Importance of Fish Behaviour Studies in Fishing Gear Design

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Introduction

There has been a paradigm shift in the philosophy of fishing, primarily due to the alarming rate of decline of major fish stocks and secondly due to the improved understanding of habitat and ecosystem impacts of fishing. As a corollary to the developments in the fishing sector in the last decade, the priority of research in fishing technology now is towards conservation and development of fishing gears and methods, that least affect the fish stocks, habitats and the ecosystem.

Sustainable capture fisheries would mean selective fishing using fishing gears, with least impact to the non-target organisms and other biota, which, would require an in-depth knowledge of the behaviour of the organisms that are targeted and non-targeted. Therefore, knowledge of the behaviour of fish in relation to fishing gear and fishing methods is a pre-requisite to design, construct and operate responsible fishing gears. Studies with conclusive results on the behaviour response towards stimuli associated during fishing are very limited and the problem of multi-species fisheries further baffles the problem of selective capture in fishing gears. Experimental studies to understand the behaviour of fishes near fishing gear are very few, and this is due to the inherent difficulties in recording and studying behaviour in the actual field conditions and the huge cost involved for studying behaviour of fish near the gear, particularly for active gears like trawls.

A large body of work exists, on development of selective gears mostly developed based on trial and error methods, by conducting experimental fishing and studying the species assemblage structure. However, the gears and other technical devices are not often designed based on the behaviour ecology of the species or targeted group and hence tend to non-selective in most cases. The behavioural ecology and the knowledge of the underlying basics of responses to stimuli, associated with fishing, if considered, can help significantly in design of gears that have better species and size selection properties. 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.

Development of responsible fishing gears to reduce bycatch and discards is the mainstream of marine capture fisheries research and the research especially related to fish reaction to fishing gear has flourished, but mostly in controlled conditions, owing primarily due to the cost considerations and difficulty.

Fish behaviour on a broader sense, can be defined as adaptation of fish to external and internal environments and to natural and artificial stimuli. Fish behavior in the context of fish capture, entails the reaction of fish to the different physical and chemical stimuli associated with a particular gear and its operations and the reaction, which the fish makes in relation to movement and distribution. The importance of fish behavior in understanding and improving size and species selectivity for sustainable harvest of resource has encouraged applied fish behavior studies in the context of fish capture. Though there are a large number of stimuli that lead to an effective capture, a strong background on the visual capabilities of the fish that being targeted is the most important input for studying the behaviour of fish.

Vision and its applications in fish capture

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 a number of 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 fish eyes.
Photosensitivity is the ability of fish eye 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 awide 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, but in general it is understood that light coloured netting panels are more difficult to detect against a bright back ground because of low contrast and reverse for materials that strongly contrast with their surroundings, when viewed (fig. 1).

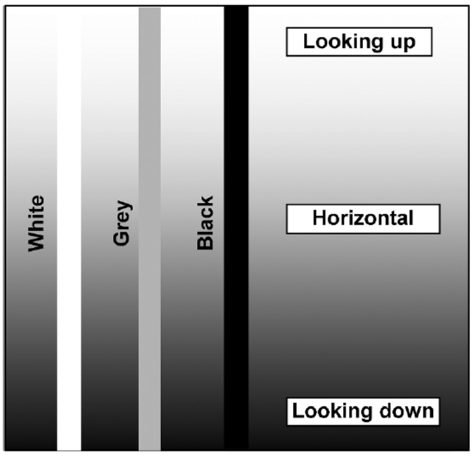

Fig. Contrast of white, grey and black twines hung vertically in water in relation to viewing angle (Source: He, 2010)

