Université de Montréal

Analyse comparative de modèles de la qualité des habitats basés sur la densité instantanée et cumulative de poissons

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Mémoire présenté en vue de l'obtention du grade de Maîtrise ès sciences en Sciences biologiques

Mai 2021

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Résumé

Les écosystèmes aquatiques contiennent environ 25% de la biodiversité globale et sont parmi les plus affectés par l'activité humaine. Cela est entre autres causé par la position de « receveur » des rivières, lacs et océans dans leur bassin versant. Les espèces aquatiques, en eau douce particulièrement, sont ainsi hautement à risque d'être affectées par l'activité humaine. La protection de ces espèces peut inclure la protection et la restauration de leurs habitats. Les modèles de qualité d'habitats (MQH) peuvent être utilisés afin de déterminer quels habitats protéger et restaurer. Les MQH définissent la relation entre un indice de qualité d'habitats (IQH, e.g. densité) et des conditions environnementales. Toutefois, la performance des MQH dépend de l'IQH sélectionné. Ici, notre objectif est de comparer des MQH basés sur deux IQH estimés pour des poissons en rivière : 1) la densité instantanée, échantillonnée en transect par plongée en apnée et 2) la densité cumulative, échantillonnée en point fixe par caméra-vidéo en stéréo. Au total, douze modèles ont été construits et nos analyses indiquent que les MQH basés sur la densité instantanée ont des capacités explicatives significativement supérieures. Les variables environnementales retenues pour expliquer la distribution de chaque espèce sont toutefois différentes. Cela semble être causé en partie par des différences inhérentes à l'échantillonnage (e.g. échelle spatiale). Ces résultats démontrent que la densité instantanée en tant qu'IQH produit des MQH aux capacités explicatives supérieures et que les deux IQH semblent donner des informations complémentaires sur les caractéristiques des habitats à protéger et à restaurer.

Mots clés : Caméra-vidéo, plongée, modèle de qualité des habitats, indice de qualité des habitats, densité instantanée, densité cumulative, poisson, écosystème aquatique.

Abstract

Aquatic ecosystems contain approximately 25% of the global biodiversity and are among the most affected by human activity. This may be caused by the position of "receivers" rivers, lakes and oceans have in their watershed. Aquatic species, specially in freshwater, are thus at high risk of being affected by human activity. Assuring the survival of these species may include protecting and restoring their habitats. Habitat quality models (HQM) can be used to determine which habitats to protect and how to restore damaged habitats. HQM are relationships between habitat quality indices (HQI, e.g., density) and environmental conditions prevailing in those habitats. However, how well an HQM performs depends on the chosen HQI it is computed with. For this research, we compared HQM based on two HQI estimated for fish in a river : 1) instantaneous density, sampled by transect snorkeling survey and 2) cumulative density, sampled by fixed stereo-video recording. Analyses of twelve HQM show that, contrary to our hypothesis, HQM based on instantaneous density had higher explanatory capacities. However, environmental conditions selected by both types of HQM to explain a species' distribution were different. This may in part be explained by inherent differences of the sampling methods (e.g., spatial scale). We conclude that instantaneous density as HQI produces HQM of higher explanatory capacities, yet both HQI may provide complementary information on the characteristics of habitats to protect and restore.

Key words : Video camera, snorkeling, habitat quality model, habitat quality indices, instantaneous density, cumulative density, fish, aquatic ecosystem.

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CVS : Caméra-vidéo en stéréo

Denom : denominator

HQI : Habitat quality indice

HQM : Habitat quality model

IQH : Indice de qualité de l'habitat

Max : Maximum

Min : Minimum

MQH : Modèle de qualité de l'habitat

Num : numerator

p : p-value

PVC : Polyvinyl chloride

ΔR^2adj : différence des R^2 ajustés

R^2adj : R^2 ajusté

S.d. : Standard deviation

SS : Snorkeling survey

SVR : Stereo-video recording

TPA : Transect en plongée en apnée

Unités

^{o}C : Degré Celsius

m : Mètre

n : Nombre d'individus

sec : Secondes

μS : Microsiemens

Remerciements

Cette étude est le résultat de l'effort combiné de plusieurs personnes ayant contribuées chacune à leur façon, mais dont les plus importantes ont été mon directeur Daniel Boisclair et ma collègue Emmanuelle Chrétien. Je souhaite souligner l'effort de ceux qui ont participé à la récolte des données, Emmanuelle, Gabriel et Noémie. Une mention particulière à Noémie Vanier qui a aussi contribué au visionnement des enregistrements et aux traitements des données. Nous avons passé quelques centaines d'heures devant nos écrans à chronométrer chaque poisson… Ton aide a été précieuse!

Un gros merci à mes parents, Annie Guéveneux et Jean-Claude Julien, de même qu'à toute ma famille de m'avoir encouragée et motivée tout au long de mon parcours, me poussant à me dépasser et à ne jamais abandonner.

À tous ceux qui liront ce mémoire, merci de votre temps et de l'intérêt que vos portez à ce projet.

1. Introduction Générale

1.1 Mise en contexte

1.1.1 Écosystèmes aquatiques

Les écosystèmes aquatiques couvrent plus de 70% de la Terre et contiennent environ 25% de la biodiversité mondiale (Mora et al., 2011). Ils procurent à l'humain de nombreux services et ressources pour lesquels il n'existe parfois aucun substitut (Wolter and Arlinghaus, 2003; Foley et al., 2005; Dudgeon et al., 2006; Carpenter et al., 2011), le maintien de leur intégrité est donc primordial. Les écosystèmes aquatiques, particulièrement ceux d'eau douce, sont parmi les écosystèmes les plus affectés par l'activité humaine (Ricciardi and Rasmussen, 1999; Foley et al., 2005; Syvitski et al., 2005; Carpenter et al., 2011). Plusieurs facteurs sont en cause et contribuent à leur altération à divers niveaux.

L'urbanisation du paysage (e.g. détournement de cours d'eau, encloisonnement des berges, drainage et remblai des milieux humides et des plaines inondables, etc.) contribue à l'altération morphologique des écosystèmes aquatiques principalement en eau douce (Arlinghaus et al., 2002). L'ampleur des conséquences de ces modifications varient d'un système à l'autre, mais la structure des berges, le débit des rivières et la connectivité des écosystèmes sont inévitablement affectés.

La position de receveur des écosystèmes aquatiques dans leur bassin versant amplifie l'effet d'altérations de nature physicochimique. Comme dans un entonnoir, les rivières, les lacs et les océans subissent l'effet de toute activité ayant lieu dans leur bassin versant (Hopkinson and

Vallino, 1995; Kim et al., 2002; Hundecha and Bárdossy, 2004; Dudgeon et al., 2006). Les résidus (e.g. contaminant, sédiments, débris) issus d'activités humaines (e.g. agriculture, industrie, coupe forestière) s'y retrouvent par ruissellement et diffusion (Carpenter et al., 1998). L'effet inverse a aussi été observé dans certaines rivières, où la construction de barrages et de réservoirs a grandement réduit l'apport en sédiments aux zones côtières des océans (Syvitski et al., 2005). Ces activités contribuent à une variété d'altérations physicochimiques : contamination, eutrophisation ou oligotrophisation, baisse du taux d'oxygène dissous, etc. (O'Reilly et al., 2003; Pretty et al., 2003; Smith, 2003; Quinton et al., 2010; Carpenter et al., 2011).

De telles altérations affectent à leur tour la biodiversité (Hampton et al., 2008). La modification de l'équilibre physicochimique d'un milieu affecte la distribution des espèces y vivant en le rendant inhospitalier (Cheung et al., 2009). En fonction des espèces (e.g. capacité d'adaptation, limites physiologiques) et des milieux (e.g. l'accessibilité d'habitats alternatifs), ces modifications peuvent entrainer la perte d'espèces (Coutant, 1990; Pretty et al., 2003). La disparition d'une espèce d'un milieu peut à son tour déclencher une cascade trophique, affectant l'ensemble des espèces de la communauté (McQueen et al., 1989). L'introduction volontaire ou accidentelle d'espèces exotiques (e.g. pour la pêche sportive ou résultant du commerce mondial) est un autre facteur découlant de l'activité humaine pouvant impacter la biodiversité (Ross, 1991; Williamson and Fitter, 1996; Maceda-Veiga, 2013) en entrainant la réduction ou la disparition des espèces natives soit par compétition directe ou cascade trophique (Ross, 1991; Moyle and Light, 1996; Wilcove et al., 1998; Sala et al., 2000).

1.1.2 Biodiversité

Les écosystèmes aquatiques abritent environ le quart de la biodiversité mondiale connue (Mora et al., 2011). Cette biodiversité est une ressource importante mondialement (e.g. récréation, culture, nutrition), particulièrement les poissons (Naylor et al., 2000). Ceux-ci correspondent à 16.6% des protéines animales consommées par la population mondiale, mais ce pourcentage peut atteindre 100% dans les pays peu développés ou en voie de développement (Tacon and Metian, 2013; McIntyre et al., 2016).

