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Forecasting Yields of Two-Sea-Winter Atlantic Salmon (*Salmo salar*) from Icelandic Rivers

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To forecast yields of two-sea-winter Atlantic salmon (*Salmo salar*) from 15 Icelandic rivers, I developed predictive regression equations based on yields of grilse of the same smolt class harvested in the previous year. The relationships were positive and significant ($P < 0.05$) for all rivers. The logarithm of grilse catch explained 25–85% of the variation in logarithm of two-sea-winter salmon catch the following year. Inasmuch as statistical tests for linearity between the variables were difficult to interpret and showed conflicting conclusions, I consider them inadequate for assessing whether density dependence occurs between grilse and two-sea-winter salmon. Linear or near linear relationships, which imply no density dependence, appear to occur between log grilse and log two-sea-winter salmon yields. The critical period determining run size from a given escapement thus occurs either during the freshwater rearing phase or during the first year the salmon are at sea.

Afin de prédire les rendements du saumon de l'Atlantique (*Salmo salar*) ayant passé deux hivers en mer et peuplant 15 rivières d'Islande, l'auteur a mis au point des équations de régression pour l'extrapolation basées sur les rendements de madeleineaux appartenant à la même classe de saumoneaux et pêchés l'année précédente. Pour toutes les rivières, les relations étaient positives et significatives ($P < 0{,}05$). Le logarithme de la prise de madeleineaux expliquait dans une proportion de 25 à 85 % la variation du logarithme de la prise, l'année suivante, de saumon ayant passé deux hivers en mer. Puisque les tests statistiques de la linéarité entre les variables étaient difficiles à interpréter et généraient des conclusions opposées, l'auteur les considèrent comme inadéquates pour déterminer s'il existe une dépendance relative à la densité entre les madeleineaux et les saumons ayant passé deux hivers en mer. Des relations linéaires ou presque linéaires, qui ne dénotent aucune dépendance par rapport à la densité, semblent exister entre les rendements (log) des madeleineaux et des saumons ayant passé deux hivers en mer. La période critique qui détermine l'importance de la remonte à partir d'une échappée donnée a donc lieu soit pendant la phase de croissance en eau douce, soit pendant la première année de vie en mer.

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If fishery managers can forecast how many salmon of a particular stock will be available to a fishery before the fishing season, they can adjust harvest rates to provide adequate escapement, and fishermen can allocate their labor and capital in accordance with anticipated fishing success.

One approach to forecasting the yield and escapement of anadromous salmonids (*Salmo* sp. and *Oncorhynchus* sp.) is based on the yield and escapement of fish of the same smolt class that returned to the rivers the previous year. For Atlantic salmon (*S. salar*), this approach usually involves estimating the projected combined yield and escapement of two-sea-winter salmon from the yield and escapement of grilse the year before. Since Atlantic salmon escapement is seldom known, biologists often assume a constant or abundance-dependent harvest rate, or a constant effort between years, and then predict the anticipated yield for a given amount of fishing effort. With such a method, the abundance of two-sea-winter salmon can sometimes be predicted accurately.

This forecasting method has a long history. Jacobsson and Johanssen (1921), who summarized catch data for Atlantic salmon from the Frisenvold Weir on the Gudenaa River, Denmark, wrote:

> The summer salmon consists mainly of two groups: Group A, which spawn ca. 18 months after the migration to the sea [grilse], ... and Group B, the spawning time of which occurs ca. 2-½ years after the migration to the sea [2 sea-winter salmon] ... We have been able to distinguish between salmon of Group A and salmon of Group B ... by means of ... the size of the specimens and by an investigation of the scales of a smaller group of specimens ... It will be seen ... that from a certain year will partly originate A-salmon 3 years later, partly B-salmon 4 years later, and ... an obvious connection exists between the number of A-salmon in a certain year and the number of B-salmon in the following year ... If we investigate ... the correlation between the catch anomalies for A-salmon in one year and ... B-salmon the following year in the period 1899–1913, ... the calculation ... shews [*sic*] that we, with a considerable certainty, can predict that if relatively many A-salmon are caught in a certain year, relatively many B-salmon will be caught in the following year, and that a small catch of A-salmon will be followed by a small catch of B-salmon the following year.

