

Quantifying the effectiveness of regional habitat quality index models for predicting densities of juvenile Atlantic salmon (*Salmo salar* L.)

Hedger RD, Dodson JJ, Bergeron NE, Caron F. Quantifying the effectiveness of regional habitat quality index models for predicting densities of juvenile Atlantic salmon (*Salmo salar* L.). Ecology of Freshwater Fish 2004: 13: 266–275. © Blackwell Munksgaard, 2004

Abstract – The suitability of using regional Habitat Quality Index (HQI) models for predicting distributions of juvenile salmon (*Salmo salar* L.) was examined using data acquired from selected rivers within Québec, Canada. Regional HQI models were derived by identifying preferences of salmon fry and parr for the habitat properties of flow velocity, water column depth and granulometric index (an index of substrate size) for groups of rivers. These were compared with local HQI models, derived from preferences for habitat properties within individual rivers. Relationships between HQI values and densities of juvenile salmon were established through the use of nonlinear regression. In all cases, the regional HQI models were less effective for explaining distributions of juvenile salmon than local HQI models based on individual rivers. Regional HQI models were relatively ineffective when the habitat characteristics of the river to which they were applied differed greatly from the characteristics of the other rivers within the region. It is inferred that the relationship between the effectiveness of the regional HQI model and the difference in characteristics between individual rivers and those of the region may be used in an *a priori* determination of whether a regional HQI may be applied effectively to any given river.

**R. D. Hedger¹, J. J. Dodson¹,
N. E. Bergeron², F. Caron³**

¹Département de Biologie, Université Laval,
²Institut National de la Recherche Scientifique–
Eau, Terre et Environnement (INRS-EET), ³Société de la Faune et des Parcs du Québec, QC,
Canada

Key words: juvenile Atlantic salmon; Habitat Quality Index models; transferability

Richard D. Hedger, Département de Biologie, Université Laval, Québec, QC, Canada G1K 7P4; e-mail: richard.hedger@bio.ulaval.ca

Accepted for publication August 26, 2004

Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

Habitat quality index (HQI) models provide a quantitative means of determining the quality or suitability of a habitat to support biota (such as salmon). Thus, they fulfil the role of providing a link between scientific investigations into species/habitat relationships and the requirements of an effective management programme. Given the decline in stocks of salmon (Noakes et al. 2000; Lackey 2003), the necessity for an effective quantification of river habitat quality through the use of HQI models has increased.

The dominant method for producing a HQI model for juvenile salmon has been to examine the preferences of juvenile salmon for different river habitat

properties. Given that salmon has been intensely researched (Klemetsen et al. 2003), numerous studies have related distributions of juvenile salmon to properties such as the flow velocity, water column depth, substrate size, bed topography and topology and river width (DeGraffe & Bain 1986; Morantz et al. 1987; Heggnes 1990; Caron & Talbot 1993; and Scruton & Gibson 1993; Bardonnet & Balinière 2000). Preference curves are produced by investigating the distribution of salmon throughout the ranges of habitat properties, and these preferences for different properties are then combined into a HQI model. Two types of HQI models are currently used: (i) local HQI models, which are based on single streams (Leclerc et al. 1996; Guay et al. 2000) and (ii), regional HQI models,

which are produced from data acquired from different rivers across a region (Scruton & Gibson 1993; Lamouroux et al. 1999; Mäki-Petäys et al. 2002). Regional HQI models have the utility that relationships established for the region may be applied to rivers where data on salmon densities are absent, but are limited by the fact that the salmon/habitat relationships used to calibrate them may differ from those of the river to which they are to be applied.

The issue of applying HQI models that were derived from one river or a set of rivers within a region to predict habitat quality in a different river has gained increasing attention. Many studies have rejected the notion of transferability (Grosheims & Orth 1994; Leftwich et al. 1997; Strakosh et al. 2003). The dominant explanation for a lack of transferability is that populations of the same fish species may have different observed preferences, and thus produce different HQI models, in different rivers (Glozier et al. 1997). Observed preferences may differ between rivers because of differences in (i) inter- and intraspecific competition, (ii) habitat availability and (iii) food abundance (Leftwich et al. 1997). The greater these differences, the lesser the transferability. Other studies, however, have suggested that HQI models may be transferred from one river or set of rivers to another – at least at the regional scale (Freeman et al. 1997; Lamouroux et al. 1999). Transferability of HQI models tends to be strongest (i) when the HQI models are calibrated from the habitat properties that most strongly affect fish densities (Nykanen & Huusko 2004) and (ii) when fish occupy distinct microhabitats (Freeman et al. 1997). However, there has been a lack of research relating transferability of HQI models to the similarities or differences between rivers in terms of habitat properties.

In this paper, we examine the utility of using regional HQI models for predicting population densities of juvenile Atlantic salmon. We produce HQI models by examining the preferences of juvenile salmon for flow velocity, water column depth and substrate size, taking into account the availability of the habitat, the fact that preferences for specific habitat properties are not independent of preferences for other

properties, and that certain ranges of habitat will be actively preferred or avoided. We then compare the regional HQI models with local HQI models determined from individual rivers as a means of quantifying the effectiveness of regional HQI models.

Study area

Five rivers were used in this study: the Sainte-Marguerite, Grande Rivière de la Trinité (the Trinité), the Saint-Jean, the Bec-Scie and the Jupiter (Fig. 1).

