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Stock-recruitment relationship in River Ellidaar and River Vesturdalsa, Iceland

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Introduction

Stock-recruitment relationship in two rivers in Iceland were examined. The rivers were R. Ellidaar, SW-Iceland (Figure 1) and R. Vesturdalsa, NE-Iceland (Figure 2). These two rivers are similar in size and the conductivity of their water is similar. R. Ellidaar are located in SW-Iceland where climate and ocean condition are more stable than in NE- Iceland, where R. Vesturdalsa is located. The salmon returns predominantly as 1 SW fish in R. Ellidaar but 1 SW and 2 SW salmon are of approximately equal number in R. Vesturdalsa on average. The fluctuation in catch from the same smolt cohort are 3-4 fold in R. Ellidaar, but up to 45 fold in R. Vesturdalsa.

Methods

Size of the spawning stock

For decades salmon ascending R. Ellidaar has been counted. First by traps, but later by mechanical counter, and during the last few years an electronic fish counter using infra-red light gate has been used (Gudjonsson and Gudmundsson 1994). The counter is located 500 meters from the estuary in a fence crossing the river.

To count all salmon (TR= total run) entering the river the catch in the river below the counter (CB=catch below) was added to the total run through the counter (CR=counter run). TR=CB+CR. To calculate the size of the spawning stock (N_0) the catch above the counter (CA=catch above) was subtracted from the total run through the counter (CR) as well as the number of salmon caught that were caught to get eggs for the hatchery (H=hatchery). N_0 = CR-CA-H. Only very few salmon are left below the counting fence at the end of the fishing season.

The number of eggs spawned in R. Ellidaar was estimated based upon the number of female salmon in the river and their size, but data on egg number and size of salmon females is available for rivers in Iceland (Gudbergsson and Gudjonsson unpublished data). The equation used were;

For 1 SW females

Number of eggs (NE) = -3605 + 157,3 * length (cm)

For 2 SW females

Number of eggs (NE) = -19721,6 + 408,0 * length (cm)

The females were divided into several size groups and it was assumed that the same size distribution was in the spawning stock as in the catch. The number of eggs were calculated as follows;

$$TNE = [N_0 / (TR)] * \sum_{i=minW}^{max W} ENi * Vi$$

where:

TNE : total number of eggs in the end of catch season

N_0: spawning stock

TR: total run of salmon

ENi : number of eggs in each female

Vi : number of females in each weight group

min W : lowest weight group of females

max W : highest weight group of females

The salmon run in R. Vesturdalsa is not known until last 2 years. The catch reflects the total run as fishing effort is always the same. This is the case in rivers where counting of salmon is executed (Gudjonsson et al. 1996). It is assumed that 50 % of the run is caught. (based on the experience last 2 years). It is assumed that the size distribution in the catch and in the spawning stock is the same. To calculate the number of eggs the same formulas were used as in R. Ellidaar.

Spawner recruit relationship

To examine the spawner recruit relationship we used the estimated number of laid eggs by the spawning stock and the juvenile index derived from electro-fishing (Antonsson *et al.* 1998) n years later as recruitment. We added year-class indexes to smoothen annual variation in the indexes. The index for 1+ parr in the year n was added to the index for 2+ parr in the year n+1 (the same year-class measured two years).

The data were examined and both Ricker´s and Beverton and Holt's equations were fitted (Ricker 1975).

Ricker´s equation:

$$\mathbf{R = \alpha\, S\, e^{-\beta S}}$$ where

R = recruitment

S = spawning stock

α = dimensionless parameter

β = parameter with dimensions of 1/P

Beverton and Holt´s equation is:

$$\mathbf{R = 1 / (\alpha + (\beta / S))}$$

Results

Number of eggs

During the period 1962-1995 the total number of eggs in R. Ellidaar was from 1 to 17 millions (Figure 3). The data from 1984 was not included in the analysis since counting that year is incomplete (Antonsson 1998). 6.1 million eggs were spawned annually on the average and the total bottom area in the river is 185.000 m^2 (Antonsson *et al.* 1998) that means 32.9 eggs per m^2.

In R. Vesturdalsa the exploitation rate is unknown, but is assumed to be 50 %. The total number of eggs varied from 114.000 in 1981 up to 3,2 million in 1978 (Figure 4). 0,99 million eggs were spawned annually on the average and the total bottom area in the river is 496.000 m^2 (Antonsson *et al.* 1998) that means 2.0 eggs per m^2.

