animals to avoid the stimuli in which another threshold level can be defined. The relationship between the stimuli intensity (I) and the response level(R) can be expressed as $\log R = K + \log I$, according to the deduction from the Weber's law of $dI/I = K$, Fechner-Weber's law of $dS = K\ dI/I$, and Steven's Law of $S = K\ I\ n$, with the function of sensitivity(S) of each sense organ.

The Attraction Effect can be expected through the artificial stimuli such as the light, bait, artificial reef or floated FADs and so on. If the stimulation was properly done in the best condition of intensity against the ambient environment, the directional movement as the convergent activity toward the stimuli source will be released. In case of the Repulsion Effect, the artificial stimuli of electricity, air bubbles, sound and strobe light can do the opposite directional movement as the divergent activity. Both of the Attraction and Repulsion can be the effective tools for capture purpose to increase the density around the gear, or to force them from one site of difficult operation ground to the best site suitable for easier capture condition. In these cases, the stimuli are defined as the temporally and spatial disturbance in the natural environment which can create the unstable condition of fish forcing them the secondary response for approach or avoidance.

The directional movement of fish due to the Attraction or Repulsion stimuli can be intercepted by the Barrier, as the blockage horizontally or vertically. The stationary barrier such as the fence net or leader net in the set-net can intercept the migration of fish, and guide them towards the main net entrance. The wall net confining fish in the final trap are also defined as the stationary barrier. The mobile barrier can prevent the directional movement of fish as similar as the stationary barrier, which can herd the fish for concentrating them in higher density or to the intended place of final traps.

All the net gear possess the Barrier effects with the arrangement of netting panels from 2-dimensions as the gill-net or trammel net, to the 3-dimensions as the purse seine, trawl or setnet of very compound constructions. The mesh size of each part of netting is the important for the selectivity concept, while even the larger mesh netting can prevent the escape as a good barrier for confining effect. It is called the sensory barriers of netting, so that the initial stage of capture process in all the net gears utilize this kind of barrier system.

The sensory barrier is the great R&D goal both in the limited space of the tank or pond, and in the natural environment of the bays to the open sea. Several ideas for barrier (or so called Curtain and Screen) have been suggested with some experimental successes such as the light curtain, air bubble curtain, sound curtain, laser beam projection or strobe light, and in the greater environmental disturbance of the inner wave motion or the temperature-controlled water mass. The stimuli source arrangement will be the important factor for successful results of sensory barriers. For the purpose of Attraction or Repulsion, the single stimuli source is enough to be given. In case of the Barrier stimulation such as the guiding, confining and herding effect, the stimuli source should be the line or area patterns including the arrangement of single source.

The Trapping effect is the final stage of capture process. In the wider definition, it includes all the actions such as the Hooking & Spearing, Gilling & Entangling, Scooping & Pumping, and all the Stupefying and Immobilizing techniques to assisting the separation of fish out of the water. In the narrower definition, the trapping can be the confining effect in the limited space with non-return devices of funnels or chutes, by either of the guiding or the herding effects.

4. WHAT IS THE ENVIRONMENTALLY FRIENDLY FISHING TECHNOLOGY?

Fig.6 can give the idea what is the goal of selective fishing, modified from the LOOT strategy in Viking Handbook 6). Here, the definition of the good catch and poor catch seems simple without serious arguments. In the practical aspects of fishing activities, however, the bycatch /discards create the serious problems due to the confusion for bycatch definition. In some fisheries especially for the tropical waters, all the catch can be fully utilized without wasting where no discards problems occur. There must not be any problems when these are the traditional and small-scale fisheries. Even in this kind of fisheries, so many tragedies have been reported toward the endangered stock conditions, mainly due to the rapid modernization of fishing technology and the increased fishing intensity without the scientific stock management issues.