This fundamental method of prediction has been used for

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TABLE 1. Correlation coefficients between grilse catches and two-sea-winter salmon catches the following year, coefficients of variation in grilse catches, and results of density dependence tests for 15 Icelandic rivers (* $p < 0.05$; ** $p < 0.01$).

River	Correlation coefficients: Residual degrees of freedom	Correlation coefficients: Untransformed	Correlation coefficients: Log-transformed	Coefficients of variation for grilse catches[a]	Density dependence (Morris test, $P < 0.05$)[b]
Laxá í Kjós	23	0.59**	0.53**	0.30	Yes
Laxá í Leirársveit	19	0.68**	0.66**	0.47	Yes
Laxá í Dölum	33	0.71**	0.55**	0.56	Yes
Fáskrúd	31	0.66**	0.61**	0.51	Yes
Langadalsá	17	0.87**	0.86**	0.56	No
Hrútafjardará	17	0.75**	0.82**	0.54	Yes
Vesturá	23	0.74**	0.84**	0.53	No
Núpsá	23	0.56**	0.68**	0.54	Yes
Austurá	23	0.78**	0.89**	0.71	Yes
Midfjardará	23	0.79**	0.87**	0.55	Yes
Vídidalsá	20	0.52*	0.50*	0.46	Yes
Vatnsdalsá	18	0.81**	0.74**	0.64	Yes
Laxá á Ásum	21	0.74**	0.82**	0.51	No
Vesturdalsá	22	0.93**	0.88**	0.74	No
Hofsá	20	0.87**	0.92**	0.78	No

[a]From Scarnecchia (1984).
[b]Varley–Gradwell tests showed no density dependence for any of the 15 rivers.

various salmon stocks since then with only minor statistical modifications. In Oregon, Gunsolus (1978) predicted returns of mixed stocks of coho salmon (*O. kisutch*) from returns the previous year of precocious males ("jacks"). Peterman (1982) improved forecasts of abundances of several North American stocks of sockeye salmon (*O. nerka*) by using functional regressions (Ricker 1973) and by transforming the data to natural logarithms. Because of the strong linear correlations between abundance of returning fish of a given smolt class in one year and the abundance of returning fish of the same smolt class in the following year, Gunsolus (1978) and many others have argued that if salmon suffer density-dependent mortality at sea, it most likely occurs soon after the smolts enter the sea, rather than later when the salmon are large.

In Iceland, river owners and managers want to know how many two-sea-winter salmon will return to the rivers, anglers want to accurately forecast the quality of fishing for two-sea-winter salmon the following year, and salmon ranchers want to forecast the number of two-sea-winter fish that will be returning to their smolt release sites. Biologists and salmon ranchers also wish to know if density-dependent mortality acts on salmon between the grilse stage and the two-sea-winter salmon stage. Kristjánsson (1982) first documented the close relation between yield of grilse in one year and yield of two-sea-winter salmon the next year for three northeastern Icelandic rivers. In this paper, I extend his work to several other stocks, modify and extend the statistical analyses, and include earlier yield data.

My objectives were to develop predictive regression equations for yield of two-sea-winter salmon for 15 Icelandic stocks of Atlantic salmon and to make inferences about density dependence between the grilse and two-sea-winter salmon stages.

Methods

Since no long-term escapement data were available by smolt class for Icelandic rivers, all relations analyzed were based on yields. For 15 rivers (see Scarnecchia 1984 for locations), I determined annual yield of salmon of each smolt class from actual counts of salmon caught by anglers. Weight and sex of each salmon had been recorded when captured. For each year's data, yields of grilse and two-sea-winter salmon (sexes combined) were computed with the aid of weight–frequency distributions. Scales from a few stocks were also read to clearly define the weight at which grilse and two-sea-winter salmon should be separated (Jacobsson and Johansen 1921; Scarnecchia 1983). Three-sea-winter salmon were not considered because they were scarce on most rivers. Catch on Midfjardará was the sum of catches on its tributaries Vesturá, Núpsá, and Austurá, plus lower river fish from all three stocks.

