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SHORT COMMUNICATION

THE ROLE OF THE PECTORAL FINS IN STATION-HOLDING OF ATLANTIC SALMON PARR (*SALMO SALAR* L.)

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Benthic fish resist downstream displacement in a current by balancing drag, the force orientated downstream, with the friction force. The friction force is $\mu(W_0-L)$, where μ is the friction coefficient, W_0 the weight force of the fish in water (N), and L the lift force (N) acting on the body and fins (Arnold and Weihs, 1978). Above a critical speed, friction is insufficient to counteract drag and the fish must either swim or seek shelter from the flow. This note reports tests of the commonly proposed hypothesis (e.g. Kalleberg, 1958; Keenleyside and Yamamoto, 1962; Jones, 1975; Wankowski, 1981) that the pectoral fins are important to station-holding in Atlantic salmon, acting as hydrofoils generating negative lift.

Parr were obtained by electrofishing in the River Frome and were transported by road to Lowestoft in insulated containers. Fish were held in tanks with an underwater gravel filter, continuously aerated and flushed with water at 10–11°C. Parr were fed daily on chopped fish.

Station-holding parr were observed in a flume (Arnold, 1969) on both a smooth (Perspex) and a rough substratum. The rough substratum was subrounded gravel (mean diameter 5.2±0.8 mm; mean±2 S.E.). Telecentric, parallax-free photographs (Arnold and Nuttall-Smith, 1974) were taken of parr holding station on Perspex. A dye stream injected just upstream of the pectoral fin was also photographed. A lateral viewing, rigid Endoprobe (Inspection Instruments Ltd) was used to take head-on photographs. The probe had a field of view of 30° and could focus from 4 mm to infinity. Parr used in these experiments averaged 127±13 mm in total length.

The function of the pectoral fin was tested by comparing station-holding performance of intact parr (length 122±16 mm) and parr from which the pectoral fins had been amputated (length 115±14 mm). Parr were anaesthetized in 0.5 ml l^{-1} phenoxyethanol and either the pectoral fins or part of the dorsal and adipose fins were amputated.

The same protocol was used for all experiments. Fish were allowed 24–48 h to

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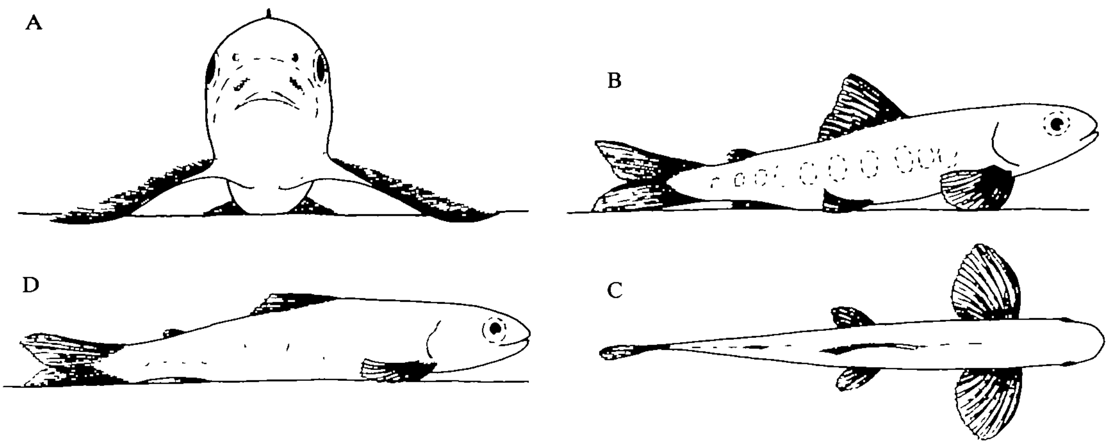

Fig. 1. Drawings of Atlantic salmon parr resting on a Perspex substratum. (A) Front view drawn from an Endoprobe photograph of an Atlantic salmon parr resting with the proximal portions of the pectoral fins lifted clear of the substratum. (B,C) Side and top views of an Atlantic salmon parr resting in the posture typical of water current speeds of less than $0.5\,\mathrm{m\,s^{-1}}$ (actual free-stream current speed was $0.23\,\mathrm{m\,s^{-1}}$). (D) Side view of a parr in the posture typical for speeds greater than $0.5\,\mathrm{m\,s^{-1}}$ (actual speed was $0.59\,\mathrm{m\,s^{-1}}$).