The relation ship of number of spawners/eggs and number at later life stages.

In R. Ellidaar 10 years of data were available for the analysis. The juvenile indexes varied a lot while number of eggs did not vary a lot (Figure 5). The Beverton-Holt´s equation did not fit the data at all, and poorly to the Ricker´s equations. (Table 1).

The life span of the majority of salmon in R. Ellidaar is 5 years (1 year as egg, 3 years in the river as juvenile and 1 year at sea). The Beverton-Holt´s equation did not fit this data, but the Richer´s model was almost significant (Table 1 and Figure 6)

In R. Vesturdalsa the Ricker´s equation could describe the relationship between the egg number and juvenile indexes (Figure 7 and Table 1). The number of eggs in 1978 is detrimental. If that data point is not included completely different relationship can be observed (Figure 8). The same was observed by using the Beverton-Holt´s equation Figure 9). The results are therefore that there is positive significant relationship between number of eggs and number of juveniles and juvenile from these eggs some years later. (Table 1).

The life span of salmon in R. Vesturdalsa is more heterogeneous than in R. Ellidaar. Therefore it is more crude method to examine the relationship of number of eggs and spawners one generation later. It is assumed that the life span of 1 SW salmon is 6 years and 7 years for 2 SW salmon. No significant relationship was found.

Discussion

To ensure minimal spawning to fully utilise available nursery areas is crucial to maintain the well being of any fish stock. Salmon managers have tried to define save biological criteria in number of ways. One way is to establish minimal number of spawned eggs (Symons 1979). Such definition has been used for Canadian rivers where 2,4 eggs per m^2 is needed (Anon 1997).

It is more likely to observe spawner recruit relationship where environmental factors are stable. When the environment is not affecting survival rate at different life stages the spawner/recruit relationship of the population should be easier to observe if it exists at all. Salmon goes through two phases during its life span. First in fresh water and later at sea. Therefore each phase must be looked at separately. In R. Ellidaar no relationship were seen between spawners and the recruit in the river, but in R. Vesturdalsa this relationship is clear. This result was surprising since the environment is more stable in R. Ellidaar. It should though be noted that only 10 data points are still available for R. Ellidaar.

There is no relationship between the spawning stock (estimated in number of eggs) and the recruit returning from sea in R. Vesturdalsa, but such a trend can be seen in R. Ellidaar. The ocean conditions in the sea North and East of Iceland are very variable and survival at sea is also very variable (Antonsson *et al.* 1998). This will fade out all relationship in R. Vesturdalsa. The trend seen in R. Ellidaar perhaps shows that more data points are needed on the juvenile stock to show the relation of spawner- recruit in the river.

The number of eggs per square unit is high in R. Ellidaar and it can be concluded that the number of eggs has always been high enough to fully utilise the nursery areas. No density dependent affects can though be seen on growth and number of parr (Antonsson 1998). In R. Vesturdalsa number of eggs are much lower, so it is possible that all nursery areas are not always utilised. Data points where the number of eggs is high are few. In 1978 when the number of spawners was highest, only few fry emerge because of extreme cold summer in 1979 (Jonsson 1993). In very variable environment as in R. Vesturdalsa it can be difficult to find relationship that can always be employed. Large changes in climatic condition occur in N- and NE-Iceland. Oceanic condition govern the climatic condition on land (Bergthorsson 1994). In some years warm and saline Atlantic sea flows into the area north of Iceland from the west (Stefansson 1981). In such years the condition at sea are favourable for salmon at sea and also in the rivers. In some years only polar water occur in the area and the conditions are unfavourable at sea and it is colder on land. This affects the temperatures in the rivers and affects also the length of the summer in the river i.e. the growth period for salmon juveniles and timing of hatching. During this century periods of some warm years in row and the some cold years in row have been the experience (Antonsson et al. 1996). Therefore it is likely that during cold years there are small runs of salmon and hence small spawning stock and because of poor condition in the river small recruit will appear. During warm favourable years it is likely that the runs are larger and, hence larger spawning stock and because of favourable condition in the river larger recruitment will appear. During years when conditions are changing as in 1978/1979 the relation is completely different. This might explain highly significant relationship between spawning stock and juvenile index in River Vesturdalsa, in spite of very variable environmental conditions.