Les poissons font face à de nombreuses menaces : dégradation et perte d'habitats, pollution, surpêche et introduction d'espèces invasives (Allan et al., 2005; Dudgeon et al., 2006; Coll et al., 2008; Maceda-Veiga, 2013). Afin de prévenir la perte d'espèces aquatiques à cause ces activités, des méthodes telles que la protection et la restauration d'habitats peuvent être utilisées (Beck et al., 2001; Dudgeon et al., 2006; Lassalle et al., 2008; Maceda-Veiga, 2013). Toutefois, pour assurer l'efficacité de ces efforts de conservation, l'identification des habitats à protéger et des moyens à prendre pour les restaurer nécessitent une évaluation de la qualité des habitats (Wohl, 2005).

1.2 Modélisation

L'un des principaux défis de l'écologie consiste à comprendre ce qui détermine la distribution des organismes en nature (Holt, 1985; Ricklefs, 1987; May, 1999; Guisan and Zimmermann, 2000; Rose, 2000). La modélisation est un outil permettant d'expliquer les variations de distribution des organismes en réponse aux variations de conditions environnementales

(Guisan and Thuiller, 2005; Morán-Ordóñez et al., 2017). La modélisation a de nombreuses applications en écologie : l'étude d'impact d'espèces invasives (Rouget et al., 2004; Johnson et al., 2008), l'étude des tendances globales de la biodiversité (M.R. Willig et al., 2003; Ricklefs, 2003; Ortega-Huerta and Peterson, 2004) ou encore l'étude de la distribution spécifique d'une espèce ou d'un groupe d'espèces semblables (Hugall et al., 2002; Araujo et al., 2004; Beaumont et al., 2005). Les modèles de qualité des habitats (MQH) sont un type de modélisation qui peut être utilisé afin de décrire la distribution spécifique d'une espèce ou un groupe d'espèces semblables, en évaluant la qualité des habitats et en identifiant les conditions environnementales qui la définissent (Girard et al., 2003; Larson et al., 2004; Allouche et al., 2006; Lassalle et al., 2008; Falcucci et al., 2009). Ce type de modélisation peut être utilisée afin de comprendre et prévoir l'effet de l'activité humaine sur la qualité des habitats et la distribution des poissons.

1.2.1 Modèle de qualité des habitats

Les MQH sont utilisés pour définir la relation entre des indices de qualité des habitats (IQH) et les conditions environnementales (e.g. substrat, température, végétation) observées dans une série d'emplacements (i.e. surface ou volume défini dans un écosystème), chacun caractérisé par un ensemble de conditions environnementales relativement constantes (Gilliers et al., 2006; Hirzel et al., 2006; Bouchard and Boisclair, 2008; DeCesare et al., 2014). Une grande variété de MQH peuvent être développés en fonction de l'espèce, du stade de vie, de la période (e.g. été/hiver, jour/nuit) et de l'échelle spatiale (i.e. des micro-habitats aux régions biogéographiques; Orth, 1987; Beaumont et al., 2005; Bouchard and Boisclair, 2008; Capra et al., 2017). Diverses mesures peuvent être utilisées comme IQH, par exemple la présence/absence, la biomasse ou la densité (Guay et al., 2000; Fukuda et al., 2012; Rodwell et al., 2003). Développer un MQH consiste donc à attribuer une valeur d'IQH à une série d'emplacements, en fonction des conditions environnementales qui les définissent.

1.2.2 Indices de qualité des habitats

1.2.2.1 Densité instantanée

Les MQH pour les poissons utilisent fréquemment la densité (i.e. nombre d'individus par surface ou volume) comme IQH (Guay et al., 2000; Rosenfeld et al., 2005; Bouchard and Boisclair, 2008; Cote et al., 2013). Cela suppose que la densité est positivement corrélée à la qualité d'un habitat (Boyce and McDonald, 1999; Gilliers et al., 2006; Denney et al., 2017), à l'exception toutefois des habitats « puits » (Van Horne, 1983; Howe et al., 1991). L'estimation de la densité de poissons peut s'effectuer de diverses façons : pêche en chalut, pêche électrique, seine et décompte visuel (Zalewski, 1985; Pierce et al., 1990; Petrakis et al., 2001; Macnaughton et al., 2015). Ces méthodes échantillonnent typiquement les poissons de façon instantanée, c'est-à-dire, à un moment précis dans le temps.

Le mouvement des poissons rend toutefois difficile l'attribution d'un IQH comme la densité estimée instantanément à un emplacement spécifique. Par exemple, une forte «densité instantanée» pourrait être observée dans un emplacement où se retrouvent momentanément un grand groupe d'individus (Fraser et al., 1999). Au contraire, une faible densité instantanée pourrait être observée dans un emplacement où se retrouvent normalement un grand nombre d'individus. Dans de telles situations, les valeurs d'IQH attribuées à ces emplacements risquent d'être respectivement surévaluées ou sous-évaluées, considérant qu'ils sont normalement caractérisés par une faible ou un forte densité de poissons.

L'observation que les animaux ont tendance à avoir un taux de mouvement réduit et à passer plus de temps dans un emplacement de bonne qualité démontrent d'autant plus l'inadéquation de méthodes d'échantillonnage attribuant un IQH tel que la densité estimée instantanément à un emplacement (Avgar et al., 2011; Kuefler et al., 2012). Cela suggère que l'utilisation d'un IQH permettant l'incorporation du temps passé dans un emplacement par un individu permettrait de combler cette lacune en contrastant d'avantage la qualité des emplacements. Cela aurait pour effet d'améliorer les capacités explicatives d'un MQH basé sur un tel IQH. De plus, il est possible que les capacités explicatives d'un MQH basé sur un tel IQH augmentera avec le temps ininterrompu que passerons les poissons dans le volume observé par CVS. Par exemple, un poisson restant de nombreuses secondes (e.g. ≥ 10 sec) dans un habitat, à une reprise, signifierait que cet habitat est de meilleure qualité qu'un poisson restant quelques secondes (e.g. 2 sec), à plusieurs reprises (e.g. 5), dans un autre habitat. Au total, les deux individus auraient passé 10 secondes dans un habitat, mais le premier étant une période ininterrompue, l'utilisation d'un seuil démontrerait une qualité supérieure pour ce premier habitat.

1.2.2.2 Densité cumulative

L'échantillonnage par caméra-vidéo permet l'incorporation du temps dans un IQH, en permettant de mesurer le temps passé par un poisson dans un emplacement. On peut ainsi estimer une «densité cumulative» (i.e. poisson-secondes) dans un emplacement (Boisclair and Sirois, 1993; Marchand and Boisclair, 1998; Guénard et al., 2008). Des valeurs instantanées (e.g. densité, abondance) de descripteurs de communautés (e.g. espèces, groupes d'espèces, classes de tailles, etc.) ont été comparés à des valeurs correspondantes obtenues par caméra-vidéo à plusieurs reprises (Bortone et al., 1986, 1991; Francour et al., 1999; Langlois et al., 2010; Pelletier et al., 2011). Selon leurs analyses, i) la proportion observée des espèces est généralement similaire (i.e. lorsqu'une communauté est observée à plusieurs reprises par les deux types de méthodes, les espèces dominantes sont les mêmes), ii) les méthodes d'estimation instantanée (e.g. transect en plongée) semblent détecter un plus grand nombre d'espèces en général (i.e. les espèces non détectées par les méthodes d'estimation cumulative sont souvent peu abondantes), tandis que iii) les méthodes d'estimation cumulative (e.g. caméra-vidéo fixe) semblent plus efficace à détecter les espèces carnivores. Toutefois, à ce jour, aucune étude n'a comparé le potentiel de la densité instantanée à celui de la densité cumulative en tant qu'IQH pour des MQH de poissons. Certains défis sont associés à une telle comparaison, due à la différence de taille des emplacements i) dans lesquels la densité instantanée (x 10^2 m^3) (Macnaughton et al., 2015) et la densité cumulative (x 10^0 m^3, en eau peu transparente [1-3 m]) (Harvey et al., 2010) sont estimées, ii) auxquels les MQH basé sur ces IQH peuvent être appliqués et iii) dans lesquels on doit partitionner un écosystème afin de le modéliser.

1.2.3 Méthodes d'échantillonnage visuel

Dans cette étude, nous avons comparé des MQH calculés avec deux types d'IQH estimés visuellement : 1) la densité instantanée, échantillonnée en transect en plongée en apnée (TPA) et 2) la densité cumulative, échantillonnée en point fixe par caméra-vidéo en stéréo (CVS).

1.2.3.1 Échantillonnage visuel en transect en plongée en apnée

L'échantillonnage visuel TPA ou en plongée libre est une méthode abondamment utilisée dont les avantages et les désavantages sont bien connus (Brock, 1954; Sale and Douglas, 1981). Cette méthode permet d'échantillonner les communautés aquatiques sans causer de dommage aux individus ou aux emplacements (Dickens et al., 2011) et la mobilité des plongeurs favorise la détection des espèces cryptiques (Watson et al., 2005). L'efficacité de l'échantillonnage visuel dépend de la visibilité (e.g. relief, transparence) et en se déplaçant et en contournant les obstacles un plongeur peut faciliter l'identification des individus au comportement cryptique. En contrepartie, les mouvements des plongeurs peuvent parfois avoir un effet répulsif (Titus et al., 2015). Cette méthode nécessite un entrainement rigoureux pour assurer la qualité et l'uniformité des identifications d'espèces, des estimations de tailles et du dénombrement d'individus qui doivent être fait instantanément (Dickens et al., 2011).