Swimming speed

The speed of swimming is an important metric that influences the catchability of the species. There are a large number of body shapes in fishes and swimming is a direct determinant of the body shape of the organism. Swimming again is an energy dependent activity and hence has positive correlations with sustained swimming, which is very important in case of active swimming gear like 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. Energy consumption increases with the type of fish and also the speed with which the fish swims. The highest level of energy consumption measured in fish are about 4W/kg (Videler, 1993). 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.1) The exact shape of the curve depends mainly on the species, size, temperature, and condition of the fish. Owing to the shape of the curve, there is one optimum speed at which the ratio of metabolic rate over speed reaches a minimum. This ratio represents the amount of work a fish has to do to cover 1m. To make comparisons, the optimum speed (U_{opt}), 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 U_{opt}. Temperature has a profound effect on the swimming capability both with regard to speed and with regard to endurance and maximum swimming speed doubles with every 10^0 increase in temperature. It is usually difficult to derive this metric is field conditions and research is often conducted in circular tanks (Fig. 2) The U_{opt} speeds of some commercially important species are shown in Table 1.

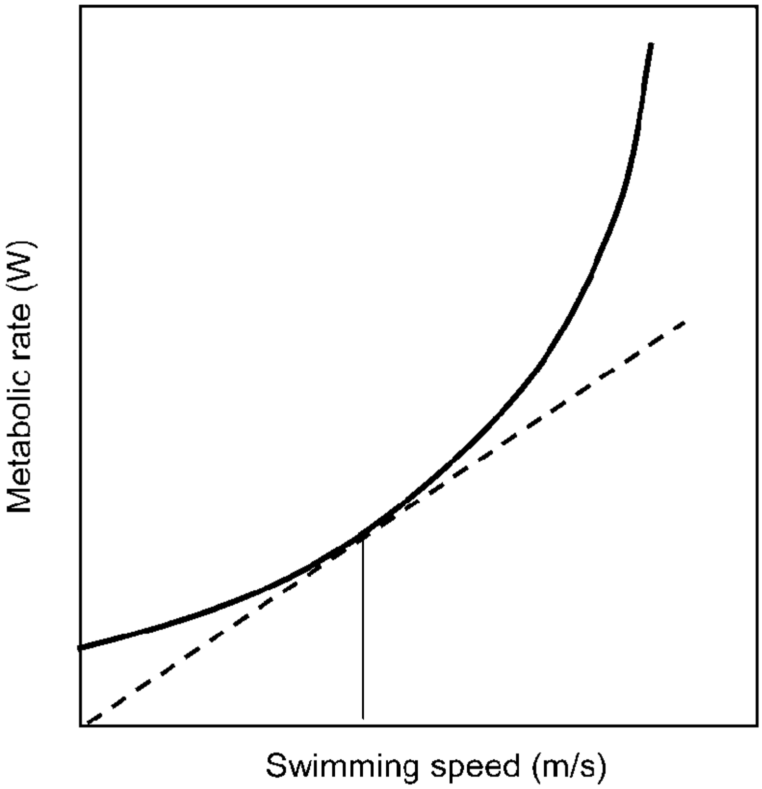

Fig. 2 Theoretical curve of the rate of work as a function of swimming speed. The amount of work per unit distance covered (J/m) is at a minimum at U_{opt}.

Fig. 3 Moving gantry system installed at ICAR-CIFT for studying swimming speed of fish

Table 1. Maximum sustained swimming speed (Umax) of some marine species (source: He, 2010)

SL.No	SPECIES	LENGTH (CM)	U_{Max} (Cm/s)	U_{MIN} (L/s)
1	Atlantic cod	40	42	1.1
	Gadus morhua	49	45	0.9
2	Atlantic cod	36	75	2.1
	Gadus morhua	36	90	2.5
3	Atlantic herring *Clupea harengu*	25	102	4.1
4	Atlantic mackerel *Scomber scombrus*	31	110	3.6
5	American shad *Alosa sapidissima*	42		
6	Haddock *Melanogrammus aeglefinus*	17	44	2.6
	Melanogrammus aeglefinus	24	53	2.2
7	Jack mackerel	14	90	6.4
	Trachurus japonicus	21	90	4.3
8	Japanese mackerel *Scomber japonicus*	10	99	9.9
9	Red fish *Sebastes marinus*	17	52	3.1
	Sebastes marinus	16	52	3.3
	Sebastes marinus	16	52	3.3
10	Saithe *Pollachius virens*	25	88	3.5
	Pollachius virens	34	100	2.9
11	Striped bass *Morone saxatilis*	42-57		

