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PAR

YVES PARADIS

FACTEURS DÉTERMINANT LA RÉPARTITION SPATIALE ET L'ABONDANCE DES STADES LARVAIRE ET JUVÉNILE DE LA PERCHAUDE DANS L'ÉCOSYSTÈME FLUVIAL DU LAC SAINT-PIERRE (QUÉBEC)

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RÉSUMÉ

Espèce emblématique du lac Saint-Pierre, la perchaude (*Perca flavescens*) revêt une importance économique considérable au Québec et dans les régions limitrophes des Grands Lacs. Au lac Saint-Pierre, où la perchaude subit une intense pression d'exploitation par la pêche sportive et commerciale, il est essentiel de mieux comprendre l'écologie des jeunes stades, car par leur abondance et leur condition, ils déterminent l'avenir des pêcheries futures. L'objectif principal de cette étude était de documenter l'habitat préférentiel des jeunes stades de la perchaude et de caractériser les facteurs biotiques et abiotiques influençant leur répartition spatiale et leur abondance au lac Saint-Pierre (Chapitre II). Afin d'assurer l'estimation de l'abondance des jeunes stades de la perchaude et de quantifier les facteurs environnementaux qui affectent ces derniers, nous avons également développé et validé une technique d'échantillonnage propre aux stades larvaire et juvénile de la perchaude (Chapitre III). Finalement, nous nous sommes intéressés aux techniques de préservation des échantillons de l'ichtyofaune en quantifiant l'effet de différentes méthodes de préservation sur les jeunes stades de la perchaude, et en développant des équations pour convertir les données morphométriques préservées (longueur et poids) en données morphométriques initiales (Chapitre IV). Deux périodes de quinze jours en mai (stade larvaire) et en juillet (stade juvénile) ont été sélectionnées pour échantillonner au lac Saint-Pierre dans les baies de Maskinongé (rive nord) et Fer à Cheval (rive sud). La régression logistique a été utilisée pour déterminer les variables influençant la probabilité de présence des jeunes stades de la perchaude (distribution) et la régression linéaire multiple a été utilisée pour quantifier les variables affectant l'abondance des jeunes perchaudes. Chez les stades larvaires, le pouvoir prédictif des modèles de régression logistique était élevé, et la répartition spatiale était corrélée à la vitesse des vents et au type de substrat. L'abondance des larves de perchaude était expliquée par la profondeur et la densité de végétation submergée. Chez les stades juvéniles de la perchaude, la répartition spatiale des individus était corrélée à la vitesse des vents, à la densité de végétation submergée, à la conductivité et à la température de l'eau. L'abondance des juvéniles était quant à elle déterminée par la vitesse et la direction des vents, le substrat, la densité de végétation submergée et la profondeur. Nos résultats suggèrent que les facteurs influençant la répartition spatiale et l'abondance des jeunes perchaudes de l'année dépendent du stade ontogénique observé.

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Dédicace

Je dédie ce mémoire à monsieur Serge R. Bisaillon, biologiste et professeur au Cégep de Baie-Comeau, pour avoir été une grande source d'inspiration dans mon cheminement professionnel.

AVANT-PROPOS

Conformité des manuscrits

Conformément aux articles D45-46-47 du règlement des études de cycle supérieur de l'Université du Québec à Trois-Rivières, ce mémoire est présenté sous forme d'articles scientifiques. Le chapitre I de ce mémoire présente une synthèse en français résumant les principaux résultats du projet de maîtrise (chapitre II-III-IV).

Le chapitre II est constitué d'un manuscrit ayant pour titre « *Factors determining the distribution and abundance of larval and juvenile yellow perch (Perca flavescens) in a fluvial lake, St. Lawrence River (Québec) Canada* ». Le manuscrit sera soumis au périodique *Transactions of the American Fisheries Society* à des fins de publication.

Le chapitre III est constitué d'un manuscrit ayant pour titre « *Selectivity and precision of pop-nets, push-nets and seines for sampling larval and juvenile fish in shallow vegetated habitats* ». Le manuscrit sera soumis au périodique *North American Journal of Fisheries Management* à des fins de publication.

Le chapitre IV est constitué d'un manuscrit ayant pour titre « *Length and weight reduction in larval and juvenile yellow perch preserved in dry ice, formalin and alcohol* ». Le manuscrit sera soumis au périodique *North American Journal of Fisheries Management* à des fins de publication.

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INTRODUCTION GÉNÉRALE

PROBLÉMATIQUE

Espèce emblématique du lac Saint-Pierre, la perchaude (*Perca flavescens*) revêt une importance économique considérable au Québec et dans les régions limitrophes des Grands Lacs. Pouvant être pêchée aussi bien l'été que l'hiver, elle fait l'objet d'un prélèvement par la pêche sportive et commerciale particulièrement intensif depuis les années 1980 (Guénette et al. 1994). À elle seule, la pêche commerciale prélevait en moyenne 213 tonnes de perchaudes par année au lac Saint-Pierre entre 1986 et 1994 (rendement historique moyen). Sans être menacée, la population était alors considérée comme fortement exploitée et déclarée fragile (Mailhot et al. 1987).

Les réductions recommandées à l'époque par les gestionnaires n'ont pas été appliquées et un même effort de pêche a été maintenu. À partir de 1995, les prises annuelles ont accusé une baisse rapide et continue jusqu'à 66 tonnes en 1998, soit une baisse de 69 % du rendement historique moyen (Mailhot & Dumont 1999). Selon les gestionnaires de l'actuel ministère des Ressources naturelles et de la Faune du Québec, la diminution de la ressource a vraisemblablement été causée par le maintien d'une pression de pêche trop prononcée au cours d'une période où de faibles cohortes de perchaudes ont été produites durant plusieurs années consécutives (Mailhot 2001). Afin de protéger les stocks, le ministère des Ressources naturelles et de la Faune du Québec instaura une taille minimale d'exploitation pour les perchaudes pêchées commercialement. Cette mesure, mise en place en 1997, fixait la longueur minimale des captures à 165 mm, permettant ainsi à un plus grand nombre de femelles de se reproduire avant d'être capturées. Cette mesure de mitigation, combinée à une diminution de l'effort de pêche, a permis aux stocks de perchaudes de se reconstituer, du moins partiellement (Magnan 2002).

En dépit d'une pression halieutique moins grande, le taux annuel de mortalité des perchaudes au lac Saint-Pierre demeure très élevé. Estimée en moyenne à 74 % entre 1997 et 2000, cette mortalité résulterait principalement des activités halieutiques commerciales (Magnan 2002). Les valeurs élevées des taux de mortalité des perchaudes fragilisent l'exploitation commerciale, car la structure en âge des classes exploitables ne

repose que sur une ou deux cohortes (Guénette et al. 1994, Mailhot & Dumont 1999, Mailhot 2000).

La dynamique des populations de perchaudes a été étudiée dans différents types d'écosystèmes soumis à divers degrés de pression halieutique. Il est fréquemment rapporté que l'abondance des stocks de perchaudes subit des fluctuations annuelles importantes (Noble 1968, Craig & Kipling 1983, Newsome & Aalto 1987). Ces variations d'abondance sont généralement observées chez les adultes et parfois difficiles à expliquer. Newsome et Aalto (1987), Houde (1987) et Casselman & Lewis (1996) ont relié ce type de fluctuations, parfois extrêmes, à des variations environnementales survenant au cours des premières étapes du développement. Cependant, l'étude détaillée de ces relations est souvent limitée par l'absence de techniques précises pour l'estimation de l'abondance des juvéniles (Serafy et al. 1988, Fisher et al. 1999, Tischler et al. 2000).

La perchaude, présente en abondance au lac Saint-Pierre, constitue une étape trophique importante dans l'utilisation et la transformation de l'énergie dans cet écosystème fluvial. Dans un contexte de gestion prédictive des pêcheries commerciales et sportives, il est crucial de procéder à une évaluation annuelle de la force des jeunes classes d'âge (i.e. 0 et 1 an) et de comprendre les facteurs qui influencent leur abondance (Magnan 2002). Les estimations de productivité et le rendement halieutique des écosystèmes dépendent directement de l'abondance des jeunes stades de la perchaude (i.e. 0 et 1 an), eux-mêmes fortement influencés par les variables environnementales (Noble 1968, Nielsen 1978, Casselman 2002). Pour assurer la pérennité des pêcheries, il est donc essentiel de mieux comprendre les facteurs qui déterminent l'abondance des jeunes perchaudes et ainsi prédire les fluctuations éventuelles des débarquements. Afin d'assurer l'estimation de l'abondance des jeunes perchaude et de quantifier les facteurs environnementaux qui affectent ces dernières, il importe également de développer et de valider une technique d'échantillonnage propre aux stades larvaires et juvéniles.

OBJECTIFS DE L'ÉTUDE

L'objectif principal de cette étude est de documenter les facteurs déterminant la répartition spatiale des jeunes stades de la perchaude et de caractériser les facteurs biotiques et abiotiques influençant leur abondance au lac Saint-Pierre. Pour ce faire, nous

avons documenté la dynamique spatiale et temporelle des jeunes stades de la perchaude à l'échelle d'une saison de croissance. Des sites d'échantillonnage situés sur la rive nord et la rive sud du lac Saint-Pierre ont été sélectionnés afin d'obtenir un contraste de conditions environnementales. Cette étude vise aussi à développer et à calibrer des techniques d'échantillonnage et de préservation adaptées aux stades larvaire et juvénile de la perchaude dans l'écosystème particulièrement peu profond et dense en végétation du lac Saint-Pierre.

SITE D'ÉTUDE

Le lac Saint-Pierre, situé entre Sorel et Trois-Rivières (46° 15' N, 72° 50' W), est le plus grand lac fluvial du fleuve Saint-Laurent. Il occupe une superficie d'environ 350 km^2. Caractérisé par une grande diversité floristique et faunique, le plan d'eau a été classé site RAMSAR en 1998 et bénéficie, depuis novembre 2000, du titre de réserve mondiale de la biosphère, décerné par l'Organisation des Nations Unies pour l'éducation, la science et la culture (UNESCO) (Thiffault 2002). D'une profondeur moyenne de 3 m, le lac Saint-Pierre est classé dans la catégorie « marais profond » selon le système de classification des terres humides du Québec (Jacques & Hamel 1982). Un relevé de la végétation, effectué par Lalonde et Létourneau (1996), révèle que la surface du lac Saint-Pierre est couverte, au milieu de l'été, par environ 44 % de macrophytes submergés, 10 % de macrophytes émergeants et 46 % d'eau libre.

Le lac Saint-Pierre est caractérisé par trois masses d'eau principales (Figure 1.1), dont les mélanges latéraux sont réduits jusqu'aux rapides de Deschambault situés environ 50 km en aval. Ces trois masses d'eau associées à la rive nord, au chenal et à la rive sud, ont des caractéristiques physico-chimiques distinctes (Frenette et al. 2003). La rive nord est caractérisée par des eaux brunes, turbides et riches en matière en suspension et en carbone organique dissous (COD). Le chenal maritime canalise des eaux vertes provenant du bassin des Grands Lacs, avec de faibles concentrations de COD et de particules en suspension (Frenette et al. 2003). La masse d'eau associée à la rive sud présente une concentration relativement élevée en COD, mais une faible quantité de particules en suspension. Les signatures physico-chimiques très contrastées de ces trois masses d'eau leur confèrent un potentiel productif très différent, principalement lié à la lumière disponible dans la colonne d'eau et aux concentrations en nutriments carbonés. La rive sud est donc généralement plus productive que la rive nord.

La faible pente latérale du lac Saint-Pierre favorise une grande surface inondée lors des crues printanières. Ces milieux constituent alors une zone très fréquentée par les poissons pour la reproduction et l'alimentation. Les activités d'échantillonnage de ce projet de recherche ont été concentrées dans la Baie de Maskinongé sur la rive nord et dans la Baie Fer à cheval sur la rive sud (Figure 1.1). Ces baies sont typiques du littoral de chacune des rives, elles sont soumises à une pression comparable de pêche tant commerciale que sportive et sont des sites naturels de fraie pour la perchaude.

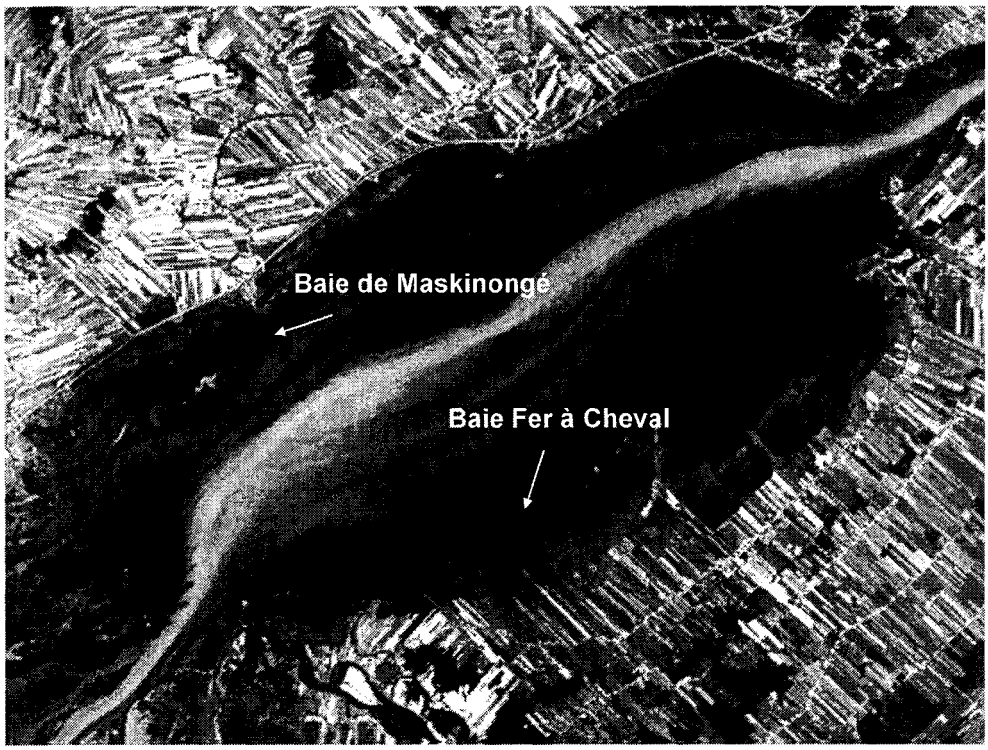


Figure 1.1. Localisation des sites d'échantillonnage et la charge sédimentaire des trois principales masses d'eau du lac Saint-Pierre (image Landsat 5, août 1989).

MÉTHODOLOGIE

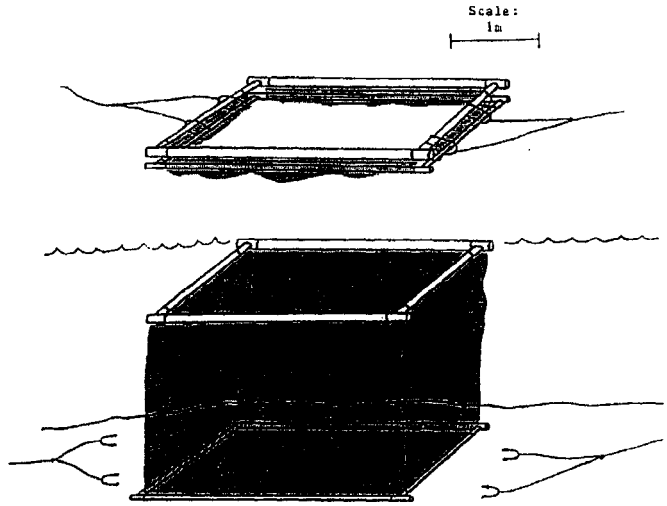
Engins de capture

Les larves ont été échantillonnées à l'aide de pièges-enclos (pop-net) et de petits chaluts propulsés (push-net) en mai, et à l'aide de pièges-enclos et de seines pélagiques et littorales en juillet. Le piège-enclos permet d'échantillonner des quadrats de dimensions standard (4 m x 4 m) dans tous les habitats du littoral, dont la profondeur est <1,5 m (Serafy et al. 1988). Cet engin est constitué d'un cadre supérieur flottant et d'un cadre inférieur lesté, tous les deux fermés latéralement par un filet seine de 1,5 m de hauteur

(Figure 1.2a). Une fois le filet-enclos installé, les cadres supérieur et inférieur étaient réunis et l'engin était déposé délicatement au fond de l'eau. Le piège était déclenché 12 heures plus tard pour que les poissons recolonisent l'habitat à une distance d'environ 15 mètres pour éviter le dérangement. La fuite des poissons était réduite par la remontée rapide du cadre supérieur (<2 secondes). Les captures du piège-enclos ont ensuite été prélevées à l'aide d'une seine à bâtons déployée quatre fois. Lorsque la végétation était trop abondante à l'intérieur du piège-enclos, les macrophytes étaient enlevés du quadrat échantillonné afin de faciliter le prélèvement des spécimens.

Le petit chalut propulsé a été utilisé afin d'assurer une couverture spatiale des habitats disponibles plus en profondeur (i.e. 0,50 à 2,5 m). Cet engin de capture consiste en une série de filets à plancton d'une longueur de 2 mètres, d'une ouverture de 40 cm et d'une maille de 500 µm, reliés par un support métallique à une embarcation qui propulse les filets le long d'un transect (Figure 1.2b). Les filets étaient poussés à une vitesse constante de 1 m/s en actionnant un moteur à essence. L'utilisation de petits chaluts peut être très efficace dans la capture des stades larvaires (i.e. <25 mm de longueur totale), mais son utilisation tard en saison est limitée par la réponse d'évitement des stades juvéniles dont la capacité natatoire augmente exponentiellement avec la taille (Tischler et al. 2000). Afin d'éviter un biais lié à la sélectivité de l'engin de capture, les petits chaluts propulsés ont été employés seulement en début de saison (i.e. mai). Les seines littorales (12,5 m x 4,5 m; 3,2 mm maille étirée) et pélagiques (12,5 x 6,5 m; 3,2 mm maille étirée), non biaisées par une réponse d'évitement des juvéniles, ont été utilisées en juillet.

a)



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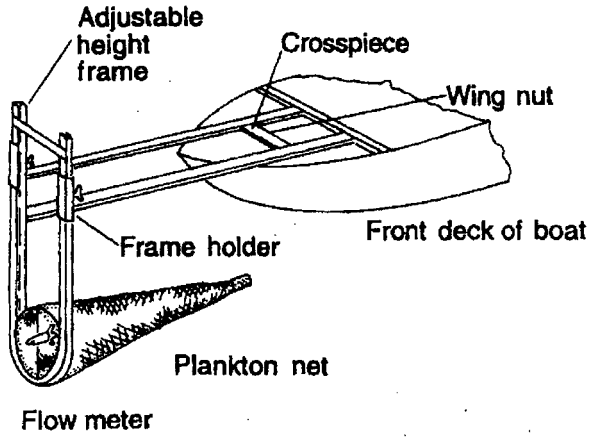

Figure 1.2. Engins de capture utilisés pour l'échantillonnage des larves de perchaude (a) piège-enclos (Serafy et al. 1988) (b) petit-chalut propulsé (Kelso & Rutherford 1996).

Stratégie d'échantillonnage

Les périodes d'échantillonnage, d'une durée approximative de quinze jours, ont eu lieu aux mois de mai (stade larvaire; longueur totale moyenne de 13,8 ± 2,8 mm) et juillet (stade juvénile, longueur totale moyenne de 56,5 ± 22,8 mm). Pour chacune de ces périodes, les rives nord et sud du lac Saint-Pierre ont été échantillonnées simultanément à l'été 2003. En mai, les zones peu profondes du littoral (0,5-1,5 m) ont été échantillonnées à l'aide des pièges-enclos disposés aléatoirement dans une variété d'habitats. En combinaison à chacun de ces pièges-enclos, des transects de petits chaluts d'une longueur de 50 mètres ont été effectués en zones plus profondes (0,5-2,5 m), parallèlement à la ligne de rivage, dans un gradient de profondeur allant de la berge vers la zone pélagique. Comme l'utilisation des pièges-enclos est limitée par les niveaux d'eau et que les petits chaluts peuvent devenir sélectifs envers les larves de taille supérieure à 30 mm, les petits chaluts ont été utilisés seulement en mai. En juillet, les pièges-enclos ont été utilisés en combinaison avec les seines littorales et pélagiques (couverture spatiale : 0,6-2,2 m).