L'estimation de la densité en TPA se fait de façon instantanée : on estime la variation de la densité d'individus à un moment précis, soit le passage du plongeur dans un emplacement. À cause du mouvement des poissons, l'échantillonnage instantané de la densité est susceptible d'obtenir des faux-positifs (i.e. présence d'individus dans un habitat de moindre qualité) et aux faux-négatifs (i.e. absence d'individus dans des habitats de bonne qualité).

1.2.3.2 Échantillonnage visuel en point fixe par caméra-vidéo en stéréo

L'utilisation de CVS pour échantillonner en milieu aquatique est possible depuis quelques décennies et s'améliore constamment grâce aux avancées technologiques. Cette méthode offre certains avantages comme la possibilité d'échantillonner des milieux peu accessibles, pendant de longues périodes de temps, en nécessitant peu de manipulations (e.g. changement de batteries et de carte-mémoire) et permet d'obtenir des enregistrements permanents d'une communauté, rendant possible la vérification ultérieure des observations (Francour et al., 1999; Srbek-Araujo and Chiarello, 2005; Lyra-Jorge et al., 2008). L'immobilité des CVS fixes est à la fois un avantage et un désavantage. L'effet répulsif sur les poissons est minimisé (Francour et al., 1999), mais il est impossible de fouiller les emplacements, rendant cette méthode moins efficace dans la détection d'espèces cryptiques. Quoiqu'elle nécessite moins de manipulations sur le terrain, cette méthode requiert un équipement plus dispendieux que l'échantillonnage en TPA. De plus, le temps de traitement des données est significativement plus grand, comme il nécessite le visionnement des enregistrements après l'échantillonnage.

L'échantillonnage visuel en point fixe par CVS estime la densité de façon cumulative : on estime la variation de la densité d'individus dans le temps, à un endroit précis. La densité estimée de façon cumulative permettrait donc de diminuer les risques de faux-positifs et faux-négatifs en contrastant d'avantage la qualité des habitats.

2. Objectifs & Hypothèses

Cette étude a été réalisée dans le but de contribuer aux connaissances fondamentales sur la modélisation de la qualité d'habitats des poissons, plus précisément l'efficacité des IQH utilisés. Dans le contexte actuel, où la quantité de milieux naturels perturbés ne cesse d'augmenter, il est important de constamment tenter d'améliorer nos méthodes, permettant à leur tour d'optimiser les mesures de protection et de restauration d'habitats pour assurer la pérennité des espèces susceptibles et menacées.

L'objectif de cette étude est de comparer des MQH calculés à partir de deux IQH : 1) la densité instantanée, estimée par TPA dans une série d'emplacements et 2) la densité cumulative, estimée par CVS dans la même série d'emplacements. La question que nous posons dans ce contexte est la suivante : Pourrait-il y avoir un avantage à développer des MQH basés sur la densité cumulative estimée dans de petits volumes, comparé à des MQH basés sur la densité instantanée estimée dans de grands volumes? Nous nous attendons à ce que la densité cumulative, bien qu'estimée dans de petits volumes, permette de développer des MQH aux capacités explicative supérieures aux MQH développés à partir de la densité instantanée dans de grands volumes.

Les capacités explicatives et les conditions environnementales sélectionnées pour expliquer les variations d'IQH à travers les emplacements ont été comparées entre MQH développés avec l'un ou l'autre des deux IQH, pour chaque descripteur de communauté. Nous posons l'hypothèse que les MQH basés sur la densité cumulative comme IQH auront une capacité explicative supérieure à celle des MQH basés sur la densité instantanée, mais que les conditions environnementales sélectionnées pour expliquer la variation d'IQH entre emplacements demeureront similaires, en fonction des descripteurs de communauté modélisés. De plus, nous posons l'hypothèse que la capacité explicative des MQH basés sur la densité cumulative comme IQH augmentera avec le temps ininterrompu que passerons les poissons dans le volume observé par CVS.

3. Article – Comparison of Habitat Quality Models based on Instantaneous and Cumulative fish Density

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Article soumis à Canadian Journal of Fisheries and Aquatic Sciences

Introduction

Freshwater and marine ecosystems contain approximately 25% of the world's known biodiversity (Mora et al., 2011). They are amongst the ecosystems most affected by human activities (Ricciardi and Rasmussen, 1999; Jackson et al., 2001; Pauly et al., 2002; Halpern et al., 2008). This may be related to the position of rivers, lakes, and oceans as receivers of all activities (e.g. deforestation, agriculture, construction) taking place in their watershed (Hopkinson & Vallino, 1995; Kim et al., 2002; Hundecha & Bárdossy, 2004; Dudgeon et al., 2006). Flow further contributes to the rapid spreading of any material (e.g. contaminants, sediments, debris) associated with such activities (Maitland, 1974; Liddle and Scorgie, 1980; Sweeney et al., 2004). Combined with overfishing (Allan et al., 2005; Coll et al., 2008; Srinivasan et al., 2010), freshwater and marine fish species are at high risk of being affected by anthropogenic activities. Mitigating the loss of freshwater and marine fish species may involve protecting and restoring habitats (Liddle and Scorgie, 1980; Beck et al., 2001; Dudgeon et al., 2006; Lassalle et al., 2008; Strayer and Dudgeon, 2010; Maceda-Veiga, 2013). Identifying habitats to be protected and means to restore them require the assessment of habitat quality (Wohl, 2005; Lanthier et al., 2013).

Habitat quality models (HQM) constitute one tool to assess habitat quality and to identify it's environmental determinants (Manly, McDonaldd, & Thomas, 1993; Bouchard & Boisclair, 2008; McLoughlin et al., 2010). HQM are relationships between habitat quality indices (HQI) and environmental conditions (Randall and Minns, 2000; Boisclair, 2001) observed at a series of locations each defined as the surface area or volume of an ecosystem characterized by a common set of environmental conditions. HQM may be developed for various species, life-stages, temporal specifiers (e.g. day or night, summer or winter), and spatial grain sizes (i.e. microhabitats to biogeographic scales; Orth, 1987; Petrakis et al., 2001; Beaumont et al., 2005; Bouchard and Boisclair, 2008; Capra et al., 2017). Similarly, HQI may use a variety of metrics (presence/absence, density, biomass, growth potential, feeding opportunities, survival rates; Lo et al., 1992; Boyce and McDonald, 1999; Gilliers et al., 2006; Rosenfeld and Hatfield, 2006; Wikelski and Cooke, 2006; Halpern et al., 2012; Horodysky et al., 2015; Morán-Ordóñez et al., 2017). Developing an HQM therefore involves assigning an HQI to a series of locations.

Fish HQM often use density (i.e. number of individuals per surface area or volume) as an HQI (Guay et al., 2000; Rosenfeld et al., 2005; Cote et al., 2013; Lanthier et al., 2013; Guénard et al., 2016). This assumes that density positively correlates with habitat quality (Boyce & McDonald, 1999; Buckland, 2006; Gilliers et al., 2006; Denney et al., 2017) with the caveat that high density may be observed at locations that constitute ecological traps or sinks (Van Horne, 1983; Howe et al., 1991). Fish density may be estimated using trawling, electrical fishing, seining, and visual survey (Zalewski, 1985; Pierce et al., 1990; Petrakis et al., 2001; Macnaughton et al., 2015). These methods typically sample fish instantaneously (i.e. at one point in time). However, assigning an HQI such as fish density estimated instantaneously to a location may be misleading. For instance, high "instantaneous density" may be observed at a location that is only momentarily used by a large number of fish (e.g. during migration, in transit through a hostile habitat; Fraser et al., 1999). In contrast, low "instantaneous density" may be observed at a location that is only temporarily used by a small number of fish. Such situations may either overestimate or underestimate the HQI assigned to a location that is, in fact, generally characterized by low or high fish density.

The observation that animals may spend more time in a high-quality habitat than in a low-quality habitat further emphasizes the difficulty posed by using instantaneous sampling methods to assign an HQI such as density to a location (Avgar et al., 2011; Kuefler et al., 2012). This observation further suggests that using sampling methods that permit the incorporation in HQI of the time spent by animals in a habitat may improve the capacity to discriminate high- from low-quality habitats and the explanatory capacity of HQM.

Video recordings permit the incorporation in HQI of the time spent by fish at a particular location by allowing the calculation of metrics such as fish-seconds (Boisclair and Sirois, 1993; Guénard et al., 2008). The number of fish-seconds represents the sum of seconds fish spend at a location. Such "cumulative density", which accounts for the time spent by fish at a location, may constitute a better HQI than "instantaneous density" and allow the development of superior HQM. Fish community descriptors (e.g. species, combination of species and size class, family, etc.) obtained using methods that sample fish instantaneously have been compared with corresponding values derived using video recordings (Bortone, Martin, & Bundrick, 1991; Francour, Liret, & Harvey, 1999; Watson et al., 2005; Harvey et al., 2007; Langlois et al., 2010; Struthers et al., 2015; Denney et al., 2017; Reynolds et al., 2018). They observed that species' proportions are generally similar, but methods that sample fish instantaneously (e.g. diver transect) tend to observe a greater number of species, whereas methods that sample fish cumulatively (e.g. video recordings) tend to observe carnivorous species more often. However, no study has yet compared HQM based on instantaneous and cumulative density estimates. Challenges associated with this comparison reside in the different size of the locations at which instantaneous (x 10^2 m^3; Macnaughton et al., 2015) and cumulative (in low [1-3 m] water transparency, x 10^0 m^3; Harvey et al., 2010) fish density are often estimated, at which HQM based on these HQI can be implemented, and in which an ecosystem must be partitioned to proceed with the modeling. The general question posed in this context is: Could there be a modelling advantage in developing or using HQM based on cumulative density estimated in smaller locations compared with HQM based on instantaneous density estimated in larger locations ?

