Visual physiology of walleye pollock (Theragra chalcogramma) in relation to capture by trawl nets

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The visual function of the walleye pollock (Theragra chalcogramma) was investigated in relation to how target fish distinguish trawl fishing gear in the capture process. Retinas were sampled from the trawl catch and prepared for histological study. The visual acuity of the retina was examined to determine the scale effect of the minimum separable angle, which can be related to the maximum sighting distance of the visual target under ideal conditions of light intensity and transparency. Furthermore, a model of the escape route of fish during capture by trawl gear is discussed, as is the possible limit of escape distance in relation to the maximum sighting distance. In the case of dark optical conditions at fishing depths of 200~400 m, the weak response of walleye pollock toward the gear could be suggested to be due to lower visual acuity and reduced sensitivity to colour.

Introduction

The behaviour of fish toward trawl gear has been investigated to clarify the capture process and to establish rational designs for gear, by means of laboratory experiments and field observations summarized by Miyazaki (1965), Inoue (1985) and Wardle (1986).

The recent development of underwater observation techniques during trawl operations has provided a clearer idea of events during the capture process (Wardle, 1983, 1986; Glass and Wardle, 1989). Wardle (1986) suggested that gear avoidance by fish during capture can be predicted from the visual range and swimming speed. In this respect, the reactions of fish to trawls towed in light and dark conditions are discussed by Glass and Wardle (1989). These observations have suggested that vision is the most important sense in the various reactions of fish to approaching gear.

How can fish see the gear? This question can be explained by the following four factors of the visual function: form vision, motor vision, colour vision and photosensitivity of the target fish. A physiological approach can be an appropriate aid to understanding their visual functions such as visual acuity, retinomotor response, flicker fusion frequency, and photosensitivity/ spectral sensitivity with the aid of histological and electrophysiological techniques (Ali, 1975; Nicol, 1989; Douglas and Djamgoz, 1990). Behavioural studies can also be helpful in obtaining basic knowledge of fish response toward stationary and moving nets (Blaxter and Parrish, 1965; Parrish, 1969; Cui et al., 1991).

Several pioneer studies advanced net avoidance models depending upon differences between fish swimming speeds and towing speed in relation to the scale of gear (Blaxter et al., 1964; Barkley, 1972; Wardle, 1986). According to the wide range of accumulated knowledge on fish behavioural responses, the visual response may be considered to be one of the most important factors, with fish being able to detect an object by contrast discrimination against the background. The visual function of fish is, however, determined by light intensity, which is influenced by the depth and time of day and water transparency.

The present paper describes and discusses the visual acuity of walleye pollock (Theragra chalcogramma) in relation to their maximum sighting distance to recognize the gear. The relationship between maximum sighting distance and maximum swimming speed in the trawl capture process is discussed from the viewpoint of possible limits to escape distance.
Materials and methods

To examine the visual function of walleye pollock, retinas were collected from the codend catch immediately after being hauled on board. Fish were taken from a depth of 200–400 m on the east coast of the Kamchatka Peninsula and off the northern island (Hokkaido) of Japan in 1988, 1989, and 1991. By histological examination of the retinas, the minimum separable angle, or visual acuity, was determined from the density of the visual cells (cones) in the retinal region, using maximum density calculated from a formula given by Tamura (1957). The maximum sighting distance of walleye pollock and its scale effect were estimated from the visual acuity. A model of the escape route of fish ahead of a mid water trawl net was also constructed. The possible limit of escape distance was compared with the maximum sighting distance at which gear could be recognized for various target sizes and swimming speeds.

Results

Visual acuity of fish

The morphological acuity is the angle subtended at the nodal point of the eye by two adjacent receptors. Acuity in simple cases depends on both the target size and the density of cones. The change in minimum separable angle was examined using 14 walleye pollock ranging in size from 11 cm to 65 cm as shown in Figure 1. The visual acuity is here defined as the reciprocal of this angle. The results showed an increasing tendency in visual acuity with size of fish, and the minimum separable angle of walleye pollock was stable at approximately 10 min (0.17 degrees) for fish larger than 30 cm. Visual acuity of walleye pollock is assumed to be poorer than that of skipjack tuna (Euthynnus pelamis) (2.3 min) and king mackerel (Scomberomorus cavallai) (4.2 min) determined by Tamura and Wisby (1963). The retinal structure of walleye pollock showed lower visual acuity and higher photosensitivity when compared with these pelagic migrating species; walleye pollock have about one-tenth of the human visual acuity of 1 min determined by Douglas and Hawryshyn (1990). The higher acuity of larger fish indicates a capability to distinguish a smaller target object, or an object further away, than smaller fish can distinguish.

Maximum sighting distance

The maximum sighting distance of walleye pollock for different sizes of visual target can be estimated from the visual acuity as:

\[ D = \frac{l}{\alpha} \]

where \( \alpha \) is the minimum separable angle in radians, and \( l \) the target size. By assuming ideal light and clear water conditions, a target size of 2 cm, for example, gives a maximum sighting distance of 6 m for a fish longer than 30 cm, and 4 m for a 20 cm fish. The maximum sighting distance is also determined by the target size, as shown in Figure 2. The results show that a target size of 4 cm can be recognized from a distance of 13 m by large pollock in ideal optical conditions. In other words, the diameter of a float or rope smaller than 4 cm cannot be clearly distinguished by walleye pollock at a distance exceeding 13 m.