Fig.7 shows the fishing impact terminology suggesting the X-axis for conservation level and the Y-axis for food utilization level. The term of Catch itself should never be accompanied with any senses of good or bad, while it is now questioned whether to be the fish saving technology or the killing technology. The worst condition of fishing activity is so called Slaughter for wasting by killing the fish toward the extinction. In case of the higher level for food utilization without the conservation awareness, the Over-fishing problems occur to be criticized for stock endanger or species extinction. Our final goal of the Controlled Harvesting should be located in the section of higher conservation awareness with full food utilization without the wasting. This conservation idea should be emphasized not for one species stock but for the large marine ecosystem. In this point of view, the utilization of young and juveniles can not be allowed because they can never be fully utilized than the adult after a few years. The wasting for the conservation purpose is defined as the Pest Control not for the human welfare but for the ecological purposes. The practical conservation tools can be started with the selection of target and bycatch species/sizes, by separating, sorting, filtering and so on.

Fig.8 gives the idea what is the environmentally friendly fishing technology for trawl gear with 3 categories. The final tools are the human selection as the onboard sorting or market sorting. There are the questions in this stage that the un-target species can be released in safe or just discarded for wasting. The trendy tool at present is the installment of various kinds of bycatch reduction devices. In this strategy, the location of the separation in the gear may give the different effects of survival of escapee. The most friendly tool should be the exclusion of un-target species ahead of the trawl mouth by use of the active stimulator devices. 7) This strategy may give the opportunity of non-contact exclusion. These varieties of BRDs strategies are illustrated in Fig.9 by locating the selection part in the trawl gear with some ideas on the active/passive reduction or behavioural/mechanical filtration. 8,9)

5. EXCLUSION PROCESS OF UN-TARGET SPECIES/SIZE AHEAD OF THE TRAWL MOUTH

Fig.10 shows the target /bycatch categories for shrimp trawls, with the idea on mechanical separation by filtering sizes with mesh sizes or grid intervals, and behavioural separations by differences in avoidance performance which may be proportional to size. Monsters such as sharks, turtles and sea mammals are in general large and possess higher ability to avoid the gear by gear recognition and swimming performance. Fish species and sizes are varied from centimeters to meters, while the shrimp and prawn are in general smaller with lower ability of avoidance performance. The trashes such as rocks and marine debris vary in sizes , however, never possess any avoidance performances.

At first, the use of active artificial stimuli ahead of the trawl mouth is discussed for bycatch exclusion. The fish located in the center of trawl pass is considered to start the avoidance reaction by noticing the gear approach, or the artificial stimuli such as the light or sound emission devices. The minimum required distance ($\mathbf{D_{min}}$) for fish to swim away from the trawl mouth can be expressed as $\mathbf{D_{min} = V \cdot W / 2U}$, where V is the towing speed, W the width of trawl mouth, and U is the escape speed by burst swimming, which is defined as 10 times of body length per second. In case of the vertical avoidance to swim over the headrope, the minimum required distance $\mathbf{D_{min} = V \cdot H / U}$, where H is the headrope height. The results are shown in Fig.11, according to the fish body length. The minimum required distance can be the function of the towing speed and the mouth width/height, where larger mouth for higher speed can give the less chance to escape for the smaller fish.

The next case is the sweep line exclusion of small size individuals by use of the difference in swimming ability by sizes. 10) There are several models to simulate the herding effect 11,12) or gear efficiencies 13,14) in trawl capture process. Here, the fish ahead of the sweep line passage may recognize it approach and start the avoidance swimming at a certain reaction distance (C), and then may swim at the right angle against the sweep line. The distance from the sweep line to the fish (P) can be expressed as $\mathbf{P = t (U - V \sin \theta) + C}$, where **t** is the time after the first contact, **U** is the swimming speed, **V** is the towing speed, and θ is the sweep angle. When the distance from the sweep line **P = 0**, **t** is defined as the time until being overtaken by the sweep line after the first contact . A shorter reaction distance due to the lower visual and acoustic recognition may lose the chance for smaller fish to swim longer until being overtaken. Fig.12 shows an example of simulation for the 30 degree sweep angle with the towing speed of 1m/s and 2m/s, according to the swimming speed with different reaction distances.