Une comparaison de l'efficacité de différents engins à capturer des stades larvaires et juvéniles de la perchaude a été effectuée sur les rives nord et sud du lac Saint-Pierre à chacune des périodes d'échantillonnage (i.e. mai et juillet). Cette validation a été effectuée avec des engins de captures différents en pêchant dans trois strates de profondeur (i.e. 50-75, 75-100 et 100-115 cm) et dans des densités de végétation comparables (i.e. 0-4). L'essentiel de l'approche utilisée pour la comparaison des engins de capture est présenté sous forme détaillée au chapitre III.

Traitement des échantillons

Les larves capturées ont été identifiées à l'espèce à l'aide de la clé développée par Auer (1982) couvrant la biodiversité ichtyenne des Grands Lacs. La longueur standard et totale des larves a été mesurée à l'aide d'un vernier électronique (± 0,01 mm), et un sous-échantillon d'environ 30 larves de perchaude ont été pesées individuellement (± 0,001 g) pour chacune des stations échantillonnées. Les larves recueillies sur le terrain ont été préservées dans l'éthanol 75 %, dans le formol 10 % ou déposées sur la glace sèche (-80°C) pour une identification ultérieure en laboratoire. La longueur et le poids des larves ont été corrigés en fonction de la durée d'exposition à l'agent de préservation utilisé (éthanol, formol, glace sèche), c'est-à-dire le temps écoulé entre l'échantillonnage du spécimen et sa caractérisation morphométrique et gravimétrique en laboratoire. Afin

de quantifier la déshydratation des larves en fonction du temps d'exposition et du type d'agent de préservation utilisé, une centaine de larves fraîchement échantillonnées ont été mesurées et pesées individuellement, puis exposées à un traitement (éthanol, formol, glace sèche). Après différentes périodes d'exposition à l'agent de préservation, les larves ont été mesurées et pesées à nouveau afin de calculer un facteur de rétrécissement. Les résultats détaillés de cette expérience complémentaire à ce projet de maîtrise sont présentés au chapitre IV.

Analyses statistiques

Le comportement grégaire des larves et des juvéniles peut entraîner dans un même habitat une répartition en taches de densité très variable. La disparité des observations crée des matrices de données difficiles à traiter du point de vue statistique (Pennington 1996, Brosse & Lek 2002). Pour contourner cette embûche, nous avons décomposé la matrice de données afin d'effectuer deux analyses complémentaires. Dans un premier temps, l'absence et la présence d'individus ont été analysées à l'aide de la régression logistique multivariée. Dans un second temps, les facteurs déterminant les variations de l'abondance des individus ont été identifiés en utilisant la régression linéaire multiple. Afin de limiter le nombre de variables explicatives dans les analyses multivariées, les variables environnementales ont été sélectionnées *a priori*, basées sur la littérature et sur des analyses graphiques univariées. Il est à noter que plusieurs facteurs biotiques d'intérêts, telle l'abondance des proies planctoniques et des espèces compagnes n'ont pas été inclus dans ce mémoire. Une analyse détaillée des communautés fera l'objet d'un projet de recherche ultérieur.

RÉSULTATS

Dans l'environnement hétérogène du lac Saint-Pierre, la sélection de l'habitat des jeunes perchaudes de l'année (i.e. 0+) a été caractérisée pour deux stades de développement ontogénique (stade larvaire échantillonné en mai et stade juvénile échantillonné en juillet). La combinaison d'engins de capture a permis l'échantillonnage de l'ensemble des habitats du littoral. Afin d'éviter d'inclure un biais attribuable à l'utilisation de différents engins de capture, nous avons modélisé l'habitat des jeunes perchaudes indépendamment pour chacun des engins.

Facteur déterminant la répartition et l'abondance des stades larvaires

Pour les stades larvaires, la régression logistique a permis d'obtenir un modèle parcimonieux avec un pouvoir prédictif satisfaisant (n=75 et R^2=0,56). La vitesse du vent et le type de substrat prédisaient le mieux la présence de larves de perchaude. La vitesse du vent était corrélée positivement à la présence de larves de perchaude. Les substrats nus composés principalement d'argile, de limon et de sable diminuaient la probabilité d'observer des larves de perchaude comparativement aux substrats colonisés par la végétation. L'abondance des larves était reliée négativement à la profondeur et positivement corrélée à la densité de végétation submergée (régression multiple: n=42 et R^2=0,52).

Facteur déterminant la répartition et l'abondance des stades juvéniles

La présence de perchaudes juvéniles était prédite par la vitesse du vent, la densité de végétation submergée, la conductivité et la température de l'eau (régression logistique : n=79 et R^2=0,45). La vitesse des vents et la température étaient corrélées négativement à la probabilité d'observer des perchaudes juvéniles, alors que la densité de végétation submergée et la conductivité augmentaient cette probabilité. La direction du vent, la vitesse du vent, le type de substrat, la densité de végétation submergée et la profondeur étaient les facteurs déterminant l'abondance de perchaudes juvéniles (n=53et R^2=0,42).

Comparaison des engins de capture

En mai, le nombre de capture de larves de perchaude variait entre 0 et 31 325 individus pour un volume d'eau de 100 m^3. La fréquence d'occurrence et l'abondance des larves de perchaude échantillonnées avec le chalut propulsé étaient significativement plus élevées dans les habitats sans végétation comparativement aux captures du pièges-enclos (Tableau 3.1a) Aucune différence n'a été observée entre l'efficacité (abondance et occurrence de perchaudes) des pièges-enclos et des chaluts propulsés dans les habitats avec présence de végétation submergée (Tableau 3.1a). Les captures de perchaudes âgées d'un an (i.e. 1+) étaient très faibles dans les pièges-enclos et nulles dans les chaluts propulsés (Tableau 3.1a). En juillet, la seine s'est avérée plus efficace que le piège-enclos pour la capture de perchaudes juvéniles (i.e. 0+ et 1+) (Tableau 3.2). La variabilité inter-réplicat était plus élevée pour les captures obtenues à l'aide du piège-enclos. Cette variabilité élevée entraîne une faible précision des estimés d'abondance de larves de perchaude obtenue à l'aide des pièges-enclos. Les résultats détaillés de la comparaison de

l'efficacité et de la précision de la seine, du piège-enclos et du chalut propulsé pour l'échantillonnage de jeunes perchaudes sont présentés au chapitre III.

Comparaison des méthodes de préservation

Le plus faible changement dans la longueur totale fut observé pour des spécimens préservés dans le formol (court terme : 2,1% et 0,1%; long terme 10,1% et 1,2% pour les stades larvaires et juvéniles respectivement), suivi des spécimens préservés sur la glace sèche (court terme : 4,0% et 1,4%; long terme 7,2% et 3,9%) et dans l'alcool (court terme : 9,6% et 1,2%; long terme 11,7% et 1,2%). Le même patron de rétrécissement a été observé pour la réduction de la masse des spécimens larvaires et juvéniles. Les résultats détaillés de cette comparaison sont présentés au chapitre IV.

Discussion

La plupart des connaissances écologiques et théoriques concernant la sélection de l'habitat des jeunes perchaudes proviennent d'expériences effectuées sur la perche européenne (*Perca fluviatilis*). En Amérique du Nord, ces connaissances sont souvent dérivées d'expériences effectuées dans des écosystèmes artificiels où les pressions de prédation et de compétition diffèrent beaucoup de celles observées en conditions naturelles (Elköv & Hamrin 1989, Diehl 1993, Elköv & Persson 1996). Il y a donc un besoin de comparer les informations acquises sur la perche européenne à des écosystèmes naturels et riches en espèces, tel que le lac Saint-Pierre.

En mai, la présence de larves de perchaude était associée aux substrats avec végétation. Ces substrats peuvent contribuer à améliorer la qualité des refuges en augmentant la complexité et l'hétérogénéité des habitats (Weaver et al. 1997, Brosse & Lek 2002). La vitesse des vents était également corrélée de façon positive à la présence de larves de perchaude. L'effet des vents sur le développement et la survie des stades larvaires est fréquemment mentionné dans la littérature (Clady 1976, Aalto & Newsome 1993, Dumont 1996). La répartition spatiale des larves de perchaude semble affectée par l'action des vents, ce qui contribue dans certains systèmes à la dispersion passive des larves des habitats littoraux aux habitats pélagiques (Coles 1981, Urho 1996, Craig 2000). L'abondance de larves de perchaude en mai était reliée à la densité de végétation submergée. Les larves de perche (*P. fluviatilis*) sont généralement retrouvées en

association avec la végétation submergée (Diehl 1993, Persson & Elköv 1995). Les macrophytes sont très bénéfiques pour l'alevinage car ils augmentent la diversité des habitats et des ressources alimentaires et réduisent la vulnérabilité à la prédation (Elköv & Diehl 1994, Jacobsen & Berg 1998),.

En juillet, la présence de perchaudes juvéniles était négativement reliée à la vitesse du vent. La vitesse du vent était également une variable importante prédisant l'abondance des perchaudes juvéniles. En juillet, les perchaudes juvéniles avaient atteint une taille suffisante pour la nage active (Whiteside et al. 1985). Ainsi, les facteurs affectant leur répartition spatiale (vitesse du vent, densité de végétation submergée, conductivité et température de l'eau) et leur abondance (vitesse du vent, direction du vent, substrat et profondeur) devraient refléter une sélection active de l'habitat. Les perchaudes juvéniles devraient donc répondre à ces conditions environnementales afin de maximiser leur taux de survie, leur croissance, tout en réduisant le risque de prédation (Werner et al. 1983a, Werner et al. 1983b). Une discussion complète sur les facteurs déterminant la répartition spatiale et l'abondance des stades larvaires et juvéniles de la perchaude est présentée au chapitre II.

Dans cette étude, nous avons également développé et validé une stratégie d'échantillonnage propre aux stades larvaires et juvéniles de la perchaude, appropriée aux habitats fortement végétalisés et peu profonds du lac Saint-Pierre. Pour les stades larvaires, le petit chalut propulsé s'est avéré l'engin de capture le plus efficace en terme d'abondance de perchaudes capturées et le plus précis en terme de variances inter-réplicats. Cependant, l'utilisation du petit chalut propulsé est limitée aux larves de taille inférieure à 25 mm (Tischler et al. 2000). Pour l'échantillonnage de perchaudes juvéniles, la seine de rivage s'est avérée l'engin de capture le plus efficace et le plus préçis. Une discussion complète portant sur l'efficacité de différents engins de capture dans l'échantillonnage des larves de perchaude est présentée au chapitre III.

RÉFÉRENCES

Aalto, S.K. & G.E. Newsome. 1993. Winds and the demic structure of a population of yellow perch (Perca flavescens). Can. J. Fish. Aquat. Sci. 50: 496-501.

Auer, N.A. 1982. Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission Special Publication 82-3, Ann Arbor, Michigan. 744 pp.

Brosse, S. & S. Lek. 2002. Relationships between environmental characteristics and the density of age-0 Eurasian perch *Perca fluviatilis* in the littoral zone of a lake: a nonlinear approach. Transactions of the American Fisheries Society 131: 1033-1043.

Casselman, J.M. 2002. Effects of temperature, global extremes, and climate change on year-class production of warmwater, coolwater, and coldwater fishes in the Great Lakes Basin. American Fisheries Society Symposium 32: 39-60.

Casselman, J.M. & C.A. Lewis. 1996. Habitat requirements of northern pike (Esox lucius). Can. J. Fish. Aquat. Sci. 53: 161-174.

Clady, M.D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. Journal of Fisheries Research Board of Canada 33: 1887-1893.

Coles, T.F. 1981. The distribution of perch, *Perca fluviatilis*, L., throughout their first year of life in Llyn Tegid, North Wales. J. Fish. Biol. 18: 15-30.

Craig, J.F. 2000. Percid Fishes: systematics, ecology and exploitation, Oxford. 368 pp.

Craig, J.F. & C. Kipling. 1983. Reproduction effort versus the environment; case histories of Windermere perch, *Perca fluviatilis*, and pike, *Esox lucius*. J. Fish Biol. 22: 713-727.

Diehl, S. 1993. Effects of habitat structure on resource availability, diet and growth of benthivorous perch, *Perca fluviatilis*. Oikos 67: 403-414.

Dumont, P. 1996. Comparaison de la dynamique des populations de perchaudes (*Perca flavescens*) soumises à des niveaux différents de stress anthropique. Ph. D. thesis, Université du Québec à Montréal, Montréal. xxvi + 286 pp.

Elköv, P. & S. Diehl. 1994. Piscivore efficiency and refuging prey: the importance of predator search mode. Oecologia 98: 344-353.

Elköv, P. & S.F. Hamrin. 1989. Predator efficiency and prey selection: interactions between pike (*Esox lusius*), perch (*Perca fluviatilis*) and rudd (*Scardinius erythrophtalmus*). Oikos 56: 149-156.

Elköv, P. & L. Persson. 1996. The response of prey to the risk of predation: proximate cues for refuging juvenile fish. Animal Behaviour 51: 105-115.

Fisher, S.J., C.R. Pyle & D.W. Willis. 1999. Habitat use by age-0 yellow perch in two South Dakota glacial lakes. Ecology of Freswater Fish 8: 85-93.

Frenette, J.-J., M.T. Arts & J. Morin. 2003. Spectral gradients of downwelling ligth in a fluvial lake (Lake Saint-Pierre, St-Lawrence River). Aquatic Ecology 37: 77-85.

Guénette, S., Y. Mailhot, I. McQuinn, P. Lamoureux & R. Fortin. 1994. Paramètres biologiques, exploitation commerciale et modélisation de la population de Perchaude (*Perca flavescens*) du lac St-Pierre, Ministère de l'Environnement et de la Faune, Université du Québec à Montréal, Québec.

Houde, E.D. 1987. Fish early dynamics and recruitment variability. American Fisheries Society Symposium 2: 17-29.

Jacobsen, L. & S. Berg. 1998. Diel variation in habitat use by planktivores in field enclosure experiments : the effect of submerged macrophytes and predation. Journal of Fish Biology 53: 1207-1219.

Jacques, D. & C. Hamel. 1982. Système de classification des terres humides du Québec. pp. 131 pp., Ministère du Loisir, de la Chasse et de la Pêche. Direction générale de la faune, Québec.

Kelso, W.E. & A.D. Rutherford. 1996. Fisheries techniques, second edition. pp. 255-302. *In:* A.F. Society (ed.), Maryland.

Lalonde, S. & G. Létourneau. 1996. Sensibilité de la Télédétection Spatiale pour le Suivi des Milieux Humides, St-Lawrence Centre, Environment Canada, Montréal, Québec.

Magnan, P. 2002. Avis scientifique sur l'état du stock de perchaudes au lac Saint-Pierre, les indicateurs biologiques utilisés pour effectuer son suivi et la pertinence de protéger la période de fraye de façon partielle ou totale. Université du Québec à Trois-Rivières, Trois-Rivières, 52 p.

Mailhot, Y. 2000. Évaluation du taux annuel de mortalité totale des perchaudes du lac Saint-Pierre et de son archipel en 1999. pp. 197-204. *In* M. Bernard et C. Groleau (éd.), Compte rendu du cinquième atelier sur les pêches commerciales, Faune et Parcs du Québec, Direction de la coordination opérationelle.

Mailhot, Y. 2001. Évaluation du taux annuel de mortalité totale des perchaudes du lac Saint-Pierre entre 1997 et 2000. *In* M. Bernard et C. Groleau (éd), Compte rendu du sixième atelier sur les pêches commerciales. pp. 7, Faune et Parcs Québec, Direction de la coordination opérationnelle.

Mailhot, Y., F. Axelsen, P. Dumont, H. Fournier, P. Lamoureux, C. Pomerleau & B. Portelance. 1987. Avis scientifique sur le statut de la population de la perchaude au lac Saint-Pierre. Ministère du Loisir, de la Chasse et de la Pêche du Québec et Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Plan de gestion de la pêche. Comité scientifique conjoint. Avis scientifique 87/3, 26 p.

Mailhot, Y. & P. Dumont. 1999. Mise à jour de l'état de la population de la perchaude lac Saint-Pierre. pp. 147-151. *In* M. Bernard et C. Groleau (éd.), Compte rendu du quatrième atelier sur les pêches commerciales, Faune et Parcs Québec, Direction de la faune et des habitats, Direction de la coordination opérationelle.

Newsome, G.E. & S.K. Aalto. 1987. An egg-mass census method for traking fluctuations in yellow perch (*Perca flavescens*) populations. Can. J. Aquat. Sci. 44: 1221-1232.

Nielsen, L.A. 1978. Mechanisms regulating recruitment of juvenile yellow perch (*Perca flavescens*) to the adult stock in Oneida lake, New-York, Cornell University. 73 pp.

Noble, R.L. 1968. Mortality rates of pelagic fry of the yellow perch, *Perca flavescens* (Mitchill), in Oneida lake, New-York, and an analysis of the sampling problem, Cornell University. 104 pp.

Pennington, M. 1996. Estimating the mean and variance from highly skewed marine data. U.S. National Marine Fisheries Service Fishery Bulletin 94: 498-505.

Persson, L. & P. Elköv. 1995. Prey refuges affecting interactions between piscivorous perch and juvenile perch and roach. Ecology 76: 70-81.

Serafy, J.E., R.M. Harrell & J.C. Stevenson. 1988. Quantitative sampling of small fishes in dense vegetation : Design and field testing of portable «pop-nets». Journal of Applied Ichthyology 4: 149-157.

Thiffault, N. 2002. Adaptation d'un modèle de planification et de gestion pour la mise en valeur de l'écotourisme dans la réserve de bioshère du Lac Saint-Pierre, Mémoire de maîtrise, Université de Trois-Rivières. 83 p.

Tischler, G., H. Gassner & J. Wanzenböck. 2000. Sampling characteristics of two methods for capturing age-0 fish in pelagic lake habitats. Journal of Fish Biology 57: 1474-1487.

Urho, L. 1996. Habitats shifts of perch larvae as survival strategy. Ann. Zool. Fennici 33: 329-340.

Weaver, M.J., J.J. Magnuson & M.K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. Can. J. Fish. Aquat. Sci. 54: 2277-2289.

Werner, E.E., J.F. Gilliam, D.J. Hall & G.G. Mittelbach. 1983a. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

Werner, E.E., G.G. Mittelbach, D.J. Hall & J.F. Gilliam. 1983b. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. Ecology 64: 1525-1539.

Whiteside, M.C., C.M. Swindoll & W.L. Doolittle. 1985. Factors affecting the early life history of yellow perch, *Perca flavescens*. Environmental Biology of Fishes 12: 47-56.

CHAPITRE II

FACTORS DETERMINING THE DISTRIBUTION AND ABUNDANCE OF LARVAL AND JUVENILE YELLOW PERCH (*PERCA FLAVESCENS*) IN A FLUVIAL LAKE, ST. LAWRENCE RIVER (QUÉBEC) CANADA

Factors determining the distribution and abundance of larval and juvenile yellow perch (*Perca flavescens*) in a fluvial lake, St. Lawrence River (Québec) Canada

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ABSTRACT

Young-of-the-year (YOY) yellow perch, *Perca flavescens*, were sampled at different sites and periods of the summer to determine factors affecting their spatial distribution and abundance in Lake St-Pierre, a 350 Km^2 fluvial lake in the St. Lawrence River (Québec). Logistic regression was used to predict the presence of individuals and multiple regression was used to identify factors predicting their abundance. Wind speed and substrate type were the main variables predicting the presence of larval yellow perch ($n=75$, $R^2=0.56$), while depth and submerged vegetation density mainly determined their abundance ($n=42$, $R^2=0.52$). The presence of juveniles was largely explained by wind speed, submerged vegetation density, conductivity and water temperature ($n=79$, $R^2=0.45$). Wind direction and speed, substrate, submerged vegetation density, and depth mostly predicted the abundance of juvenile ($n=53$, $R^2=0.42$). Our study revealed that factors affecting distribution and abundance of YOY yellow perch evolved with their ontogeny. Distribution of larval yellow perch was governed by physical forces such as wind at the larval stage, suggesting a passive habitat selection by individuals. Conversely, habitat selection of juveniles appeared to be more active. These results will be useful to understand growth, predation and ultimately survival of YOY yellow perch in fluvial lakes.