Perhaps it is better then to use sets of relationships depending on the environmental condition as Warren and Liss (1980) have suggested. Such an approach is though difficult and requires even longer data series.

Even though some relationship is found in R. Vesturdalsa between the magnitude of the spawning and the number of recruit in juveniles, it can not be seen in the number of returning adults. This is because survival at sea is very variable depending on the oceanic conditions (Antonsson et al. 1996, Scarnecchia 1984). This makes all management effort of such a stock even more difficult.

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Figure 1. The River Ellidaar SW Iceland.

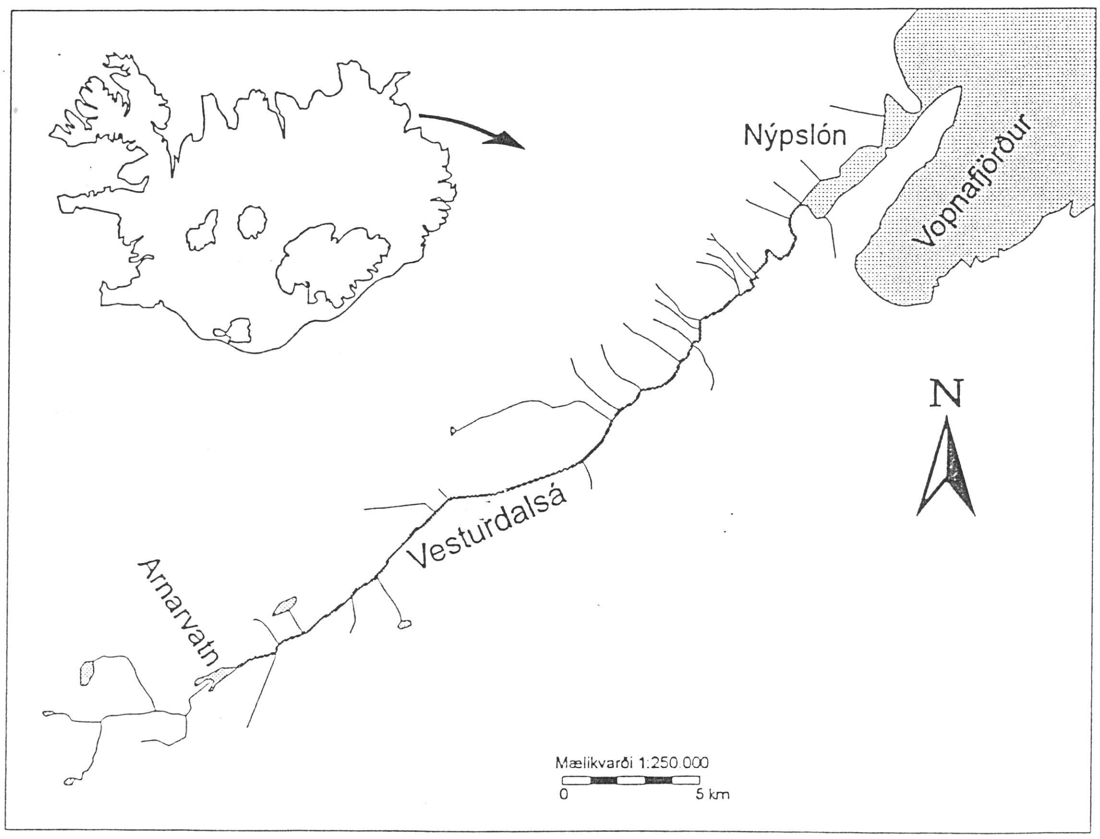

Figure 2. The Vesturdalsa river system NE Iceland.