For Red Sea Bream Pagrus major, the maximum sustaining speed is approximately 30cm/s(3.8 BL/s) for juveniles (8cm in BL), and 60cm/s(2.8 BL/s) for adult (18-24cm in BL). In case of the towing speed of 60cm/s(approximately 1 knot), adult fish can sustain the speed ahead of the sweep line and be concentrated toward the trawl mouth. The juveniles can be overtaken in a short time at the swimming speed of 30cm/s, even with the longer reaction distance, and excluded from the trawl pass. When the juveniles try to swim at 60cm/s, they will be exhausted in a few minutes due to the shorter endurance time at this speed.

6. CONCLUSIVE REMARKS

For the purpose to improve these types of exclusion process by utilizing the behavioural differences due to the species and sizes 10), the physiological approach on the sensory modalities for Input and the swimming performance for Output mechanism can be greatly helpful to accelerate the further research and development. Concerning the fish response to BRDs inside the codend, there are several questions still left. The swimming performance of target / bycatch species are yet unknown due to the vague information on the flow pattern in the net. The escape through the meshes or grid intervals is not yet clarified whether it is active or passive. Numerous numbers of previous works may give the idea to solve these questions, however, the complete answer may not be the same according to the species and sizes in each regional fishing ground, and for each type of fishing gear. An encouraging stimulation to the researchers will be required by informing some success stories toward the final goal of conservation harvesting technology.

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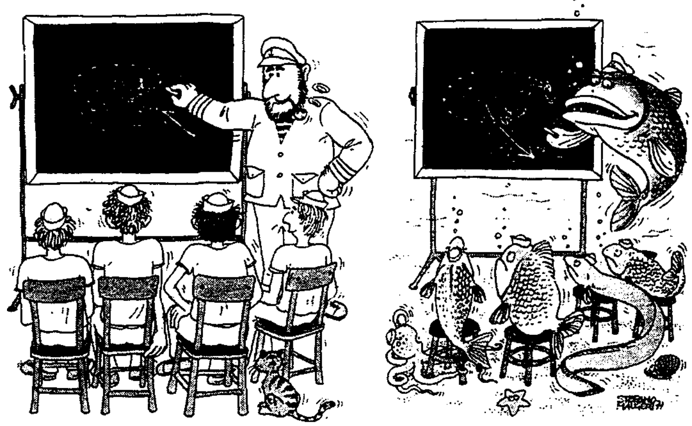
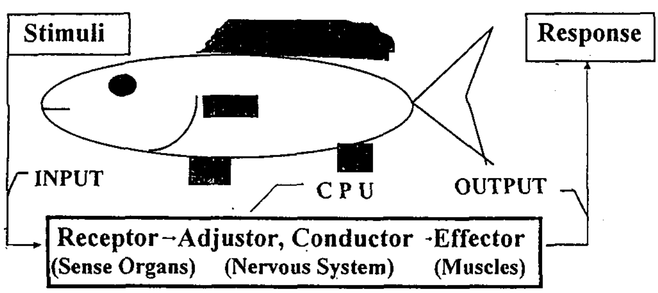


Who will 'outsmart' whom?

Fig. 1 Fish behaviour approach for fishing technology[1)]

Importance of Stimuli-Response System



Sensory Modalities of Animals

Chemo-reception
Chemicals, Humidity
Temperature
Non-Infra-Red, Infra-Red Radiation
Mechano-reception
Bending Amplitude, Sound Amplitude, Sound Pressure
Electro-reception
Photo-reception
Nociception(Pain)