KEY WORDS: Age-0, young-of-the-year, nursery habitat, habitat selection, habitat modelling

INTRODUCTION

Nursery requirements of young-of-the-year (YOY) fish are much less studied than spawning habitat requirements (Lane et al. 1995, Casselman & Lewis 1996). Lack of knowledge on YOY led to the misconception that nursery habitats are less limiting than spawning habitat (Casselman & Lewis 1996). However, year-class strength were shown to be associated with nursery habitat quality rather than spawning habitat in some species (Houde 1987, Böhling et al. 1991, Casselman & Lewis 1996). Habitat selection of YOY fish is known to be a function of food availability, habitat structure, water depth and substrate (Brosse & Lek 2000, Lewin et al. 2004). Knowing the large inter-annual variability in YOY fish (Craig 2000), there is a need to understand the relationship between environmental conditions and YOY fish productivity in order to better predict year-class strength (Clapp & Dettmers 2004) and to prioritize conservation areas (Rosenfield & Hatfield 2006).

Temperature (Pope et al. 1996, Tardif et al. 2005), wind exposition (Clady 1976), substrate (Brosse & Lek 2002), vegetation (Weaver et al. 1997), and zooplankton abundance (Masson & Brandt 1996, Fisher et al. 1999) were recognized to affect yellow perch (*Perca flavescens*) YOY habitat selection. However, most of the knowledge on YOY yellow perch habitat selection was derived from experiments on the Eurasian perch (*Perca fluviatilis*; hereafter: perch). These works were conducted in artificial and controlled environments under predation and competition pressures, which were highly variable (Elköv & Hamrin 1989, Diehl 1993, Elköv & Persson 1996). Scandinavian lakes, where most of these works were conducted include competitor like roach (*Rutilus rutilus*) and bream (*Abramis brama*), which are absent from North American lakes and that likely influence perch foraging behaviour and habitat selection (Diehl 1988, Persson & Greenberg 1990, Persson & Elköv 1995).

Yellow perch is one of the most important fish species of Lake Saint-Pierre, a 350 km^2 fluvial lake of the St. Lawrence River (Quebec) Canada (La Violette et al. 2003). This fluvial lake exhibit important contrasts in environmental conditions (Vincent & Dodson 1999, Frenette & Vincent 2003) and thus is a good model to investigate the determinants of distribution and abundance of YOY yellow perch. Because *Perca sp.* inhabit areas with considerable heterogeneity (Brosse & Lek 2002), this species is likely to respond to spatial variations in biotic and abiotic factors observed in Lake Saint-Pierre.

The goal of this study was to investigate biotic and abiotic factors governing the distribution and abundance of larval and juvenile yellow perch in Lake Saint-Pierre. Sampling sites were located in contrasted environments and sampled twice during the summer to investigate these questions at two different stages of the yellow perch ontogeny, larvae and juveniles.

MATERIAL AND METHODS

Study site

The study was conducted in two shallow areas of Lake Saint-Pierre (Maskinongé Bay: 46°12'N, 72°58'W (north shore) and Fer à Cheval Bay: 46°11'N, 72°45'W (south shore); Figure 1), a large fluvial lake of the St. Lawrence River, Québec, Canada. The length of Lake Saint-Pierre is about 35 km, the width is about 15 km and the average depth is 3.17 m at mean discharge, except for the 11.3 m deep navigation channel that bisects the lake. Water mass originating from Lake Ontario is predominant in terms of flow (50-80 % of discharge), but is mainly restricted to the navigation channel (Vis et al. 2003). The lake is composed of several water masses with very limited lateral mixing and exhibits distinct river plumes over hundreds kilometres (Frenette et al. 2003). The

different water masses have contrasting physico-chemical characteristics depending on their multiple sources (Frenette et al. 2003). They originated from several tributaries with various flow rates and concentrations of dissolved and particulate organic and inorganic suspended matter (Frenette & Vincent 2003). The water mass flowing on the northern shore of the lake is the most turbid and is characterized by brown-coloured water, rich in suspended particles, high total phosphorus concentration and relatively high dissolved organic carbon (DOC) (Frenette et al. 2003). Tributaries draining farmlands bring nutrient-rich waters along the south shore (Vis et al. 2003). The greater productivity in the south shore were reported for different trophic level including zooplankton (Basu et al. 2000), invertebrates (Huggins et al. 2004), YOY fish (Tardif et al. 2005) and adult fish (La Violette et al. 2003).

Major seasonal flooding and great irradiance of the water column in the littoral zone contribute to the growth of submerged and emerged aquatic vegetation (Fortin et al. 1993, Frenette & Vincent 2003, Vis et al. 2003). During mid-summer, approximately 44% of the surface area of Lake Saint-Pierre is composed of submerged macrophytes, 10% of emergent macrophytes, and 46% of open water. Lake Saint-Pierre supports an important fish and bird diversity (Langlois et al. 1992) and was designated in 2000 by the UNESCO as a world heritage ecological reserve. The fish community include approximately 45 species (La Violette et al. 2003) and is dominated by yellow perch, which supports an important commercial fishery.

Fish collection

YOY fish were sampled twice during the summer of 2003; 26 May - 9 June (hereafter larvae; mean total length: 13.8 ± 2.8 mm) and 2-17 July (hereafter juvenile; mean total length: 56.5 ± 22.8 mm). Within each site (Maskinongé and Fer

à Cheval bays), we used push-net in May and seine in July, to account for growth of YOY yellow perch through summer. The push-net is inadequate for larvae >30 mm total length (TL) (Tischler et al. 2000), and the seine can be labour intensive for catching small post-hatching larvae (Whiteside & Hatch 1997). The push-net (Tischler et al. 2000) consisted of three zooplankton nets, each with a 0.40 x 0.40 m square opening; 1.5 m long; 500 μm mesh) mounted on an adjustable steel frame placed in front of the boat so that three strata of the water column were sampled simultaneously. The number of vertical strata sampled (each of 0.40 m) was adjusted according to the maximum depth at each site (i.e., one stratum when maximum depths were <0.90 m, two strata for depths 0.90 m–1.30 m, and three strata for depths >1.30 m). The nets were pushed at ~1 $m \cdot s^{-1}$ along 50 m transects (sometimes 25 m due to vegetation limitation). The volume sampled using the push-net ranged between 4.0 and 16.0 m^3 (average 9.7 m^3).

Seine samples were collected with a beach seine (12.5 m x 4 m; 3.2 mm stretched mesh) and with a pelagic seine (12.5 m x 6.5 m; 3.2 mm stretched mesh) with floats on the top line and a lead core bottom line. The two types of seine were used to sample shallow and deeper habitats of the floodplain. The seine was deployed from a boat along a large circle in the chosen habitat. Estimates of sample volume were based on the theoretical cylinder of water enclosed by the net (i.e., 122.7 m^2 x sampling depth). The volume sampled using the seine ranged between 66.3 and 147.2 m^3 (average 109.1 m^3). The abundance of YOY yellow perch was expressed in terms of catch per unit effort (CPUE), and standardized to the number of fish per volume of sampled water (100 m^3). The vertical strata of 0.40 m sampled with the push-net were pooled and considered as one effort unit (Tischler et al. 2000).

Within each site (Maskinongé and Fer à Cheval bays) 49 and 44 stations were sampled with the push-net (May) and 47 and 43 stations were sampled with the seine (July) in three depth strata: 0.50-0.75 m, 0.75-1.00 m, and 1.00-1.25 m. The stations were chosen randomly within each depth strata.

Fish were anesthetized in 10% eugenol and preserved immediately in 10 % formalin or in 75% alcohol. Two different preservatives were used for further analysis in the laboratory (not presented in this paper). All fish captured were identified to species (Scott & Crossman 1973, Auer 1982).

Environmental variables

Depth was measured to the nearest 1 cm at each station. Submerged aquatic vegetation density was recorded by visual inspection on a semi-quantitative scale, ranging from 0 (open water) to 4 (very dense macrophytes) and the dominant structure of submerged vegetation was noted as linear (e.g. *Juncus* sp.), floating (e.g. *Nymphea* sp.) or arbustive (e.g. Potamot sp.). Water temperature was also recorded at each sampling station, and the dominant substrate type was noted (vegetation, sand, silt, clay). Temperature data were missing for 93 sampling stations. For these stations we used the data from two thermographs (Minilog-T, Vemco^{tm}; ± 0.1°C) recording water temperature on a hourly basis at each sampling site (Maskinongé and Fer à Cheval Bay). The thermographs were protected from direct solar radiation and placed at 0.2 m from the bottom. The data from the thermographs were highly correlated with those recorded regularly at the sampling stations ($n=172$, $r^2=0.84$, $p<0.001$). For each sampling station, wind speed ($km \cdot hr^{-1}$) and wind direction (geographic direction) at the moment of sampling were obtained from the Trois-Rivières weather station (46°21'N, 72°31'W). A water sample of 120 ml was

collected at each station and placed in the dark at 4°C for further conductivity and turbidity analyses.

Statistical analyses

Due to the usual patchy distribution of YOY fish (Kubecka & Svatora 1993), abundance data exhibited a substantial proportion of zero values, which led to right-skewed statistical distributions. To circumvent this problem, we used a two step modelling approach by creating two sets of data from the original one (Fletcher et al. 2005). The first contained presence-absence data while the second contained the logarithm of the abundance when presence was observed. Logistic regression was used to predict the presence of individuals while multiple regression was used to identify factors predicting their abundance (Quinn & Keough 2002). Prior to data analysis, Pearson's correlation matrix were used to detect colinearity among independent variables (Tabachnick & Fidell 2001). Univariate graphical analysis with locally weighted scatterplot smoother (LOWESS) were used to visualise the shape of the relationship between explanatory and predicted variables (Wilkinson 2002). Second order terms were included in models among the potential predictors to allow for significant non-linear effects in addition to linear ones (Quinn & Keough 2002).

Variable selection

To avoid meaningless relationships, we limited the number of independent variables included in the models (Tabachnick & Fidell 2001). Independent variables were *a priori* selected based on the literature and on univariate graphical analysis to identified candidate variable for the multivariate models (Tableau 2.1; Hosmer & Lemeshow 2000). Both forward and backward stepwise selection procedures were used to determine which variables should be retained in the models. When divergence was found between the two

procedures, only the most parsimonious model was retained. We used a nominal cut-off point of 0.05 for the multiple logistic regression and 0.15 for the multiple linear regression in the stepwise selection procedure. A more severe cut-off point was used in logistic regression model to reduced the number of independent variables (Hosmer & Lemeshow 2000) (no important changes in the explained variance). A more liberal cut-off point was used for the multiple linear regression, allowing the entry of more variables resulting in increasing explained variance (Quinn & Keough 2002). Tolerance was fixed at 0.6 when modelling log abundance data with multiple linear regression to avoid collinear terms to enter in the model (Wilkinson 2002).

Hosmer-Lemeshow and residuals Chi-square tests were used to assess the adequacies of the logistic regression models (i.e. goodness-of-fit) (Hosmer & Lemeshow 2000). The evaluation of the classification accuracy (sensitivity, the correct classification of presence, and specificity, the correct classification of absence) from the logistic models was assessed using a jackknife resampling procedure. This validation method resulted in relatively unbiased estimates of model performance and a powerful tool in modelling fish species distribution (Olden et al. 2002). The optimal cut-off point for the classification was selected using the ROC curve which allow to maximise both sensitivity (ability to correctly predict presence) and specificity (ability to correctly predict absence) (Hosmer & Lemeshow 2000). The fit of the multiple linear regression models were assessed by inspecting the residuals. Logistic regression analyses were performed using PROC LOGISTIC procedure in SAS 8.02, and multiple linear regression analyses were performed using generalized linear models procedure (GLM) in SYSTAT 10.2.

RESULTS

Larval stage

Logistic regression yielded a highly significant model to predict the presence of larval yellow perch (Table 2.2). Wind speed was positively correlated with the probability to observe yellow perch larvae while clay, silt and sand substrates decreased the probability to sample larval yellow perch compared to habitat with vegetated substrate (Table 2.2). The classification table revealed a sensitivity and a specificity of 73.0% and 78.9% respectively.

The multiple linear regression explained 52% of the variation in the abundance of larval yellow perch, which was negatively correlated with depth, and positively correlated to submerged vegetation density (Table 2.3).

Juvenile stage

Logistic regression also yielded a highly significant model to predict the presence of juvenile yellow perch (Table 2.2). Wind speed and water temperature decreased the probability to catch juvenile yellow perch while submerged vegetation density and conductivity increased this probability (Table 2.2). Sensitivity and specificity of the model were 52.4% and 75.5% respectively.

The multiple linear regression explained 42% of the variation in the abundance of juvenile yellow perch (Table 2.3), which was positively correlated with wind direction (from 100 to 300°; from East to North-West; Figure 2.1) and sand substrate and negatively correlated with wind speed (Table 2.3). Quadratic function of depth was retained by the stepwise procedure (Table 2.3) and univariate inspection of the

relationship indicated an optimal abundance of juvenile yellow perch between 1.0-2.0 m depth.

DISCUSSION

Larval stage

The presence of yellow perch larvae was positively related to a vegetated substrate and their abundance, positively associated with submerged vegetation density. Similarly, larval yellow perch are generally found in flooded vegetation (Diehl 1993, Persson & Elköv 1995, Weaver et al. 1997). Submerged macrophytes increase the diversity of habitats and resources, reduce the vulnerability of individuals to piscivores (Elköv & Diehl 1994, Diehl & Kornijów 1998, Jacobsen & Berg 1998) and thus represent a high quality nursery habitat. The role of the substrate in predicting YOY yellow perch habitat selection is mentioned in other studies, although selected substrate type may largely vary (Copp 1992, Brosse & Lek 2002, Lewin et al. 2004). Vegetated substrate could contribute to the refuge quality by increasing the structural heterogeneity (Weaver et al. 1997, Brosse & Lek 2002).

Wind speed during sampling was also found to be positively related to the occurrence of larval yellow perch. Although still not fully understood, the effects of winds on the development and survival of YOY yellow perch is frequently reported (Clady 1976, Aalto & Newsome 1993, Dumont 1996, Pope et al. 1996). The distribution of newly hatched larvae can be affected by wind action which probably contribute to disperse them from the littoral to the pelagic zone (Coles 1981, Urho 1996, Craig 2000). At time of capture, larval yellow perch did not get enough swimming capability to develop active movements (Whiteside et al. 1985). Therefore, larval yellow perch could potentially be

passively dispersed when episodes of high wind occurred (Treasurer 1988, Wang & Eckmann 1994).

The highest abundance of larval yellow perch were found in the upper littoral zone and decreased gradually with depth. Brosse and Lek (2002) and Fisher et al. (1999) found comparable results, confirming that larval yellow perch are concentrated in the shallow habitats of the littoral zone in their early ontogeny (Whiteside et al. 1985, Post & McQueen 1988).

Juvenile stage

The occurrence as well as the abundance of juvenile yellow perch was negatively related to wind speed. Thermal and wind conditions prevailing during the early development of percids were identified as the most important physical factors affecting year-class strength (Koonce et al. 1977, Kallemeyn 1987, Dumont 1996, Craig 2000). In July, the juvenile yellow perch were sufficiently developed to swim actively (Whiteside et al. 1985). To survive, they could potentially use the highly vegetated littoral zone as a refuge when episode of high winds occurred in Lake Saint-Pierre, explaining their positive relationship with submerged vegetation density. Refuges, offering shelters during lake physical processes (e.g. waves action, turbulence), are important in yellow perch nursery habitat quality (Klumb et al. 2003). The negative relationship between wind speed and juvenile yellow perch abundance could not be explained by the difficulty to deploy correctly the seine during episodes of high winds because similar results were obtained during the same period using pop-net (which were not affected by weather conditions; Paradis et al. unpublished data). Winds blowing from West were associated with the highest abundance of juvenile yellow perch while winds blowing from North to the lowest. Winds blowing from North generally induce important waves in Lake Saint-

Pierre which likely induced major physical perturbations. Such perturbations potentially affected the habitat selection by juvenile yellow perch towards refuges.

The occurrence of juvenile yellow perch also increased with the density of submerged vegetation. Submerged macrophytes increase the diversity of habitats and resources and reduce the vulnerability of prey fish to piscivorous (Elköv & Diehl 1994, Diehl & Kornijów 1998). Basu et al. (2000) also shown that total zooplankton biomass was nine-fold higher within macrophyte beds than in either the open water or areas with sparse vegetation. The high zooplankton productivity and high quality refuge of vegetated habitats of the littoral zone seems the more profitable nursery habitats for larval and juvenile perch (Weaver et al. 1997, Brosse & Lek 2002), as well as juvenile stages of other species (Lane et al. 1995, Casselman & Lewis 1996, Lewin et al. 2004). The highest juvenile abundance was found at sites with sandy substrate. Higher proportion of juvenile perch stages were also found in sandy habitats in some studies (Elköv 1997, Fisher et al. 1999, Fladung et al. 2003) while other found juvenile in a variety of substrates (Copp et al. 1994). Lewin et al. (2004) mentioned an higher presence of YOY perch in sandy habitats. However, potential causality underlying this relationship was not discussed. Decreasing sediment grain size is known to have a positive influence on the abundance of chironomids (Cobb & Watzin 1998), which is known to be an important prey for YOY perch (Persson et al. 2000). Sandy substrate could thus represent a profitable foraging habitat for juvenile yellow perch.

The presence of juvenile yellow perch in our study increased along a conductivity gradient and decreased with the water temperature. Conductivity is an important abiotic factor structuring fish communities (Tonn et al. 1990, Persson 1997). Some authors

mentioned that, across systems, adult yellow perch and larval fish (including yellow perch) abundance were positively correlated with the conductivity (Sabo et al. 1991, Hinch & Collins 1993) while others mentioned the opposite (Fladung et al. 2003). Sabo et al. (1991) and Claramunt et al. (2000) showed that the quality of nursery habitat of YOY fish was associated with high conductivity. Conductivity is an index of dissolved ion concentrations and positively associated with survival of YOY perch (Ribi 1992). The negative relationship between the occurrence of juveniles and the water temperature in July could be related to hyperthermic habitats avoided by yellow perch (Smale & Rabeni 1995). In July, the water temperature in Lac Saint-Pierre reached 29°C which is close of the critical thermal maxima of warmwater fish species (Smale & Rabeni 1995).

Conclusion

Habitat use by YOY fish in natural environments is governed by many factors (Brosse & Lek 2000, Brosse & Lek 2002, Lewin et al. 2004) and mediated by biotic factors including predation risks, intra-specific competition and prey availability (Mittelbach 1986). Our study revealed that factors affecting distribution and abundance of YOY yellow perch evolved through their ontogeny. Distribution of larval yellow perch seems to be governed by physical forces such as winds and might reflect passive habitat selection. Dispersal process of larval yellow perch through active swimming or passive transportation is much debated (Whiteside et al. 1985, Post & McQueen 1988, Urho 1996). However, evidences of passive transportation are increasing in the literature (Coles 1981, Treasurer 1988, Dettmers et al. 2005). In our study, the swimming capacity of juvenile yellow perch was well developed because they were able to avoid our push-net in July. Thus, factor predicting their distribution (wind speed, submerged vegetation density, conductivity, water temperature) and abundance (wind direction, wind speed,

substrate, and depth) should reflect active habitat selection. Juvenile yellow perch should respond to these environmental conditions in order to maximise their survival rate, their growth and to reduce predation risks (Werner et al. 1983a, Werner et al. 1983b, Urho 1996).