River Ellidaar

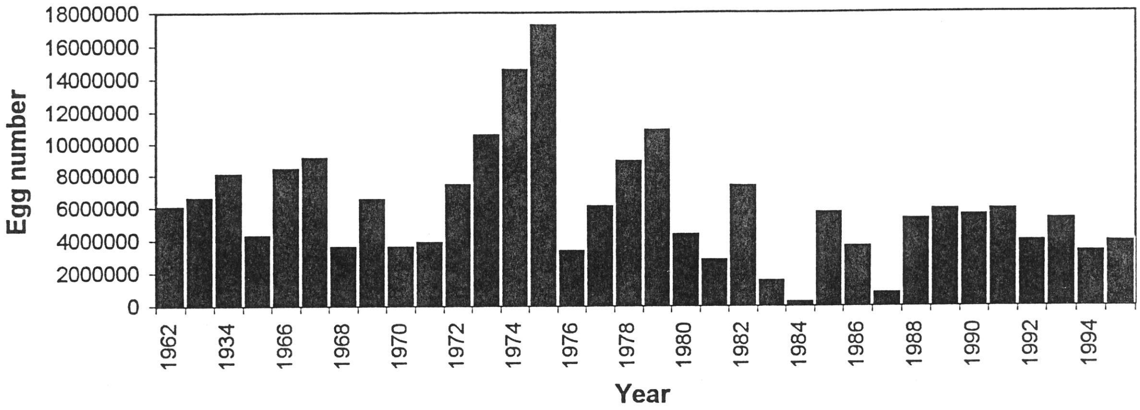

Figure 3. Estimated number of salmon eggs in River Ellidaar 1962 - 1995

River Vesturdalsa

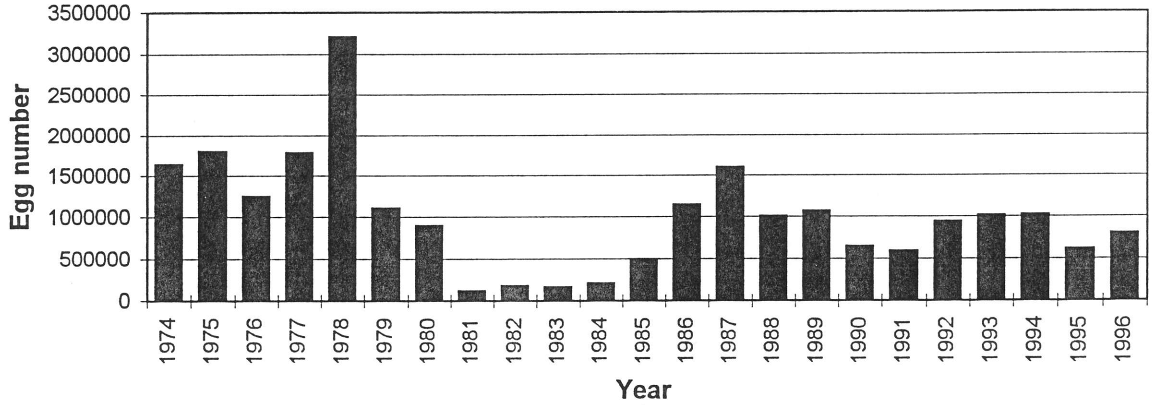

Figure 4. Estimated number of salmon eggs in River Vesturdalsa 1962 - 1995.

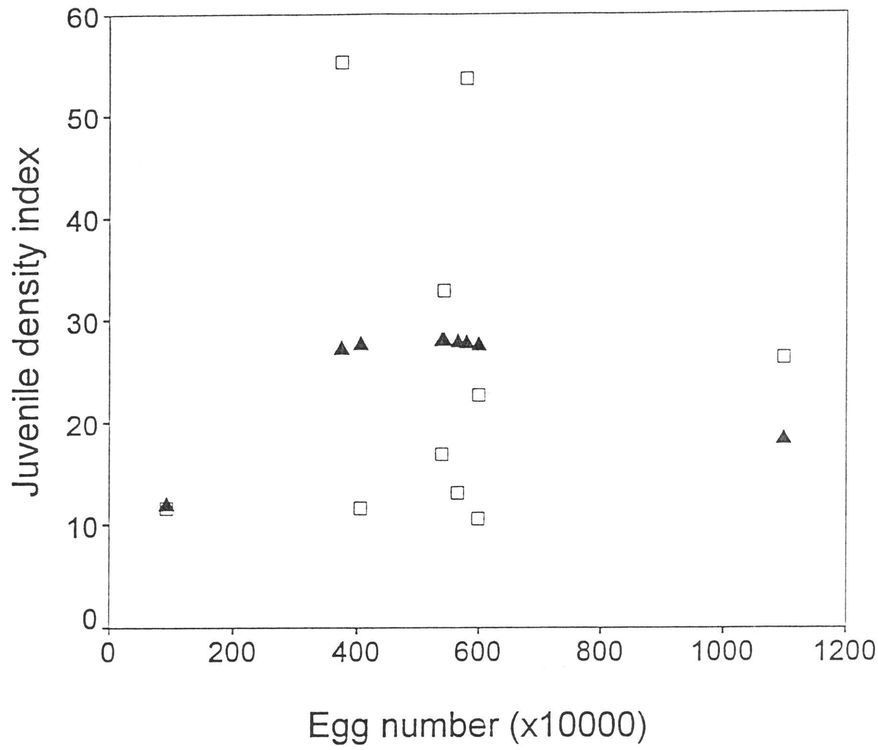

Figure 5. Stock recruitment relationship between egg number and juvenile abundance in River Ellidaar 1987-1996. Ricker equation is fitted.