Fig. 2 Input and Output for Stimuli - Response system

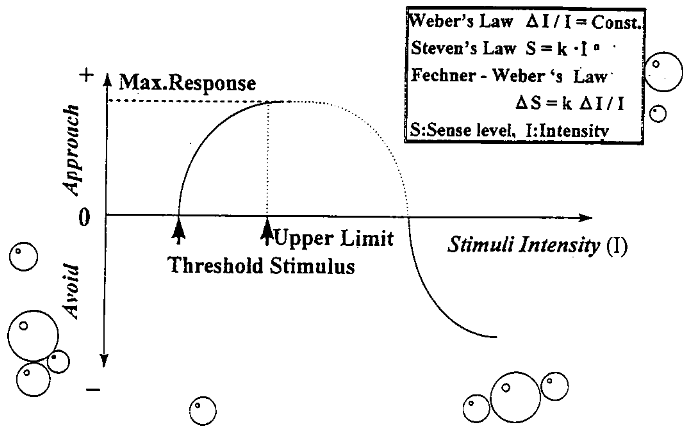


Fig. 3 Response level according to the stimuli intensity

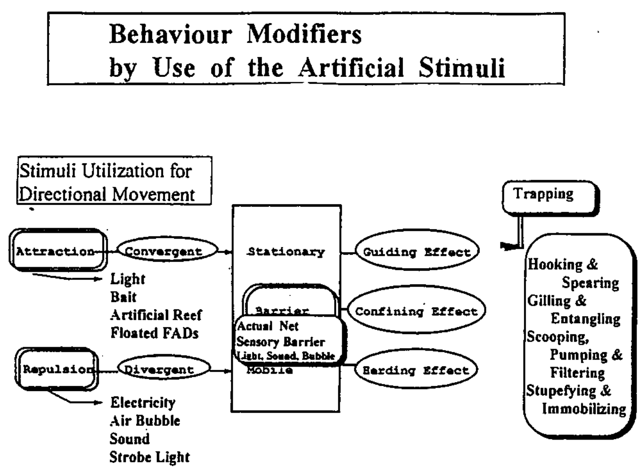


Fig. 4 Behaviour modifiers by use of the Artificial Stimuli

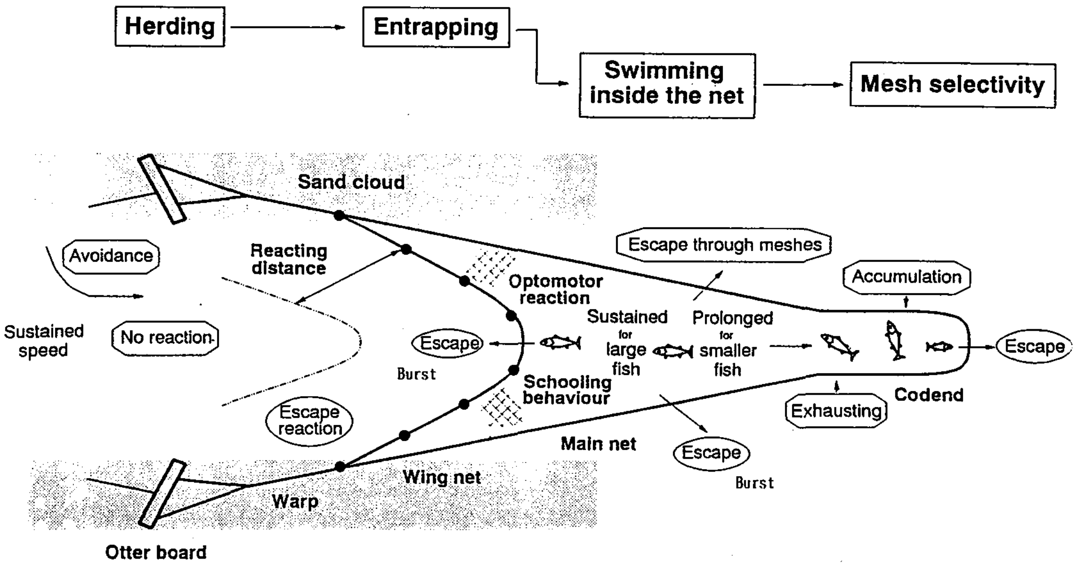


Fig. 5 Capture process of trawl gear (modified from Wardle[4])