There is no significant fishery in the ocean by Icelanders (Ísaksson 1980) that would bias catches in the rivers, although the effects of the Greenland and Faroese fisheries on the stocks remain largely unknown. Nominal fishing effort on 12 of the 15 rivers was nearly constant over the period of study (Scarnecchia 1984); however, effective effort may have increased in recent years if the higher cost of permits induced more aggressive angling. I assumed that changes in fishing were slight between adjacent years, even though moderate effort changes may have occurred between the earliest and latest years considered in the study.

Relations between grilse catches in one year and two-sea-winter salmon catches the next year were computed for both untransformed and logarithmically transformed data with predictive linear regressions (Snedecor and Cochran 1967). To evaluate whether the observed logarithmically transformed relations deviated from linearity, I used a two-tailed t statistic to test if the slopes of the log–log relations were equal to 1 (Morris 1959); I also used the Varley–Gradwell test described by Southwood (1978). The tests were two-tailed, because I believed that either negative density dependence (increased mortality) or positive density-dependence (delayed maturation) could occur. I attempted to determine how well the two regression assumptions of homoscedasticity and normality of residuals were met. Homoscedasticity was tested with Kendall's (1955) Tau statistic by plotting absolute values of

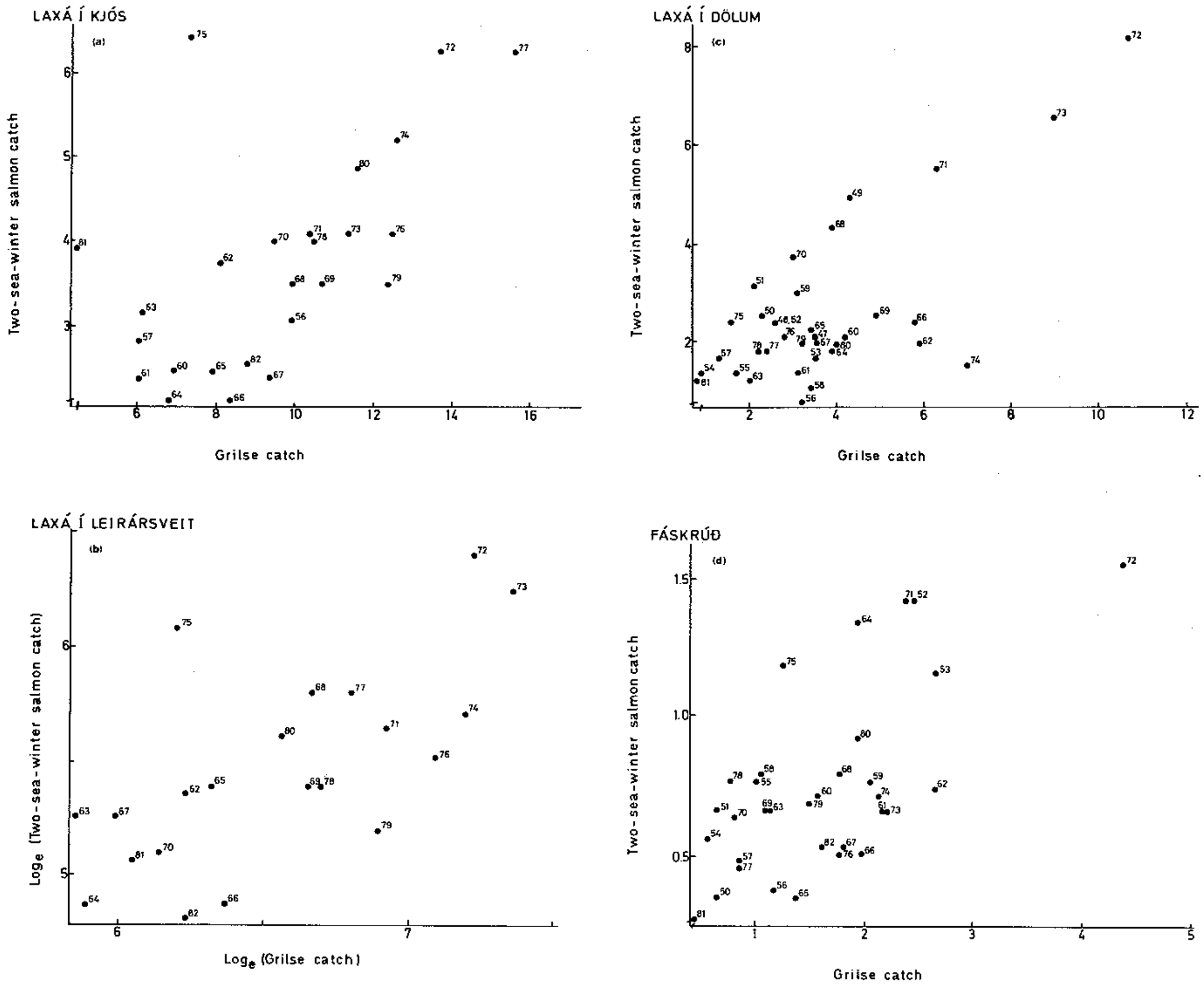

FIG. 1. Relations between yield of two-sea-winter salmon and yield of grilse the previous year for various Icelandic rivers. Year of two-sea-winter salmon catch (e.g. 61 = 1961) is marked on the graphs. (a) Catches on Laxá í Kjós (hundreds of fish); two-sea-winter catch = 0.278(grilse catch) + 109.127. (b) Log catches on Laxá í Leirársveit; log (two-sea-winter catch) = 0.640 log (grilse catch) + 1.278. (c) Catches on Laxá í Dölum (hundreds); two-sea-winter catch = 0.535(grilse catch) + 62.083. (d) Catches on Fáskrúd (hundreds); two-sea-winter catch = 0.265(grilse catch) + 33.140.