The Sainte-Marguerite (48.1636°N, 69.5585°W) and the Trinité (49.4105°N, 67.3366°W) are situated on the north coast of the Saint-Lawrence. The bedrock on the north coast of the Saint-Lawrence is that of the Canadian Granitic shield, which causes the water of both of these rivers to have low conductivity (15–20 $\mu\text{mhos cm}^{-1}$) and pH (5.5–6). The Sainte-Marguerite drains into the Saguenay fiord whereas the Trinité drains directly into the Saint-Lawrence. The Sainte-Marguerite is the larger of the two rivers, draining a basin of 2130 km², along its principle branch (98 km in length) and its north-east branch (97 km in length); the Trinité drains a basin of 562 km² along its length of 80 km. Both the Sainte-Marguerite and the Trinité have a succession of different circulation features: rapids, sills and channels, typically populated by rocks and stones in fast flowing water and, sand and gravel in slower flowing waters (Caron et al. 2000; Eaton & Lapointe 2001; Talbot & Lapointe 2002).

The Saint-Jean (48.7828°N, 64.3712°W) is situated at the extreme east of the Gaspé peninsular. The Gaspé peninsular is dominated by calcareous sedimentary rocks, which results in the high conductivity (c. 250 $\mu\text{mhos cm}^{-1}$) and pH (c. 8) of Saint-Jean. It drains a basin of 1134 km² along its principle branch (115 km in length) and flows into a large estuary sheltered by a spit. The river has a regular slope with a rapid circulation (Caron & Raymond 2000). The coarsest substrates occur in steps, the dominant link features.

The Bec-Scie (49.4772°N, 63.6081°W) and the Jupiter (49.7105°N, 64.0518°W) are situated on the

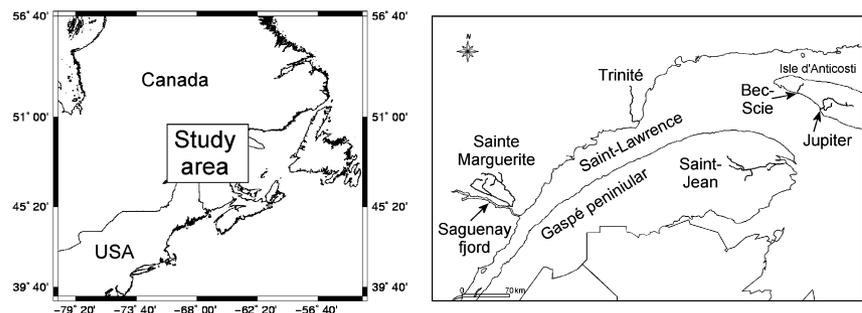


Fig. 1. Positions of the rivers Sainte-Marguerite, Trinité, Saint-Jean, Bec-Scie and Jupiter.

Isle d'Anticosti. Like the Gaspé peninsular, Isle d'Anticosti is dominated by sedimentary rocks, resulting in a conductivity and pH similar to that of the Saint-Jean. The Jupiter is the larger of the two rivers, draining a basin of 984 km² along its length of 75 km, whereas the Bec-Scie drains a basin of 131 km² along its length of 19 km. Both rivers exhibit rapid flows throughout their lengths. Substrate sizes are coarse, and the dominant circulation features are sills.

Methods

Sampling

Population densities of juvenile salmon and characteristics of the river habitat were determined by *in situ* sampling from 1988 to 1992 for the Sainte-Marguerite and the Saint-Jean; from 1986 to 1990 for the Trinité, from 1985 to 1994 (excluding years 1986 and 1993) for the Bec-Scie and in 1990 and 1992 for the Jupiter. Sampling was conducted during daylight between 9:00 and 14:40 hours. The bulk of the sampling occurred in late July and August, although sampling was occasionally conducted in early September. Sampling stations were situated along the length of each river and were chosen to encompass the range of habitat characteristics that was present. At each station, one to three parcels were selected, each of dimensions 5 m × 20 m. Parcel positions were chosen to represent the average habitat characteristics of each station, with the caveat that it was necessary for the water column depth to be less than *c.* 1.5 m for the electro-fishing to work correctly. It is unlikely that our inability to sample at depths >1.5 m would have affected our determination of salmon preferences because most juvenile Atlantic salmon exploit river depths <1 m (DeGraffe & Bain 1986; Gries & Juanes 1998; Mäki-Petäys et al. 2002).

Population densities of juvenile salmon (both fry and parr) were estimated by electro-fishing. One-pass electro-fishing was used in the Trinité, three-pass electro-fishing was the dominant approach used in the other rivers, but up to five passes were made in certain parcels (typically under 20% of parcels) in the Saint-Jean, the Bec-Scie and the Jupiter. Fish densities were determined in both closed stations (using block nets) and open stations (using dip nets). For the three-pass (or more) electro-fishing, the method of Rextad & Burnham (1991) was used to estimate densities in the closed stations, and the method described by Caron & Ouellet (1987) and tested by Jones & Stockwell (1995) was used to estimate densities in the open stations. This enabled the calibration of estimates in the open stations by the percentage effectiveness of the electro-fishing of the first pass in the closed stations, which reduced the bias that has been noted when

comparing open stations with closed stations (see Vadas & Orth 1993). Lengths of salmon parr were also measured. The measured river habitat properties were mean flow velocity (to a precision of 0.05 m s⁻¹), mean water column depth (to a precision of 0.05 m), and proportional composition of substrate within each parcel. According to the scale of Boudreault (1984), substrate type was classified into granulometric classes according to size. Granulometric class 1 consisted of sand (< 5 mm); class 2, gravel (5–40 mm), class 3, pebbles (40–80 mm); class 4, cobbles (80–250 mm); class 5, boulders (250–500 mm); class 6, bedrock. Proportional substrate composition was estimated visually to the nearest 5%, and then combined into a granulometric index as follows (Boudreault 1984):

$$G_i = \sum (G_c \times G_p) \quad (1)$$

where G_i is the granulometric index, G_c is the granulometric class and G_p is the proportion of the substrate composed of that class.