Results of this study will help identifying high quality nursery habitats and habitat requirements of YOY yellow perch and identify conservation zones and management priorities in fluvial ecosystems. These results will also help to manage water levels along the St-Lawrence River in order to protect high quality nursery habitats during sensible stages of their ontogeny.

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REFERENCES

Aalto, S.K. & G.E. Newsome. 1993. Winds and the demic structure of a population of yellow perch (*Perca flavescens*). Can. J. Fish. Aquat. Sci. 50: 496-501.

Auer, N.A. 1982. Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission Special Publication 82-3, Ann Arbor, Michigan. 744 pp.

Basu, B.K., J. Kalff & A.B. Pinel. 2000. The influence of macrophyte beds on plankton communities and their export from fluvial lakes in the St Lawrence River. Freshwater Biology 45: 373-382.

Böhling, P., R. Hudd, H. Lehtonen, P. Karas, E. Neuman & G. Thoresson. 1991. Variations in year-class strength of different perch (*Perca fluviatilis*) populations in the Baltic Sea with special reference to temperature and pollution. Canadian Journal of Fisheries and Aquatic Sciences 48: 1181-1187.

Brosse, S. & S. Lek. 2000. Modelling roach (*Rutilus rutilis*) microhabitat using linear and nonlinear techniques. Freshwater Biology 44: 441-452.

Brosse, S. & S. Lek. 2002. Relationships between environmental characteristics and the density of age-0 Eurasian perch *Perca fluviatilis* in the littoral zone of a lake: a nonlinear approach. Transactions of the American Fisheries Society 131: 1033-1043.

Casselman, J.M. & C.A. Lewis. 1996. Habitat requirements of northern pike (*Esox lucius*). Can. J. Fish. Aquat. Sci. 53: 161-174.

Clady, M.D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. Journal of Fisheries Research Board of Canada 33: 1887-1893.

Clapp, D.F. & J.M. Dettmers. 2004. Yellow perch research and management in Lake Michigan: evaluating progress in a cooperative effort, 1997-2001. Fisheries 29: 11-19.

Claramunt, R.M. & D.H. Wahl. 2000. The effects of abiotic and biotic factors in determining larval fish growth rates: a comparison across species and reservoirs. Transactions of the American Fisheries Society 129: 835-851.

Cobb, S.E. & M.C. Watzin. 1998. Trophic interactions between yellow perch (*Perca flavescens*) and their benthic prey in a littoral zone community. Canadian Journal of Fisheries and Aquatic Sciences 55: 28-36.

Coles, T.F. 1981. The distribution of perch, *Perca fluviatilis*, L., throughout their first year of life in Llyn Tegid, North Wales. J. Fish. Biol. 18: 15-30.

Copp, G.H. 1992. An empirical model for predicting microhabitat of 0+ juvenile fishes in a lowland river catchment. Oecologia 91: 338-345.

Copp, G.H., G. Guti, B. Rovný & J. Cerný. 1994. Hierarchical analysis of habitat use by 0+ juvenile fish in Hungarian/Slovak flood plain of the Danube River. Environmental Biology of Fishes 40: 329-348.

Craig, J.F. 2000. Percid Fishes: systematics, ecology and exploitation, Oxford. 368 pp.

Dettmers, J.M., J. Janssen, B. Pientka, R.S. Fulford & D.J. Jude. 2005. Evidence across multiple scales for offshore transport of yellow perch (*Perca flavescens*) larvae in Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 62: 2683-2693.

Diehl, S. 1988. Foraging efficiency of three freshwater fish: effects of structural complexity and light. Oikos 53: 207-214.

Diehl, S. 1993. Effects of habitat structure on resource availability, diet and growth of benthivorous perch, *Perca fluviatilis*. Oikos 67: 403-414.

Diehl, S. & R. Kornijów. 1998. Influence of submerged macrophytes on trophic interactions among fish and macroinvertebrates. pp. 24-46. *In:* E. Jeppesen, M. Søndergaard, M. Søndergaard & K. Christoffersen (ed.) The structuring role of submerged macrophytes in lakes, Springer, New-York.

Dumont, P. 1996. Comparaison de la dynamique de populations de perchaudes (*Perca flavescens*) soumises à des niveaux différents de stress anthropique. Ph. D. thesis, Université du Québec à Montréal, Montréal. xxvi + 286 pp.

Elköv, P. 1997. Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (*Perca fluviatilis*) and pike (*Esox lusius*). Canadian Journal of Fisheries and Aquatic Sciences 54: 1520-1531.

Elköv, P. & S. Diehl. 1994. Piscivore efficiency and refuging prey: the importance of predator search mode. Oecologia 98: 344-353.

Elköv, P. & S.F. Hamrin. 1989. Predator efficiency and prey selection: interactions between pike (*Esox lusius*), perch (*Perca fluviatilis*) and rudd (*Scardinius erythrophtalmus*). Oikos 56: 149-156.

Elköv, P. & L. Persson. 1996. The response of prey to the risk of predation: proximate cues for refuging juvenile fish. Animal Behaviour 51: 105-115.

Fisher, S.J., C.R. Pyle & D.W. Willis. 1999. Habitat use by age-0 yellow perch in two South Dakota glacial lakes. Ecology of Freswater Fish 8: 85-93.

Fladung, E., M. Scholten & R. Thiel. 2003. Modelling the habitat preferences of preadult and adult fishes on the shoreline of the large, lowland Elbe River. Journal of Applied Ichthyology 19: 303-314.

Fletcher, D., D. Mackenzie & E. Villouta. 2005. Modelling skewed data with many zeros: A simple approach combining ordinary and logistic regression. Environmental and Ecological Statistics 12: 45-54.

Fortin, G.R., L. St-Cyr & M. Leclerc. 1993. Distribution of submersed macrophytes by echo-sounder tracings in Lake Saint-Pierre, Québec. J. Aquat. Plant Manage. 31: 232-240.

Frenette, J.-J., M.T. Arts & J. Morin. 2003. Spectral gradients of downwelling ligth in a fluvial lake (Lake Saint-Pierre, St-Lawrence River). Aquatic Ecology 37: 77-85.

Frenette, J.-J. & W.F. Vincent. 2003. Bio-optical variability in the littoral zone: Local heterogeneity and implications for water quality monitoring. pp. 41-59. *In:* M. Kumagai & W.F. Vincent (ed.) Freshwater management: Global versus local perspectives, Springer, Tokyo.

Hinch, S.G. & N.C. Collins. 1993. Relationships of littoral fish abundance to water chemistry and macrophyte variables in central Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 50: 1870-1878.

Hosmer, D.W. & S. Lemeshow. 2000. Applied logistic regression. Wiley Series in Probability and Statistics, New-York. 375 p.

Houde, E.D. 1987. Fish early dynamics and recruitment variability. American Fisheries Society Symposium 2: 17-29.

Huggins, K., J.-J. Frenette & M.T. Arts. 2004. Nutritional quality of biofilms with respect to light regime in Lake Saint-Pierre (Québec, Canada). Freshwater Biology 49: 945-959.

Jacobsen, L. & S. Berg. 1998. Diel variation in habitat use by planktivores in field enclosure experiments : the effect of submerged macrophytes and predation. Journal of Fish Biology 53: 1207-1219.

Kallemeyn, L.W. 1987. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management 7: 513-521.

Klumb, R.A., L.G. Rudstam, E.L. Mills, C.P. Schneider & P.M. Sawyko. 2003. Importance of Lake Ontario embayments and nearshore habitats as nurseries for larval fishes with emphasis on alewife (*Alosa pseudoharengus*). Journal of Great Lakes Research 29: 181-198.

Koonce, J.F., T.B. Bagenal, R.F. Carline, K.E.F. Hokanson & M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. Journal of Fisheries Research Board of Canada 34: 1900-1909.

Kubecka, J. & M. Svatora. 1993. Abundance estimates of perch fry (*Perca fluviatilis*), complicated by grouped behaviour. Ecology of Freshwater Fish 2: 84-90.

La Violette, N., D. Fournier, P. Dumont & Y. Mailhot. 2003. Caractérisation des communautés de poissons et développement d'un indice d'intégrité biotique pour le fleuve Saint-Laurent, 1995-1997. Société de la faune et des parcs du Québec, Direction de la recherche sur la faune. 227 p.

Lane, J.A., C.B. Portt & C.K. Minns. 1995. Nursery habitat requirements of Great Lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2338.

Langlois, C., L. Lapierre, M. Léveillé, P. Turgeon & C. Ménard. 1992. Synthèse des connaissances sur les communautés biologiques du Lac Saint-Pierre. Centre Saint-Laurent,Conservation et Protection, Environnement Canada. 236 p.

Lewin, W.-C., N. Okun & T. Mehner. 2004. Determinants of the distribution of juvenile fish in the littoral area of a shallow lake. Freshwater Biology 49: 410-424.

Masson, D.M. & S.B. Brandt. 1996. Effect of alewife predation on survival of larval yellow perch in an embayment of Lake Ontario. Canadian Journal of Fisheries and Aquatic Sciences 53: 1609-1617.

Mittelbach, G. 1986. Predator-mediated habitat use: some consequences for species interactions. Environmental Biology of Fishes 16: 159-169.

Nagelkerke, N.J.D. 1991. A note on general definition of the coefficient of determination. Biometrika 78: 691-692.

Olden, J.D., D.A. Jackson & P.R. Peres-Neto. 2002. Predictive models of fish species distributions: a note on proper validation and chance predictions. Transactions of the American Fisheries Society 131: 329-336.

Persson, L. 1997. Competition, predation and environmental factors as structuring forces in freshwater fish communities: Sumari (1971) revisited. Canadian Journal of Fisheries and Aquatic Sciences 54: 85-88.

Persson, L., P. Byström, E. Wahlström, A. Nijlunsin & S. Rosema. 2000. Ressource limitation during early ontogeny: constraints induced by growth capacity in larval and juvenile fish. Oecologia 122: 459-469.

Persson, L. & P. Elköv. 1995. Prey refuges affecting interactions between piscivorous perch and juvenile perch and roach. Ecology 76: 70-81.

Persson, L. & L.A. Greenberg. 1990. Juvenile competitive bottlenecks: the perch (*Perca fluviatilis*)-roach (*Rutilus rutilus*) interaction. Ecology 71: 44-56.

Pope, K.L., D.W. Willis & D.O. Lucchesi. 1996. Diffential relations of age-0 black crappie and yellow perch to climatological variables in a natural lake. Journal of Freshwater Ecology 11: 345-350.

Post, J.R. & D.J. McQueen. 1988. Ontogenic changes in the distribution of larval and juvenile yellow perch (*Perca flavescens*) : a response to prey or predators ? Canadian Journal of Fisheries and Aquatic Sciences 45: 1820-1826.

Quinn, G.P. & M.J. Keough. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge. 537 pp.

Ribi, G. 1992. Perch larvae (*Perca fluviatilis* L.) survive better in dilute sea water. Aquatic Sciences 54: 85-90.

Rosenfield, J.S. & T. Hatfield. 2006. Information needs for assessing critical habitat of freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 63: 683-698.

Sabo, M.J., W.E. Kelso, F.C. Bryan & A.D. Rutherford. 1991. Physicochemical factors affecting larval fish densities in Mississippi river floodplain ponds, Lousiana (U.S.A.). Regulated Rivers: Research & Management 6: 109-116.

Scott, W.B. & E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. 966 pp.

Smale, M.A. & C.F. Rabeni. 1995. Hypoxia and hyperthermia tolerances of headwater stream fishes. Transactions of the American Fisheries Society 124: 698-710.

Tabachnick, B.G. & L.S. Fidell. 2001. Using multivariate statistics 4 th ed. Allyn and Bacon. 966 pp.

Tardif, D., H. Glémet, P. Brodeur & M. Mingelbier. 2005. RNA/DNA ratio and total length of yellow perch (*Perca flavescens*) in managed and natural wetlands of a large fluvial lake. Canadian Journal of Fisheries and Aquatic Sciences 62: 2211-2218.

Tischler, G., H. Gassner & J. Wanzenböck. 2000. Sampling characteristics of two methods for capturing age-0 fish in pelagic lake habitats. Journal of Fish Biology 57: 1474-1487.

Tonn, W.M., J.J. Magnuson, M. Rask & J. Toivonen. 1990. Intercontinental comparison of small-lake fish assemblages: the balance between local and regional processes. American Naturalist 36: 345-375.

Treasurer, J.W. 1988. The distribution and growth of lacustrine 0+ perch, *Perca fluviatilis*. Environmental Biology of Fishes 21: 37-44.

Urho, L. 1996. Habitats shifts of perch larvae as survival strategy. Ann. Zool. Fennici 33: 329-340.

Vincent, W.F. & J.J. Dodson. 1999. The need for an ecosystem-level understanding of large rivers: the Saint-Lawrence River, Canada-USA. Japn. J. Limnol. 60: 29-50.

Vis, C., C. Hudon & R. Carignan. 2003. An evaluation of approaches used to determined the distribution and biomass of emergent and submerged aquatic macrophytes over large spatial scales. Aquatic Botany 77: 187-201.

Wang, N. & R. Eckmann. 1994. Distribution of perch (*Perca fluviatilis*) during their first year of life in Lake Constance. Hydrobiologia 277: 135-143.

Weaver, M.J., J.J. Magnuson & M.K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. Can. J. Fish. Aquat. Sci. 54: 2277-2289.

Werner, E.E., J.F. Gilliam, D.J. Hall & G.G. Mittelbach. 1983a. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

Werner, E.E., G.G. Mittelbach, D.J. Hall & J.F. Gilliam. 1983b. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. Ecology 64: 1525-1539.

Whiteside, M.C. & J.T. Hatch. 1997. Quantitative sampling techniques for age-0 fish from diverse lake habitats. Archives for Hydrobiology, Special Issues: Advances in Limnology 49: 99-116.

Whiteside, M.C., C.M. Swindoll & W.L. Doolittle. 1985. Factors affecting the early life history of yellow perch, *Perca flavescens*. Environmental Biology of Fishes 12: 47-56.

Wilkinson, L. 2002. Systat 10.2, Statistics. SYSTAT, Inc., Chicago. 1086 pp.

Table 2.1. Independent variables used in the logistic and multiple linear regressions used to predict the presence and the abundance of larval and juvenile yellow perch, respectively. Second order terms were included in the models when univariate graphical inspection of the relationship between explanatory and predicted variables showed non-linear effects.

Categories	Variables	Sampling periods				Units
		May		July		
		range	mean ± S.D.	range	mean ± S.D.	
First order terms	*Continuous variables*					
	Wind direction	3-36	13.5 ± 8.7	6-36	20.3 ± 7.4	10's Deg
	Wind speed	0-33	10.9 ± 5.2	4-33	16.3 ± 8.3	km/h
	Depth	0.65-1.97	1.27 ± 0.42	0.54-2.30	1.42 ± 0.49	m
	Turbidity	2.2-17.0	8.1 ± 3.4	1.6-30.8	6.3 ± 4.04	Nephelometric Turbidity Units (NTU)
	Conductivity	142.5-378.0	207.3 ± 43.4	184.0-271.0	232.8 ± 22.9	µS/cm
	Water temperature	13.0-26.6	20.0 ± 2.3	19.0-29.0	23.2 ± 2.1	°C
	Categorical variables					
	Submerged vegetation density	-	-	-	-	0-1-2-3-4
	Submerged vegetation type	-	-	-	-	Linear-Floating-Arbustive
	Substrat	-	-	-	-	Vegetation-Silt-Clay-Sand
Second order terms	Turbidity^2	-	-	-	-	NTU
	Depth^2	-	-	-	-	m
	Conductivity^2	-	-	-	-	µS/cm
	Water temperature^2	-	-	-	-	°C

Table 2.2. Results of the logistic regression models to predict the presence of larval and juvenile YOY yellow perch sampled in Lake Saint-Pierre. The R^2 of models are based on the max-rescaled r-square (Nagelkerke 1991) and *P* value of the models on the likelihood ratio statistics.

Ontogeny stages	Sampling gear / depth range	Model			Variables	Estimates	S.E.	Wald Chi-Square	*P*	Odds ratio	95% bounds	
		n	R^2	*P*							upper	lower
Larvae	Push-net	75	0.56	<0.0001	Intercept	-0.921	0.936	0.968	0.325	-	-	-
	(0.65-1.90m)				Wind speed	0.278	0.099	7.957	0.005	1.320	1.088	1.601
					Substrat (Clay vs Vegetation)	-4.419	1.066	17.169	<0.001	0.012	0.001	0.097
					Substrat (Silt vs Vegetation)	-2.359	0.947	6.204	0.013	0.094	0.015	0.605
					Substrat (Sand vs Vegetation)	-3.489	0.984	12.581	<0.001	0.031	0.004	0.210
Juvenile	Seine	79	0.45	<0.0001	Intercept	1.341	4.339	0.096	0.757	-	-	-
	(0.55-2.30m)				Wind speed	-0.088	0.041	4.677	0.031	0.916	0.845	0.992
					Submerged vegetation density	1.058	0.291	13.187	<0.001	2.882	1.628	5.102
					Conductivity	0.041	0.015	7.892	0.005	1.042	1.013	1.072
					Water temperature	-0.448	0.155	8.373	0.004	0.639	0.472	0.865

Table 2.3. Results of the multiple regression explaining the abundance [(CPUE $100m^3)^{-1}$ log transformed] of larval and juvenile yellow perch.

Ontogeny stages	Sampling gear / depth range	n	R^2	Variables	Coefficient	Std error	Std Coefficient	F-ratio	*P*
Larvae	Push-net	42	0.52	Constant	4.269	0.350	0.000	12.208	<0.001
	(0.65-1.85m)			Depth (log)	-4.423	1.016	-0.559	-4.353	<0.001
				Submerged vegetation density	0.587	0.297	0.254	1.976	0.05
Juvenile	Seine	53	0.42	Constant	2.779	0.926	0.000	3.002	0.004
	(0.62-2.20m)			Wind direction	0.048	0.018	0.308	2.623	0.012
				Wind speed (log)	-0.690	0.308	-0.259	-2.237	0.030
				Substrate (Clay vs Vegetation)	-0.191	0.582	-0.046	-0.328	0.744
				Substrate (Silt vs Vegetation)	0.132	0.526	0.039	0.251	0.803
				Substrate (Sand vs Vegetation)	0.989	0.404	0.396	2.540	0.018
				$Depth^2$ (log)	-2.370	0.803	-0.348	-2.952	0.005

Figure caption

Figure 2.1. Locations of the sampling sites on the north and south shore of the Lake Saint-Pierre (Québec, Canada). (a) Maskinongé Bay and (b) Fer à Cheval Bay.