residuals against the independent variable (Peterman 1982). Normality of residuals was tested with the Kolmogorov–Smirnov one-sample goodness-of-fit statistic. Statistics were computed with the aid of the *Statistical Package for the Social Sciences* (Nie et al. 1975; Hull and Nie 1981).

Results

For 14 of the 15 rivers, there were highly significant ($P < 0.01$) positive relations between the catch of grilse in one year and the catch of two-sea-winter salmon in the following year. For the remaining river, Vídidalsá, the relations were also significant, but at $P < 0.05$ (Table 1; Fig. 1). The relations for logarithmically transformed data were slightly stronger or weaker for various cases, but their statistical significance at the 0.01 and 0.05 levels remained unchanged (Table 1). Depending on the river, log grilse catch explained from 25 to 85% of the log catch of two-sea-winter salmon in the next year. For some rivers (e.g. Laxá í Kjós, Fig. 1a), the relation improved markedly if anomalous data for one year were removed. For only one of the rivers, Laxá á Ásum, did the ratio of grilse (t) to salmon ($t + 1$) change significantly ($P < 0.05$) over the time periods investigated; in this river, significantly fewer grilse were caught relative to older salmon in recent years than in earlier years.

Of the 15 relations for the log-transformed data, 10 were significantly different from linear as judged by the Morris test; none were judged different from linear with the Varley–Gradwell test (Table 1).

The variances of some of the catches were stabilized by transforming the data to natural logarithms. Untransformed data from six rivers resulted in significantly ($P < 0.05$) positively heteroscedastic relations, but after transformation, only three were heteroscedastic, one of which was previously homoscedastic but became negatively heteroscedastic (Table 2). All residuals were normally distributed for both untransformed and logarithmically transformed data.

