Principles of Fishing Gear Design and Importance of Fish Behaviour Studies for Gear Improvement

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The choice of fishing gear and its design is determined by the biological, behavioural, and distribution features of the target species. There is no such thing as universal fishing that is suited for all fishing situations and resources. Fishing gear must be chosen or developed with the greatest number of features appropriate for the specific fishing condition and resource in mind, and trade-offs may be required.

The scale of operations, the size and engine power of the fishing vessel, energy conservation objectives, selectivity, and resource conservation objectives, catch volume requirements, operational and handling requirements of the gear, prevailing weather conditions, skill required for fabrication, maintenance and operation, material availability, local traditions, and economic considerations will all influence the choice of fishing gear and its design features.

The primary mechanisms used in fish capture are (i) filtering, such as in trawls, seines, and traps; (ii) tangling, used in gill nets, entangling nets, and trammel nets; (iii) hooking, in hand line, long line, and jigging; (iv) trapping, used in pots and pound nets; and (v) pumping, such as fish pumps. The main behaviour controls utilised in the fish capture process are (i) attraction, by using bait, light, and shelter, and (ii) repulsion or avoidance reaction, used for herding or guiding by netting panels in set nets and trawls or sweeps.

Though the primary mechanism is non-specific, the design considerations for the gear, would require information that is specific to the targeted species and the mechanical properties of the structure/material that is used for capture. Body size and shape dictates the mesh size necessary to enmesh and hold the fish in gill nets, as well as the mesh size required to keep the desired size groups of the species in trawls, seines, and traps without gilling. This is also linked to the tensile strength requirements for netting twine in gill nets, as well as hook size and lines in hook and line. Again, body size is directly linked to swimming speed. Swimming speed is directly related to body size, which is an important factor to consider while fishing with towed gear.

To direct finfish into trawl codend, big mesh trawls and rope trawls utilize the principle of herding, in which front trawl sections are replaced by very large meshes or ropes to decrease drag. The otter boards, wires, and sweeps, as well as the sand-mud cloud formed by the boards on finfishes in between the boards, are used to boost the capture rate by extending the effective sweep area.

The vertical aperture of the trawl mouth, the vertical dimension of gill nets, and the catenary of the main line of the long line with branch lines and hooks all align with the vertical range of the layer of highest fish abundance, maximising catching efficiency. As a result, information regarding the vertical distribution of the species is essential to improve the horizontal and vertical dimensions of gill net netting panels, long line catenary, and trawl mouth arrangement.

Large-scale changes have occurred in the design, fabrication, operation, and catching capacity of modern fishing gears such as trawls, purse seines, and long lines due to the development and wider availability of synthetic gear materials, recent advances in vessel technology, navigational electronics, gear handling machinery, fish detection methods, and fish behaviour studies. Traditional fishing gear such as entangling nets, hooks and lines, and traps have all benefited from design improvements and increased efficiency in recent years.

Fishing gears evolved by trial and error, and until recently, only empirical methodologies rather than analytical procedures were employed to estimate design parameters. However, in recent decades, there have been design and development initiatives based on fish behaviour, engineering studies, system analysis, and model studies that incorporate resource conservation, ecological, and economic challenges. The general principles involved in development of a gear design is as below (Fig. 1):