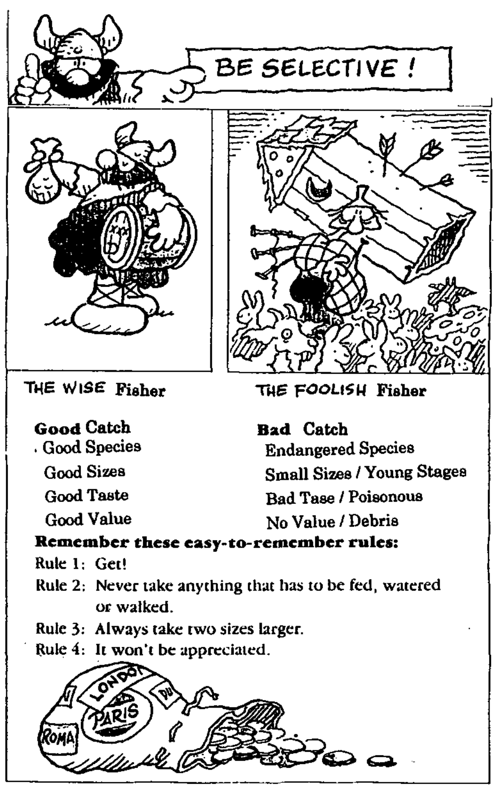


Fig. 6 Goal of selectivity in fishing (modified from Viking Handbook[6])

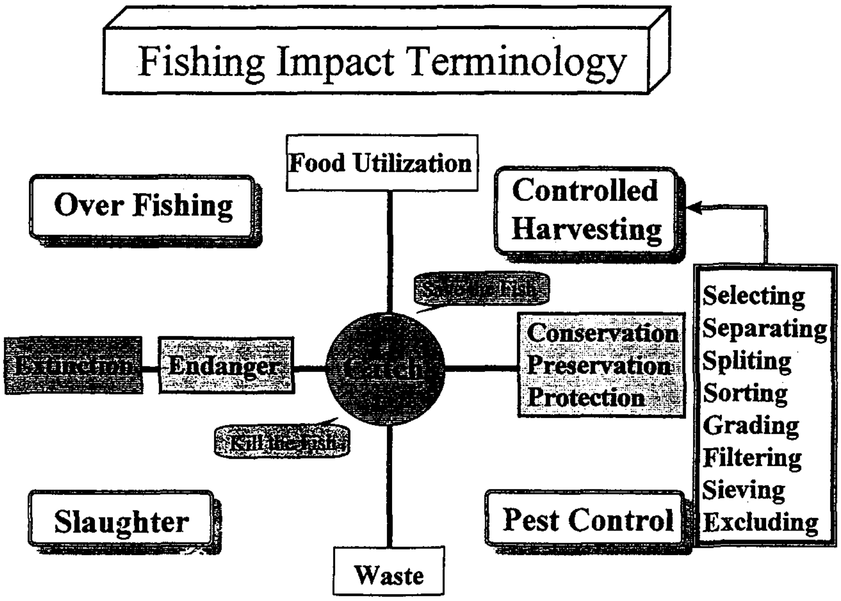


Fig. 7 Fishing Impact Terminology

What is the Environmentally Friendly Fishing Technology?