Statistical modelling

Differences between the characteristics of individual rivers and those of the others were determined using a Euclidean distance measurement (see Trainor & Church 2003):

$$ED_{ij} = \sqrt{\sum_{k=1}^n [f_k(\bar{H}_{ki}) - f_k(\bar{H}_{kj})]^2} \quad (2)$$

where ED_{ij} is the Euclidean distance between the mean of the habitat property H_k (velocity, depth or granulometric index) of the given river (i) and that of the other rivers (j), and f_k is a function to standardise the means of each habitat property. Standardisation, which resulted in the vector of mean habitat properties for a given habitat property having a mean of zero and a standard deviation of unity was undertaken because the properties of velocity, depth and substrate size were measured with different units. As a result of standardisation, velocity, depth and substrate size were assigned equal weight in the Euclidean distance measurement.

For each river under investigation, two types of HQI models were devised: first, two local HQI models (one for fry, the other for parr) using data derived solely from that river; and secondly, two regional HQI models (one for fry, the other for parr) using data derived from all the other rivers. For estimating the HQI models in our study, we used a modification of the method devised by Jacobs (1974):

$$HQI = \frac{S_{vdg} - A_{vdg}}{(S_{vdg} + A_{vdg}) \times 2(S_{vdg} \times A_{vdg})} \quad (3)$$

where S_{vdg} is the proportional utilisation by fish of a specific combination of ranges of the three habitat properties (velocity, depth and granulometric index) and A_{vdg} is the proportional availability of that interval. This method of producing an HQI model had three advantages: first, it compensated for differences in the availability of habitat; secondly, proportional utilisation and proportional availability were estimated over combinations of all properties together, so preferences of salmon for combinations of different habitat characteristics was taken into account, and thirdly, it indicated the habitat ranges being actively preferred (values >0) or avoided (values <0).

Relationships between HQI values and densities of juvenile salmon were established using the nonlinear regression model:

$$S_D = a(HQI + 1)^b \tag{4}$$

where S_D is the population density of salmon (fry or parr), HQI is the habitat quality index (fry or parr), and a and b are coefficients of the model. A boot-strapping approach was used for establishing relationships between local HQI models and densities of juvenile salmon to ensure independence between the data used to calibrate the model and those used to verify the strength of fit (Venables & Ripley 1997).

The relative effectiveness of the regional HQI models was determined by correlating the values of each local HQI model with the values of the appropriate regional HQI model (i.e., the regional HQI model that was calibrated with data from the rivers other than the one that was used for calibrating the local HQI model). The rationale to this was that the greater the correlation between local and regional HQI model values, the greater the ability of the regional HQI model for predicting habitat qualities. Relationships between (i) the correlations between the local and regional HQI models and, (ii) the Euclidean distances, were established by linear regression.

Results

Rivers had greatly different habitat characteristics (Table 1; Fig. 2). At one extreme, the Sainte-Marguerite and the Trinité were characterized by

relatively slow flow velocities (*c.* 0.25 m s⁻¹), relatively deep water column depths (*c.* 0.5 m), and intermediate substrate sizes (granulometric index values of *c.* 3.5). At the other extreme, the Bec-Scie and the Jupiter were characterized by relatively fast flow velocities (*c.* 0.5 m s⁻¹), relatively shallow water column depths (*c.* 0.25 m), and relatively coarse substrate sizes (granulometric index values of *c.* 3.8). The Saint-Jean shared characteristics of both groups of rivers: relatively fast flow velocities similar to those of the Bec-Scie and the Jupiter (*c.* 0.5 m s⁻¹), but relatively deep water column depths similar to those of the Sainte-Marguerite and the Trinité (*c.* 0.5 m). Measured substrate sizes in the Saint-Jean were relatively fine (granulometric index values of *c.* 2.75).

Fry and parr favoured different habitats (Fig. 3). Fry favoured slower velocities (the most strongly favoured velocity range occurred between 0.25 and 0.5 m s⁻¹, and velocities >0.75 m s⁻¹ were avoided) whereas parr favoured greater velocities (the most strongly favoured range occurred 0.5 and 0.75 m s⁻¹, and velocities <0.5 m s⁻¹ were avoided). Both fry and parr favoured shallow depths (<0.5 m), but the preference of fry for the shallowest depths was much stronger. Fry favoured finer substrates (granulometric index values of 2.5–4, corresponding to substrate types consisting of gravel, pebbles and cobbles) than parr (granulometric indices of 3.5–5, corresponding to substrate types consisting of pebbles, cobbles and boulders). Both fry and parr avoided sand substrates and bare rock. There was marked difference in the preferences of juvenile salmon according to the river (Fig. 4). For example, a relatively weak relationship between juvenile fry density and water column depth was found for the Saint-Jean, whereas a strong negative relationship was found for the other rivers. An analysis of variance of the combined preferences of juvenile salmon showed that there was a significant difference in the preference of juvenile salmon according to the river ($F = 3.3238$; $P = 0.01127$).

Population densities of juvenile salmon increased with increasing HQI values in an exponential manner (Fig. 5). However, HQI models were often unable to explain much of the variation in population density, and there was a wide range of densities at large HQI

Table 1. Habitat properties of the samples.