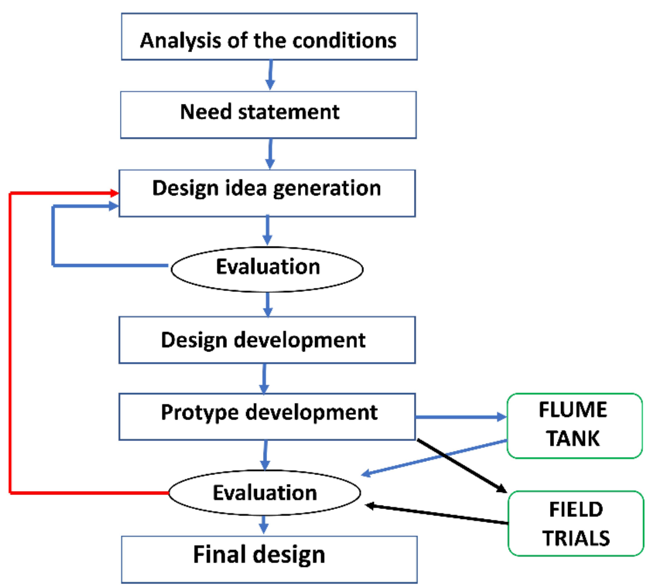

Fig. 1. Key factors involved in the designing process of a gear

A paradigm change in fishing philosophy has occurred, owing to the alarming pace of decrease of key fish species and, secondarily, greater knowledge of fishing's habitat and ecosystem implications. As a result of the changes in the fishing industry over the last decade, the focus of fishing technology research is now on conservation and development of fishing gears and methods that have the least negative impact on fish stocks, habitats, and the environment.

Selective fishing with fishing gear that has the least impact on non-target organisms and other biota would be required for sustainable capture fisheries. This will need a thorough understanding of the behaviour of both targeted and non-targeted species. As a result, understanding fish behaviour in relation to fishing gear is a prerequisite for designing, building, and operating environmentally responsible fishing gear. There are only a few studies with clear results on the behaviour reaction to fishing stimuli, and the problem of multi-species fishing further confounds the issue of selective capture in fishing gears. Experiments to understand fish behaviour near fishing gear are limited, owing to the inherent difficulty in capturing and researching behaviour in actual field settings, as well as the high expense of studying fish behaviour near fishing gear, especially for active gears like trawls. There is a considerable amount of work on the development of selective gears, much of which is based on trial-and-error approaches such as experimental fishing and examining species assemblage structure. Gears and other technical devices, on the other hand, are rarely developed with the behavioural ecology of the species or targeted group in mind, and hence are frequently non-selective. The knowledge of the behavioural responses of targeted species to stimuli associated during fishing and its field level application is a relatively new field in the Indian scenario.

The importance of fish behaviour in understanding and improving size and species selectivity for sustainable harvest of resource has encouraged applied fish behaviour studies in the context of fish capture. Fishing is a complex process, involving a large number of external and internal factors, however some of the parameters that are critical in the capture process include:

Vision

Understanding visual characteristics of fish is an important component in understanding the fish capture process and interactions between fish and fishing gear. While the structure of the eye is well known and mechanisms of vision have been described for several fish, many commercially important marine species have received little attention. Despite many years of research into the visual systems of fish, detailed knowledge and understanding of the role of fish vision in their reaction to fishing gears during capture processes needs further research.

Most fish species can distinguish colour by the use of red, green, and blue sensitive cones. At least two types of cones are required for colour discrimination, while some freshwater and shallow – living marine species have the capability to detect ultraviolet radiation with a fourth type of cone. Electroretinogram (ERG) is used to monitor the response of retina to stimulation by different wavelengths of light (i.e., color) and to determine spectral sensitivity of fisheyes.

Photosensitivity is the ability of fisheye to receive light and to get visual information in ambient light conditions. Light intensity varies with water depth, time of day, and transparency or turbidity of water. To allows fish to function visually over a wide range of light intensities in the natural environment, functional changes are made by shifting of positions of rods and cone cells in the retina. Different fishing gears provide a different contrast image according to ambient light conditions, gear type, and the visual sensitivity of the fish. The contrast of an object against the water background is more important than the brightness of the object (Wardle, 1993).

A moving image is more important to fish than a static one and detection of movement is dependent on visual acuity and persistence of time – which is the time taken to process the image by the organism. The flicker fusion frequency (FFF), which is the frequency at which flickering images fuse to produce a continuous image, is dependent on light intensity, temperature, and duration of the flash. Fish can detect motion at a wide range of light intensities from 10-7 to 10-14 lux (Protasov, 1970) and as light intensity increases, the sensitivity to detection of an image is enhanced and decreases with decreasing light.

Behavioural techniques to investigate FFF and visual acuity is by optomotor response, which is the movement of the eyes, head, curvature of the body or trunk, or movement of the entire animal in response to follow a moving image (Sbikin, 1981). Comparative studies have shown that Elasmobranchs and species living in low light conditions have lower FFF, when compared to fishes that live near the surface.

The detection of movement has important implications in how fish reacts to fishing gears, particularly in active systems like trawl gear, where the fish holds station with the gear components like floats, ropes and meshes until it becomes exhausted, by means of herding and optomotor responses.