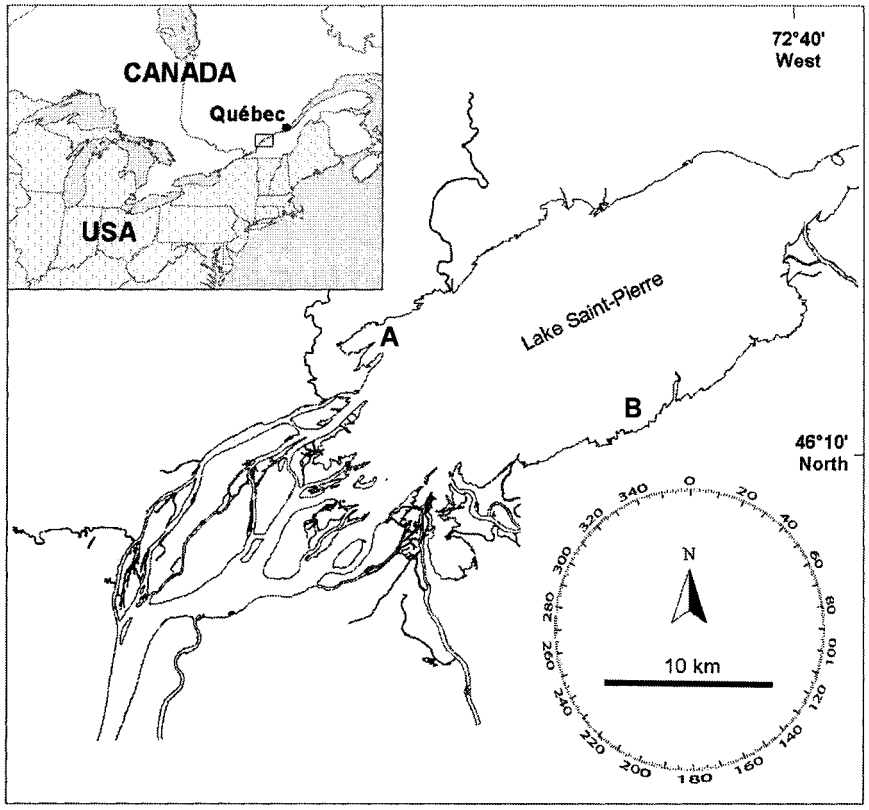
CANADA
Québec
USA
72°40'
West
Lake Saint-Pierre
A
B
46°10'
North
N
10 km
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340

Figure 2.1.

CHAPITRE III

SELECTIVITY AND PRECISION OF POP-NETS, PUSH-NETS AND SEINES FOR SAMPLING LARVAL AND JUVENILE FISH IN SHALLOW VEGETATED HABITATS

[Article]

Selectivity and Precision of Pop-nets, Push-nets and Seines for Sampling Larval and Juvenile Fish in Shallow Vegetated Habitats

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Abstract.—Abundance estimates of larval and juvenile fish require unbiased and precise sampling techniques. Even if an appropriate sampling technique is chosen, fish abundance estimates can be inaccurate if there is no assessment of the gear's precision (inter-replicate variance). The main goal of the present study was to compare the selectivity and the precision of pop-nets, push-nets, and seines for estimating both species diversity and yellow perch, *Perca flavescens,* abundance in different vegetation densities. Age-0 fish were collected during two periods, once using pop-nets and push-nets in May (larval stages) and once using pop-nets and seines in July (juvenile stages). Early in the growing season (May), the species richness of the larval stages sampled using the push-net was low compared to the pop-net in both non-vegetated and vegetated sites. The push-net was more selective than the pop-net for some species such as catostomids, percids, and cyprinids, and this was independent of the vegetation density. The catchability (occurrence and abundance) of larval yellow perch was higher for the push-net than for the pop-net in open-water habitats while it was the same in vegetated sites. Later in the season (July), the pop-net and the seine showed high age-0 species richness (i.e., 25 species), with a higher Shannon diversity index for samples collected with the seine in both sparsely and densely vegetated habitats. In densely vegetated habitats, the pop-net showed more diverse samples, suggesting that vegetation might decrease the efficiency of the seine for older fish. Our results showed that high precision levels can be attained with pop-nets and push-nets in May, when sampling yellow perch larval stages, but that the precision level is low in July, when sampling juvenile stages with the pop-net and the seine. Guidelines to obtain estimates of larval and juvenile yellow perch abundance with a desired level of precision using pop-nets, push-nets, and seines are provided to help researchers to plan their sampling designs.

Quantitative estimates of larval and juvenile fish populations are essential to manage fish stocks and develop new theories on population dynamics (Cyr et al. 1992; Clapp and Dettmers 2004). The preferred habitats and spatial distribution of fish larvae are often heterogeneous and samples usually show high variance among replicates. Sampling the various habitats selected by larval and juvenile fish is often necessary but requires several fishing gears: each gear has different characteristics in terms of selectivity (species and size) and precision (inter-replicate variance). Active gears like bongos, Tucker trawls, and push-nets designed to collect age-0 fish in open waters (Pepin and Shears 1997; Wanzenböck et al. 1997) are inappropriate in shallow, densely vegetated habitats (Bagenal and Nellen 1980; Whiteside and Hatch 1997; Tischler et al. 2000). In contrast, passive gears like pop-nets are relatively unbiased for sampling age-0 fish in vegetated shallow waters (Serafy et al. 1988; Dewey et al. 1989; Dewey 1992); however, the area sampled is generally small. Zones with dense vegetation might interfere with efforts to collect fish, bias catch estimates, and lead to an underestimation of their importance as nursery or feeding habitats (Serafy et al. 1988). It might also be necessary to use different sampling gears when comparing the same sites over time because of the ontogenic changes in fish morphology and behaviour (Whiteside et al. 1985), because of increasing swimming capability with increasing fish size (Tischler et al. 2000), and because the vegetation grows over time. In this context, estimations of the selectivity and precision of the different fishing gears used to sample fish larvae and juveniles are necessary to determine their complementarities and reliability. Furthermore, when the variance is high among replicates, abundance estimates can be useless without any assessment of the precision of fishing gears (Cyr et al. 1992).

Lake Saint-Pierre is the largest fluvial lake of the St. Lawrence River (Quebec, Canada). It is characterized by a large, shallow flood plain covered by vegetation patches of

varying densities. Lake Saint-Pierre's fish community includes about 40 species and is dominated by yellow perch, *Perca flavescens,* one of the most important commercial and recreational freshwater species in North America. The high diversity of fish species and habitats make Lake Saint-Pierre an appropriate system to test different fishing techniques.

The goal of the present study was to compare the selectivity and the precision of pop-nets, push-nets, and seines to estimate both species diversity and yellow perch abundance in different vegetation densities and during two periods of the growing season. Our second objective was to develop equations to predict the number of samples required to reach various levels of precision. We focused on age-0 yellow perch because it is by far the most abundant species in our study site.

Methods

Fish sampling and laboratory analyses.—The sampling was conducted in the Lake Saint-Pierre area (St. Lawrence River, Québec, Canada), in two shallow wetlands of ~3 km^2 each (Maskinongé Bay: 46° 12.402' N, 72° 56.953' W; and Fer à Cheval Bay: 46° 09.578' N, 72° 48.696' W). This fluvial lake is large (~350 km^2), shallow (average depth is 3.17 m at mean discharge), and extensively covered by macrophytes during the summer (see Frenette et al. 2003 for a detailed description of the study site).

Fish larvae were collected in spring 2003 (26 May – 9 June; hereafter May) and juveniles during the summer of the same year (2 – 17 July; hereafter July). To compensate for the fast growth and ontogenetic development of age-0 yellow perch, sampling gears were chosen according to their a priori effectiveness regarding fish size and habitat characteristics (vegetation). The push-net is known to be inadequate for larvae >30 mm total length (TL) (Tischler et al. 2000), and the seine can be labour intensive or biased for catching small post-hatch larvae (Whiteside and Hatch 1997). Age-0 yellow perch generally

reach the limiting size of 30 mm in early July (Tardif et al. 2005), thus we compared the pop-net to the push-net in May and the pop-net to the seine in July. Fish were collected during daylight at two sites (Maskinongé and Fer à Cheval bays) according to a stratified sampling procedure, with each site divided into three depth strata (0.50-0.75 m, 0.75-1.00 m, and 1.00-1.25 m). Within each stratum, replicate samples were collected at random locations by pop-net (7-16 replicates in May and 9-22 replicates in July), push-net (4-10 replicates in May), and seine (5-10 replicates in July). To avoid biases due to temporal and spatial variations, the sampling techniques were used simultaneously in the same depth strata (0.50-0.75 m, 0.75-1.00 m, and 1.00-1.25 m).

Each pop-net consisted of two 4 x 4 m frames of rigid 5-cm diameter polyvinyl chloride (PVC) pipe, one floating with the air trapped and one weighted with steel rods and anchored at the bottom (Serafy et al. 1988; Dewey et al. 1989). A net (1.5 m high, 1.2 mm mesh) linked the two frames, with the top and bottom open. The upper and lower frames were tied together and held to the bottom of the sampling site, allowing time for fish to recolonize the site. Twelve hours later, a pin-key attached to a trip cord (see Fig. 1a in Morgan et al. 1988) was used to release the buoyant frame from the ballast frame. After dense vegetation had been removed, fish were collected from within the pop-net using a small haul seine with a 1.2-mm mesh size (four hauls according to Dewey 1992). The volumes sampled using the pop-net ranged between 7.8 and 18.9 m^3 (average 12.2 m^3), depending on the depth of the water column.

The push-net (Kelso and Rutherford 1996; Wanzenböck et al. 1997; Tischler et al. 2000) consisted of three zooplankton nets, each with a 0.40 x 0.40 m square opening; 1.5 m long; 500 μm mesh) mounted on an adjustable steel frame placed in front of the boat so that three depths of the water column were sampled simultaneously. The nets were pushed at

~1 $m \cdot s^{-1}$ along 50 m transects (sometimes 25 m). The number of vertical strata sampled (each of 0.40 m) was adjusted according to the maximum depth at each site (i.e., 1 stratum when maximum depths were <0.90 m, two strata for depths 0.90 m–1.30 m, and three strata for depths >1.30 m). The volume sampled by the push-net was calculated by multiplying the net opening by the length of the transect. The volume sampled using the push-net ranged between 4.0 and 16.0 m^3 (average 9.7 m^3).

Seine samples were collected with a beach seine (12.5 m x 4 m; 3.2 mm stretched mesh) with floats on the top line and a lead core bottom line. The seine was deployed by boat in a circle in the chosen habitat. In the selected habitats, estimates of sample volume were based on the theoretical cylinder of water enclosed by the net (i.e., 122.7 m^2 x sampling depth). The volume sampled using the seine ranged between 66.3 and 147.2 m^3 (average 109.1 m^3).

At each sampling site, the depth was measured and the vegetation density estimated following a semi-quantitative scale ranging from 0 (open water) to 4 (very dense). All age-0 and age-1 fish were preserved in 10% formalin or in 75% alcohol (for further analyses not presented here) after being exposed to eugenol. In the laboratory, fish were identified to species (Scott and Crossman 1973; Auer 1982), weighed (± 0.01 mg), and measured (± 0.01 mm TL) using an ocular micrometer mounted on a dissecting microscope for larvae and a digital caliper for juveniles. Due to the effect of preservatives on fish length and weight, we used regression equations to convert the lengths and weights of preserved fish to measurements approximating those of fresh specimens (Paradis et al., Chapitre IV)

Selectivity.—To determine the selectivity of the three sampling gears, the community structure (species richness and diversity) was compared between sampling gears in the two contrasting vegetated habitats (low and high density). We also compared the abundance,

occurrence, and average total length of yellow perch. Samples from both study sites were combined according to the vegetation density (non-vegetated and vegetated sites in May; sparsely and densely vegetated sites in July). Due to the presence of fast-growing macrophytes in the littoral zone, no sites without vegetation were found in July. The species diversity sampled by each gear type was estimated using the Shannon diversity index (H) as follows:

$$H = -\sum_{j=1}^{s} p_i \ln p_i \qquad \text{(eq. 1)}$$

where p_i represents the percentage of species i relative to the total number of fish in all sampling sites (i.e., sampled in the same period with the same gear). The abundances of age-0 and age-1 fish were expressed in terms of catch per unit effort (CPUE), estimated for the gears, and standardized to the number of fish per volume of sampled water (100 m^3). The vertical strata of 0.40 m sampled with the push-net were pooled and considered as one effort unit (Tischler et al. 2000). Yellow perch abundance was not normally distributed and exhibited a high number of zeros. The comparison between gear types was thus performed using a Mann-Whitney U test for independent samples (Pepin and Shears 1997; Tischler et al. 2000). The average total lengths of larval (May) and juvenile (July) yellow perch sampled in various vegetation densities were compared among the three gear types using an analysis of variance (ANOVA).

Precision.—Previous studies have shown that the variance between replicate samples is a constant and predictable function of their mean (Downing and Cyr 1985; Downing et al. 1987). Cyr et al. (1992) suggested that a precision of at least 0.2 is essential for observing significant differences between the mean densities in larval fish studies. Variability in larval and juvenile age-0 yellow perch CPUE was used as an index of gear precision, and the relationship between the variance and the average density was computed for each gear type (Downing et al. 1987).

Samples from each depth strata at each study site were used as replicates. As suggested by Karjalainen et al. (1996), the sampled volume was included in the relationship to improve the fit of the predicted variance:

$$\log_{10}(s^2) = a + b\log_{10}(x) + c\log_{10}(V) \qquad \text{(eq. 2)}$$

where s^2 is the variance, x the mean yellow perch CPUE, a the intercept, b the slope of the mean CPUE, and c the slope of the sample volume. The effect of the three sampling techniques on the CPUE variance was assessed for yellow perch with an analysis of covariance (ANCOVA) using $\log_{10}(s^2)$ as a function of $\log_{10}(x)$ (Pepin and Shears 1997; Tischler et al. 2000).

Equation 2 was also used to predict the a priori number of samples required to reach acceptable levels of precision in the abundance estimates of age-0 yellow perch (Downing et al. 1987). To do so, the precision with which age-0 fish abundance is measured was estimated as the coefficient of variation of the mean ($CV_x = SE / x$) (Cyr et al. 1992). The coefficient of variation of the mean is a function of the average number of yellow perch larvae (x), the inter-replicate variance (s^2), the number of replicates (n), and the sample volume (V) (Downing et al. 1987):

$$CV_x = [\, n\,(a \bullet x^{(b-2)} \bullet V^c)^{-1}\,]^{-0.5} \qquad \text{(eq. 3)}$$

where a, b, and c are the regression coefficients from equation 2. Knowing the expected precision of a sampling gear (CV_x; eq. 3) for each sampling period, we computed the

number of replicate samples (n) required to reach a precision (CV_x) of 0.15 and 0.20 with the following equation (Downing et al. 1987):

$$n = a \bullet x^{(b-2)} \bullet V^c \bullet CV_x^{-2} \qquad \text{(eq. 4)}$$

where a, b, and c are the regression coefficients from equation 2, x the average number of yellow perch, V the sample volume, and CV_x the desired precision of the sampling program. All computations using the regression coefficients of equation 2 were corrected after being transformed from the logarithmic to the arithmetic scale (Sprugel 1983). The statistical analyses were performed using SYSTAT 10.2 (Wilkinson 2002).

Results

Selectivity

In May, pop-nets sampled a higher number of larval fish species than push-nets in both vegetated and non-vegetated sites (Table A.3.1), even though the Shannon diversity indices were slightly higher for push-nets. No fish older than age-0 were caught with the push-net in May (Table A.3.1). In July, pop-nets and seines sampled a similar number of juvenile fishes in both the sparsely and densely vegetated sites, while the Shannon diversity indices were higher for seines than for pop-nets. In sparsely vegetated sites in July, seines sampled a higher number of fish species older than age-0 and exhibited higher Shannon diversity indices than the pop-nets, while the opposite results were observed in densely vegetated sites (Table A.3.1). All sampling gears used in May and July showed a higher species richness for larval and juvenile stages than for older fish. As revealed by the average CPUE, larval and juvenile yellow perch dominated the samples (Table A.3.1).

In May, estimates of the frequency of occurrence and the abundance of larval yellow perch sampled in non-vegetated habitats were significantly higher using push-nets than pop-nets; no differences were found in vegetated sites (Table 3.1a). For age-1 yellow perch, there were no significant differences in the occurrence frequency nor in the abundance (low catch numbers) calculated from push-nets and pop-nets in either vegetation density (Table 3.1b). In July, the seine was the most effective gear for sampling juvenile and age-1 yellow perch in terms of occurrence and abundance in both vegetation densities (Table 3.2a-b).

To determine if sampling gears were size-selective for larval and juvenile yellow perch, we compared the average total fish length sampled using the three techniques. In May, the average total length of larval yellow perch sampled using the pop-net was significantly higher than with the push-net in non-vegetated (TL = 14.41 ± 0.27 mm and 13.32 ± 0.19 mm, respectively; ANOVA: $F = 12.96$, $p<0.001$) and in vegetated habitats (TL = 13.49 ± 0.09 mm and 13.99 ± 0.11 mm, respectively; ANOVA: $F = 12.60$, $p<0.001$; Figure 3.1). In July, the average total length of juvenile yellow perch sampled using the seine was significantly higher than using the pop-net in sparsely vegetated (TL = 43.73 ± 0.36 mm and 35.77 ± 0.49 mm, respectively; ANOVA: $F = 170.94$, $p<0.001$; Figure 3.1) and in densely vegetated (TL = 45.52 ± 0.62 mm and 40.30 ± 1.09 mm, respectively; ANOVA: $F = 17.30$, $p<0.001$; Figure 3.1) habitats.

Precision

Based on age-0 yellow perch catches, the relationship between sample variance and average abundance density was highly significant for pop-nets and push-nets in May ($r^2 = 0.99$ for both) and for pop-nets and seines in July ($r^2 = 0.98$ and 0.92, respectively; Figure 3.2). For larvae sampled in May, the ANCOVA revealed that the slope of the variance-to-mean

relationship was significantly higher for push-nets than for pop-nets ($F = 12.70$; $P < 0.01$; Figure 3.2a). For juveniles sampled in July, the intercept of the variance-to-mean relationship was significantly higher for pop-nets than for seines ($F = 30.39$; $P < 0.01$; Figure 3.2b). The precision, as computed by equation 3, was higher for push-nets than for pop-nets in May and was higher for seines than for pop-nets in July (Table 3.3). Furthermore, the precision levels reached by sampling gears were higher in May than in July (Table 3.3). Using equation 4, we calculated the number of replicates required to reach precisions (CV_x) of 0.15 and 0.20 in May and July (Figure 3.3). For a given abundance of age-0 yellow perch and a desired precision level, the number of replicates required was higher when using the pop-net than the push-net in May and than the seine in July (Figure 3.3).

Discussion

The selection of a sampling gear is usually determined by considering the need to collect fish in a variety of habitats that change over space and time. In this study, we compared the selectivity and the precision of pop-nets, push-nets, and seines for collecting larval and juvenile fish in shallow habitats covered by various vegetation densities. Since larval and juvenile yellow perch were dominant in our samples, we used data available for this species to assess and compare both the selectivity and precision of the three sampling gears.

Pop-net versus Push-net

Early in the growing season (May), the species richness of larval stages sampled using the push-net was low compared to the pop-net in both non-vegetated and vegetated sites. Comparable fish abundances sampled with the pop-net and push-net led to higher values of the Shannon diversity index for the push-net. The push-net was more selective than the pop-net for some species such as catostomids, percids, and cyprinids, and this was independent of the

vegetation density. Several authors reported a high selectivity for percids and a low species diversity when using active gears such as the push-net, Miller sampler, or towed net (Wanzenböck et al. 1997; Whiteside and Hatch 1997; Tischler et al. 2000; Claramunt et al. 2005). Schooling behaviour and swimming capability of these species might explain their enhanced catchability by active sampling gears. Water temperature is critical for the growth of early stages (Clady 1976). Since percid larvae select the warmer upper water layer (Wang and Appenzeller 1998), temperature can also influence the position of young fish in the water column and thus their catchability. The size selectivity of the push-net compared to the pop-net is supported by the lower mean size of age-0 yellow perch sampled and by the absence of older fish in captures by the push-net. These results can be explained by gear avoidance by larger fish: the ability of age-0 fish to avoid pushed or towed nets increases exponentially with body length (Tischler et al. 2000). Tischler et al. (2000) illustrated the size selectivity of the push-net for yellow perch larger than 30 mm. The present study documents the size selectivity of the push-net for perch ≤20.4 mm. Like the push-net, the pop-net exhibited a low efficiency for sampling fish >age-0, suggesting that it is selective for certain sizes of fish. Serafy et al. (1988) recommended the use of the pop-net for fish <150 mm while Dewey et al. (1989) and Dewey (1992) recommended its use for age-0 fish only, although they did not analyze the size frequency distribution of sampled fish. Our results indicate that the size selectivity of a given sampling gear should be considered when comparing length distributions obtained with different techniques.