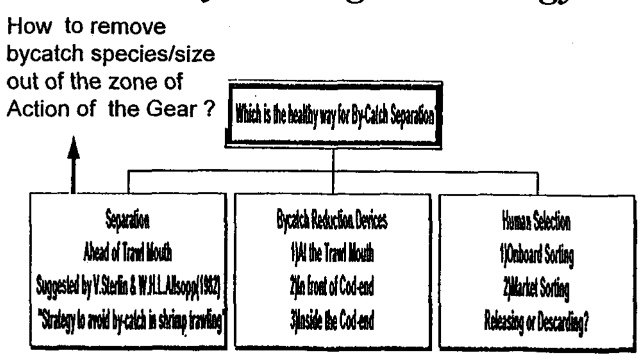


Fig. 8 Three stage of bycatch separation

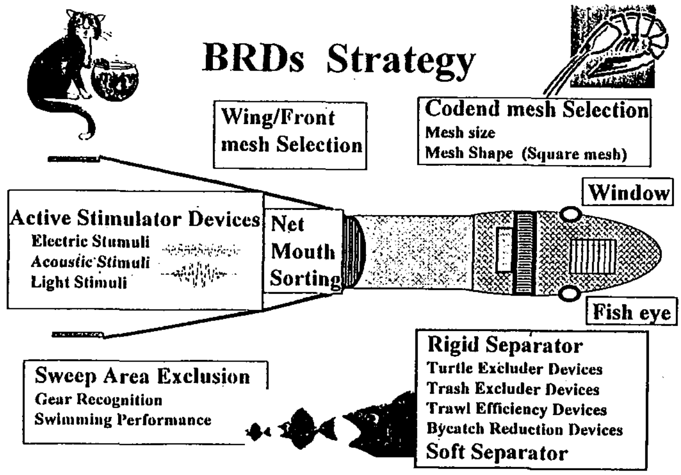


Fig. 9 Strategy for Trawl Bycatch Reduction Devices (modified from Drummond [9])

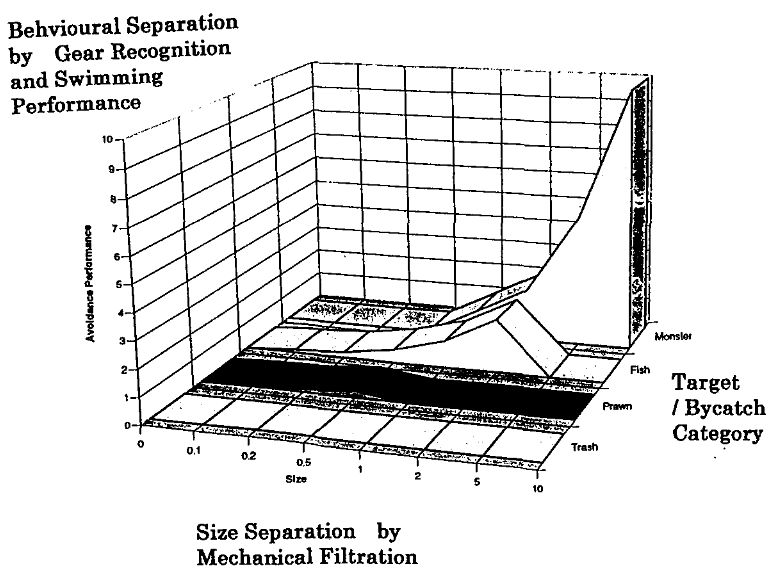


Fig. 10 Target/bycatch category

Sorting by Artificial Stimuli ahead of the Trawl Mouth

Minimum Required Distance

$= V \cdot T$

$= V \cdot W/2 \cdot /U$

$= VW / 2U$ (HorizontalAvoidance by swimming halfwidth from the center)

or $= VH / U$ (Vertical Avoidance to clear the headrope from the seabed)

Where V : Towing Speed

T : Given Time for fish to swim away

W: Trawl Mouth Width

H : Trawl Mouth Height

U : Escape Speed(Burst Speed as 10BL)