The visual contrast of the fishing gear against the background is more important that the brightness of the gear underwater. It is understood that there is a complex relationship between colour and contrast of gear components, ambient light intensity and quality of water. In general, it is interpreted that light coloured netting panels are more difficult to detect against a bright background because of low contrast and reverse for materials that strongly contrast with their surroundings, when viewed (Fig. 2).

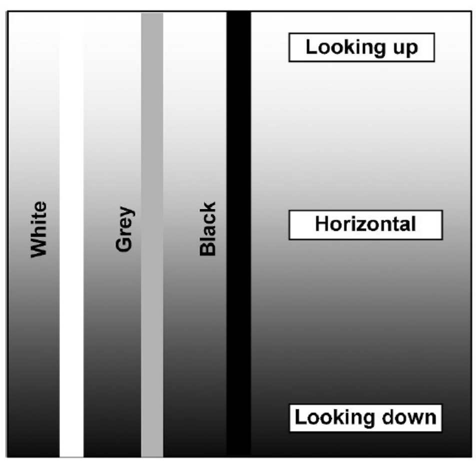

Fig 2. Contrast of white, grey and black twines hung vertically in water in relation to viewing angle (Source: He, 2010)

Swimming speed

Swimming speed is an essential parameter that impacts the species' catchability. Fish have a wide variety of body forms, and swimming is a predictive factor of the organism's body shape. Swimming is an energy-dependent activity; hence it has favourable associations with persistent swimming, which is critical in active swimming gear such as trawls. Quantification of the swimming speed of targeted fishes is a very important metric that can help in designing the gear and has significant impact on the fuel consumption in an active fishing gear. Swimming involves large expenditure of energy and hence will also affect the quality of harvested fish.

There are two types of swimming noticed in fish: sustained swimming speed and burst swimming. Sustained swimming speed involves regular swimming speeds at constant speeds, whereas burst swimming involves sudden spurts, which often involves very high demand on energy. The energetic cost of swimming is the sum of the resting or standard metabolic rate and the energy required to produce thrust. Expressed in watts (joules per second), it increases as a J-shaped curve with speed in m/s (Fig.3) The exact shape of the curve depends mainly on the species, size, temperature, and condition of the fish. Because of the curve's form, there is only one ideal speed at which the metabolic rate to speed ratio is at its lowest. This ratio reflects the amount of effort required for a fish to cover one metre. To make comparisons, the optimum speed (Uopt), where the amount of energy used per unit distance covered in the minimum, is used as the benchmark. Fish use an average of 0.07J/N to swim their body length at Uopt. Temperature has a significant impact on swimming capacity, both in terms of speed and endurance, with maximal swimming speed doubling for every 10^0 increases in temperature. It is usually difficult to derive this metric in field conditions and research is often conducted in circular tanks (Fig. 4) The Uopt speeds of some commercially important species are shown in Table 1.

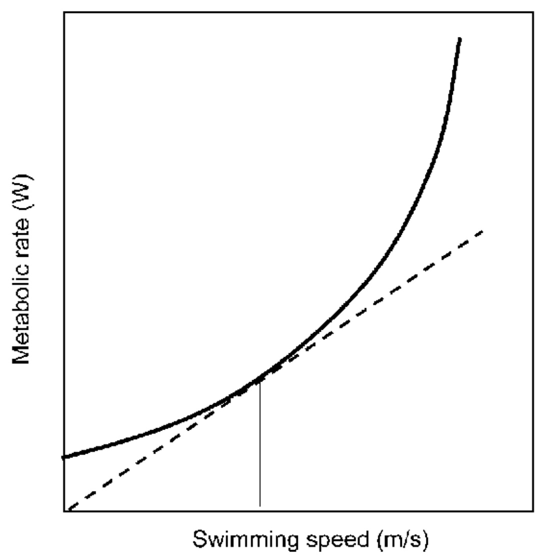

Fig. 3 Theoretical curve of the rate of work as a function of swimming speed. The amount of work per unit distance covered (J/m) is at a minimum at Uopt.

