EXPERIMENTAL INVESTIGATIONS OF THE RELATIONSHIPS BETWEEN GROWTH AND DENSITY OF JUVENILE ATLANTIC SALMON IN THE WILD

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Introduction

Recent models of the factors that influence growth, weight and densities of wild juvenile *Salmo* spp. have raised a paradox (Armstrong, 1997). There is evidence that salmon self-thin, which indicates strong density-dependence of growth and/or mortality. However, the most influential models suggest that growth and mortality are largely independent of density. The purpose of our work was to examine experimentally first, whether growth does vary with local density, and second, whether populations of stocked juvenile Atlantic salmon fully utilise the carrying capacity of their habitat as they develop (which would be expected if they self-thin).

Methodology

Experimental procedure

The experimental site was the Cochill Burn, Perthshire, Scotland (03°48'W, 56°32'N), which is isolated from populations of naturally-spawned salmon in the main River Tay system by a waterfall. Twenty-four sites (eight groups of three) of 20 m length were marked, separated by at least 100 m of stream between the upstream end of one site and the downstream end of the next. Sites were chosen subjectively to be as homogeneous as possible with respect to substrate and cover and to be similar to each other. Within each group of three, sites were randomly allocated to one of three treatments: unfed fry only (UF), fed fry only (F) and unfed & fed fry together (UF+F).

Fry for stocking were obtained from eggs from wild fish caught in the River Braan (1998) or River Almond (1999) which were held, stripped and reared at the FRS Almondbank hatchery. Fish for the unfed treatment were stocked when the majority of the yolk sac had been absorbed. Each stocking group consisted of a mixture of three or four crosses of different parentage. Unfed fry were at a density of approximately 10 m^{-2}. Fork length (FL) and weight (Wt) of 20 randomly selected individuals were recorded prior to stocking.
One third of each stocking group were retained and fed on commercial salmon food for approximately 12 weeks.

One week before stocking, all of these fed fry were anaesthetised with benzocaine solution and their adipose fins removed. Two or three days before stocking, sites to receive fed fry only were electrofished and any unfed fry found were removed. FL and Wt of the first 20 individuals (or all if less than 20 were caught) were recorded. Fed fry were stocked at a density of approximately 5 m^{-2}. FL and Wt were recorded for 20 randomly selected individuals on each occasion.

All sites were electrofished for remaining fry between 25 Aug and 17 Sep 1998 and 30 Aug and 6 Sep 1999. Only the middle 10 m of each site was fished to control for edge effects. A minimum of three electrofishing passes was performed; if more than five fry were caught on the third pass, an additional pass was undertaken. The identity and FL of all fish caught were recorded and Wt of the first 20 unfed or fed (fin-clipped) fry were also recorded. Water temperatures were logged every hour automatically.

Data analyses

Data on the number of fish of each species/life stage of interest (0+ salmon, older salmon, brown trout) caught in each pass were used to generate maximum likelihood estimates of total numbers and confidence intervals. Numbers were converted to densities (nos. m^{-2}) using site dimensions. Numbers and FL/Wt were compared between experimental treatments using multivariate analysis of variance (MANOVA).

Linked experiments

Separate complementary experiments (not detailed here) were conducted to assess dispersion and affects of stocking density on growth.

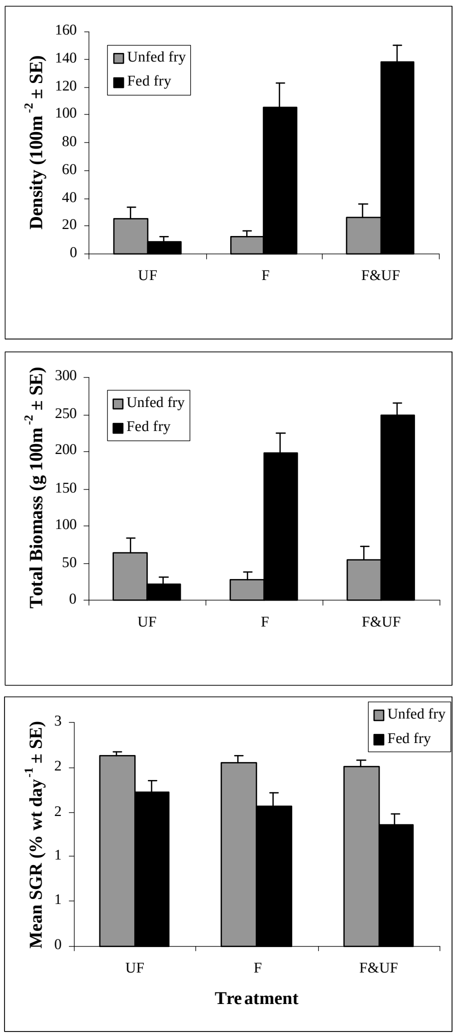
Results

Growth rates of unfed fry in 1998 were density dependent (plot of residuals from the Elliott &Hurley (1997) model, $r^2 = 0.366$, $F_{1,10} = 5.6$, $p=0.037$). When resampled, densities of unfed fry were similar between areas with and without stocking of fed fry (Fig. 1a). However, the total biomass of salmon was five-fold higher in sites that had been overstocked with fed fry (Fig. 1b). Growth rates were not significantly different between treatments (Fig. 1c) but were consistently higher among unfed fry compared with fed fry. Similar patterns resulted from the experiments conducted in 1999.

Discussion

Growth of salmon fry was density dependent, consistent with self-thinning. However, when the sections were overstocked, biomass could be increased by five-fold. The overstocked fish were smaller than those salmon stocked as unfed fry. Moreover, the unfed fry would have enjoyed the advantage of having prior residence. These factors explain why the density and growth of unfed fry were similar between overstocked and control sections. The data indicate that although the unfry were stocked at high densities and their growth was constrained, four weeks later there was substantial capacity for increasing production higher than the standing stock. The experiments are consistent with the concept that the populations of unfed fry self-thinned during an early critical period but were then well below the carrying capacity of the stream.

Fig. 1. Comparisons of (a) density, (b) biomass and (c) growth of salmon parr stocked as unfed (UF), fed-on (F) and both fed and unfed (F&UF) fry in 1998. Bars show the means and standard errors.



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