River	Velocity (m s ⁻¹)				Depth (m)				Granulometry			
	Min.	Mean	Max.	SD	Min.	Mean	Max.	SD	Min.	Mean	Max.	SD
Sainte-Marguerite	0.00	0.24	2.05	0.24	0.00	0.51	1.20	0.22	1.00	3.31	4.95	1.08
Trinité	0.00	0.24	2.05	0.25	0.05	0.50	1.10	0.22	2.00	3.51	4.95	0.92
Sainte-Jean	0.05	0.48	1.10	0.31	0.17	0.45	0.95	0.15	0.00	2.85	4.45	1.16
Bec-Scie	0.01	0.48	1.18	0.28	0.08	0.25	0.61	0.11	1.10	3.75	6.00	0.77
Jupiter	0.00	0.51	1.20	0.24	0.00	0.23	0.57	0.10	2.75	3.81	4.71	0.50

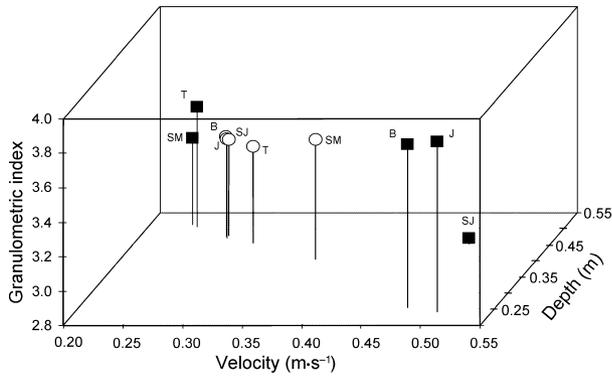


Fig. 2. Mean habitat properties of rivers: filled squares indicate mean properties of specified rivers; empty circles indicate mean characteristics of all rivers except for the specified river: SM, Sainte-Marguerite; T, Trinité; ST, Saint-Jean; B, Bec-Scie; J, Jupiter.

values. The strongest relationship between population densities of parr and local HQI values was for the Jupiter ($R^2 = 0.69$) whereas the weakest relationship was for the Trinité ($R^2 = 0.35$). Stronger relationships

were generally found for parr than for fry, although the difference in the strength of the relationship was river-specific. For the Trinité, the strength of relationship was similar; for the Jupiter, the strength of the relationship for parr was greater than twice that of fry when local HQI models were used.

Relationships between the population density and regional HQI models were weaker than those between the population density and local HQI models, although, again, the difference in the strength of the relationship was river-specific. Strongest relationships were found for the Sainte-Marguerite and the Trinité, a weaker relationship was found for the Saint-Jean, and weakest relationships were found for the Bec-Scie and the Jupiter. There was an inverse relationship between (i) the correlation between the local and regional HQI values and (ii) the Euclidean distance between the mean habitat characteristics of the river and those of the region (Fig. 6). For example, as the mean habitat characteristics of the Jupiter differed greatly from those of the region, there was little correlation between the values of the local HQI model based on the Jupiter

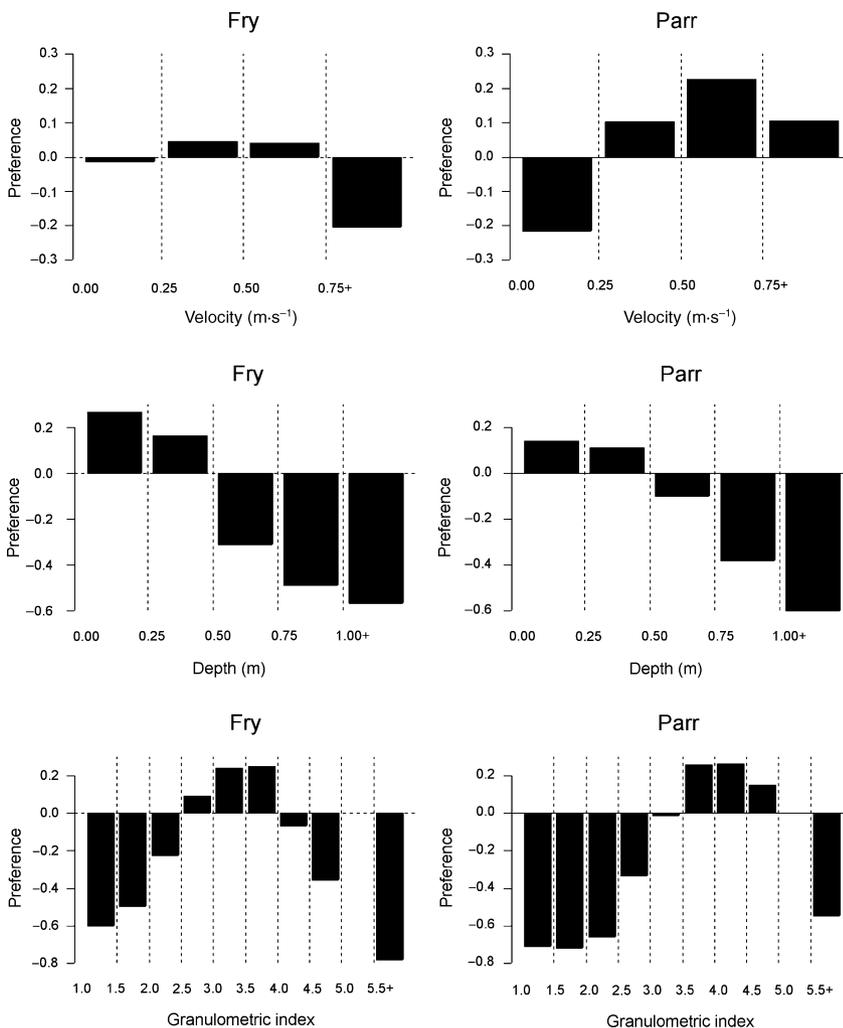


Fig. 3. Individual preferences of fry and parr for velocity, depth and granulometric index (mean of all rivers).

