Effect of light intensity on activity and food-searching of larval herring, *Clupea harengus*: a laboratory study

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Abstract

Larvae of *Clupea harengus* were reared from spawning herring caught in March 1982 and 1983 in the Firth of Clyde, Scotland. An infra-red observation technique was used to record the behaviour of larval herring both in shallow dishes using a top view and in a tank 2 m deep using a side view. The amount of time larvae spent swimming, which was minimum in complete darkness, increased with increasing light intensity and as the larvae grew. Maximum swimming speeds of feeding larvae were recorded at light intensities between 10 and 100 lux. The presence of food organisms (*Artemia* sp., Brazilian strain) at light intensities below the feeding threshold (0.1 lux) caused an increase in the proportion of time spent active, but light intensities above the threshold had different effects, depending on developmental stage: larvae of 12 mm increased swimming speed, but 21 mm larvae decreased speed. In the 2 m deep tank in darkness, larvae displayed inactive periods wherein they sank head first, interspersed with periods of upward swimming. As light intensity increased, vertical swimming was replaced by horizontal swimming. These results are discussed with reference to food searching and vertical migration of larval herring in the sea.

Introduction

The effect of light intensity on swimming behaviour of fish larvae has implications for its effects on feeding success, duration, rate of food searching, and, in the herring *Clupea harengus* at least, vertical migration. In general, herring larvae are found near the surface at dawn and dusk and at a depth of 20 to 40 m during the day. In laboratory experiments using thermistor probes to detect activity of larvae, Blaxter (1973) demonstrated that larvae would remain at the water surface of a vertical tube in darkness and that, as light intensity was increased, they moved away from the surface. Later, Wales (1975) repeated these experiments with eyeless larvae and found the same migration, indicating that vertical migration is dependent on an extraretinal light sense. The organ responsible for this extraretinal light sense was not demonstrated. Woodhead and Woodhead (1955) showed that changing light intensity may control this vertical migration by changing the orientation of swimming movements from mainly vertical, in low-light intensities, to horizontal in high-light intensities. This mechanism together with the negative buoyancy of larvae would cause them to move down during the day until they reached a depth at which sufficient vertical swimming is stimulated to allow them to hold station. Herring larvae are not always found in the sea at the surface during the night, and have been found distributed evenly over a wide range of depths by Zijlstra (1970) and Wood (1971).

Work on the chemoreception of larval herring (Dempsey, 1978) showed, again using the thermistor-probe technique, that increases in activity can occur in response to extracts of food organisms such as nauplii of the barnacle *Balanus balanoides* and *Artemia* sp. Increased activity in response to the presence of barnacle nauplii occurred in yolk-sac larvae, but larvae only responded to *Artemia* sp. after they had established feeding on this species. All Dempsey’s experiments were carried out at a light intensity of 5 lux and only on first-feeding larvae.

Larval herring feed visually, and the light threshold for feeding is about 0.1 lux (Blaxter, 1968). Measurements of food-searching potential (Rosenthal and Hempel, 1970; Blaxter and Staines, 1971) have been made at considerably higher intensities than this threshold: at 500 to 1,500 lux. It is doubtful that larval herring would be subjected to such high light intensities in the sea, since they migrate away from the surface during the day.

The present study uses a technique for observing fish larvae with infra-red illumination and television (Batty, 1983) which allows the swimming behaviour of larval
herring to be recorded in varying visible light intensities, from darkness upwards. It is intended to demonstrate the effect of different light intensities on searching behaviour. This will provide an estimate of food-searching potential at more realistic light intensities and also in conditions close to the threshold, such as would occur at dawn and dusk and during full moonlight. Changes in behaviour which occur when prey organisms are added have also been investigated to identify the nature of the change in behaviour and to determine if different effects occur over a range of light intensities. The effect of light intensity on the orientation of swimming in a vertical tank has also been investigated.

Materials and methods

Spawning herring (Clupea harengus) were caught on Balantrae bank in the Firth of Clyde, Scotland, in early March of 1982 and 1983. The gonads of these fish were transported to the laboratory, where the eggs were artificially fertilized. Once the yolk sac had been resorbed, larvae were fed on live Brazilian Artemia sp. and natural zooplankton. The rearing tanks were illuminated with artificial light with an intensity of approximately 50 lux at the water surface. The lights were set to come on and off at the same time as natural dawn and dusk.