Discussion

Since no long-term escapement data are available for any of

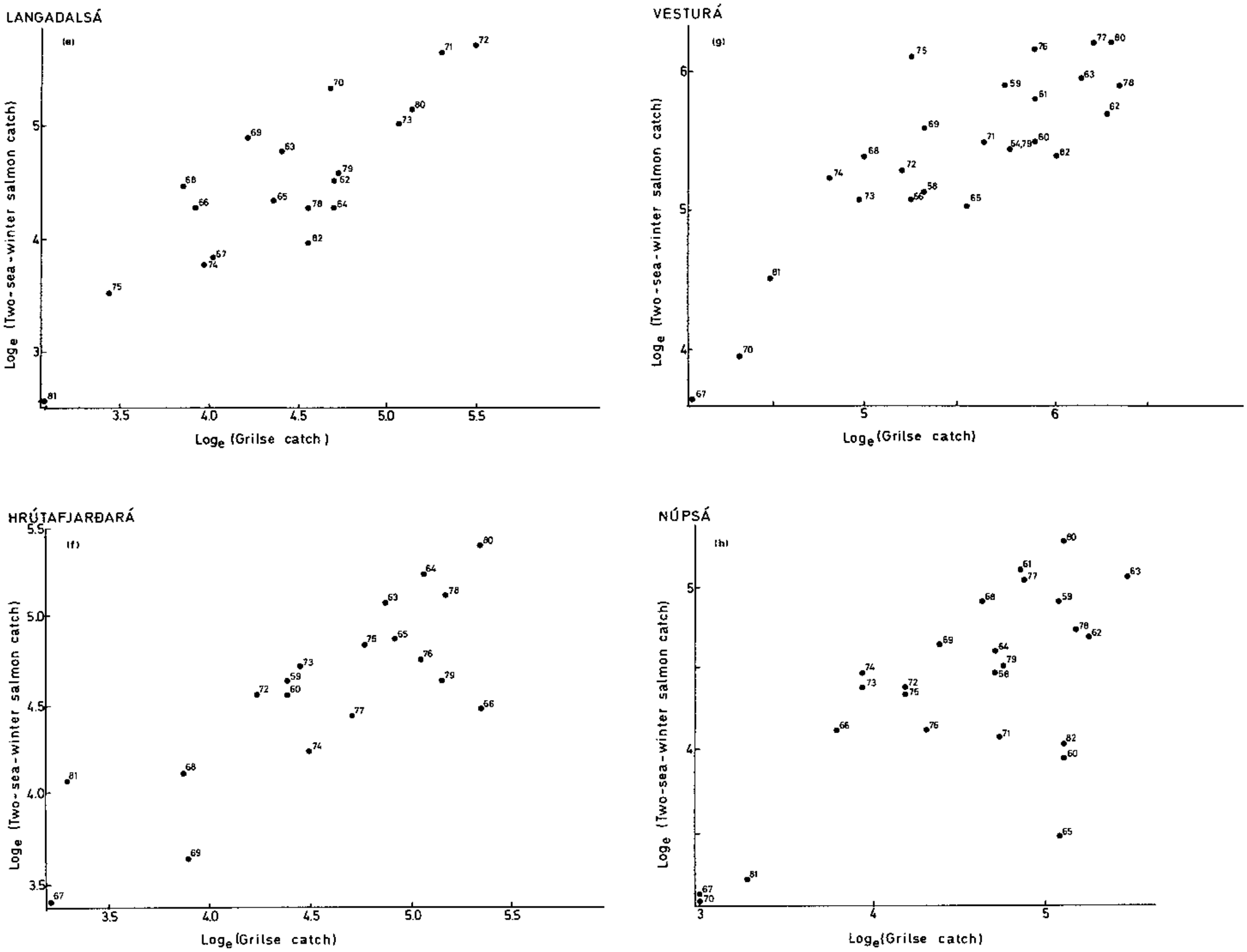

FIG. 1 (*Continued*). (e) Log catches on Langadalsá; log (two-sea-winter catch) = 1.095 log (grilse catch) − 0.418. (f) Log catches on Hrútafjardará; log (two-sea-winter catch) = 0.660 log (grilse catch) + 1.553. (g) Log catches on Vesturá; log (two-sea-winter catch) = 0.878 log (grilse catch) + 0.581. (h) Log catches on Núpsá; log (two-sea-winter catch) = 0.605 log (grilse catch) + 1.639.

the 15 rivers, I cannot ascertain if the relations between total abundance of grilse and two-sea-winter salmon are linear. Although the relation between harvest rate and total abundance need not be constant, linear, or nearly linear relations exist between yields of grilse and of two-sea-winter salmon for these rivers, at least over the observed ranges of catches. The widely differing conclusions on density dependence obtained from use of the Morris and the Varley–Gradwell methods do not clarify whether linear relations exist. Southwood (1978) and Benson (1973) discussed the controversies and problems surrounding the tests; Peterman (1978) found large discrepancies between the conclusions depending on which test he used. For the Icelandic data, the discrepancies between tests and difficulties in interpretation make them of little value for assessing the presence or absence of density dependence.