The objective of this study was to compare HQM based on two HQI: i) instantaneous density estimated by snorkelers moving into a series of locations; ii) cumulative density estimated by stationary video recordings in these same locations. HQM developed using either of two HQI were compared using their respective explanatory capacity and the environmental conditions selected to explain among-location variations in HQI. We hypothesize that HQM based on cumulative density would have a higher explanatory capacity than, and include the same explanatory variables as, the HQM based on instantaneous density. We also hypothesized that the explanatory capacity of HQM developed using cumulative density would increase with the uninterrupted period of time spent by fish in the volume filmed by the video recordings.

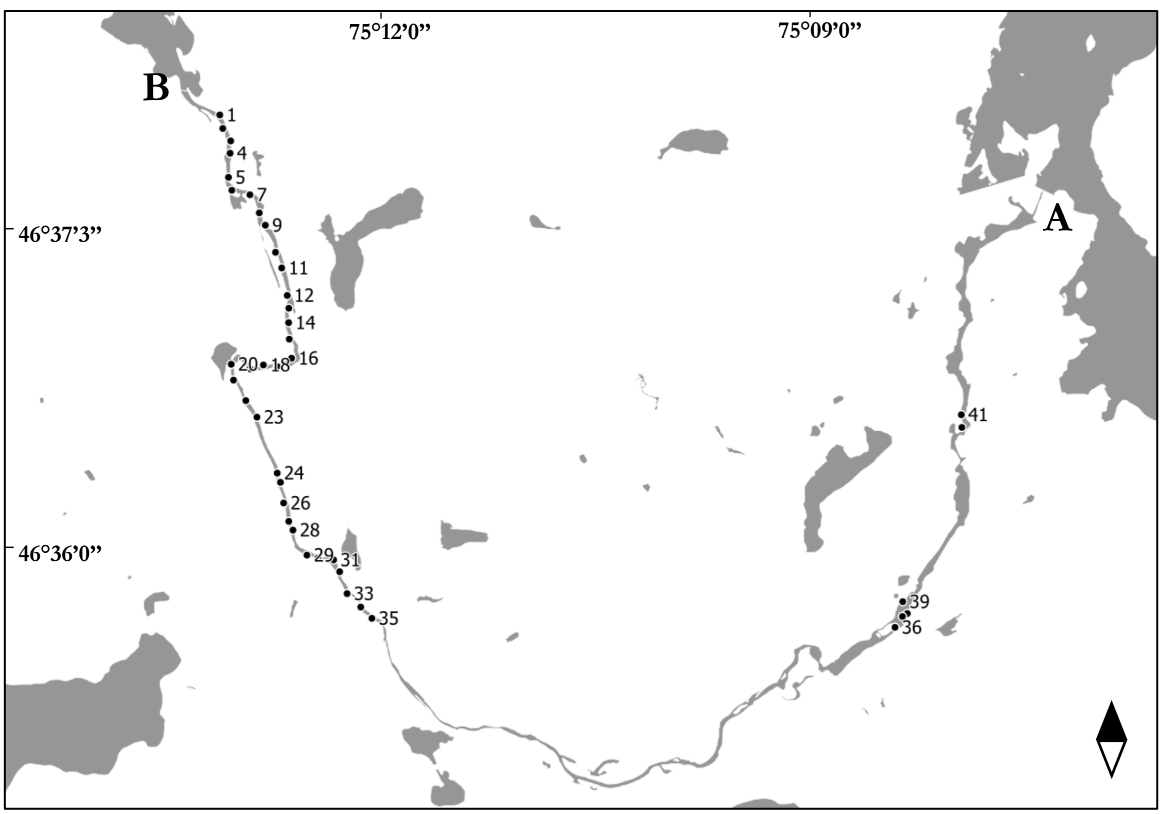
Material and methods

Achievement of our objective required the estimation of instantaneous and cumulative fish density at a series of locations of an ecosystem, the assessment of environmental conditions at these locations, and the development of HQM based on either instantaneous or cumulative fish densities.

Study site

Sampling was conducted in a 16 km segment of the Kiamika River (Laurentians region of Quebec, Canada) located between the Kiamika Dam and Petit Lac Kiamika (Figure 1). The landscape along this segment is characterised by an unaltered forest (mixture of deciduous and coniferous trees). River width within this segment ranges from 27 m to 120 m. The channel consists of a succession of riffles and pools (maximum depth of approximately 8.5 m) covered with substrate ranging from clay to boulders.

Figure 1 : Segment of the Kiamika river sampled. The segment is delimited upstream by the Kiamika dam (A) and downstream by the Petit Lac Kiamika (B). Forty-one locations (black dots) were sampled within the segment. The middle section of this segment comprises high velocity riffles that prevented sampling.



Sampling

Instantaneous and cumulative fish density together with environmental conditions were estimated at 41 locations distributed along the study site (Figure 1). The position of the first location (1 in Figure 1) was selected at random at the first road access to the Kiamika River upstream of the Petit Lac Kiamika, and subsequent sampling sites were positioned following a systematic sequence (i.e. left shore, middle, right shore, left shore, etc.). Consecutive locations were separated by a minimum of 60 m to avoid spatial autocorrelation (Legendre, 1993).

Locations were selected to maximize: i) environmental homogeneity within location (e.g. river width, depth, flow velocity, substrate composition, etc.), ii) environmental heterogeneity among location, and iii) sampling suitability (i.e. flow velocity ≤ 2 m·s^{-1} and depth ≤ 1.7 m to allow snorkelers to stand, install video-cameras, and swim upstream with ease). This strategy resulted in locations having surface areas ranging from 157.5 m^2 to 300 m^2, with a mean of 296.7 m^2 (31.5 m to 60 m, mean of 58.3 m longitudinally [parallel to the shore] x 5 m to 6 m, mean of 5.1 m perpendicular to shore).

Sampling was performed between 9h00 to 16h00, from August 7th to 23rd 2017 on days without precipitations. Instantaneous and cumulative density were estimated at each location, on consecutive days in a random order.

Instantaneous density was estimated by snorkeling survey (SS). Snorkelers were previously trained for a month to ensure accurate fish species identification, count, and size estimates (size class in total length: 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, etc.). SS was done by a team of two snorkelers, swimming upstream side by side, in a mirrored zig-zag pattern each covering 50% of locations. Snorkelers covered the surface area of a location within 15 to 30 minutes (ca 6 seconds per m^2). Fish data were noted on a polyvinyl chloride (PVC) tube worn on the forearm by the snorkelers.

Cumulative density was estimated using stationary stereo-video recordings (SVR). SVR were used because they permit the identification of fish species, count, and size estimation. SVR also allows the estimation of the volume surveyed and the time spent by fish in this volume (Harvey et al. 2010).

SVR was done using two video-cameras (GoPro HERO4 v05.00) placed in stereo, positioned randomly along the longitudinal axis of a location (no closer than 2 m from a location's edge), oriented to film fish present upstream of the video-cameras, and mounted on a concrete block to maintain the video-cameras at 30 cm from the riverbed and their optical axes approximately parallel to the riverbed.

SVR in any location lasted 45 minutes beginning with a 15-minute buffer period allowing snorkelers to calibrate the cameras and exit the location, and fish to resume normal behavior (Boisclair, 1992).

The video-cameras were calibrated by filming a plastic plate marked with a 20 cm band, held approximately perpendicular to the optical axes of the video-cameras, at various distances from the video-cameras (from 20 cm to 3 m at 20 cm intervals). Combined with the stereo placement of the video-cameras, we were able to later estimate fish sizes and volume surveyed.

Environmental conditions estimated during this study were chosen on the basis of previous studies (Senay et al., 2015) to explain among-location variations in instantaneous or cumulative fish density (Table 1). Cloud cover (%) and canopy cover (%) over the locations were visually estimated. River width (m) and the distance to the closest shore (m) were measured using a Rangefinder Bausch and Lomb. Depth (m) was measured using a Marsh-McBirney Flo-Mate 2000 flow meter's wading rod (Hach Company, Loveland, CO, USA; Macnaughton et al., 2015). Transparency (m) was measured with a Secchi disk held vertically and observed horizontally by a snorkeler. Water temperature (^{o}C) and adjusted conductivity (µS) were measured using a YSI Model 30 handheld conductivity meter (YSI inc., Yellow Springs, OH, USA) and flow velocity ($m \cdot s^{-1}$) was measured using a Marsh-McBirney Flo-Mate 2000 flow meter and wading rod. Substrate composition (proportion [%] of clay, silt, sand, gravel, pebble, cobble, and/or boulders) as well as the coverage (%) of woody debris, macrophytes (i.e. completely submerged plants) and emerging plants were estimated visually over a surface area of 0.25 m^2. The estimation or measurement of canopy cover, depth, flow velocity as well as substrate composition were replicated 10 times, at points distributed randomly within each location surveyed by SS. For SVR, environmental conditions were quantified once directly in front of the video-cameras. All estimates and measurements were done after visual surveys.