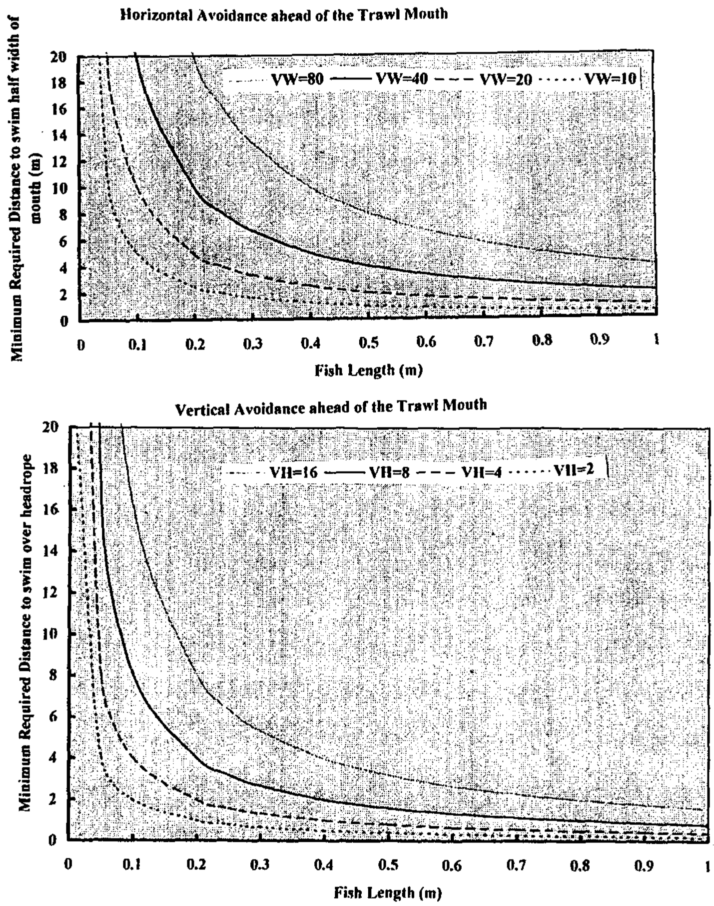


Fig. 11 Exclusion by active artificial stimuli

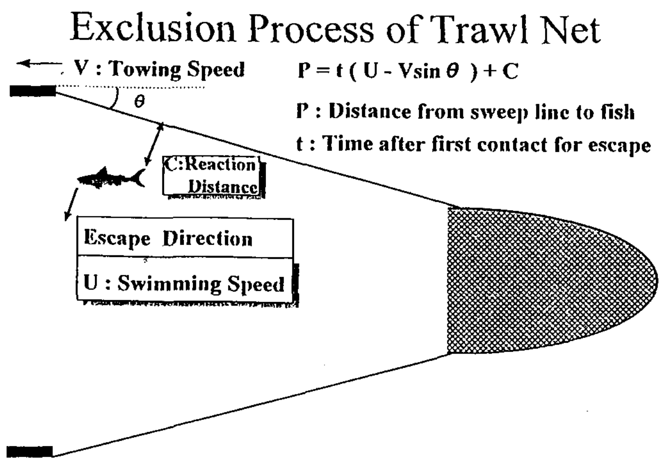


Fig. 12 Exclusion process model by sweep line (modified from Isaksen [10])

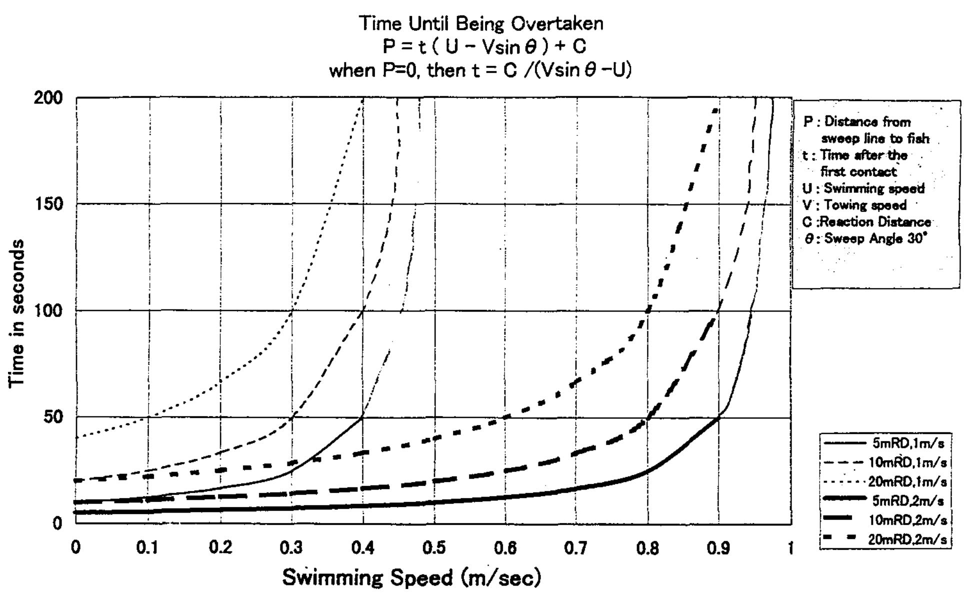


Fig. 13 Time until being overtaken by sweep line