If significant density-dependent mortality occurs at sea, studies of Atlantic salmon (Jacobsson and Johansen 1921; Kristjánsson 1982; this paper), coho salmon (Gunsolus 1978) and sockeye salmon (Peterman 1982) indicate that it must occur mainly during the first year the salmon are in the sea. The critical period determining run size must also be during the freshwater rearing phase or during the first year the fish are at sea.

Although Peterman (1982) found that log transformations substantially improved stability of variance and normality of residuals for several stocks of Pacific salmon, I found that the benefits of log transformations of the Icelandic data ranged from moderate to nil, depending on the stock. For these data, a log transformation should not necessarily be preferred over untransformed data, since the data may be overtransformed (e.g. to negative heteroscedasticity) in searches for higher correlation coefficients.

The closest linear fits between log-transformed grilse and two-sea-winter salmon were for the northern rivers Austurá, Hofsá, and Vesturdalsá, which showed the three highest annual variations in grilse catches (Table 1). Variations in grilse catches were lower and correlations between grilse and two-sea-winter salmon yields were poorer in Vídidalsá, as well as in the southwestern rivers Laxá í Kjós and Laxá í Leirársveit. The better predictive fits for the northern rivers apparently result in part from the instability in their annual yields, which produces a

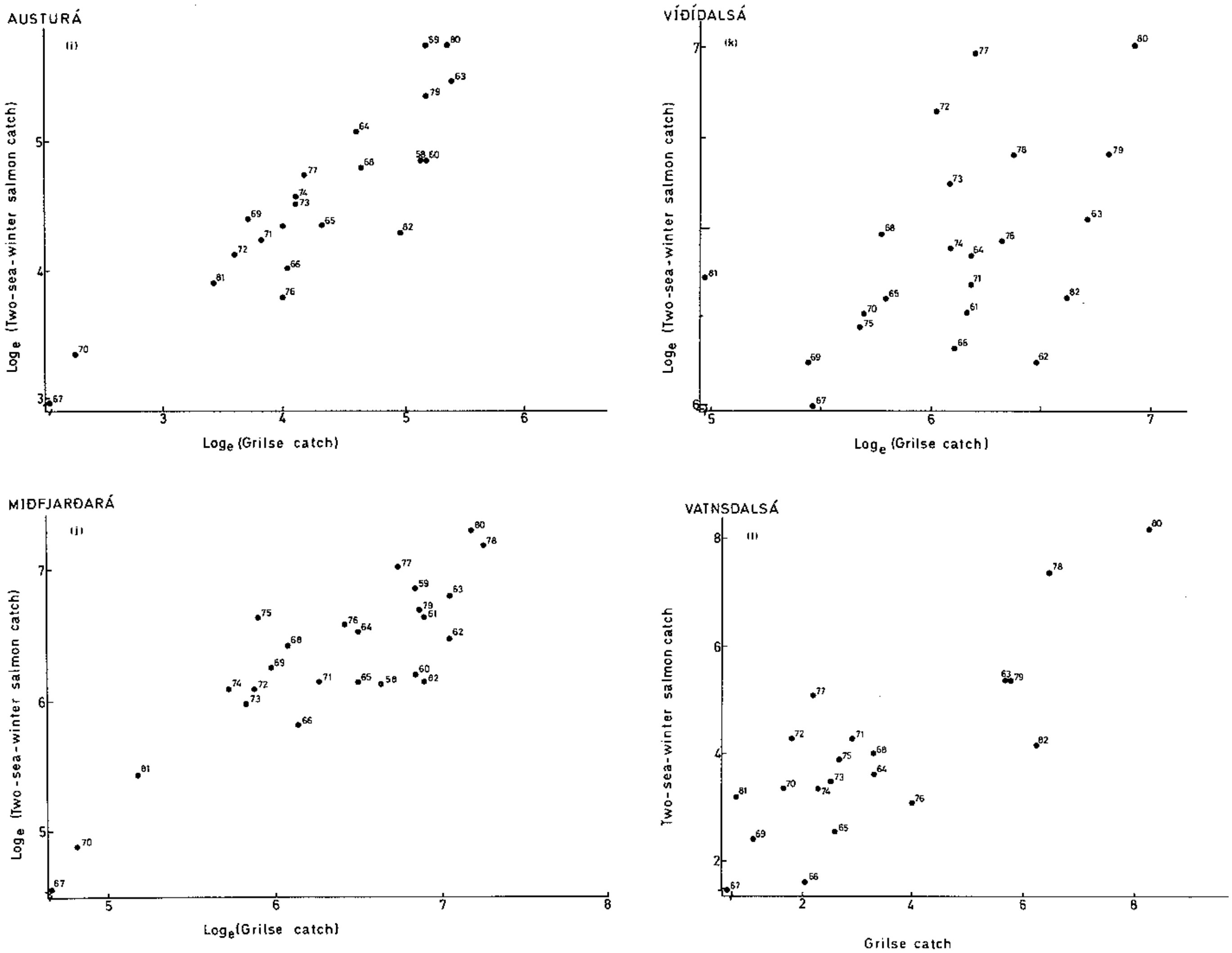

FIG. 1 (*Continued*). (i) Log catches on Austurá; log (two-sea-winter catch) = 0.679 log (grilse catch) + 1.612. (j) Log catches on Midfjardará; log (two-sea-winter catch) = 0.785 log (grilse catch) + 1.329. (k) Log catches on Vídidalsá; log (two-sea-winter catch) = 0.288 log (grilse catch) + 4.671. (l) Catches on Vatnsdalsá (hundreds); two-sea-winter catch = 0.636(grilse catch) + 185.518.

TABLE 2. Results of tests of homoscedasticity for predictive regressions for 15 Icelandic rivers ($*p < 0.05$; $**p < 0.01$).