acclimate to the flume at a water current speed of less than $0.1\,\mathrm{m\,s^{-1}}$. Current speed was then increased in increments of $0.05–0.1\,\mathrm{m\,s^{-1}}$ every 10 min to a maximum of about $0.95\,\mathrm{m\,s^{-1}}$. Free-stream current velocity was measured at a height of 0.15 m above the bottom of the flume. In the experiments to determine the effect of pectoral fin amputation on station-holding, the number of fish holding station was recorded every 2 min. The critical water current speed was recorded as the free-stream speed at which fish began continuous swimming (Saunders, 1965).

Fish in the flume spent most of their time on the bottom, but occasionally swam or drifted a short distance up- and downstream, respectively. Parr usually settled in a characteristic 'parr posture', standing on the tips of their extended pectoral fins (Fig. 1) and heading upstream with the body at an angle of 10–15° to the substratum (Fig. 1B,C). As the free-stream velocity increased, this angle decreased, until the body was parallel with the bottom in flows greater than $0.5\,\mathrm{m\,s^{-1}}$ (Fig. 1D) and the dorsal fin was progressively furled. Such behaviour would promote station-holding by reducing drag.

On gravel, the pelvic fins were also often extended and, with the anal fins, lowered into the interstices between the gravel. Gravel was sometimes grasped between the pelvic fins. These behaviour patterns would promote station-holding by increasing the friction force opposing drag. Expulsion of air from the swimbladder was observed in a number of fish, which would have the same effect by increasing W_o.

Flow visualization (Fig. 2) showed that the streamlines followed the camber of the pectoral fin and flow was diverted away from the substratum. Such flow

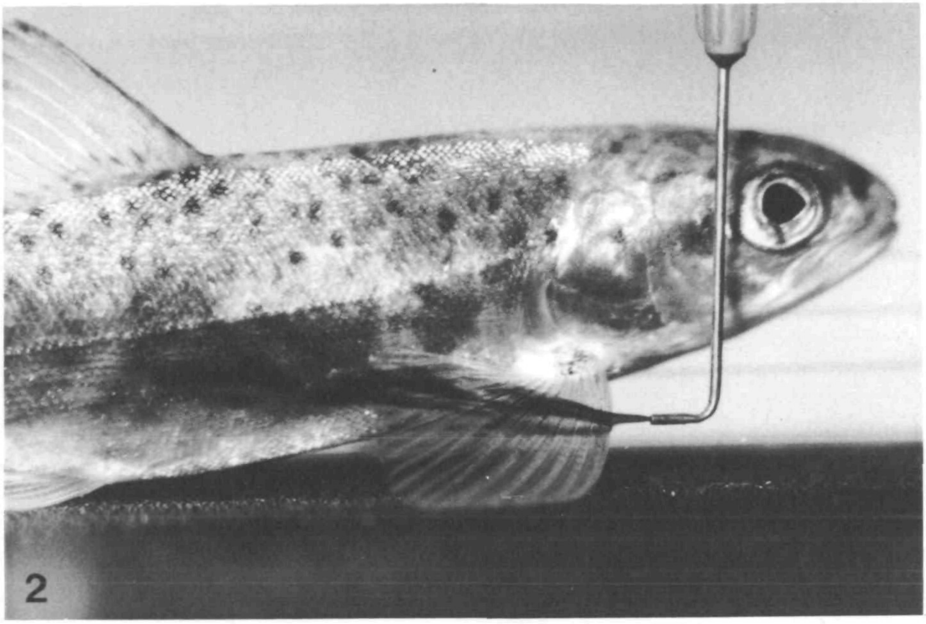

Fig. 2. The flow patterns around the right-hand pectoral fin of an Atlantic salmon parr at a water current speed of $0.29\,m\,s^{-1}$. The streamlines follow the camber of the fin but detach and flow becomes turbulent towards the trailing edge.

deflection is associated with momentum changes in the correct direction to generate the downward force postulated as the basis of station-holding by these fish.