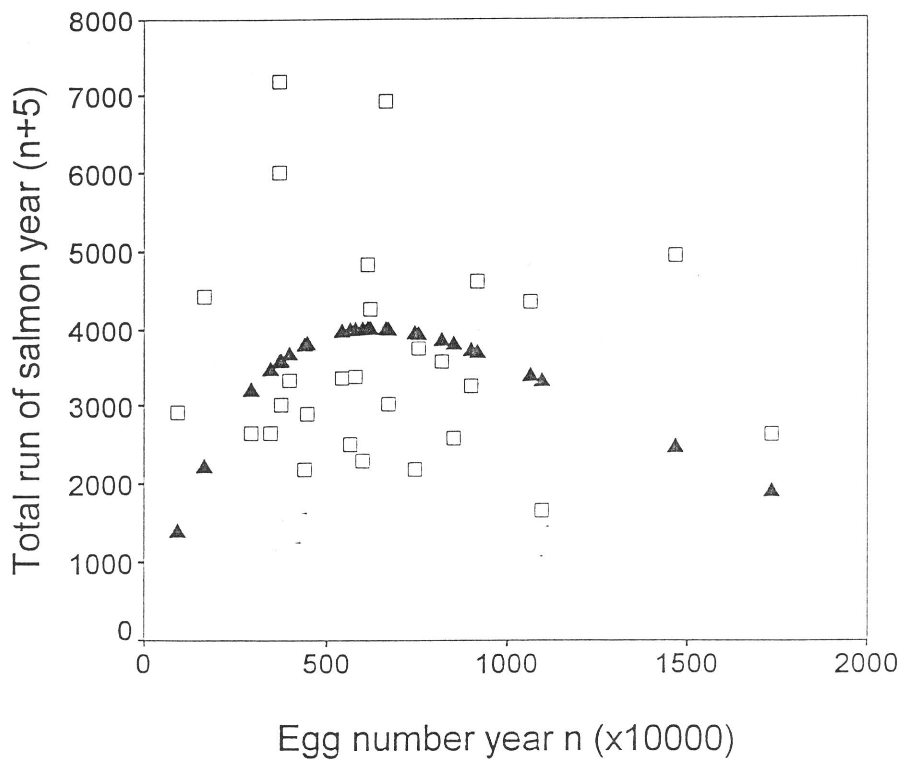

Figure 6. Stock recruitment relationship for salmon in River Ellidaar 1962-1995. Ricker equation is fitted.