![Figure 1. Visual acuity of 14 individual walleye pollock according to fish length.](image)

![Figure 2. Maximum sighting distance of walleye pollock for different target sizes.](image)
Possible limit of escape distance

A schematic model of the escape route of fish ahead of a midwater trawl net is illustrated in Figure 3. For this purpose, it is assumed that the fish are located in the centre of the frontal area of the net mouth. If fish swim in a direction at an angle of 90° to the towing direction and at maximum swimming speed, the possible limit of escape distance ($D_p$) can be obtained by the following equation:

$$D_p / V_t = 0.5H / V_{f(max)}$$

Where $V_t$ is the towing speed, $H$ the headline height, and $V_f$ the maximum swimming speed. During trawling, the possible limit of escape distance of fish to overcome the approaching headline, footline or wings can be considered by using the maximum swimming speed at different temperatures as determined by Arimoto et al. (1991). Figure 4 shows the relationship between the maximum sighting distance and the possible limit of escape distance from the midwater trawl. Assuming a headline height of 50 m and towing speed 4 kt, in the case of a rope of diameter 2 cm, the minimum distance for escape is far beyond the maximum sighting distance. When the gear approaches close enough for fish to recognize it, the fish may remain inside the minimum distance and cannot avoid the headline even with the shortest route and maximum speed. But in the case of a 6 cm target size, the larger fish can recognize the gear at 20 m, which may give a sufficient chance of escape reaction at temperatures of 2~10°C. The higher swimming activity at higher temperatures indicates an increasing likelihood of escape owing to the elevation of swimming capability. To successfully avoid the gear, the fish is required to start its escape reaction at a distance of 20 m ahead of the trawl net in water of 2°C, but the possible limit of escape distance can be reduced to 14 m when the temperature is 10°C owing to the higher maximum speed achieved by the fish at higher temperatures.

Discussion

How a fish recognizes a trawling gear should be the first step in understanding the capture process. The visual function of fish is known to differ among species and is also influenced by the optical condition of their habitat. In this report, the visual acuity of walleye pollock was examined by histological observations on the density of visual cells (cones). This information leads to the concept of maximum sighting distance, then a limit of possible escape distance using information on the maximum swimming speed of fish. It should be noted that the maximum sighting distance is predicted from the relationship between the visual cell density and the visual angle at which the fish can just distinguish two points (such as meshes or knots) as separate targets. However, acuity can also be expressed as line acuity and grating resolution (Schwassmann, 1975; Miyazaki and Nakamura, 1990), which tend to be larger than visual acuity. In the capture process, the trawl gear presents complex multiple visual stimuli, so that line acuity may be considered to be a most important factor in the visual range of gear such as ropes or net twines which present line targets. The shape of the target also influences the visual range for response (Kawamura and Shimowada, 1983; Douglas and Hawryshyn, 1990). From these points of view, it can be suggested that fish may have larger visual ranges for a trawl net than the maximum sighting distance derived from the visual acuity. Further work is required, especially to quantify the characteristics of these complex visual stimuli and to observe fish responses in different parts of the gear.

Visual acuity is known to be greatly influenced by light intensity. In addition, the visual range can be determined by the contrast of the target. Anthony (1981) reported a reduction of reaction distance with reduced contrast. The most important factor of gear as the visual cue, then, may be the whole image with its contrast.
against the background. Fish may detect the overall image of approaching trawl gear even if the details of ropes and meshes cannot be recognized beyond the maximum sighting distance. Besides, the vision of marine fish has been found particularly well adapted to detecting very small differences in contrast. In very clear water, the visual range of fish can be considered to be longer than the maximum sighting distance for the isolated components of the gear as larger parts of the gear are seen as collections of components.

Concerning the visual function of fish, one of the determining factors is the retinomotor response. That is the alternation between the light-adapted state (photopic vision) and the dark-adapted state (scotopic vision) which can be defined by depth and time of day. Jerlov (1976) indicated that below 100 m depth, the wavelength becomes a narrow spectral range of mostly blue light. The intensity of the light is also rapidly reduced with depth. In the case of trawling on the North Pacific fishing ground at 200–400 m depth, this means that light levels are extremely low. In this dark environment with a dim monochromatic background, the scotopic or the mesopic vision state may give a higher photosensitivity but with lower acuity and less capability for colour and motor vision, as summarized by Blaxter (1980). The visual function of walleye pollock in these conditions is considered too weak to recognize the approach of a trawl net as a visual cue, especially at night.

Wardle (1986) emphasized the importance of knowledge about the visual range and swimming capability as parameters in the trawl capture process. The swimming performance of fish depends on fish length and water temperature, so that the possibility of net avoidance is greatly influenced by these two factors. In this report, the possible limit of escape distance has been obtained from an evasion model, and was considered to be the determining factor in comparison with the maximum sighting distance. The fish cannot avoid the approaching gear when the possible limit of escape distance is beyond the maximum sighting distance. Further investigation into the visual function and response of fish toward trawl gear is required, to establish higher efficiency and selectivity in size and species, in relation to the swimming capability of fish.

Acknowledgements

We thank Drs Y. Inoue, Y. Sakurai, S. Akiyama, and everyone concerned in this study. Thanks are also due to the captain and crew of “No. 107 Seitoku-maru”, as well as the Honma Gyogyo Co., Ltd. for the great help they provided us during the cruise.

References