The efficiency the push-net (occurrence and abundance) in catching larval yellow perch was higher than for the pop-net in open-water habitats while it was the same in vegetated sites. The two gears sampled a comparable volume of water. However, the push-net covered a larger variety of habitats, and the length of the transect (50 m) probably lowered the effect of patchy fish distribution in the open-water habitat. Although the accuracy of the push-net in open-water

and pelagic habitats has been demonstrated (Wanzenböck et al. 1997; Tischler et al. 2000), the efficiency of the push-net to sample fish larvae in shallow vegetated habitats compared to a specialized sampling gear such as the pop-net had not been documented before this study. The pop-net and the push-net showed relatively low variances among replicates for sampling larval stages, as revealed by the coefficients of variation (0.02 and 0.01 respectively). The generally high precision of both sampling gears in May could be explained by the fact that yellow perch larvae were dispersed in the littoral zone at the beginning of the growing season. However, the significantly steeper slope of the variance-to-mean relationship for the push-net suggests that it was more precise than the pop-net when the mean abundance of larval fish was low (see Figure 2a). The higher precision of the push-net means that a smaller sampling effort is required to reach comparable abundance estimates. Although described as an effective sampling gear (Serafy et al. 1988; Dewey et al. 1989; Dewey 1992), the pop-net is not comparable to the push-net in terms of efficiency and precision.

Pop-net versus Seine

Later in the season (July), the pop-net and the seine showed high age-0 species richness (i.e., 25 species), but the Shannon diversity index was higher for samples collected with the seine in both sparsely and densely vegetated habitats. The smaller area sampled using the pop-net (16 m^2) compared to the seine (122.7 m^2) likely explains the difference in the observed community composition. Our results are consistent with those of Dewey et al. (1989), who showed that samples collected with the pop-net were not as diverse as those collected with the seine. The seine exhibited high species richness, with a Shannon diversity index higher for older fish collected in sparsely vegetated habitats. In densely vegetated ones, the pop-net showed more diverse samples, suggesting that the vegetation might decrease the efficiency of the seine for

older fish. The difficulty in deploying and retrieving the seine in densely vegetated sites probably allows more time and gaps for fish older than age-0 to escape.

For age-0 and age-1 yellow perch, the seine was more efficient than the pop-net in terms of occurrence, abundance, and precision, even in densely vegetated habitats. The higher efficiency of the seine in sampling age-0 and age-1 yellow perch could be explained by the fact that it sampled a larger area. Furthermore, the difficulty in operating the pop-net in July might have contributed to its lower efficiency. In July, mats of filamentous algae covered the water surface, preventing the upper frame from quickly rising to the water surface. This reduced efficiency might have contributed to the higher selectivity of the pop-net in densely vegetated habitats. Although the pop-net is designed and presented as an effective technique to collecting age-0 fish in vegetated habitats (Serafy et al. 1988, Dewey et al. 1989, Dewey 1992), our results suggest that its efficiency can be limited at very high vegetation densities. The higher efficiency of the seine compared to the pop-net contrasts with the results of Serafy et al. (1988), who showed a higher efficiency of the pop-net in dense submerged macrophytes. Dewey et al. (1989) found inconsistencies in catches between the two gears in vegetated and non-vegetated sites, with the seine being more efficient than the pop-net in non-vegetated sites. The study of Serafy et al. (1988) did not allow a rigorous comparison due to the lack of replicates (n=2), and the analyses of Dewey et al. (1989) included a temporal effect (fish caught from May to October) that might have biased their analyses.

Implications for sampling design

The design of an effective program to sample larval and juvenile fish depends on the study objectives and the limits of the fishing gears. This is particularly true when fish abundance has to be monitored over time: complications arise because of changes in habitat structure (e.g.,

vegetation density) and fish swimming ability and distribution during ontogeny (Whiteside et al. 1985). Each fishing technique has its advantages and disadvantages, and a single gear rarely allows an efficient and representative sampling in different conditions. To overcome the limitation of each fishing gear and to sample all usable habitats, it is generally suggested that a combination of sampling techniques be used because of changes in habitat (e.g., vegetation), changes in swimming ability, and changes in fish spatial distribution (Tischler et al. 2000).

The pop-net can be used all along the growing season in a variety of shallow habitats (0.5-1.3 m), is suitable for sampling age-0 fish, and is adequate to relate fish catches to habitat characteristics. Furthermore, the pop-net can be modified to allow sampling fish in deeper waters (Morgan et al. 1988). In the field, the push-net was faster and easier to use than the pop-net. Due to its higher efficiency and precision in both vegetated and non-vegetated habitats, the push-net appeared to be mostly appropriate for newly hatched larvae, both in the littoral and pelagic zones (Claramunt et al. 2005). The push-net also has the advantage of having a fixed sampling depth, thus the details of the vertical distribution of larvae are known (Post and McQueen 1988). Due to its selectivity towards small catostomids, cyprinids, and percids larvae, the push-net is not an effective sampling gear for community assemblage studies. Later in the growing season, when larvae have reached a size >20 mm, the push-net system should be replaced by a less size-selective sampling gear. The seine appears well suited for collecting diverse age-0 fish in a great variety of habitats, including densely vegetated ones, but the efficiency of the seine varies with the structure of the littoral zone. Physical obstructions such as rocks, logs, branches, and some species of macrophytes prevent the sampling of the entire water column, and abundance estimates should be corrected in these habitats (Pierce et al. 1990). Except for the seine used in July, none of the sampling gears tested in the present study was particularly suitable for capturing fish older than age-0.

In addition to the importance of choosing an accurate (unbiased) sampling technique, assessing the precision level is especially important considering that the majority of the published larval fish density estimates have low precisions (Cyr et al. 1992). Cyr et al. (1992) suggested that a precision of at least 0.2 is essential for observing significant differences between the mean densities in larval fish studies. Our results showed that this precision level can be attained with the pop-net and the push-net in May, when sampling larval stages, but is more difficult to attain in July, when sampling juvenile stages with the pop-net and the seine. The precision of abundance estimates could have been enhanced in July by increasing the sample size (Cyr et al. 1992) and, to a lesser extent, by increasing the sample volume (Downing et al. 1987; Karjalainen et al. 1996; Tischler et al. 2000). In this paper, we provide guidelines to obtain estimates of larval and juvenile fish abundance with a desired level of precision. However, sampling variation might differ among ecosystems because of differences in physical structure (e.g., thermal stratification, vegetation density, physical obstruction) or processes (e.g., fish schooling) that influence larval distribution (Pepin and Shears 1997). Careful consideration of the sampling precision in the context of the study objectives and study site should improve the quantitative estimates of fish population (Cyr et al. 1992).

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References

Auer, N. A. 1982. Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission Special Publication 82-3, Ann Arbor, Michigan.

Bagenal, T. B. and, W. Nellen. 1980. Sampling eggs, larvae and juvenile fish. Pages 13-33 *in* T. Backiel and R. L. Welcomme, editors. Guidelines for sampling fish in inland waters. The European Inland Fisheries Advisory Commission, Rome.

Clady, M. D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. Journal of Fisheries Research Board of Canada 33: 1887-1893.

Clapp, D. F. and, J. M. Dettmers. 2004. Yellow perch research and management in Lake Michigan: evaluating progress in a cooperative effort, 1997-2001. Fisheries 29: 11-19.

Claramunt, R. M., D. E. Shoup and, D. H. Wahl. 2005. Comparison of push nets and tow nets for sampling larval fish with implications for assessing littoral habitat utilization. North American Journal of Fisheries Management 25: 86-92.

Cyr, H., J. A. Downing, S. Lalonde, S. B. Baines and, M. L. Pace. 1992. Sampling larval fish populations: choice of sample number and size. Transactions of the American Fisheries Society 121: 356-368.

Dewey, M. R. 1992. Effectiveness of a drop net, a pop net, and an electrofishing frame for collecting quantitative samples of juvenile fishes in vegetation. North American Journal of Fisheries Management 12: 808-813.

Dewey, M. R., L. E. Holland-Bartels and, S. J. Zigler. 1989. Comparison of fish catches with buoyant pop nets and seines in vegetated and nonvegetated habitats. North American Journal of Fisheries Management 9: 249-253.

Downing, J. A. and, H. Cyr. 1985. Quantitative estimation of epiphytic invertebrate populations. Canadian Journal of Fisheries and Aquatic Sciences 42: 1570-1579.

Downing, J. A., M. Pérusse and, Y. Frenette. 1987. Effect of interreplicate variance on zooplankton sampling design and data analysis. Limnology and Oceanography 32: 673-680.

Frenette, J.-J., M. T. Arts and, J. Morin. 2003. Spectral gradients of downwelling ligth in a fluvial lake (Lake Saint-Pierre, St-Lawrence River). Aquatic Ecology 37: 77-85.

Karjalainen, J., S. Ollikainen and, M. Viljanen. 1996. Estimation of the year-class of newly hatched fish larvae in Finnish lakes-how sampling design can influence abundance estimations ? Archives for Hydrobiology, Special Issues: Advances in Limnology 50: 73-80.

Kelso, W. E. and, A. D. Rutherford. 1996. Collection, preservation, and identification of fish eggs and larvae. Pages 255-302 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Morgan, R. P., K. J. Killgore and, N. H. Douglas. 1988. Modified popnet design for collecting fishes in varying depths of submersed aquatic vegetation. Journal of Freshwater Ecology 4: 533-539.

Pepin, P. and, T. H. Shears. 1997. Variability and capture efficiency of bongo and Trucker trawl samplers in the collection of ichtyoplankton and other macrozooplankton. Canadian Journal of Fisheries and Aquatic Sciences 54: 765-773.

Pierce, C. L., J. B. Rasmussen and, W. C. Leggett. 1990. Sampling littoral fish with a seine corrections for variable capture efficiency. Canadian Journal of Fisheries and Aquatic Sciences 47: 1004-1010.

Post, J. R. and, D. J. McQueen. 1988. Ontogenic changes in the distribution of larval and juvenile yellow perch (*Perca flavescens*) : a response to prey or predators ? Canadian Journal of Fisheries and Aquatic Sciences 45: 1820-1826.

Scott, W. B. and, E. J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184, Fisheries Research Board of Canada.

Serafy, J. E., R. M. Harrell and, J. C. Stevenson. 1988. Quantitative sampling of small fishes in dense vegetation : Design and field testing of portable «pop-nets». Journal of Applied Ichthyology 4: 149-157.

Sprugel, D. G. 1983. Correcting for bias in log-transformed allometric equations. Ecology 64: 209-210.

Tardif, D., H. Glémet, P. Brodeur and, M. Mingelbier. 2005. RNA/DNA ratio and total length of yellow perch (*Perca flavescens*) in managed and natural wetlands of a large fluvial lake. Canadian Journal of Fisheries and Aquatic Sciences 62: 2211-2218.

Tischler, G., H. Gassner and, J. Wanzenböck. 2000. Sampling characteristics of two methods for capturing age-0 fish in pelagic lake habitats. Journal of Fish Biology 57: 1474-1487.

Wang, N. and, A. Appenzeller. 1998. Abundance, depth distribution, diet composition and growth of perch (*Perca fluviatilis*) and burbot (*Lota lota*) larvae and juveniles in the pelagic zone of Lake Constance. Ecology of Freshwater Fish 7: 176-183.

Wanzenböck, J., J. Matena and, J. Kubecka. 1997. Comparison of two methods to quantify pelagic early life stages of fish. Archives for Hydrobiology, Special Issues: Advances in Limnology 49: 117-124.

Whiteside, M. C. and, J. T. Hatch. 1997. Quantitative sampling techniques for age-0 fish from diverse lake habitats. Archives for Hydrobiology, Special Issues: Advances in Limnology 49: 99-116.

Whiteside, M. C., C. M. Swindoll and, W. L. Doolittle. 1985. Factors affecting the early life history of yellow perch, *Perca flavescens*. Environmental Biology of Fishes 12: 47-56.

Wilkinson, L. 2002. Systat 10.2, Statistics. SYSTAT, Inc., Chicago.

Appendix: Fish Species Sampled

TABLE A.3.1.—Age-0 (May: larval stages; July: juvenile stages) and > age-0 fish species sampled by pop-net, push-net, and seine. Numbers represent average catch per unit effort (per 100 m^3) at sites with various vegetation densities; t represents trace catches (<0.05 fish/100 m^3).

Species	May				July			
	non-vegetated		vegetated		sparsely vegetated		densely vegetated	
	pop-net (n=50)	push-net (n=76)	pop-net (n=36)	push-net (n=16)	pop-net (n=34)	seine (n=13)	pop-net (n=55)	seine (n=18)
Age-0								
Alewife *Alosa pseudoharengus*	0.0	1.2	0.0	0.0	0.0	0.1	0.0	0.0
Rock Bass *Ambloplites rupestris*	0.8	0.2	0.0	0.0	0.8	0.0	0.8	0.0
White Sucker *Catostomus commersonii*	0.0	0.0	0.0	0.0	34.3	1.1	0.2	0.1
Catostomid Catostomidae spp.	3.2	17.9	123.6	1655.5	0.7	0.4	0.7	0.1
Quillback *Carpiodes cyprinus*	0.0	0.0	0.5	0.0	0.2	0.0	0.1	0.0
Lake Whitefish *Coregonus clupeaformis*	0.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Carp *Cyprinus carpio*	0.4	0.0	0.0	0.0	6.7	1.2	13.5	6.5
Cyprinid Cyprinidae spp.	72.9	8.1	390.2	3641.4	67.3	48.3	189.9	118.1
Northern Pike *Esox lucius*	0.6	0.0	2.0	0.0	0.0	0.1	0.3	t
Tessellated Darter *Etheostoma olmstedi*	0.0	0.0	0.0	0.0	9.2	7.7	2.4	2.1
Johnny Darter *E. nigrum*	0.0	0.0	0.0	0.0	1.2	0.5	1.0	0.0
Iowa Darter *E. exile*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Banded Killifish *F. diaphanus*	3.8	0.0	1.1	0.0	95.4	39.9	130.1	18.2
Mooneye *Hiodon tergisus*	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Eastern Silvery Minnow *Hybognathus regius*	2.6	0.0	0.2	0.0	3.7	0.4	1.9	4.6
Brown Bullhead *Ameiurus nebulosus*	0.3	0.0	2.7	0.0	8.7	4.6	4.7	0.6
Brook Silverside *Labidesthes sicculus*	0.0	0.0	0.0	0.0	10.3	0.8	0.3	3.7
Pumpkinseed *Lepomis gibbosus*	1.4	0.0	0.3	0.0	132.8	24.3	256.7	65.6
Smallmouth Bass *Micropterus dolomieu*	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Largemouth Bass *M. salmoides*	0.0	0.0	0.0	0.0	5.1	0.8	16.6	1.7
Silver Redhorse *Moxostoma anisurum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Emerald Shiner *Notropis atherinoides*	0.4	0.0	0.2	0.0	0.0	0.0	0.4	0.0
Bridle Shiner *N. bifrenatus*	7.1	0.0	71.8	0.0	1.6	1.3	2.2	2.5
Blackchin Shiner *N. heterodon*	10.9	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Blacknose Shiner *N. heterolepis*	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Spottail Shiner *N. hudsonius*	0.1	0.0	0.2	0.0	139.9	20.3	36.0	11.9
Sand Shiner *N. stramineus*	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mimic Shiner *N. volucellus*	0.3	0.0	0.0	0.0	1.2	0.1	0.0	0.0
Cyprinid *N.* spp.	7.6	0.0	6.3	0.0	0.2	13.1	15.6	0.4
Golden Shiner *Notemigonus crysoleucas*	16.9	0.0	43.3	0.0	12.8	6.0	17.5	5.8
Tadpole Madtom *Noturus gyrinus*	0.7	0.0	0.0	0.0	0.9	0.5	2.5	0.1
Logperch *Percina caprodes*	24.3	310.3	0.4	37.5	1.4	5.5	0.2	2.4
Percid Percidae spp.	2.1	118.3	0.0	1013.3	0.0	0.1	0.0	0.0
Yellow Perch *Perca flavescens*	134.8	154.0	289.8	4293.8	36.1	13.8	7.7	5.6
Trout-Perch *Percopsis omiscomaycus*	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Bluntnose Minnow *Pimephales notatus*	1.7	0.0	1.6	0.0	3.0	0.0	1.4	0.1
Fathead Minnow *P. promelas*	0.3	0.0	0.2	0.0	0.9	0.0	0.0	0.0
Walleye *Sander vitreus*	0.0	3.7	0.0	0.8	0.0	0.1	0.0	0.0
Creek Chub *Semotilus atromaculatus*	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unknown	12.9	6.6	19.3	128.9	1.7	0.2	4.4	5.6
Species Richness	25	10	19	7	25	25	25	23
Shannon diversity index (H)	0.498	0.541	0.438	0.547	0.630	0.938	0.554	0.803
		> Age-0						
Rock Bass	t	0.0	t	0.0	0.1	0.2	0.2	0.1
White Sucker	0.0	0.0	0.0	0.0	0.0	0.0	t	0.0
Carp	t	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Northern Pike	0.0	0.0	0.0	0.0	t	0.1	0.1	0.5
Johnny Darter	t	0.0	0.0	0.0	0.0	0.1	t	0.0
Tessellated Darter	0.1	0.0	t	0.0	0.1	0.5	0.1	0.1
Banded Killifish	0.2	0.0	0.0	0.0	0.0	1.9	0.0	0.1
Brown Bullhead	0.3	0.0	0.7	0.0	3.4	12.2	0.4	1.6

Pumpkinseed	0.1	0.0	0.1	0.0	t	0.3	0.2	0.7
Largemouth Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Bridle Shiner	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Golden Shiner	28.8	0.0	0.9	0.0	0.0	0.0	0.1	0.1
Tadpole Madtom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Blacknose Shiner	t	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spottail Shiner	0.0	0.0	0.0	0.0	0.0	0.0	t	0.0
Cyprinid *Nototropis* spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Logperch	0.0	0.0	0.0	0.0	0.0	0.0	t	0.0
Yellow Perch	0.7	0.0	0.4	0.0	0.1	10.8	0.3	6.2
Bluntnose Minnow	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
Species Richness	10	0	6	0	7	8	15	10
Shannon diversity index	0.140	0.000	0.391	0.000	0.110	0.478	0.705	0.475

TABLE 3.1.—Catches of (a) larvae (7.2-20.4 mm) and (b) age-1 (28.09-51.66 mm) yellow perch sampled by pop-net and push-net in non-vegetated and vegetated sites in May. Significance levels (*P*) are based on a Chi-square test for occurrence data and a Mann-Whitney *U* test to compare the median catches (yellow perch per 100 m^3) between sampling gears.

Site	Sampling gear	Sample size (n)	Occurrence				Abundance (per 100 m^3)			
			presence (n)	frequency (%)	Chi-square	*P*	range	median	*U*	*P*
a)										
Non-vegetated	Pop-net	18	8	44.4	4.21	0.040	0-233	0.0	99.0	0.040
	Push-net	18	14	77.8			0-1 593	31.3		
Vegetated	Pop-net	50	32	64.0	0.45	0.504	0-6 893	30.3	583.0	0.214
	Push-net	28	20	71.4			0-31 325	137.5		
b)										
Non-vegetated	Pop-net	18	1	5.6	1.03	0.310	0-8	0.0	171.0	0.317
	Push-net	18	0	0			0-0	0.0		
Vegetated	Pop-net	50	3	6.0	1.82	0.177	0-17	0.0	714.0	0.180
	Push-net	28	0	0			0-0	0.0		

TABLE 3.2.—Catches of (a) juveniles (14.9-66.6 mm) and (b) age-1 (80-110 mm) yellow perch sampled by pop-net and seine in sparsely and densely vegetated sites in July. Significance levels (*P*) are based on a Chi-square test for occurrence data and a Mann-Whitney *U* test to compare the median catches (yellow perch per 100 m^3) between sampling gears.