Table 1 : List of the environmental conditions estimated or measured, their units, respective tools, and their precision, as well as the number of replicates per location for snorkeling survey (SS) and stereo-video recording (SVR).

#	Variable	Unit	Tool	Precision	Replicates SS	Replicates SVR
1	Cloud cover	%	Visually assessed	± 10 %	1	1
2	Canopy	%	Visually assessed	± 10 %	10	1
3	River Width	m	Rangefinder	± 5 %	1	1
4	Distance to closest shore	m	Rangefinder	± 5 %	1	1
5	Depth	m	Wading rod	± 0.05 m	10	1
6	Transparency	m	Secchi disk	± 0.1 m	1	1
7	Temperature	^{o}C	YSI	± 2 %	1	1
8	Adj. Conductivity	µS	YSI	± 2 %	1	1
9	Flow velocity	$m \cdot s^{-1}$	Flow meter	± 0.015 $m \cdot s^{-1}$	10	1
10	Clay	%	Visually assessed	± 5 %	10	1
11	Silt	%	Visually assessed	± 5 %	10	1
12	Sand	%	Visually assessed	± 5 %	10	1
13	Gravel	%	Visually assessed	± 5 %	10	1
14	Pebble	%	Visually assessed	± 5 %	10	1
15	Cobble	%	Visually assessed	± 5 %	10	1
16	Boulders	%	Visually assessed	± 5 %	10	1
17	Woody debris	%	Visually assessed	± 5 %	10	1
18	Macrophytes	%	Visually assessed	± 5 %	10	1
19	Emerging plants	%	Visually assessed	± 5 %	10	1

Computations

Instantaneous and cumulative fish density were estimated for four community descriptors: species, combination of species and size class, family, and total community.

SS were used to estimate instantaneous abundance (n) for the four community descriptors at each location. Instantaneous density ($n \cdot m^{-3}$) for all community descriptors were obtained by dividing the instantaneous abundance by the volume surveyed (m^3). The volume of each location was computed by multiplying its respective width (m), length (m), and mean depth (m).

SVR permitted the estimation of cumulative abundance (n) for the four community descriptors at each location. For each location, thirty minutes of video recordings (minutes 15 to 45) were analysed in laboratory to identify, for each fish, their species, their size, and the time spent in the volume filmed by the video-cameras during an un-interrupted time interval (between the entry of a fish in, and its exit from, the volume filmed by the video-cameras). During this analysis, images recorded simultaneously by the two video-cameras appeared on a single monitor. Cumulative density was estimated using three procedures: 1) all fish filmed were used for calculations (no time threshold); 2) only fish that remained in the volume filmed by the video-cameras more than 3 seconds were used for calculations (time threshold of 3 seconds); and 3) only fish that remained in the volume filmed by the video-cameras for more than 10 seconds were used for calculations (time threshold of 10 seconds).

Fish size was estimated using the fish's distance from the video cameras and the relationship between the actual size of an object and its apparent size on a monitor used to visualize the images recorded by video-cameras.

The fish's distance to the video-cameras was estimated following three steps. First, we defined the relationship between the known distance of an object (i.e. the 20 cm band used for calibration) from the video-cameras and the apparent displacement of a point (e.g. the tip of the 20 cm band used for calibration) on the x-axis of two images of this point recorded simultaneously by the video-cameras. The apparent displacement of a point on the x-axis was estimated as the difference between the x-coordinates of this point as it appears in the two simultaneously recorded images viewed on the monitor. Second, we measured the apparent displacement of a point on a fish (i.e. the head) on two images of this fish recorded simultaneously by the video-cameras (Boisclair, 1992). Third, the apparent displacement of a fish was used as an input to the relationship between the distance of an object from the video-cameras and the apparent displacement.

The relationship between the actual size of an object and its apparent size on the monitor used to visualize the images recorded by video-cameras involved two steps. The first step was to calculate the relationship between the apparent size on the monitors of an object (i.e. the 20 cm band used for calibration) and its known size, at various known distances. This relationship was non-linear, however the relationship between the ratios (real size/apparent size) and the distances from the video-cameras was linear. Using a fish's apparent size on screen, with the distance of a fish to the video-cameras previously computed, it was then possible to compute its real size with the appropriate real size/apparent size ratio.

The time spent by each fish at a location was summed by community descriptor and permitted the calculation of cumulative abundance (i.e. fish-seconds; n·sec) for the six community descriptors using no time threshold, a time threshold of 3 seconds, or a time threshold of 10 seconds. Cumulative density ($n \cdot sec \cdot m^{-3}$) for the four community descriptors was obtained by dividing cumulative abundance (n·sec) by the volume surveyed by video-camera (m^3) at this location.

The volume surveyed by video-cameras in each location was computed based on the pyramid shape of the video-camera's field of view, which was delimited by a vertical and horizontal angle, the surface of the water, the riverbed and the visibility (i.e. depth of the field of view). Computation was done using the measured river depth, the height of the video camera and the field of view's horizontal and vertical angles (provided by the manufacturer; see Annexe, Figure 2 for diagrams and formulas).

HQM development

HQM were developed for instantaneous and cumulative community descriptors that had values > 0 (in $n \cdot m^{-3}$ or $n \cdot sec \cdot m^{-3}$) in at least 50% of the locations. HQM were developed using multiple linear regression models (Legendre and Legendre, 2012; Lanthier et al., 2013).

During this process, instantaneous and cumulative community descriptors were either log- or square root-transformed to achieve residual normality for our models (Legendre and Legendre, 2012). HQM were computed in R (*RStudio* v.1.1.442; RStudio Team, 2015) by multiple linear regressions using *lm()* function, combined with stepwise forward selection using *step()* function to identify the set of environmental conditions that had significant effect on community descriptors. A maximum of four significant ($p<0.05$) environmental conditions were retained as explanatory variables for each HQM. Adjusted R^2 ($R^2_{adj.}$) values were used to compare instantaneous and cumulative HQM of each community descriptors (Ohtani, 2000).

Results

Fish density

The volume of locations surveyed by SS ranged from 103.2 m^3 to 375.6 m^3 (mean = 246.1; standard deviation = 56.1) and that surveyed by SVR ranged from 0.7 m^3 to 2.5 m^3 (mean = 1.3; standard deviation = 0.4). Instantaneous fish density within a location surveyed by SS (mean = 0.57 $n \cdot m^{-3}$; standard deviation = 0.41 $n \cdot m^{-3}$) varied proportionally less than cumulative fish density within a location surveyed by SVR (mean = 1362.78 $n \cdot sec \cdot m^{-3}$; standard deviation = 1703.44 $n \cdot sec \cdot m^{-3}$). Instantaneous fish density within a location ranged from 0 to 1.66 $n \cdot m^{-3}$, whereas cumulative fish density within a location ranged from 11.25 to 7584.93 $n \cdot sec \cdot m^{-3}$.

Among the 18 species observed by SS, six had instantaneous density > 0 in at least 50% of the location (Table 2): banded killifish (*Fundulus diaphanus*), common shiner (*Luxilus cornutus*), fallfish (*Semotilus corporalis*), largemouth bass (*Micropterus salmoides*), pumpkinseed sunfish (*Lepomis gibbosus*), smallmouth bass (*Micropterus dolomieu*) and yellow perch (*Perca flavescens*). A total of 11 species were observed by SVR, of which 4 had cumulative density > 0 in at least 50% of the locations: fallfish, pumpkinseed sunfish, smallmouth bass, and yellow perch. These four species were selected for HQM computing because their density surveyed by both sampling methods was greater than zero in more than 50% of the locations.

Common shiner, golden shiner (*Notemigonus crysoleucas*), blacknose dace (*Notropis heterolepsis*), fathead minnow (*Pimephales promelas*), creek chub (*Semotilus atromaculatus*) and fallfish were sometimes difficult to discriminate with certainty. Given this situation, these species were combined to form an additional community descriptor hereafter referred to as "cyprinids".

Within the river segment (all 41 locations) surveyed by SS, fallfish (0.72 $n \cdot m^{-3}$) was the species with the highest overall density, followed by pumpkinseed sunfish (0.15 $n \cdot m^{-3}$), yellow perch (0.08 $n \cdot m^{-3}$) and smallmouth bass (0.06 $n \cdot m^{-3}$). When surveyed by SVR, pumpkinseed sunfish (2997.52 n·sec·m^{-3}) was the species with the highest overall density, followed by fallfish (929.11 n·sec·m^{-3}), smallmouth bass (220.73 n·sec·m^{-3}) and yellow perch (163.97 n·sec·m^{-3}).

For any given species, over 50% of individual fish belonged to a single size class. This situation rendered impossible the analysis by size class. The concept of size class was therefore excluded from further analyses.

Cyprinids' overall density (SS: 3.30 n·m^{-3}; SVR: 6147.64 n·sec·m^{-3}) was much higher than that of any given species. The total community was also used as a community descriptor for HQM computing. Combining all species, the total community had the highest overall density (SS: 23.36 n·m^{-3}; SVR: 55874.15 n·sec·m^{-3}). For each of the six community descriptors (four species, one family, and total community), two HQM were computed: instantaneous and cumulative.