Hearing in fishes and its application in fish capture

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. In Japan, acoustical signals are used to attract demersal fishes like red sea bream, this traditional method is called "*boko*". This device consists of a conical shaped lead that has a hole at the bottom that produces sounds greater than 100 dB.
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 (Anraku, et al., 2006). 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 recently 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 cavitations, produce large lobes of high-intensity noise. Misund, 1994 has shown that this intense outwards movement of sound attracts fish inwards towards the vessel track, which would be favourable in case of trawling often called as "Pursuit effect".
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 harass 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 in fishes and its role fish capture

The relative importance of the sensory modalities differ among species, and depends on the basis of prey preferences, the relative size of the sensory organs, brain anatomy, diel activity rhythms 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 swimming speed and the activity of the fish also depends on the efficiency of the fishing method. 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.

Fish behaviour in response to bycatch reduction devices (BRD)

The behaviour of fishes to these devices has been thoroughly evaluated in many cases and is known to be influence by a variety of intrinsic factors such as physiological condition, motivational state, fish size, visual ability and extrinsic factors such as ambient light conditions, water temperature, BRD design, position and orientation. A general concept is that the variation in behaviour of species is highly variable and many non-targeted species seem to actively seek areas of reduced flow from which they could prefer to swim actively to freedom. Though evidence are not so conclusive, it is considered that upward excluding grids improve fish exclusion rates because downwelling light is reflected from bars of the grid and this increases the distance at which grids becomes visible and hence the escape from the grids. It is argued that for an effective exclusion to happen in case of fishes, the water flow in and around a BRD should be little more than 0.4 m/s. This flow is particularly effective in shrimp trawls, for exclusion of fish bycatch from the trawls.

Overcoming the optomotor reflex to facilitate fish escapement has to date not been effectively achieved and also requires further research. Reducing the visual stimulus (contrast) of the trawl extension, codend, and BRD is an obvious first step but requires a greater understanding of the visual capabilities of fish under a range of ambient light levels encountered in the fishery and their response under these various conditions.

Escape vents in pots have been found to be very effective in release of juveniles that enter the trap and creation of turbulence in the region of the escape vents is found to be very effective for fish to find the vent.

Conclusion

Fishing is a complex process which involves the fish, the gear and the associated stimuli in the environment and capture is the result of the complex mix of these factors acting in tandem or individually. Light and vision; sound and hearing; water current and rheotaxis; and temperature are the main factors that affect the behaviour responses of fishes and these factors may act separately or simultaneously and is often difficult to "tease apart" the individual affects. The responses of the individual fish to the external stimuli and its capabilities to counter the external influences further makes the problem of studying response of fish to stimuli very perplexed.

The overarching role in the recent years by fishing technologist has been to design and develop fishing gears with conservation as priority. Therefore, knowing how fish react to different types of stimuli is critical to understanding, how they are captured in different fishing gears and also how this process can be modified to allow undersized and unwanted fish to escape from different 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. Among the many intrinsic factors, fish swimming speed is one for which estimates are available for many European fish species, but such information is lacking in the Indian scenario. In-situ studies in traps, though much easier to assess and quantify, has limitations with respect to quantifying the odour plumes though. The shape and size of the mouth and the escape vents, can be determined with good accuracy using tank based studies for traps.

Studies that correlate behaviour with designing of fishing gear is very limited in fishing technology, but this is an important information that can help in designing and developing fishing gears that are responsible.

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