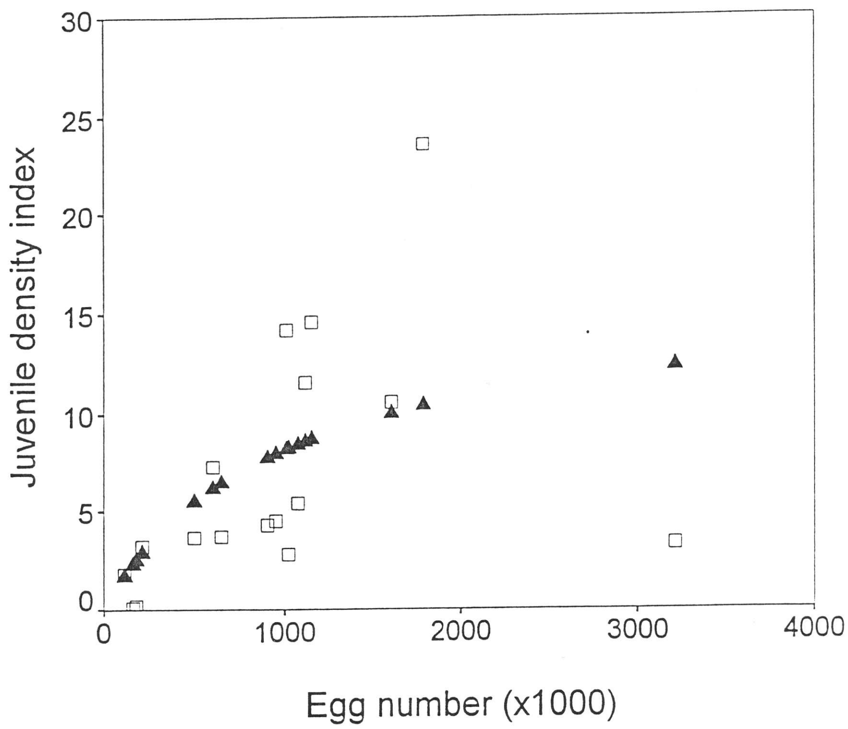

Figure 7. Stock recruitment relationship between egg number and juvenile abundance in River Vesturdalsa 1977-1996. Ricker equation is fitted.

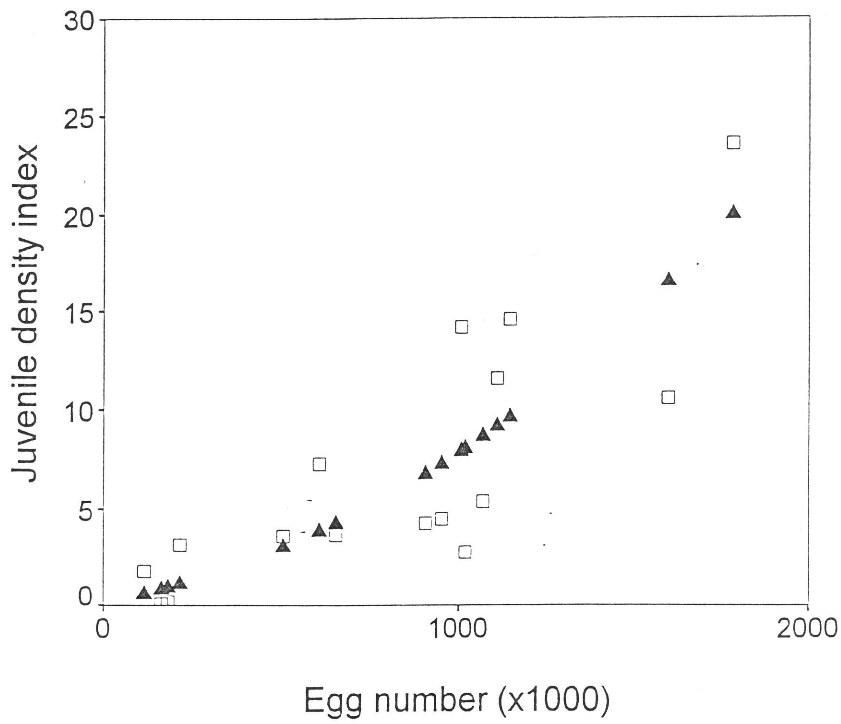

Figure 8. Stock recruitment relationship between egg number and juvenile abundance in River Vesturdalsa 1977-1996, 1978 excluded. Ricker equation is fitted.

Table 1. Stock-recruitment relationship for the salmon stocks in River Vesturdalsa and River Ellidaar. Ricker and Bevertons-Holts (B-H) models.

Stock	Number of years n	Spawning stock estimated from P	Recruitment R	Model	a	b	R2	F	P
Vesturdalsa	17	egg number	juvenile density	Ricker	0,014	0,00048	0,400	6,41	P<0,05
Vesturdalsa	16*	egg number	juvenile density	Ricker	0,049	-0,00046	0,690	33,97	P<0,001
Vesturdalsa	17	egg number	juvenile density	B-H	0,062	59,827	0,325	5,47	P<0,05
Vesturdalsa	16*	egg number	juvenile density	B-H	-0,056	185,902	0,695	35,01	P<0,001
Vesturdalsa	15	egg number	1SW (n+6)+ 2SW (n+7)	Ricker	14,245	0,018	0,005		P>0,05
Elliðaár	28	egg number	run size (n+5)	Ricker	14,551	0,0014	0,128	4,27	P~0,05
Elliðaár	10	egg number	juvenile density	Ricker	1,553	0,0203	0,047		P>0,05
Elliðaár	28	egg number	run size (n+5)	B-H	0,274	0,075	0,000		P>0,05

* 1978 excluded from calculations