	Homoscedasticity test			
	Untransformed		Log-transformed	
River	τ	P	τ	P
Laxá í Kjós	0.01	0.93	−0.13	0.38
Laxá í Leirársveit	0.36	0.02*	0.19	0.23
Laxá í Dölum	0.42	<0.01**	0.31	0.01**
Fáskrúd	0.18	0.15	0.01	0.96
Langadalsá	0.25	0.13	−0.22	0.20
Hrútafjardará	0.43	0.01**	0.11	0.53
Vesturá	0.15	0.28	−0.15	0.28
Núpsá	0.13	0.35	0.03	0.82
Austurá	0.50	<0.01**	0.34	0.02*
Midfjardará	0.29	<0.05*	0.03	0.85
Vídidalsá	0.11	0.46	0.04	0.78
Vatnsdalsá	0.07	0.65	−0.09	0.56
Laxá á Ásum	0.34	0.03*	−0.03	0.85
Vesturdalsá	0.19	0.20	−0.51	<0.01**
Hofsá	0.17	0.27	−0.22	0.15

wider range of regression points. Vídidalsá, which had the most variable grilse to salmon ratio, yielded many large, older salmon that may have been misclassified by weight–frequency curves. For example, fish classified as three-sea-winter may be large two-sea-winter males. More scales are needed to verify and improve age determination for Icelandic rivers, especially for rivers such as Vídidalsá with large, older fish. Improved age determination will lead to better separation of weight frequency curves and more accurate predictions.

For several rivers (e.g. Midfjardará, Laxá í Leirársveit, Fáskrúd, and Laxá í Kjós), omission of the 1975 data point would have considerably improved the correlation coefficients. That several rivers should independently show low ratios of grilse to salmon for this smolt class indicates that consistent, widespread environmental influences act on the grilse to salmon ratios. Scarnecchia (1983) documented the correlation between sea temperatures (and accompanying air and river temperatures) and variations in percentages of grilse and older salmon *between* different Icelandic stocks of Atlantic salmon. Such factors must also produce variations in grilse to salmon ratios *within* a river. Another possible reason for anomalous 1975 data points is that yield to escapement (Y/E) ratios for grilse in 1974 may have been abnormally low, or the Y/E ratio for two-sea-winter