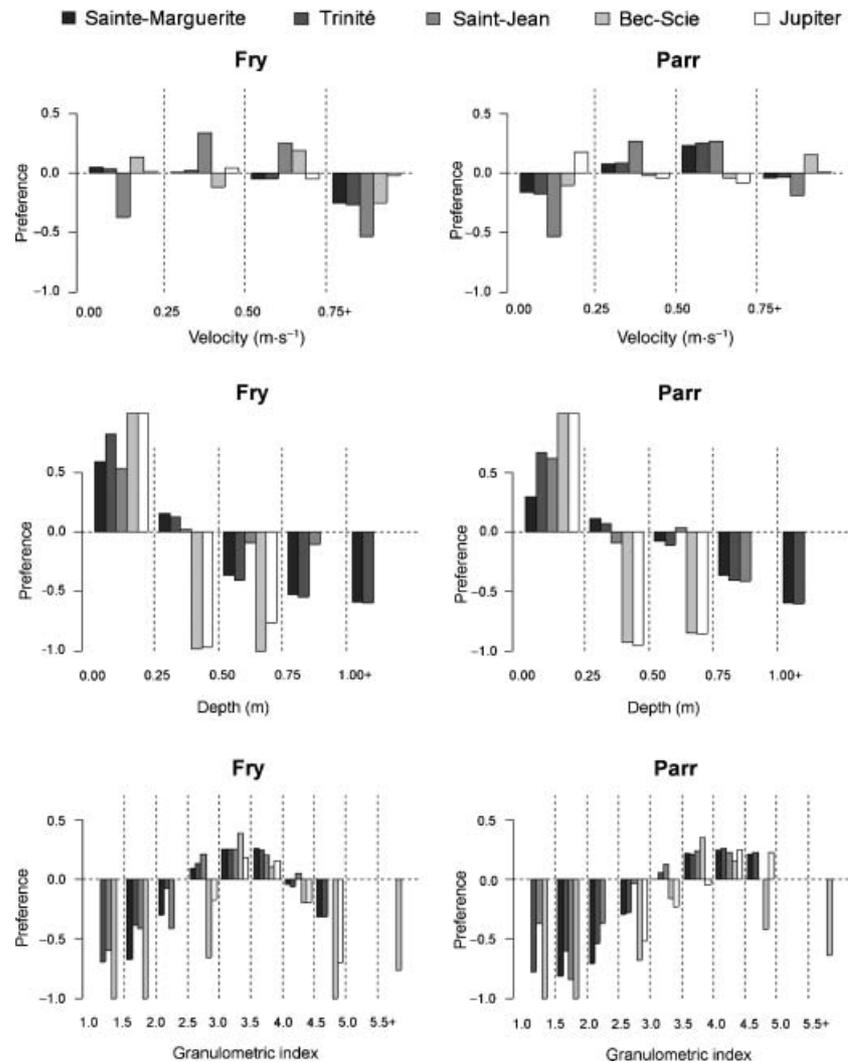


Fig. 4. Individual preferences of fry and parr for velocity, depth and granulometric index (rivers considered separately).

and the values of the regional HQI model based on the other rivers. As the mean habitat characteristics of the Trinité were more similar to those of the region, there was greater correlation between its local HQI model and the regional HQI model.

Discussion

Two hypotheses are proposed for the river-specific differences in observed preference of juvenile salmon. First, differences between the rivers in terms of the mean size of the juvenile salmon may have resulted in different preferences. For example, mean juvenile salmon length in the (northern) Bec-Scie was 74 mm, which was significantly greater than the mean length of 69 mm in the Saint-Jean ($t = 3.43$, $P = 3.102 \times 10^{-4}$). As the relatively large juveniles in the Bec-Scie may have different requirements or tolerances than the smaller juveniles in the Saint-Jean – for example, a tolerance for greater flow

velocities – they may consequently manifest different preferences. Secondly, it is possible that a *spatial* relationship between population density and the contiguity of different habitats existed: that the population density of juvenile salmon within a given area depended not only on the habitat characteristics of the area in which the juvenile salmon were found, but also on the habitat characteristics of surrounding areas. This contiguity of different habitats would have differed between the rivers, thus ensuring different distributions of juvenile salmon and different observed preferences. However, it was not possible to detect such a component within the data used in this study because they were relatively sparse – only several observations per year of population densities of juvenile salmon and habitat characteristics per segment of river, the length of which could be greater than several kilometres.

The most noteworthy characteristics of the relationships between the population density of juvenile