Site	Sampling gear	Sample size (n)	Occurrence				Abundance (per 100 m^3)			
			presence (n)	frequency (%)	Chi-square	*P*	range	median	*U*	*P*
a)										
Sparsely vegetated	Pop-net	61	14	23.0	10.733	0.001	0-477	0.0	447.0	0.014
	Seine	21	13	61.9			0-46	1.4		
Densely vegetated	Pop-net	28	12	42.9	4.077	0.043	0-78	0.0	119.0	0.462
	Seine	10	8	80.0			0-22	3.3		
b)										
Sparsely vegetated	Pop-net	61	14	23.0	13.277	<0.001	0-414	0.0	437.5	0.011
	Seine	21	14	66.7			0-92	2.0		
Densely vegetated	Pop-net	28	9	32.1	9.894	0.002	0-78	0.00	91.5	0.082
	Seine	10	9	90.0			0-51	2.31		

TABLE 3.3.—The precision of sampling gear (based on equation 3; see text) and the parameters (± S.E.) of equation 2, $\log(s^2) = a + b \log(x) + c \log(V)$, for the pop-net, push-net, and seine during the two sampling periods. Regression equations are based on larval (May) and juvenile (July) yellow perch catches. Equation parameters are defined as s^2= variance of density, a = intercept, b = slope of the mean density x $(100\ m^3)^{-1}$, c = slope of the sample volume V (m^3), and log = $\log_{10}$.

Sampling period/ Sampling gear	n	a	± S.E.	b	± S.E.	c	± S.E.	r^2	Precision (CV_x)
May									
Pop-net	6	1.65	0.42	0.79	0.05	-0.44	0.16	0.996	0.02
Push-net	6	-0.34	0.15	1.10	0.02	0.12	0.06	0.999	0.01
July									
Pop-net	6	-0.66	0.45	0.97	0.05	0.49	0.19	0.993	0.24
Seine	5	-0.77	2.08	0.98	0.23	0.27	0.76	0.924	0.20

Figure caption

FIGURE 3.1.—Size frequency distributions (total length) of larval (May) and juvenile (July) age-0 yellow perch captured by pop-net, push-net, and seine in non-vegetated (May only) or sparsely vegetated (July only) and vegetated habitats (May and July). n= number of measured yellow perch.

FIGURE 3.2.—Variance-to-mean relationship of age-0 yellow perch sampled by (a) pop-net and push-net in May (larval stages) and by (b) pop-net and seine in July (juvenile stages).

FIGURE 3.3.—Predictions of the minimum number of samples needed (n) to reach a precision (CV_x) of 0.15 and 0.20 at varying abundances of age-0 yellow perch. Minimum numbers of replicate samples are presented for a) pop-net and push-net in May (larval stages) and for b) pop-net and seine in July (juvenile stages). Predictions are based on equation 4 (see text), assuming a fixed volume (V) of 100 m^3 for all sampling gears.

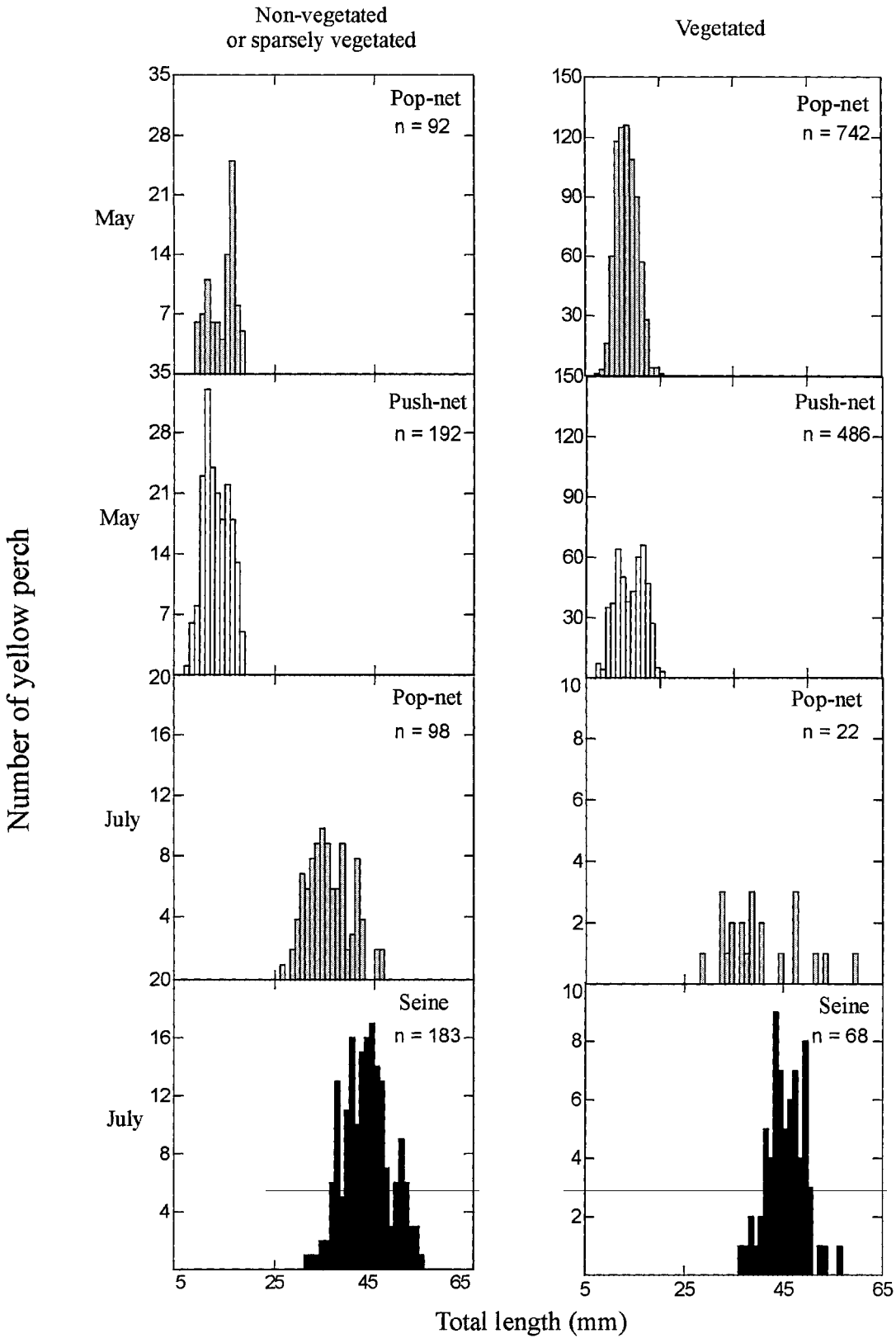
Non-vegetated
or sparsely vegetated
Vegetated
Pop-net
n = 92
Pop-net
n = 742
May
Push-net
n = 192
Push-net
n = 486
May
Pop-net
n = 98
Pop-net
n = 22
July
Seine
n = 183
Seine
n = 68
July
Number of yellow perch
Total length (mm)

FIGURE 3.1

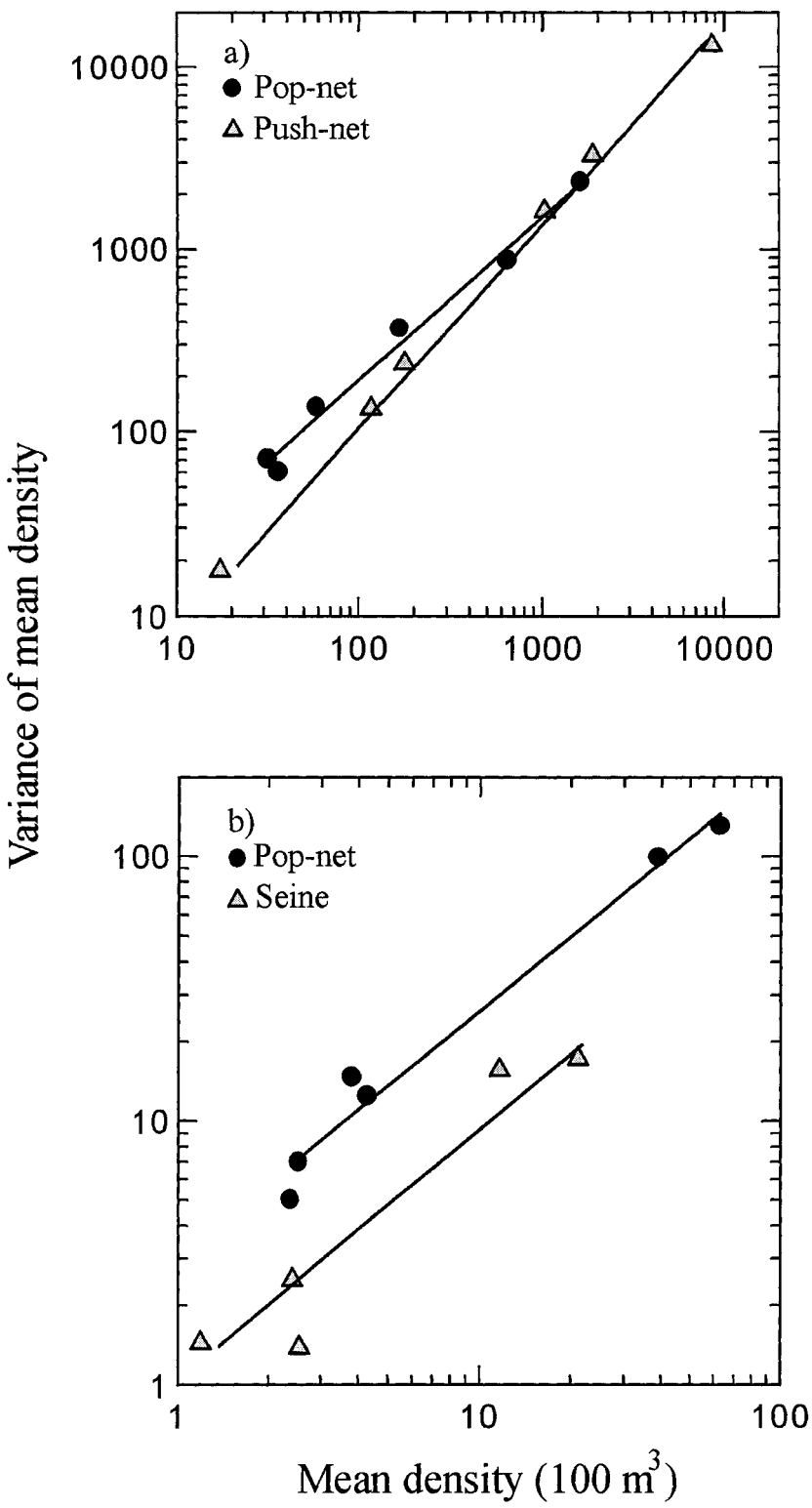
a)
Pop-net
Push-net
10000
1000
100
10
10
100
1000
10000
b)
Pop-net
Seine
100
10
1
1
10
100
Variance of mean density
Mean density (100 m3)

FIGURE 3.2

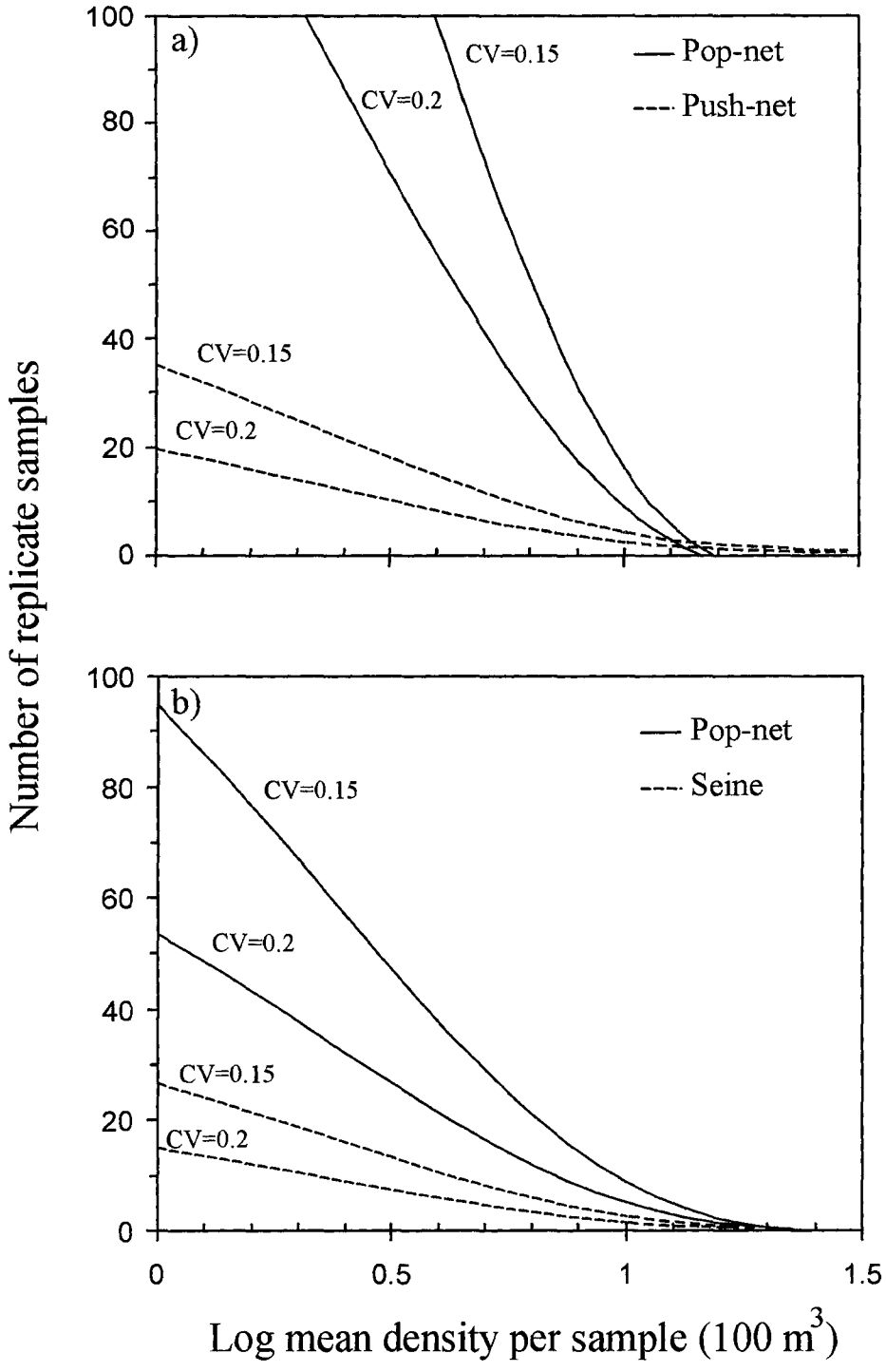
a)
CV=0.15
CV=0.2
Pop-net
Push-net
CV=0.15
CV=0.2
b)
Pop-net
Seine
CV=0.15
CV=0.2
CV=0.15
CV=0.2
Number of replicate samples
Log mean density per sample (100 m3)
0
20
40
60
80
100
0
0.5
1
1.5

FIGURE 3.3

CHAPITRE IV

LENGTH AND WEIGHT REDUCTION IN LARVAL AND JUVENILE YELLOW PERCH PRESERVED IN DRY ICE, FORMALIN AND ALCOHOL

[Management Brief]

Length and Weight Reduction in Larval and Juvenile Yellow Perch Preserved with Dry Ice, Formalin and Alcohol

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Abstract.—Due to the increasing interest in biochemical indices such as the RNA-DNA ratio used to measure fish growth, fish often need to be stored frozen with dry ice (i.e., –80°C). The objectives of this study were to (i) quantify the effects of dry ice on both the length and weight of larval and juvenile yellow perch preserved for storage periods of 15 days and 7-8 months, (ii) compare these effects with those of two commonly used preservatives, 10% formalin and 75% alcohol and (iii) provide equations to convert the lengths and weights of larval and juvenile perch preserved with dry ice, formalin and alcohol back to their initial unpreserved values. For all preservation methods, fish weight was more affected than length. The smallest length reduction was observed with formalin (short-term: 2.1% and 0.1%; long-term: 10.1% and 1.2% for larvae and juveniles, respectively), followed by dry ice (short-term: 4.0% and 1.4%; long-term: 7.2% and 3.9%) and alcohol (short-term: 9.6% and 1.2%; long-term: 11.7% and 1.2%). The smallest weight reduction was also observed with formalin (short-term: 21.9% and 2.2%; long-term: 23.2% and 3.9% for larvae and juveniles, respectively), followed by dry ice (short-term: 54.0% and 11.1%; long-term: 52.8% and 8.4%) and alcohol (short-term: 61.1% and 22.0%; long-term: 66.0% and 26.0%). Except for one case, all regression equations that were built to convert lengths and weights of larval and juvenile perch preserved with dry ice, formalin and alcohol back to initial measurements were highly significant, with a mean R^2 of 0.90.

Accurate length measurements are fundamental when investigating population dynamics of larval and juvenile fish (Jennings 1991). It is rarely possible to measure lengths and weights during fieldwork and so fish are preserved for later measurements in the laboratory. Fixation and preservation techniques are known to change larval length and weight for a number of fish species (Parker 1963; Leslie and Moore 1986; Kelso and Rutherford 1996) and to introduce bias in morphometric analyses (Sagnes 1997). For yellow perch *Perca flavescens,* the effects of formalin and alcohol on larval length have been documented (Treasurer 1992; Fisher et al. 1998), and the impact of formalin and freezing at –18°C and –25°C have been evaluated for age-1 juveniles and adults (Stobo 1972; Engel 1974; Treasurer 1990). To date, the effects of formalin and alcohol on the weight of small post-hatching yellow perch larvae are still not known. The effect of dry-ice preservation (–80°C) also remains undocumented, even though an increasing number of biochemical methods require that fish be preserved with dry ice (Weber et al. 2003). Dry-ice preservation avoids the denaturation of nucleic acids, which are necessary, for example, to measure instantaneous fish growth with the RNA-DNA ratio approach (Bergeron 1997; Pepin et al. 1999; Tardif et al. 2005). Tardif et al. (2005) suggested that a correction factor be developed to calculate the initial fish length from preserved larvae to avoid misinterpreting the biochemical growth indices.

The objectives of this study were (i) to quantify the effect of dry ice on both the lengths and weights of larval and juvenile yellow perch preserved for storage periods of 15 days and 7-8 months, (ii) to compare these effects of dry ice with two commonly used preservatives, 10% formalin and 75% alcohol and (iii) to provide equations to convert the lengths and weights of larvae and juvenile perch preserved with dry ice, formalin and alcohol back to their initial unpreserved values.

Methods

Fish samples were collected in shallow wetlands of Lake Saint-Pierre (46° 15' N, 72° 50' W, Québec, Canada). Larval yellow perch (7.1-19.0 mm) were collected with push-nets (0.40 m square mouth opening; 500 μm mesh) in May 2003 and June 2004, while juveniles (33.9-58.7 mm) were caught with beach seines (12.5 m • 4 m; 3.2 mm stretched mesh) in July 2003 and August 2004. Fish samples were transported in cold water to the laboratory and divided into three subsamples. After being blotted dry with paper towels, each fish was weighed (± 0.001 g) and measured (± 0.01 mm total length; TL); measurements were made using an ocular micrometer mounted on a dissecting microscope for larvae and a digital caliper for juveniles. Fish were then individually preserved in vials using one of the following preservatives: 10% formalin, 75% alcohol (anhydrous ethyl alcohol), or dry ice (freezing at –80°C). The elapsed time between capture and preservation never exceeded 12 hours. Larvae and juveniles were dead at the time of preservation; thus, this study is not an attempt to estimate live lengths and weights from preserved larval and juvenile yellow perch. To investigate the effect of each preservation method on yellow perch length and weight, fish were remeasured and reweighed after a period of 15 days (hereafter "short preservation period") and after 8 months for larvae and 7 months for juveniles (hereafter "long preservation period"). Before the second measurement, frozen fish were thawed at room temperature and individuals from all preservation methods were blotted with paper towels. Independent samples were used for the short-term and long-term effect of preservation.