Fig. 4 Moving gantry system installed at ICAR-CIFT for studying swimming speed of fish

Hearing

Sound travels at a speed of about 1500 m/s underwater and it can be used to control fish behaviour over a longer distance compared with chemical or visual stimuli. There are several methods, that use sound in fishing operations to attract fishes. It is recorded that fish schools can be driven into the set-nets by vocal sound of dolphins and yellowtail (*Seriola quinqueradiata*) can be attracted from the deep layers by the swimming and feeding sounds of its conspecifics.

Sound has been used as an active guidance method to transport fish over long distance for transport of fish seedlings to a desired location in sea without physical handing. The studies using sound as an attracting device is mostly being used in aquaculture facilities, where certain amount of conditioning would be required, which would not be easily possible for wild fish, however traditional methods still employ sound for capture.

It has been hypothesised that sound could be an important factor in FAD based fishing, in which the underwater sound generated by the materials, could act as an acoustic sensory cue for fishes to aggregate. It has been understood that the reaction of fish to an approaching vessel follows similar responses of that of a prey fleeing from predator. It has been reported that cod were capable of initiating avoidance response at distances ranging from 470 m to 1470 m from the approaching fishing vessel. The “butterfly pattern” produced in either sides of the vessel, as a result of hull’s ability to shadow propeller cavitation, produce large lobes of high-intensity noise.

Sound is also increasing being used to deter Endangered threatened and Protected (ETP) species form commercial gears, like gillnets and purse seines. Pingers , which produce sounds at frequencies that deter cetaceans are already in market and are effectively being used in different fisheries. Habituation is one problem that is being encountered when these devices and the efficacy is found to decrease with regular use of these deterring devices.

Olfaction

The proportional relevance of sensory modalities varies between species and is determined by prey choices, sensory organ size, brain structure, diel activity cycles, and visual stimuli.

Olfaction as a stimulus is being used increasingly in the long lines and trap fishery world over. Since this capture process depends on the odour plume concentration and its direction, the inherent swimming speed and the activity of the fish also depends on the efficiency of capture. Larger fast swimming species have higher probability of encountering the stimulus. Using dispersion models, it is understood that fish responds to thresholds to bait odour from 10 m to several kilometres, depending on the state of food deprivation, rage of attractant release from the bait and current velocity. Food deprivation is found to have significant effect on the odour tracking ability of fishes, with a study showing increase in attraction of feed deprived sablefish by factor of 57 over that of a fish fed to satiation. Rheotaxis also is an important factor in fishing methods using olfaction as cue, since flow pattern would disorganise the fish that is actively searching for the source of the plume. So, it is suggested that it would be beneficial, to develop artificial baits that would release plumes at a high rate to attract fishes from long distances and then sustained release of plumes to allow the fish to get close to the source.

The attraction towards baits, can also be effectively used for exclusion of non-targeted species like sharks in long lines. An artificial bait using squid liver developed for tuna longlining and tested off the Hawaiian Islands, showed significant reduction in the shark bycatch, with catch rates that were 67% lower than with traditional squid bait (Januma et al., 2003). Other examples of using this technique included reduction in sea turtle bycatch in US Atlantic swordfish fishery, using mackerel baits.

Conclusion

Fishing is a complicated process that involves the fish, the gear, and the environment's related cues, and capture is the consequence of a complex combination of these variables functioning in unison or independently. The key elements that determine fish behaviour reactions are light and vision, sound and hearing, water current and rheotaxis, and temperature. These factors may work individually or concurrently, and it is frequently difficult to "tease apart" the distinct effects. Individual fish reactions to external stimuli, as well as their ability to counteract external influences, further complicate the difficulty of analysing fish responses to stimuli.

In recent years, the main objective of fishing technologists has been to design and develop fishing gear with conservation in mind. As a result, understanding how fish react to various stimuli is crucial to understanding how they are caught in various fishing gears, as well as how this process may be changed to allow undersized and undesirable fish to escape from various fishing gears.

Quantifying the response of fish to all the stimuli is difficult to imitate on field and hence some of the factors (extrinsic/intrinsic) that influence the behaviour of fishes in the capture process can be imitated in the laboratory using suitable techniques.

In fishing technology, studies that link behaviour with fishing gear design are few, yet this is crucial information that may aid in the design and development of responsible fishing gear.