Visual Characteristics of Three Species of Salmonids Stocked from Japanese Hatcheries

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The optomotor reaction is defined as any movement by an animal that retains the image and direction of a visual target. In fishes, this reaction plays an important role in rheotaxis (Lyon 1904), migration (Jones 1968), and schooling behaviour (Shaw and Tucker 1965; Shaw and Sachs 1967). Consequently, improved knowledge of this reaction can help us to understand numerous forms of fish behaviour. Inoue and Kondo (1972, 1973) investigated the optomotor reaction of fishes in order to understand their reaction to fishing gears by using visual patterns such as stripes, net mesh, rope and fish as targets. Optomotor reactions have also been used to measure the pigment sensitivity of fishes (Northmore et al. 1981; Schaerer and Neumeyer 1996; Krauss and Neumeyer 2003; Neuhauss 2003). Cronly-Dillon and Muntz (1965) obtained photopic spectral sensitivity curves for the goldfish (*Carassius auratus*), by means of the optomotor reaction. The reaction has also been to measure the spectral sensitivity of fishes under scotopic conditions (Hasegawa 1998). In those experiments, the spectral sensitivity curve of medaka (*Oryzias latipes*) and cobaltcap silverside (*Atherina tsurugae*) coincided well with the absorption spectrum of their rod visual pigments. Recently, the optomotor reaction of the red sea bream (*Pagrus major*) was measured to determine its spectral sensitivity in photopic conditions (Hasegawa 2005). This paper describes experiments that use the optomotor reaction to measure the spectral sensitivity and polarized light sensitivity of juveniles of three salmonid fish: chum salmon (*Oncorhynchus keta*), pink salmon (*O. gorbuscha*) and masu salmon (*O. masou*). These fish were treated according to the guidelines of the Japan Ethological Society for animal behaviour research. Juveniles are defined as being in the ''swim-up'' stage meaning they can feed spontaneously.

In addition, the possible role of the biological clock was evaluated by examining the periodicities in swimming depths for chum salmon returning to the coast for spawning. The polarized light sense and the biological clock relate to the function of the direction search of the salmon.

The equipment used to measure the optomotor response is essentially the same as that used in Hasegawa et al. (2001) and Hasegawa (2005). Suspended particles (i.e., kaolin in a concentration of 28.6 NTU) were added to the water of the measurement tank in an effort to scatter light rays making them visible in the transverse direction.

A halogen lamp was used as a light source and the light was divided into 12 equal parts using optical fibres. A convex lens was installed in the tip of each fibre. These lights were shone vertically through the water. The lights were installed in a rotating base that was able to turn clockwise and anticlockwise at various speeds. A cylindrical acrylic tank was filled with water containing a little kaolin and set on the rotating base. Monochromatic light of 400, 440, 480, 520, 560, 600 and 620 nm were obtained by the use of interference filters (Andover Corporation Optical Fiber) that were inserted in the mouths of the optical fibres. The light intensity was adjusted to be 2.0×10^{-2} μ mol•m^{-2}•s^{-1} at each wavelength. In addition, sensitivity to polarized light was examined by measuring the optomotor reaction with the visual target that alternately arranged the polarized light filter as the penetration vibration side of light was orthogonal.

A fish was transferred into the experimental tank, and left to adapt for five minutes in the state where stimulus light (visual target) was irradiated. The visual target was then started in a clockwise direction and fish behaviour observed for five minutes. The time (T) taken for the trial fish to swim in the same direction as the visual target was considered to be the optomotor reaction rate. That is to say, the rate of optomotor reaction was calculated using the following formula, (T min / 5 min) × 100% (Arimoto et al. 1979). The tangential velocity of the visual target was $\pi/2$ rad•sec^{-1}.

The optomotor reaction rate of chum salmon was highest at 520 nm, with no significant differences among reaction rates at 400 nm, 440 nm and 520 nm (Mann-Whitney U-test, $p > 0.05$). The optomotor reaction rate of pink and masu salmon was highest at 560 nm and in pink salmon it was significantly different from that at wavelengths shorter than 480 nm ($p < 0.01$). In masu salmon there were significant differences from the other wavelengths except for 400 nm ($p < 0.05$). In masu salmon a high reaction rate was observed at 400 nm, suggesting that these fish are sensitive to ultraviolet light (UV). The pectoral fins of masu salmon are UV reflective at 350 nm as indicated by photographs taken using an UV transmitting filter. Attenuation of reflectance was observed by

nearly 360 nm shorter than the shortest wavelength with visible light. In the sample used, several juvenile masu salmon were observed with damaged pectoral fins. This damage likely resulted from interference aggression among individuals (Kobayashi 1994). Abbott and Dill (1985) report high rates of nipping at the pectoral fin in juvenile steelhead trout (*O. mykiss*) which are also UV reflective in the pectoral fin region. Given that masu salmon and steelhead trout are closely related species (Phillips et al. 1992; Osinov and Lebedev 2000), nipping might also be highly concentrated at the pectoral fin. Sensitivity to UV may facilitate the use of the reflective pectoral fin patch as a cue or target for nipping.

Although the sensitivity curve of the closely related chum and pink salmon was similar, there is a small difference in the composition of visual pigment between the two species. The rhodopsin ratio of chum salmon is higher than that of pink salmon (Hasegawa et al. 2002). The difference of the λ max between both species may be a reflection of this phenomenon. Moreover, although these two species have violet/ultraviolet-sensitive opsin (Dann et al. 2004), the rate of optomotor reaction in the short wavelength region was low. However, Nicol (1989) has indicated that several kinds of photopic spectral sensitivity curves vary according to experimental conditions and so it will be necessary to re-examine these results using other action indices, in order to determine whether the results described here are valid.

The rates of optomotor reaction were compared when the optical penetration direction side of the polarized light filter was alternately put every 90 degrees and when the same side was alternately put. The rate of the former was better ($p < 0.01$). Therefore, it was suggested that masu salmon are sensitive to polarized light. The importance of polarized light sense was not demonstrated for chum salmon or pink salmon. It is necessary to examine other action indices for these species. However, a 24 h periodicity was confirmed by changes in the swimming depth of chum salmon. Salmon that have a biological clock and are sensitive to polarized light will be able to perceive the direction of movement of the sun and moon.

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