Table 2 : Number of locations where each species was observed (Occurrences; maximum of 41) and for which instantaneous (n·m^{-3}) and cumulative (n·sec·m^{-3}) density were estimated per location, minimum (Min), maximum (Max) and mean (Mean) instantaneous or cumulative density per location, for each community descriptor targeted for HQM development.

Community descriptor	Occurrences		Density					
			Instantaneous (n·m^{-3})			Cumulative (n·sec·m^{-3})		
	SS	SVR	Min	Max	Mean	Min	Max	Mean
Fallfish	36	31	0	0.72	0.17	0	929.11	182.59
Pumpkinseed sunfish	36	34	0	0.15	0.06	0	2997.52	421.72
Smallmouth bass	33	25	0	0.06	0.01	0	220.73	17.04
Yellow perch	32	27	0	0.08	0.03	0	163.97	31.27
Cyprinids	31	20	0	0.43	0.10	0	2504.42	112.58
Community	39	41	0	1.66	0.42	11.25	7584.93	1362.78

Environmental conditions

Environmental conditions estimated during sampling were characterized by different degrees of variability either among volumes surveyed using SS or SVR or, in some instances, among volumes surveyed using SS and SVR (Table 3).

Cloud cover (0 to 100%), canopy cover (0 to 100%), river width (27 to >100m), distance from closest shore (0 to 34 m) and depth (0.24 to 1.66 m) varied in a similar way at least 3-fold among days or volumes surveyed using SS or SVR. In contrast, transparency (2.1 to 3.4 m), temperature (19.5 to 21.3 C°) and adjusted conductivity (μS) varied no more than 1.62-fold among days or volumes surveyed using SS or SVR. However, a one-way ANOVA test showed that the mean temperature did vary significantly between volumes surveyed by SS or SVR ($F=7.626$; $p=0.007$; num df=1; denom df=80). Flow velocity was the only environmental condition that seemed to vary more among volumes surveyed using SS (-0.04 to 1.35 $m \cdot s^{-1}$; a negative value indicating an upstream flow caused by a gyre) than among those surveyed using SVR (-0.06 to 0.54 $m \cdot s^{-1}$). Despite this, the mean flow velocity recorded in volumes surveyed using SS did not vary significantly from the corresponding value in volumes surveyed using SVR ($F=2.789$; $p=0.0988$; num df=1; denom df=80).

Specific categories of substrate such as silt (0 to 100%), sand (0 to >80%), cobble (0 to ≥70%) and boulders (0 to ≥65%) also varied widely, but in a very similar fashion among volumes surveyed using SS or SVR. However, other categories of substrate such as clay, gravel and woody debris seemed to vary more among volumes surveyed using SS than among volumes surveyed using SVR. One-way ANOVA indicated that, the mean values of clay (F=1.468; p=0.229; num df=1; denom df=80), gravel (F=0.002; p=0.966; num df=1; denom df=80) and woody debris (F=0.127; p=0.722; num df=1; denom df=80) recorded in volumes surveyed by SS did not vary significantly from corresponding values in volumes surveyed by SVR.

The range of macrophyte cover recorded in volumes surveyed by SS and SVR was identical (0 to 100%) but the means were statistically different (F=9.091; p=0.003; num df=1; denom df=80). The mean emergent plant cover did not vary significantly among the volumes by either SS or SVR (ANOVA: F=0.787; p=0.378; num df=1; denom df=80).

To summarize, one-way ANOVA tests confirmed that 17 out of 19 environmental conditions were not significantly different between survey types, temperature and macrophytes being the only exceptions. Hence both approaches targeted similar env cond.

Table 3: Range (Min; Max), mean and standard deviation (S.d.) of surveyed locations' volume and environmental conditions.

Environmental conditions	SS				SVR			
	Min	**Max**	**Mean**	**S.d.**	**Min**	**Max**	**Mean**	**S.d.**
Cloud (% cover)	0	100	37.4	26.0	0	100	41.0	29.6
Canopy (% cover)	0	95	5.3	16.2	0	95	7.2	21.2
River width (m)	27	120	48.8	20.9	27	105	46.5	15.8
Distance to closest shore (m)	0	34	2.8	7.2	0	34	2.8	7.2
Depth (m)	0.24	1.66	0.8	0.3	0.45	1.36	0.78	18.6
Transparency (m)	2.1	3.4	2.6	0.4	2.1	3.2	2.6	0.3
Temperature (ºC)	19.7	21.3	20.5	0.4	19.5	21.1	20.3	0.4
Adjusted Conductivity (µS)	32.4	34.1	33.5	0.5	32.4	34.1	33.5	0.5
Flow velocity ($m \cdot s^{-1}$)	-0.04	1.35	0.17	0.28	-0.06	0.54	0.09	0.14
Substrate categories (% cover)								
Clay (<0.01mm)	0	90	3.1	9.1	0	20	1.7	4.1
Silt (0.01-0.06mm)	0	100	62.7	41.4	0	100	65.8	39.8
Sand (0.06-2mm)	0	100	18.7	27.8	0	84	15.5	22.3
Gravel (2-32mm)	0	85	2.9	10.5	0	45	3.1	8.8
Pebble (32-64mm)	0	60	1.7	7.3	0	30	2.7	8.0
Cobble (64-250mm)	0	90	7.4	18.0	0	70	6.1	14.1
Boulders (250-1000mm)	0	100	3.5	12.0	0	65	5.0	13.4
Woody debris (% cover)	0	95	6.4	11.7	0	25	5.9	34.4
Macrophytes (% cover)	0	100	20.6	26.1	0	100	38.3	34.4
Emergent plants (% cover)	0	40	0.7	3.2	0	15	1.2	3.1

HQM

Statistically significant HQM based on instantaneous and cumulative density were developed for the six community descriptors that had HQI > 0 in a least 50% of the locations (Table 4). HQM based on instantaneous density were initially compared to HQM based on cumulative density estimated using no time threshold. HQM for pumpkinseed sunfish and yellow perch had the highest explanatory capacities whether these were based on either instantaneous (R^2_{adj} of 0.56 and 0.50 respectively) or cumulative (R^2_{adj} of 0.39 and 0.44

respectively) density. For five of the six community descriptors, HQM based on instantaneous density had a higher explanatory capacity than those based on cumulative density ($0.10 < \Delta R^2_{adj} < 0.27$; Table 4). Smallmouth bass was the only community descriptor for which HQM based on cumulative density (0.32) had a higher R^2_{adj} than that based on instantaneous density (0.24; $\Delta R^2_{adj} = -0.08$).

As a result, the mean explanatory capacity of HQM based on instantaneous density (0.42; range: 0.24 – 0.56) tended to be higher than that of HQM based on cumulative density (0.27; range: 0.09 – 0.44). Student t-test confirms the mean of ΔR^2_{adj} is different from 0 ($t=2.85$; $p=0.0357$), therefore the R^2_{adj} of HQM based on instantaneous density are significantly higher than that of HQM based on cumulative density.

Selected environmental conditions varied between instantaneous and cumulative HQM for most community descriptors. Fallfish (transparency and adjusted conductivity) and smallmouth bass (clay) were the only species for which there was an overlap, between instantaneous and cumulative HQM, of environmental conditions that were significant predictors of these species' respective distribution. However, the other environmental conditions selected by their respective models were not the same.

Table 4: Results of the multiple linear regressions: selected environmental conditions and adjusted R^2 (R^2_{adj}) of HQM based on instantaneous and cumulative (no time threshold) density for each species and both groups of species (*p<0.05; **p<0.005).

Community descriptors	Instantaneous HQM		Cumulative HQM		ΔR^2_{adj}
	Environmental Conditions	R^2_{adj}	Environmental Conditions	R^2_{adj}	
Fallfish	Transparency*, Temperature*, Adjusted Conductivity**, Silt*	0.38**	Distance to closest shore*, Transparency**, Adjusted Conductivity**, Flow velocity*	0.20*	0.18
Pumpkinseed sunfish	Depth**, Boulders*	0.56**	Flow velocity*, Silt**	0.39**	0.17
Smallmouth bass	Distance to closest shore**, Clay*	0.24**	Adjusted Conductivity*, Clay*, Cobble**	0.32**	-0.08
Yellow perch	Depth**, Silt**	0.50**	Canopy**, Distance to closest shore**, Adjusted conductivity*, Flow velocity**	0.44**	0.10
Cyprinids	Canopy*, Distance to closest shore*, Temp*, Boulders*,	0.31**	Macrophyte*	0.09*	0.22
Community	Canopy*, Depth**, Temperature*, Silt**	0.46**	Flow velocity**	0.19**	0.27

The use of a time threshold during the calculation of cumulative density rarely increased the explanatory capacity of HQM (Table 5). The R^2_{adj} of the HQM based on the cumulative density of Smallmouth bass increased from 0.32 (no time threshold) to 0.36 when applying a time threshold of either 3 or 10 seconds. The corresponding values for Community, using a time threshold of 3 seconds, were 0.19 and 0.20. In all other cases, the use of a time threshold had no effect on, or decreased, the explanatory capacity of HQM based on cumulative density.