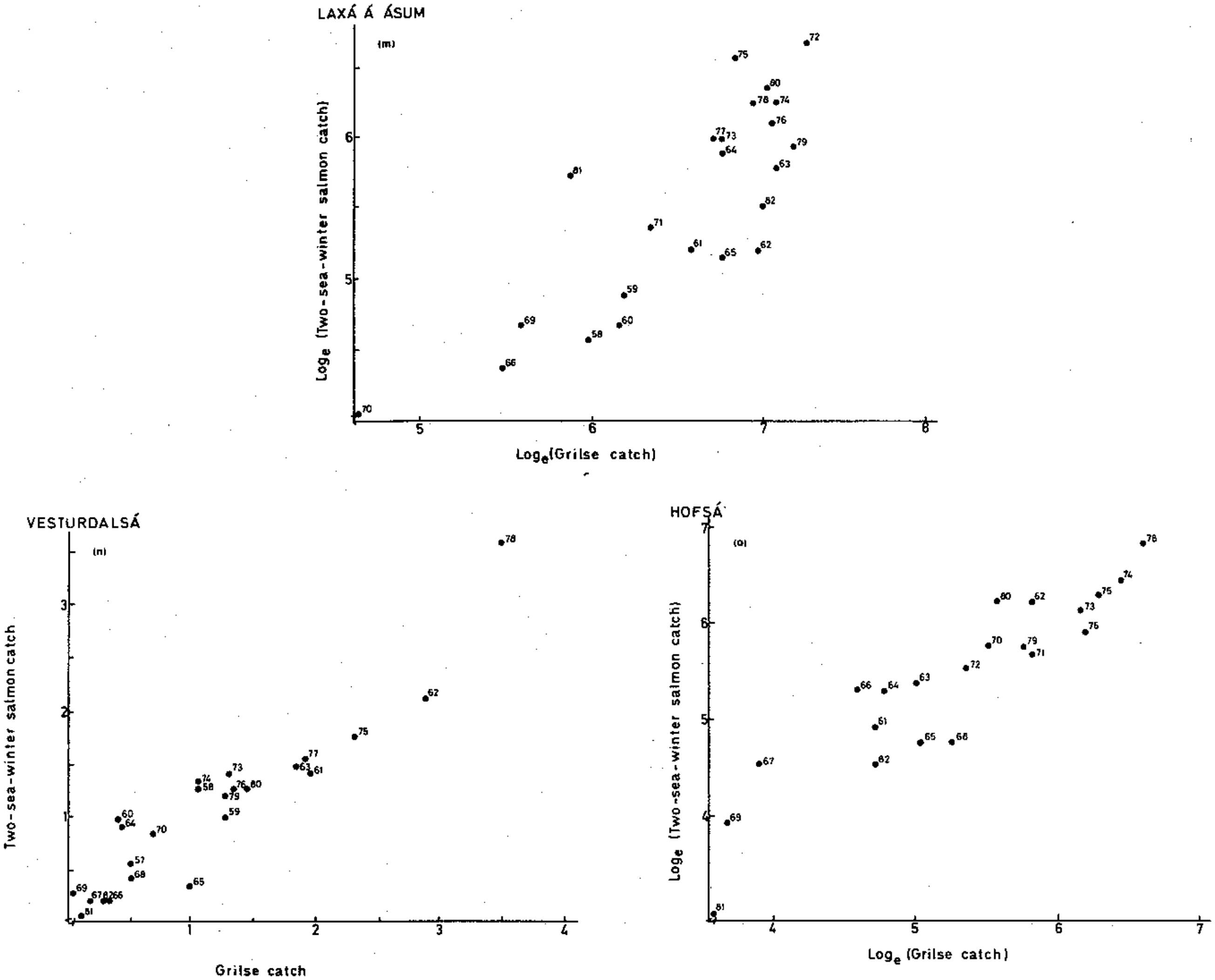

FIG. 1 (*Concluded*). (m) Log catches on Laxá á Ásum; log (two-sea-winter catch) = 0.919 log (grilse catch) − 0.476. (n) Catches on Vesturdalsá (hundreds); two-sea-winter catch = 0.796(grilse catch) + 11.522. (o) Log catches on Hofsá; log (two-sea-winter catch) = 0.928 log (grilse catch) + 0.487.

salmon in 1975 may have been unusually high. Escapement data are needed to better understand how Y/E ratios vary with such factors as relative strength of successive smolt classes, weather during the angling season, and streamflows. Effects of long-term fluctuations in ratios of grilse to two-sea-winter salmon can be partly compensated for by using predictive equations based on catch data over fewer consecutive years, or for both short-term and long-term influences, residuals can be related to prospective influential environmental variables or age-selective fishing.

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