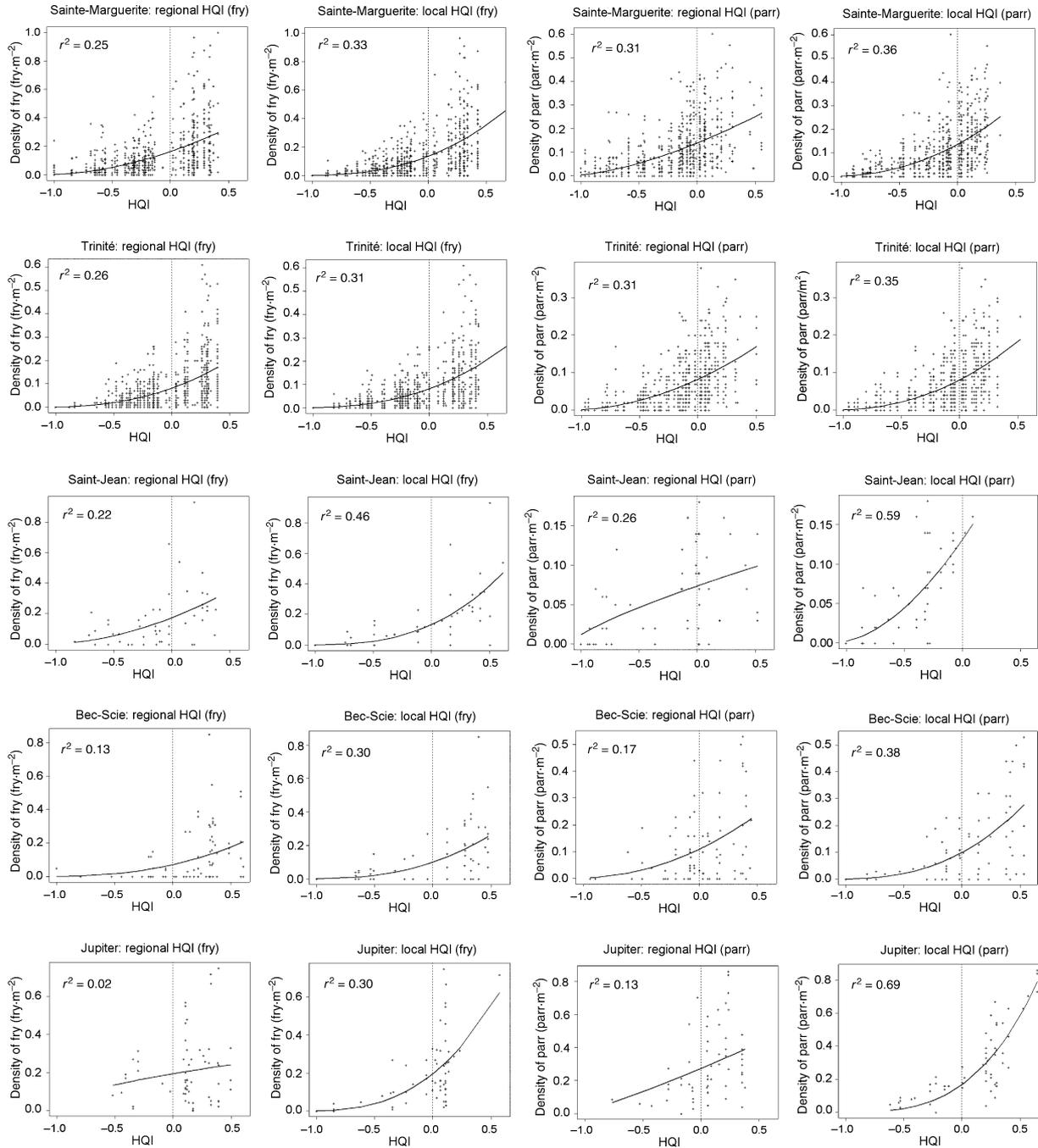


Fig. 5. Local and regional HQIs for fry and parr.

salmon and HQI models were (i) the often relatively small amount of variance in population density that was explained by the HQI models, (ii) the difference between the predictive powers of the fry HQI models and those of the parr HQI models and (iii) the difference in the predictive power of the local HQI models and those of the regional HQI models.

The amount of variance in population density that was explained by the HQI models differed according

to the river: the local HQI model for parr explained least variance for the Trinité ($R^2 = 0.35$) and most variance for the Jupiter ($R^2 = 0.69$). Some of the unexplained variance may be attributed to variation in properties other than velocity, depth or substrate size – other properties have been found to affect salmon density including temperature (Torgersen et al. 1999), light intensity (Heggenes & Dokk 2001; Girard et al. 2003) and predation (Dionne & Dodson 2002).

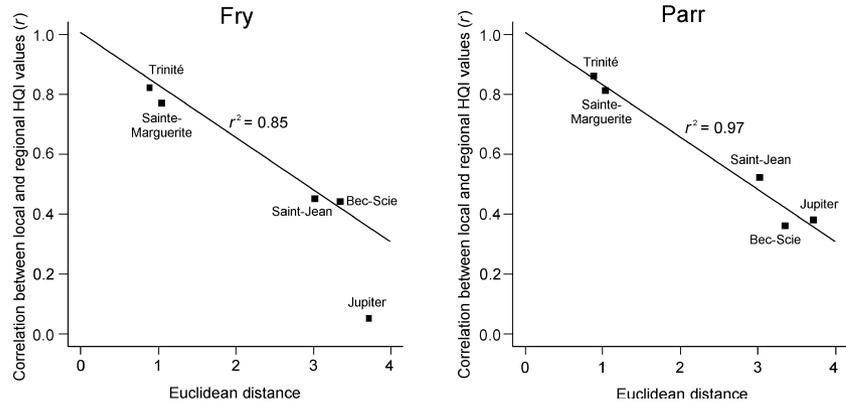


Fig. 6. Relationships for fry and parr between (i) correlations between local and regional HQI values and (ii) Euclidean distances.

Additionally, it is possible that there was a spatial pattern of habitat properties affecting densities of juvenile salmon. The population density for a given location may have depended on the surrounding habitat and the habitat of that location.

The increase in the strength of the relationship between the population density of juvenile salmon and HQI models as the life-stage changed from fry to parr may be explained by the increased motility of parr, which would enable parr to move to more favourable habitat locations. Older parr have been found several 100 m from redds (Baglinière et al. 1994), presumably exploiting more favourable habitats for that life-stage than were available at the redd.

For any given river, the regional HQI model was less effective than the local HQI model for predicting the population density of juvenile salmon because the observed preferences used to produce the regional HQI model differed from those of the river to which it was applied. The greater the similarity in mean habitat properties (i.e., the lesser the Euclidean distance), the greater the correlation between the local and regional HQI models. It follows from this that it may be possible to use the relationship between the correlations between local and regional HQI models and the Euclidean distance between mean habitat properties to determine, *a priori*, the accuracy of applying a regional HQI model to any given river. This may thus enable habitat quality modelling to be applied to rivers for which a sample of habitat properties is available but for which data on population densities of fish is absent.