The importance of this downward force was shown by a reduction in the critical water current speed from $0.81 \pm 0.03\,m\,s^{-1}$ for intact parr on Perspex (Fig. 3) to $0.12 \pm 0.04\,m\,s^{-1}$ for parr lacking pectoral fins. The difference is significant (*t*-test, $P<0.001$).

The critical water current speed exceeded the maximum sustained swimming speed of the parr, which quickly fatigued soon after swimming became necessary. Passive station-holding is therefore an important behaviour allowing parr to avoid swimming while remaining adjacent to fast currents that would otherwise be untenable. Furthermore, parr hold station in a posture that allows them to scan upstream for drifting food, while remaining poised and ready to dart into the stream to intercept it.

The water current speeds at which Atlantic salmon parr can hold station exceed the maximum sustained swimming speeds of other salmonids, as well as those of other fish of similar size (Beamish, 1978). The high station-holding performance probably makes drift resources accessible with reduced competition, by allowing the parr to utilize areas of fast-flowing water for which other species lack the necessary adaptations.

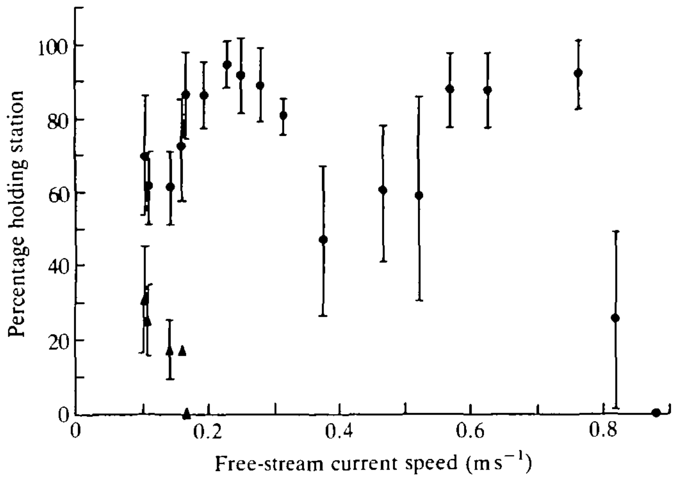

Fig. 3. The percentage of Atlantic salmon parr (N=7) passively holding station at various water current speeds. Circles represent parr with intact pectoral fins and triangles parr without pectoral fins. Solid lines are ±2 s.e.

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References

Arnold, G. P. (1969). A flume for behaviour studies of marine fish. *J. exp. Biol.* **51**, 671–679.

Arnold, G. P. and Nuttall-Smith, P. B. N. (1974). Shadow cinematography of fish larvae. *Mar. Biol.* **28**, 51–53.

Arnold, G. P. and Weihs, D. (1978). The hydrodynamics of rheotropism in the plaice (*Pleuronectes platessa*, L.). *J. exp. Biol.* **75**, 147–169.

Beamish, F. W. H. (1978). Swimming capacity. In *Fish Physiology*, vol. VII (ed. W. S. Hoar and D. J. Randall), pp. 101–187. New York, London: Academic Press.

Jones, A. N. (1975). A preliminary study of fish segregation in salmon spawning streams. *J. Fish Biol.* **7**, 95–104.

Kalleberg, H. (1958). Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *S. trutta* L.). *Rep. Inst. freshwat. Res. Drottningholm* **39**, 55–98.

Keenleyside, M. H. A. and Yamamoto, F. T. (1962). Territorial behaviour of juvenile Atlantic salmon (*Salmo salar* L.). *Behaviour* **19**, 139–169.

Saunders, R. L. (1965). Adjustments of buoyancy in young Atlantic salmon and brook trout by changes in swimbladder volume. *J. Fish. Res. Bd Can.* **22**, 335–352.

Wankowski, J. W. J. (1981). Behavioural aspects of predation by juvenile Atlantic salmon (*Salmo salar* L.) on particulate, drifting prey. *Anim. Behav.* **29**, 557–571.