Table 5: R_{adj}^2 of HQM based on cumulative density, on which we applied no threshold, a 3-seconds threshold, or a 10-seconds threshold

Community descriptors	Threshold		
	None	**3 seconds**	**10 seconds**
Fallfish	0.20	0.04	0.04
Pumpkinseed sunfish	0.39	0.39	0.37
Smallmouth bass	0.32	0.36	0.36
Yellow perch	0.44	0.43	0.30
Cyprinids	0.09	0.08	0.08
Community	0.19	0.20	0.19

Discussion

The objective of this study was to compare HQM based on two HQI: instantaneous and cumulative density. Fish density data and environmental conditions estimated or measured in 41 locations allowed us to develop and compare HQM based on two HQI for six community descriptors. Contrary to our hypothesis, the results indicate that, on average, HQM based on instantaneous density had statistically higher explanatory capacities than HQM based on cumulative density and adding a time threshold to estimate cumulative density did not significantly change these results. Values of R^2_{adj} were generally low (0.34; range: 0.09 – 0.56), which is often the case for HQM developed by surveying each location once (0.35 – 0.80: Lanthier et al., 2013; 0.30 – 0.67: Senay et al., 2017).

Contrary to our hypothesis, environmental conditions selected as explanatory variables in HQM based on instantaneous or cumulative density were often different. For four community descriptors (pumpkinseed sunfish, yellow perch, cyprinids, community), there was no overlap whatsoever between the environmental conditions selected as explanatory variables for HQM based on instantaneous or cumulative density. We assessed the possibility that this situation was the result of a statistical artifact (i.e. the order in which explanatory variables are selected during the stepwise multiple regression process) by attempting to develop new HQM. This was done: a) by forcing the selection by HQM based on cumulative density of environmental conditions used by HQM based on instantaneous density and b) by forcing the selection by HQM based on instantaneous density of environmental conditions used by HQM based on cumulative density. None of these new HQM permitted to increase the overlap between the environmental conditions selected as explanatory variables in HQM based on instantaneous and cumulative density. For the two other community descriptors (fallfish and smallmouth bass), the overlap of environmental conditions between HQM based on instantaneous and cumulative density represented ≤ 50% of the environmental conditions selected as explanatory variables.

Explanatory variables selected by HQM based on the instantaneous density of fallfish were transparency, temperature, adjusted conductivity, and silt, while HQM based on cumulative density selected distance from the shore, transparency, adjusted conductivity, and flow velocity. Transparency and adjusted conductivity, which were selected by HQM based on either HQI, therefore appeared robust predictors of the distribution of fallfish within our locations. Based on the coefficients associated with these explanatory variables for either HQM (Annexe, Table 12 and 13), fallfish seemed to prefer locations with low transparency and high adjusted conductivity. Water transparency is known to affect prey-predator encounter rate and decreased transparency is associated with higher prey density (Turesson and Brönmark, 2007). In this case, we interpret that fallfish appeared to have a prey-like behavior, preferring locations with low transparency where they can easily hide from predators. Adjusted conductivity and its effect on fish is not well understood, but it is associated with fitness (condition factor) and primary productivity (Copp, 2003; Knaepkens et al., 2002; Squire and Moller, 1982). High primary productivity will increase with nutrients and minerals' concentration in a lake, which in turn will increase the adjusted conductivity. Dennis (1995) hypothesized that adjusted conductivity may affect fish by influencing the physiological cost of ion regulation, but this has yet to be tested experimentally. While the mechanism by which adjusted conductivity may affect fallfish distribution is not clear, the present study further suggests that small variations in this environment condition (32.4 to 34.1 μS) may have a statistically significant effect on HQI – an observation confirmed by the selection of adjusted conductivity in a total of four HQM developed for three community descriptors (Table 4).

Explanatory variables selected by HQM based on the instantaneous density of smallmouth bass were distance from the shore and clay, whereas the corresponding model based on cumulative density selected adjusted conductivity, clay, and cobble. Clay was selected in both HQM developed for smallmouth bass, but their coefficients suggest that the effect of clay on fish density had opposite trends (-0.004 and 0.120; one negative, one positive). This situation further suggests that HQM based on HQI estimated over short periods of time and large volumes (instantaneous fish density estimated by SS over volumes ranging from 103.2 m^3 to 375.6 m^3) may differ from HQM based on HQI estimated over large periods of time and small volumes (cumulative fish density estimated by SVR over volumes ranging from 0.7 m^3 to 2.5m^3), both offering a somewhat unique perspective of habitat quality.

Flow velocity was selected as a significant predictor for species' distribution by only and almost all HQM based on cumulative density estimated by SVR (four out of six models). This suggests that the effect of flow velocity on fish distribution, at least within a river such as the one we surveyed, may be efficiently perceived only over long periods of time, within small volumes. It is quite possible that, despite efforts deployed to select relatively homogeneous locations to estimate instantaneous density and develop HQM using SS, environmental patchiness remained in volumes ranging from 103.2 m^3 to 375.6 m^3. For example, within the Kiamika river, flow velocity was highly variable due to the presence of structures (e.g. submerged tree, boulders) and of depth variations, which can occur often within volumes ranging from 103.2 m^3 to 375.6 m^3. Therefore, although the range of values for flow velocity was not significantly different for both types of survey, the survey over long periods of smaller volumes using SVR allowed us to observe the effect of flow velocity on cumulative fish density but the survey over short periods of larger volumes using SS did not. We hypothesize that environmental patchiness may be largely responsible for the differences in HQM developed using larger (for instantaneous density) or smaller (for cumulative density) volumes, observed over short or long periods of time, respectively. This may indicate that fish species have different mechanisms to evaluate a habitat's quality, weather they are choosing to spend time in a neighborhood ($\geq 10^2$ m^3) or a specific spot ($10^0 - 10^1$ m^3).

Taken together, the present study suggests that, within the limits of the biotic and abiotic conditions found in Kiamika River, HQM based on instantaneous density estimated by snorkelers may have a slightly, but significantly, higher average explanatory capacity than

HQM based on cumulative density estimated by video-recordings. It is hypothesized that the differences in the HQM based on the two HQI explored in the present study may be related to the different sizes of the volumes surveyed in this study to estimate instantaneous and cumulative density, as well as environmental patchiness. We found little evidence that developing HQM based on cumulative density estimated in smaller volumes, depending on the species, could provide a significant modelling advantage over HQM based on instantaneous density estimated in larger volumes. However, a combination of both types of HQM, when possible, may improve the analysis of habitat quality and the environmental conditions that define it by incorporating two distinct perspective on fish and their habitat. We conclude that both HQI can provide complementary information on the characteristics of habitats to protect and restore, and thus insure the efficiency of conservation and restoration measures for aquatic habitat.

4. Conclusion

Cette étude a été réalisée dans le but de comparer les capacités explicatives de MQH basés sur deux IQH, soit la densité instantanée et la densité cumulative estimées pour des poissons en rivière. Contrairement à nos hypothèses, les MQH basés sur la densité cumulative en tant qu'IQH ne démontrent pas des capacités explicatives supérieures aux MQH basés sur la densité instantanée et ce même si nous estimons la densité cumulative en utilisant un seuil à 3 ou 10 secondes. Pour la majorité des descripteurs de la communauté, la capacité explicative des MQH basés sur la densité instantanée (moyenne des R^2adj = 0.42) est statistiquement supérieure à celle des MQH basés sur la densité cumulative (moyenne des R^2adj = 0.27). La seule exception est l'achigan à petite bouche, pour lequel la capacité explicative du MQH basé sur la densité cumulative (R^2adj = 0.32) est supérieure à celle du MQH basé sur la densité instantanée (R^2adj = 0.24).

Contrairement à notre hypothèse, les conditions environnementales sélectionnées par les MQH basés sur la densité instantanée et cumulative ne sont pas les mêmes pour la majorité des descripteurs de la communauté. Seuls les MQH basés sur la densité instantanée et cumulative estimées pour la ouitouche et l'achigan à petite bouche font exceptions : $\leq$50% des conditions environnementales sélectionnées par leurs MQH respectifs sont les mêmes. La densité instantanée a été estimée sur de courte périodes dans de très grands volumes (103.2 à 375.6 m^3), contrairement à la densité cumulative (0.7 à 2.5 m^3). Il est possible que la haute variabilité observée entre MQH pour la plupart des descripteurs de communauté soit en partie expliquée par l'interaction entre la taille du volume dans lequel la densité est estimée et la variation temporelle (pour certaines, e.g. la vélocité) et spatiale des conditions environnementales. Les MQH basés sur la densité instantanée et cumulative semblent donc modéliser la distribution des individus en fonction de conditions environnementales dont les effets diffèrent selon la durée et l'échelle spatiale à laquelle ils sont observés.

Dans les limites biotiques et abiotiques du segment étudié de la rivière Kiamika, nos résultats nous permettent de conclure que l'ajout du temps à un IQH tel que la densité ne permet pas, pour la majorité des espèces, une distinction significativement meilleure de la qualité des habitats. Toutefois, étant donnée la présence d'une exception à cette conclusion, soit les MQH de l'achigan à petite bouche, il est envisageable que l'ajout du temps à un IQH soit profitable à la création de MQH pour certaines espèces. De plus, l'identification de conditions environnementales significatives expliquant la distribution des espèces diffère selon l'IQH utilisé. Il semble donc que des MQH basés sur la densité cumulative estimée sur de longues périodes dans de petits volumes, quoique statistiquement moins performants, aient le potentiel de donner des informations différentes et complémentaires aux des MQH basés sur la densité instantanée estimée sur de courtes périodes dans de grands volumes.