Conclusion

It has been shown in this paper that local HQI models are more effective than regional HQI models for predicting population densities of juvenile salmon from properties of the river habitat. This is unfortunate because it is regional, as opposed to local, HQI models that are of potentially more interest for the manage-

ment of salmon stocks, in terms of predicting population densities for rivers where electro-fishing data are unavailable. The relative predictive power of the regional HQI model was seen to be river-specific, depending upon how similar the mean habitat characteristics of that river were to those of the region. The relationship between the relative predictive power of a regional HQI model and the similarity of the habitat properties of a given river to those of the region may be quantified – in this paper, this has been achieved using data for five rivers, and with the inclusion of additional rivers more information on the type of relationship may be achieved, such as the existence of nonlinearity. The quantification of this relationship may be used for *a priori* determination of how effective a regional HQI model will be for predicting population densities of salmon in any given river for which information on habitat properties is available but for which information on population densities is lacking.

Resumen

1. Los modelos de índices de calidad de hábitat (HQI) que definen la calidad de un hábitat para mantener una población de peces sobre la base de las propiedades físicas del hábitat, pueden ser derivados de datos adquiridos de ríos individuales (modelos locales HQI) o de grupos de ríos de una región determinada (modelos regionales HQI). Los modelos regionales HQI tienen la ventaja de que pueden ser utilizados para predecir la calidad del hábitat en ríos dentro de una región donde no haya datos sobre las poblaciones de peces. Este trabajo examina el grado de adecuación de utilizar modelos regionales HQI para predecir las densidades de peces utilizando datos de distribución de juveniles de *Salmo salar* L. y las características del hábitat de cinco ríos de Québec (Canadá): Ríos Sainte-Marguerite, Grande Rivière de la Trinité, Saint-Jean, Bec-Scie y Júpiter.

2. Las densidades de juveniles de *S. salar* y las características del hábitat de los ríos (velocidad del flujo, profundidad de la columna de agua e índice granulométrico) fueron medidas en parcelas de 5 a 20 metros, sobre posiciones seleccionadas a lo

largo de los ríos. Los modelos locales y regionales HQI fueron derivados de algoritmos que comparan la distribución de los juveniles con la distribución de las características del hábitat. Este algoritmo procesa velocidad, profundidad y índices granulométricos simultáneamente así que las estimas de HQI no tienen errores debidos a la selección preferencial de alguna característica específica del hábitat. Las relaciones entre los valores del HQI y las densidades de juveniles fueron establecidas a través de regresiones no lineares. Los modelos regionales HQI fueron entonces utilizados para predecir la calidad del hábitat en ríos específicos. A su vez, estas predicciones fueron comparadas con la calidad del hábitat predicha por los modelos locales HQI que habían sido derivados de los ríos específicos.

3. Fuera o no el modelo regional o local HQI, una proporción grande de la variación en las densidades de juveniles permaneció no explicada. Los modelos regionales HQI fueron menos efectivos para explicar las distribuciones de juveniles de *S. salar* que los modelos locales HQI basados en ríos específicos. La eficiencia de los modelos regionales HQI estuvo inversamente relacionada a la diferencia entre las características medias de los ríos específicos a los que se aplicaron los modelos y las características medias de los ríos sobre los que se derivaron los modelos regionales HQI.

4. Inferimos que la relación entre la eficiencia del modelo regional HQI y la diferencia entre las características de los ríos específicos y los de las regiones pueden ser utilizados en determinar *a priori* si un modelo regional HQI puede ser aplicado con eficiencia a un río específico.