Changes in length and weight were expressed in percent shrinkage (Fowler and Smith 1983) for each specimen as:

$$\left[1-\frac{L_t}{L_0}\right]\bullet 100 \qquad \text{eq. (1)}$$

where L_0 is the initial length and L_t the length at time t (the same calculation was done for weight measurements). Paired t-tests were used to compare initial and preserved measurements of larval and juvenile yellow perch for the short and long preservation periods. Analyses of covariance (ANCOVA) were performed (Johnston and Mathias 1993) to compare the effects of the three preservation methods on length and weight changes. The initial length (weight) (L_0) was used as a covariable in the model. The interaction term (L_0 • preservation method) was also included in the analyses to test for differences in the slope of relationships between fresh and preserved lengths (and weights). When significant differences occurred between preservation methods, pairwise comparisons (least squares means) with Bonferroni corrections were conducted to determine which preservation methods differed from the others. The same statistical procedure was used for weight comparisons. When significant shrinkage occurred, equations were developed to convert preserved measurements into initial unpreserved ones. The relationship between initial (L_0) and preserved (L_t) measurements was calculated using a least squares linear regression (Treasurer 1990):

$$L_0 = a + b \bullet L_t \qquad \text{eq. (2)}$$

where a is the intercept and b the slope (the same calculation was done for weight measurements). All statistical analyses were performed using SYSTAT 10.2.

Results

Larvae - short preservation period.—After a preservation period of 15 days, larval yellow perch exhibited a significant average length reduction of 2.1% in formalin, 4.0% with dry ice and 9.6% in alcohol (formalin: t = 3.40, P <0.01; dry ice: t = 8.65, P <0.001; alcohol: t = 19.58, P <0.001; Table 4.1). An ANCOVA revealed that the slopes of the regressions between fresh and preserved lengths were not significantly different among the three preservation methods (F = 0.08, P = 0.923) but that the intercepts differed significantly (F = 55.14, P <0.001). Shrinkage was

significantly higher in alcohol than with dry ice (P <0.001) and formalin (P <0.001) but did not differ between dry ice and formalin (P = 0.051). Weight loss was also significant among the three preservation methods (Table 4.1), reaching 61.1% in alcohol (t = 18.27, P <0.001), 54.0% with dry ice (t = 23.62, P <0.001) and 21.9% in formalin (t = 10.61, P <0.001). Weight loss differed significantly between preservation methods (ANCOVA; slope: F = 29.17, P <0.001). Post-hoc comparisons revealed significant differences in the slope of the regression lines between alcohol and formalin (P <0.001) and between formalin and dry ice (P <0.05), but not between dry ice and alcohol (P = 0.137).

Larvae - long preservation period.—After 8 months of storage, larval yellow perch exhibited a significant average length reduction of 7.2% with dry ice, 10.1% in formalin and 11.7% in alcohol (dry ice: t = 6.68, P <0.001; formalin: t = 17.07, P <0.001; alcohol: t = 15.69, P <0.001; Table 4.1). The ANCOVA indicated that the slope of the regression between fresh and preserved lengths were not significantly different among the three preservation methods (F = 1.80, P = 0.169), but that the intercepts were significantly different (F = 7.95, P <0.001). Shrinkage was significantly lower with dry ice than in alcohol (P <0.05) and formalin (P <0.05), but did not differ between alcohol and formalin (P = 0.197). The weight of larval perch showed a mean shrinkage of 66.0% in alcohol (t = 15.69, P <0.001), 52.8% with dry ice (t = 17.07, P <0.001) and 23.2% in formalin (t = 6.68, P <0.001; Table 4.1). The ANCOVA revealed that the slopes of the regressions between fresh and preserved weights differed among the three preservation methods (F = 57.30, P <0.001) and the post-hoc comparisons indicated significant differences among all methods (P <0.05).

Juvenile - short preservation period.—After a storage period of 15 days, juvenile yellow perch exhibited a mean length reduction of 0.1% in formalin (t = 0.40, P = 0.694), 1.2% in alcohol (t = 5.38, P <0.001) and 1.4% with dry ice (t = 8.43, P <0.001; Table 4.2). The ANCOVA revealed

that the relationships between fresh and preserved lengths in alcohol and dry ice were not significantly different (slope: F = 0.47, $P = 0.497$; intercept: F = 0.80, $P = 0.374$). Weight loss was 22.0% in alcohol, 11.2% with dry ice and 2.2% in formalin (alcohol: t = 25.03, $P < 0.001$; dry ice: t = 31.63, $P < 0.001$; formalin: t = 5.85, $P < 0.001$; Table 4.2). The ANCOVA and post-hoc analyses revealed significant differences among all preservation methods (slope: F = 78.60, $P < 0.001$; post-hoc between all preservatives: $P < 0.001$).

Juvenile - long preservation period.—Juvenile yellow perch stored for 7 months showed significant length reduction in alcohol (1.2%), formalin (1.2%) and dry ice (3.9%) (alcohol: t = 2.77, $P < 0.05$; formalin: t = 2.81, $P < 0.05$; dry ice: t = 6.46, $P < 0.001$; Table 4.2). The ANCOVA revealed that the slopes of the regressions between fresh and preserved lengths differed among the preservation methods (F = 0.73, $P = 0.485$; intercept: F = 7.78, $P < 0.05$). The post-hoc tests indicated that dry ice induced more shrinkage than alcohol ($P < 0.05$) and formalin ($P < 0.05$) while no difference was found between formalin and alcohol ($P = 0.99$). Juveniles also showed a significant weight reduction in alcohol (26.0%), dry ice (8.4%) and formalin (3.9%) after the 7-month storage (alcohol: t = 16.96, $P < 0.001$; dry ice: t = 7.91, $P < 0.001$; formalin: t = 5.11, $P < 0.001$; Table 4.2). The ANCOVA revealed that the slopes of the regressions between fresh and preserved weights differed among the three preservation methods (slope: F = 8.40, $P < 0.001$). Post-hoc analysis revealed that the three preservatives differed ($P < 0.001$), with alcohol inducing the greatest weight lost followed by dry ice and formalin.

Conversion equations.—Equations to convert preserved lengths and weights of larval and juvenile yellow perch into unpreserved ones are given in Tables 4.1 and 4.2 respectively. All the regression equations but one (juvenile length in dry ice) built to convert the lengths and weights of

larvae and juvenile perch preserved with dry ice, formalin and alcohol were highly significant, with mean a R^2 of 0.90.

Discussion

The present study shows that the length shrinkage and the weight loss of yellow perch differed according to preservation method, ontogenetic stage (larvae vs. juveniles) and, to a lesser extent, the duration of the storage period. For all three preservation methods, weight was more affected than length for both larvae and juveniles. Shrinkage occurred mainly within the first 15 days of preservation and generally increased slightly after 7-8 months. This agrees with the observations of Fisher et al. (1998), who suggested that most length reduction in larval yellow perch occurred within the first 24 h of fixation. For both larvae and juveniles, length and weight reductions showed the same trend among the preservation methods over short and long storage periods: formalin reduced length and weight to a lesser extent than alcohol. These findings are consistent with those of Fisher et al. (1998), who showed that alcohol at several different concentrations caused greater length shrinkage than formalin in yellow perch larvae. The mean length reductions with formalin and alcohol reported in our study are comparable to those reported in the literature for a given fish size (Table 4.3). The weight of juvenile and adult yellow perch stored in formalin is known to increase immediately after preservation and then to gradually decrease (Stobo 1972; Treasurer 1992). The initial increase in fish weight is likely due to disrupted osmoregulation (Parker 1963). We did not observe this increase in weight because larval size was relatively small and the duration of the preservation period ($\geq$ 15 days) largely exceeded the time scale at which such an increase could be detected.

Our results revealed that the impact of dry ice differed from those of alcohol and formalin for larval and juvenile yellow perch. The decreases in length and weight were generally higher with alcohol than dry ice and lower with formalin. We could not compare the effect of freezing with dry ice to freezing at other temperatures (–15, –25°C) because of a lack of data in the literature on the effect of freezing on small post-hatching larvae of similar sizes (Table 4.3). It is noteworthy that avoiding body curvature and air contact when freezing specimens were shown to reduce damage, body shrinkage and weight loss through desiccation (Boyd et al. 1967; Armstrong and Stewart 1997).

The choice of the preservation method is determined by the study objectives. Formalin can be the best choice for minimizing fish shrinkage, but it is not recommended for studies with stable isotopes (Sarakinos et al. 2002) or otolith analysis (Essig and Cole 1986). Given that studies often focus on multiple objectives, for example, analyzing stomach contents, otoliths, stable isotopes, contaminants or RNA-DNA ratios, it is often necessary to store samples using different preservation methods (Kruse and Dalley 1990). Biochemical growth indices such as RNA-DNA ratios are increasingly used as indices of instantaneous growth rate and nutritional condition of larval fish (Bergeron 1997). Larval specimens need to be stored frozen with dry ice (i.e., –80°C) for these analyses to avoid nucleic acid denaturation (Weber et al. 2003).

The slope of the relationships between initial and preserved fish differed among preservation methods (significant interaction terms). In this context, percent shrinkage is inadequate to compare initial lengths or weights of fish stored in different preservatives. We thus recommend that the initial fresh measurements be estimated using the equations presented in Tables 4.1 and 4.2. These equations should be used for larval and juvenile yellow perch within a similar size range.

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References

Armstrong, J. D., and D. C. Stewart. 1997. The effects of initial length and body curvature on shrinkage of juvenile Atlantic salmon during freezing. Journal of Fish Biology 50: 903-905.

Bergeron, J. P. 1997. Nucleic acids in ichthyoplankton ecology: a review, with emphasis on recent advances for new perspectives. Journal of Fish Biology 51 (Supplement A): 284-302.

Boyd, J. W., B. A. Southcott, and G. F. Boothby. 1967. Desiccation of frozen fish. Journal of the Fisheries Research Board of Canada 24: 211-212.

Engel, S. 1974. Effects of formalin and freezing on length, weight and condition factor of cisco and yellow perch. Transactions of the American Fisheries Society L: 136-138.

Essig, R. L., and C. F. Cole. 1986. Methods of estimating larval fish mortality from daily increments of otoliths. Transactions of the American Fisheries Society 115: 34-40.

Fisher, S. J., M. R. Anderson, and D. W. Willis. 1998. Total length reduction in preserved yellow perch larvae. North American Journal of Fisheries Management 18: 739-742.

Fowler, G. M., and S. J. Smith. 1983. Length changes in silver hake (*Merluccius bilibearis*) larvae: effects of formalin, ethanol, and freezing. Canadian Journal of Fisheries and Aquatic Sciences 40: 866-870.

Jennings, S. 1991. The effects of capture, net retention and preservation upon lengths of larval and juvenile bass, *Dicentrarchus labrax* (L.). Journal of Fish Biology 38: 349-357.

Johnston, T. A., and J. A. Mathias. 1993. Length reduction and dry weight loss in frozen and formalin-preserved larval walleye, *Stizostedion vitreum* (Mitchill). Aquaculture and Fisheries Management 24: 365-371.

Kelso, W. E., and A. D. Rutherford. 1996. Collection, preservation, and identification of fish eggs and larvae. Pages 255-302 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Kruse, G. H., and E. L. Dalley. 1990. Length changes in capelin, *Mallotus villosus* (Müller), larvae due to preservation in formalin and anhydrous alcohol. Journal of Fish Biology 36: 619-621.

Leslie, J. K., and L. E. Moore. 1986. Changes in lengths of fixed and preserved young freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 43: 1079-1081.

Parker, R. R. 1963. Effects of formalin on length and weight of fishes. Journal of the Fisheries Research Board of Canada 20: 1441-1455.

Pepin, P., G. T. Evans, and T. H. Shears. 1999. Patterns of RNA/DNA ratios in larval fish and their relationship to survival in the field. ICES Journal of Marine Science 56: 697-706.

Sagnes, P. 1997. Potential artefacts in morphometric analyses of fish: effects of formalin preservation on 0+ grayling. Journal of Fish Biology 50: 910-914.

Sarakinos, H. C., M. L. Johnson, and J. M. Vander Zanden. 2002. A synthesis of tissue-preservation effects on carbon and nitrogen stable isotope signatures. Canadian Journal of Zoology 80: 381-387.

Stobo, W. T. 1972. Effects of formalin on the length and weight of yellow perch. Transactions of the American Fisheries Society 101: 362-364.

Tardif, D., H. Glémet, P. Brodeur, and M. Mingelbier. 2005. RNA/DNA ratio and total length of yellow perch (*Perca flavescens*) in managed and natural wetlands of a large fluvial lake. Canadian Journal of Fisheries and Aquatic Sciences 62: 2211-2218.

Treasurer, J. W. 1990. Length and weight changes in perch, *Perca fluviatilis* L., and pike, *Esox lucius* L., following freezing. Journal of Fish Biology 37: 499-500.

Treasurer, J. W. 1992. Length and weight changes in 0+ perch, *Perca fluviatilis* L., following fixation in formalin. Journal of Fish Biology 41: 1033-1036.

Weber, L. P., P. S. Higgins, R. I. Carlson, and D. M. Janz. 2003. Development and validation of methods for measuring multiple biochemical indices of condition in juvenile fishes. Journal of Fish Biology 63: 637-658.

TABLE 4.1.—Range and mean (± S.D.) of initial lengths and weights of larval yellow perch stored for 15 days of 8 months in 75% alcohol, 10% formalin or dry ice (–80°C). Mean (± S.D.) lengths and weights after the 15-day and 8-month preservation periods are also shown. The constants *a* and *b* of equation (2) are provided to convert preserved lengths and weights (L_t and W_t) to initial fresh values (L_0 and W_0). All regression equations were significant (P <0.001).

LARVAE	15-day preservation period							8-month preservation period						
Preservative	*n*	Range of fresh values (mm or g)	Mean fresh value ± S.D. (mm or g)	Mean preserved value ± S.D. (mm or g)	Constants a	Constants b	R^2	n	Range of fresh values (mm or g)	Mean fresh value ± S.D. (mm or g)	Mean preserved value ± S.D. (mm or g)	Constants a	Constants b	R^2
Length														
Alcohol	44	12.1 - 18.1	13.89 ±1.48	12.61±1.43	1.415	0.993	0.91	42	7.1 - 11.9	9.51±1.28	8.31±1.26	1.908	0.901	0.98
Formalin	43	10.8 - 18.0	13.98 ±1.64	13.61±1.58	1.273	0.928	0.87	40	12.7 – 19.2	16.01±1.97	14.37±1.71	0.998	0.836	0.91
Dry ice	24	10.9 - 14.0	12.35±0.69	11.88±0.73	1.548	0.912	0.86	36	11.4 – 19.0	15.53±2.11	14.37±1.75	2.337	0.917	0.71
Weight														
Alcohol	48	0.012 - 0.061	0.025±0.011	0.010±0.006	0.008	1.658	0.90	41	0.001 – 0.017	0.006±0.003	0.002±0.001	0.003	1.901	0.52
Formalin	49	0.013 - 0.080	0.029±0.014	0.023±0.013	0.004	1.077	0.92	40	0.012 – 0.062	0.036±0.015	0.028±0.012	0.002	1.221	0.96
Dry ice	32	0.008 - 0.021	0.013±0.003	0.006±0.002	-0.001	0.537	0.87	33	0.001 – 0.061	0.031±0.014	0.015±0.006	0.004	1.903	0.74

TABLE 4.2.— Range of initial length and weight of juvenile yellow perch stored during 15 days and 7 months in alcohol 75%, formalin 10% and dry ice (-80°C). Mean (± S.D.) length and weight after 15 days and 7 months preservation period are also shown. Constant *a* and *b* of equation (2) are provided to convert preserved length and weight (L_t and W_t) into initial fresh values (L_0 and W_0). All regression equations were significant (P <0.001).

JUVENILE	15 days preservation period							7 months preservation periods						
Preservative	*n*	Range of fresh values (mm or g)	Mean fresh value ± S.D. (mm or g)	Mean Preserved value ± S.D. (mm or g)	Constant a	Constant b	R^2	n	Range of fresh values (mm or g)	Mean fresh value ± S.D. (mm or g)	Mean Preserved value ± S.D. (mm or g)	Constant a	Constant *b*	R^2
Length														
Alcohol	35	37.0 - 58.7	47.66±4.50	47.09±4.42	0.733	0.973	0.98	19	33.9 - 51.6	45.39±1.18	44.86±4.13	0.852	0.993	0.96
Formalin	30	39.0 - 56.5	48.83±4.25	48.79±4.21	no signif. change			20	29.6 - 57.6	42.82±7.52	42.22±7.06	2.267	0.993	0.98
Dry ice	32	36.0 - 57.0	46.10±4.53	45.20±4.64	-0.331	0.993	0.99	27	36.7 - 54.6	46.64±4.61	44.76±4.29	1.091	1.017	0.89
Weight														
Alcohol	35	0.835 - 2.686	1.465±0.412	1.129±0.353	0.087	1.202	0.99	19	0.433 - 1.540	1.139±0.307	0.851±0.257	0.139	1.174	0.96
Formalin	30	0.789 - 2.555	1.606±0.442	1.574±0.443	0.038	0.996	0.99	20	0.308 - 1.939	0.939±0.464	0.911±0.468	0.037	0.990	0.99
Dry ice	35	0.572 - 2.392	1.299±0.391	1.161±0.372	0.079	1.051	0.99	27	0.577 - 2.022	1.216±0.350	1.117±0.333	0.061	1.035	0.97

TABLE 4.3.—Review of studies reporting length and weight changes of preserved larval, juvenile and adult yellow perch. Studies are sorted by preservation method, fresh size of preserved yellow perch and storage duration (hours, days, weeks or months).

Preservation method	Fresh size (mm)	Duration (h, d, w or m)	% change Length	% change Weight	Source
Alcohol 75%	Larvae 12.1-18.1	15 d	-9.6	-61.1	Present study
		8 m	-11.7	-66.0	
Alcohol (50-80-95-100%)	Larvae 10.14 (mean)	1-7-14 -21 d	-12.3	—	Fisher et al. (1998)
Alcohol 75%	Juveniles 37.0-58.7	15 d	-1.2	-22.0	Present study
		7 m	-1.2	-26.0	
Formalin 10%	Larvae 10.8-18.0	15 d	-2.1	-21.9	Present study
		8 m	-10.1	-23.2	
Formalin (5-10%)	Larvae 10.51 (mean)	1-7-14 -21 d	-2.0	—	Fisher et al. (1998)
Formalin 10%	Juveniles 39.0-56.5	15 d	-0.1	-2.2	Present study
		7 m	-1.2	-3.9	
Formalin 4-10%	Juveniles 37.8 ± 0.6	24 h to 72 w	-1.7	+18	Treasurer (1992)
Formalin 4-10%	Juveniles 54.9 ± 1.3	24 h to 72 w	-3.5	+16	Treasurer (1992)
Formalin 10%	Adults 127-160	72 h	-0.7	+0.5	Engel (1974)
Formalin 10%	Adults 68-240	250 d	-1.4	+7.5	Stobo (1972)
Dry ice (–80°C)	Larvae 10.9-14.0	15 d	-4.0	-54.0	Present study
		8 m	-7.2	-52.8	
Dry ice (–80°C)	Juveniles 36.0-57.0	15 d	-1.4	-11.1	Present study
		7 m	-3.9	-8.4	
Freezing –10°C	Adults 133-171	72 h	-0.7	-1.7	Engel (1974)
Freezing –25°C	Adults 110-340	10 to 14 w	-1.7	-2.7	Treasurer (1990)