Experiments were carried out in air-conditioned rooms at 10 ºC; larvae were transferred to the experimental tank 16 h before the experiments and were not fed during this period. All the experiments were carried out between 10.00 and 13.00 hrs. The behaviour of the larvae was observed with an infra-red sensitive television camera and silhouette illumination from a strobed infra-red emitting diode (Batty, 1983). This technique was used in two configurations in two separate series of experiments. In the first experiments, a top view of a Perspex tank 11.5 cm in diameter by 4 cm deep was used, with visible illumination (if required) also from above, but via a semi-silvered mirror. In the second series of experiments, a Perspex tank (2 m deep with a 10 cm square cross-section) was used with visible illumination from above. In this experiment, the camera and infra-red illumination were mounted on a frame surrounding the tank to give a side view. This frame was suspended so that it could move up and down the tank, allowing the camera to scan the tank vertically. In both experiments, visible illumination was provided by a projector with a 150 W tungsten-halogen bulb, and light intensity was adjusted using neutral-density filters. Heat and infra-red light were removed from the visible illumination by means of heat filters. Light intensity was measured at the water surface with a photomultiplier tube calibrated in lux (1 lux=0.5 µW cm⁻²). This unit was used both to allow comparison with earlier work and because white light was being used in shallow water. In addition, the spectral sensitivity of the eye of larval herring is similar to that of the human eye and only changes in orders of magnitude are important in these experiments.

Video-recordings were made at light intensities ranging from 0 to 10 000 lux on various stages of larval herring. The same group of 20 to 30 larvae were used throughout a series of light intensities. Experiments started in total darkness and, after each increase in light intensity, a 30 min rest followed before recording continued. Replicates were run for each experiment. In some experiments prey, Artemia sp. nauplii, were added at a concentration of 1 ml⁻¹. These nauplii were harvested after cysts had been held for 48 h in seawater at 27 ºC, and they were used immediately.

The first series of experiments were analysed by replaying video-tape recordings field-by-field into a digitizing system (Graham, 1984) connected to a computer. This device allows coordinates marked by a light pen to be entered into the computer. In order to determine the swimming speeds of larvae in these experiments, the positions of the heads of individual larvae were recorded at intervals of 10 fields (i.e., every 200 ms). The speeds of all larvae visible at any time were calculated from such position measurements at 15 s intervals during a 10 min recording at each light intensity. A minimum of 100 observations (the sum of the number of larvae observed) was made at each light intensity; the mean swimming speed was the mean of all larva observations. In addition, the numbers of larvae swimming and not swimming at each time were recorded. The “proportion swimming” was calculated as the sum of the numbers of larvae swimming divided by the sum of the numbers of larvae observed.

The product of the mean swimming speed and the proportion swimming or active gives the mean population distance covered per unit time, or search rate. This allows comparison with earlier work, wherein individuals were followed for long periods.

Results

The results for the first series of experiments with the top view of the Perspex tank, are shown in Fig. 1. The proportion of Clupea harengus larvae swimming is shown on the left of this figure, swimming speed on the right.

Fig. 1A shows the results for yolk-sac larvae at each light intensity. The proportion swimming increased with increasing light intensity. A very low proportion of 0.06 swimming was observed in total darkness, increasing to 0.3 at 10 000 lux. Conversely, the swimming speed of larvae, when they were active, was highest in darkness (8.1 mm s⁻¹) and varied little in the light, remaining at about 5 mm s⁻¹. Distance covered per unit time, the product of proportion swimming and mean swimming speed, increased from 0.5 mm s⁻² in total darkness to 1.18 mm s⁻² at 10 000 lux, demonstrating the low degree of swimming that yolk-sac larvae perform.

The behaviour of feeding larvae was examined both in the absence of prey, in filtered water, and with Artemia sp. nauplii. Larvae were seen feeding in all experiments in which prey were present and in which light intensity was