References

- Baglinière, J.-L., Prévost, E. & Maisse, G. 1994. Comparison of population dynamics of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in a small tributary of the river Scorff (Brittany, France). *Ecology of Freshwater Fish* 3: 25–34.
- Bardonnet, A. & Balinière, J.-L. 2000. Freshwater habitat of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 57: 497–506.
- Boudreault, A. 1984. Méthodologie utilisée pour la photo-interprétation des rivières à saumon de la Côte-Nord. Gilles Schooner Inc: Doc. Dactylo.
- Caron, F., & Ouellet, G. 1987. Méthodologie d'inventaire des saumon juveniles au Québec. In: Thibault, M. & Billard, R., eds. *Restauration des rivières à saumons*, Paris: Institut Nationale de la Recherche Agronomique, pp. 77–84.
- Caron, F. & Raymond, C. 2000. Rapport d'opération de la rivière Saint-Jean en 1999. Québec: Société de la faune et des parcs du Québec, Direction de la recherche sur la faune, 64 pp.
- Caron, F. & Talbot, A. 1993. Re-evaluation of habitat classification criteria for juvenile salmon (*Salmo salar*). In: Gibson, R.J. & Cutting, R.E., eds. *Production of juvenile Atlantic salmon, Salmo salar*, in natural waters. Canadian Special Publications of Fisheries and Aquatic Science, 118, 139–148.
- Caron, F., Gauthier, C. & Lamy, R. 2000. Rapport d'opération de la rivière de la Trinité en 1999. Québec: Société de la faune et des parcs du Québec. Direction de la recherche sur la faune, 97 pp.
- DeGraffe, D.A. & Bain, L.H. 1986. Habitat use and preferences of juvenile Atlantic salmon in two Newfoundland Rivers. *Transactions of the American Fisheries Society* 115: 671–681.
- Dionne, M. & Dodson, J.J. 2002. Impact of exposure to a simulated predator (*Mergus merganser*) on the activity of juvenile salmon (*Salmo salar*) in a natural environment. *Canadian Journal of Zoology* 80: 2006–2013.
- Eaton, B.C. & Lapointe, M.F. 2001. Effects of large floods on sediment transport and reach morphology in the cobble-bed Sainte Marguerite River. *Geomorphology* 40: 291–309.
- Freeman, M.C., Bowen, Z.H. & Crance, J.H. 1997. Transferability of habitat suitability criteria for fishes in warm water streams. *North American Journal of Fisheries Management* 17: 20–31.
- Girard, P., Boisclair, D. & Leclerc, M. 2003. The effect of cloud cover on the development of habitat quality indices for juvenile Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 60: 1386–1397.
- Glozier, N.E., Culp, J.M. & Scrimgeour, G.J. 1997. Transferability of habitat suitability curves for a benthic minnow, *Rhinichthys cataractae*. *Journal of Freshwater Ecology* 12: 379–393.
- Gries, G. & Juanes F. 1998. Microhabitat use by juvenile Atlantic salmon (*Salmo salar*) sheltering during the day. *Canadian Journal of Zoology* 76: 1441–1449.
- Groshens, T.P. & Orth, D.J. 1994. Transferability of habitat suitability criteria for Smallmouth Bass, *Micropterus dolomieu*. *Rivers: Studies in the Science, Environmental Policy and Law of Instream Flow* 4: 192–212.
- Guay, J.C., Boisclair, D., Rioux, D., Leclerc, M., Lapointe, M. & Legendre, P. 2000. Development and validation of numerical models for juveniles of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 57: 2065–2075.
- Heggenes J. 1990. Habitat utilization and preferences in juvenile Atlantic salmon (*Salmo salar*) in streams. *Regulated Rivers: Research and Management* 5: 341–354.
- Heggenes, J. & Dokk, J.G. 2001. Contrasting temperatures, waterflows, and light: seasonal habitat selection by young Atlantic salmon and brown trout in a boreonemoral river. *Regulated Rivers: Research and Management* 17: 623–635.
- Jacobs, J. 1974. Quantitative measurement of food selection: a modification of the forage ratio and Ivlev's electivity index. *Oecologia* 14: 413–417.
- Jones, M.L. & Stockwell, J.D. 1995. A rapid assessment procedure for the enumeration of salmonide population in streams. *North American Journal of Fisheries Management* 15: 551–562.
- Klemetsen, A., Amundsen, P.-A., Dempson, J.A., Jonsson, B., Jonsson, N., O'Connell, M.F. & Mortensen, E. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* 12: 1–59.
- Lackey, R.T. 2003. Pacific northwest salmon: forecasting their status in 2100. *Reviews in Fisheries Science* 11: 35–88
- Lamouroux, N., Capra, H., Pouilly, M. & Souchon, Y. 1999. Fish habitat preferences in large streams of southern France. *Freshwater Biology* 42: 673–687.
- Leclerc, M., Boudreau P., Bechara, J.A. & Belzile, L. 1996. Numerical method for modelling spawning habitat dynamics of landlocked salmon, *Salmo salar*. *Regulated Rivers: Research and Management* 12: 273–285.

- Leftwich, K.N., Angermeier, P.L. & Dollof, C.A. 1997. Factors influencing behavior and transferability of habitat models for a benthic stream fish. *Transactions of the American Fisheries Society* 126: 725–734.
- Mäki-Petäys, A., Huusko, A., Erkinaro, J. & Muotka, T. 2002. Transferability of habitat suitability criteria of juvenile Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 59: 218–222.
- Morantz, D.L., Sweeney, R.K., Shirvell, C.S. & Longard D.A. 1987. Selection of microhabitat in summer by juvenile Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 44: 120–129.
- Noakes, D.J., Beamish, R. & Kent, M.L. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. *Aquaculture* 183: 363–386.
- Nykanen, M. & Huusko, A. 2004. Transferability of habitat preference criteria for larval European grayling (*Thymallus thymallus*). *Canadian Journal of Fisheries and Aquatic Sciences* 61: 185–192.
- Rexstad, E. & Burnham, K. 1991. User's guide for interactive program capture. Colorado, TX: Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University. 30 pp.
- Scruton, D.A. & Gibson, R.J. 1993. The development of habitat suitability curves for juvenile Atlantic salmon (*Salmo salar*) in riverine habitat insular Newfoundland and Canada. In: Gibson, R.J. & Cutting, R.E., eds. Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publications of Fisheries and Aquatic Sciences, 118: 149–161.
- Strakosh, T.R., Neumann, R.M. & Jacobson, R.A. 2003. Development and assessment of habitat suitability criteria for adult trout in southern New England rivers. *Ecology of Freshwater Fish* 12: 265–274.
- Talbot, T. & Lapointe, M. 2002. Numerical modeling of gravel bed river response to meander straightening: the coupling between the evolution of bed pavement and long profile. *Water Resources Research* 38: 1074.
- Torgersen, C.E., Price, D.M., Hiram, W.L. & McIntosh, B.A. 1999. Multiscale thermal refugia and stream habitat associations of chinook salmon in northeastern Oregon. *Ecological Applications* 9: 301–319.
- Trainor, K. & Church, M. 2003. Quantifying variability in stream channel morphology. *Water Resources Research* 39: 1248–1259.
- Vadas, R.L. & Orth, D.J. 1993. A new technique for estimating the abundance and habitat use of stream fishes. *Journal of Freshwater Ecology* 8: 305–317.
- Venables, W.N. & Ripley, B.D. 1997. Modern applied statistics with S-Plus. New York: Springer. 548 pp.