Bien que nos données soient limitées dans le temps et l'espace (recueillies au courant d'un été, dans un court segment de rivière), nous pouvons en conclure que l'évaluation de la qualité des habitats du poisson à l'aide de la densité instantanée semble être un moyen efficace d'identifier les habitats à protéger et les moyens à prendre pour les restaurer. Toutefois, l'utilisation des deux types de densité en tant qu'IQH, lorsque possible, pourrait permettre une analyse plus complète de la qualité des habitats et les conditions environnementales qui la définissent, assurant ainsi l'efficacité des efforts de conservation et la pérennité des espèces aquatiques.

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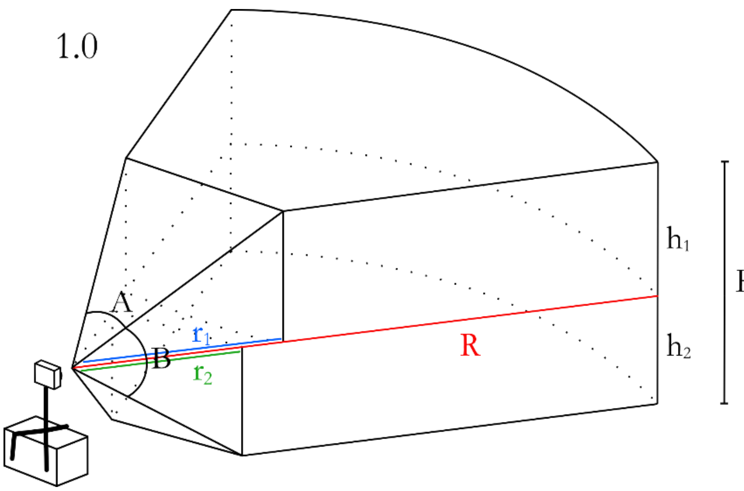
Annexe

Figure 2 : Schémas, calculs et légende permettant de calculer le volume échantillonné par caméra-vidéo. 1.0 : schéma du champ de vision (CdV); 1.1 à 1.3 : schéma de la section pyramidale i du CdV et formules associées; 1.4 : schéma de la section cylindrique coupée i du CdV et calculs de volume finaux.

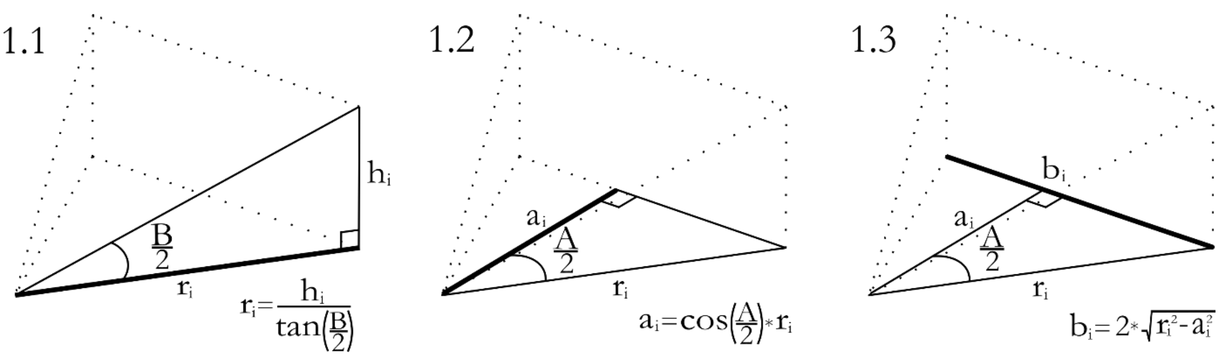
1.0



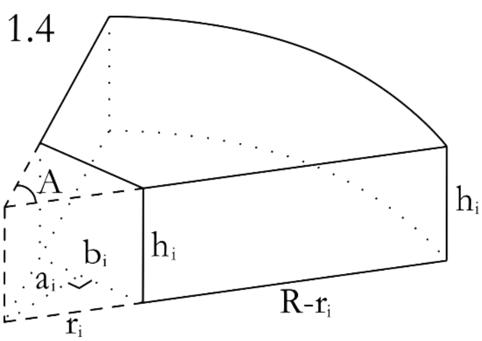
Légende :

A : Angle horizontal du champ de vision (radian)
a_i : Hauteur de la demi-pyramide i (m)
B : Angle vertical du champ de vision (radian)
b_i : Largeur de la base de la demi-pyramide i (m)
H : Hauteur de la colonne d'eau (m)
h_i : Hauteur partielle de la colonne d'eau & demi longeur de la base de la pyramide i (m)
R : Grand Rayon (visibilité max.; radian)
r_i : Petit rayon (radian)
$V_{c.i}$: Volume du cylindre coupé i (m^3)
$V_{p.i}$: Volume de la pyramide i (m^3)
V_i : Volume sous-total i (m^3)
V : Volume total (m^3)
i : 1=Au-dessus de la caméra-vidéo
2=Sous la caméra-vidéo

1.1 1.2 1.3



1.4



$$V_{c.i} = ((\pi * R^2 * h_i) * (A/6.28 \text{ radians})) - ((a_i * 2b_i/2) * h_i)$$

$$V_{p.i} = 1/2 * \left(\frac{b_i * 2h_i * a_i}{3}\right)$$

$$V_i = V_{p.i} + V_{c.i}$$

$$V = \sum V_i$$

Tableau 6 : Occurrences des 18 espèces observées par transect en plongée en apnée (TPA) et caméra-vidéo en stéréo (CVS), dans les 41 emplacements.

Espèces	**Achigan à grande bouche**	**Achigan à petite bouche**	**Grand brochet**	**Chrosomus sp.**	**Crapet soleil**	**Éperlan arc-en-ciel**	**Fondule barré**	**Méné à grosse tête**	**Méné jaune**	**Méné à museau noir**	**Méné à nageoire rouges**	**Meunier noir**	**Mulet à cornes**	**Naseux des rapides**	**Ouitouche**	**Perchaude**	**Saumon atlantique**	**Truite mouchetée**
TPA	23	33	4	1	36	10	23	2	11	12	22	2	4	1	36	32	1	1
CVS	6	25	2	-	34	2	1	-	3	-	6	1	-	-	31	27	-	-

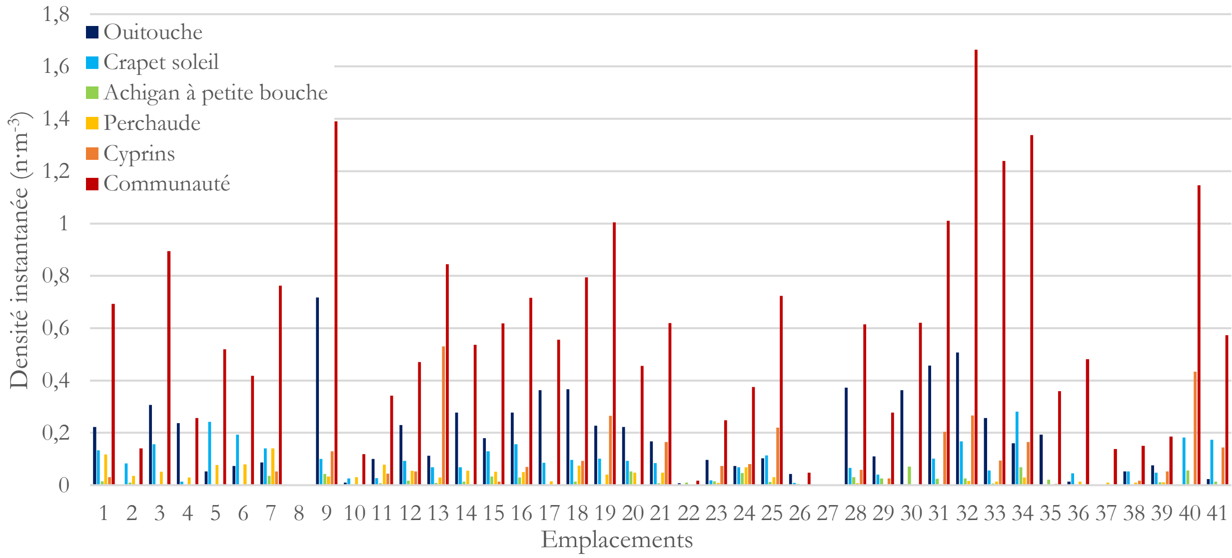
Tableau 7 : Densité instantanée (n·m^{-3}) des six descripteurs de communauté pour les 41 emplacements.

Emplacements	Ouitouche	Crapet soleil	Achigan à petite bouche	Perchaude	Cyprins	Communauté
1	0,223	0,133	0,015	0,117	0,031	0,693
2	0	0,083	0,01	0,036	0	0,14
3	0,307	0,157	0	0,051	0	0,894
4	0,237	0,014	0,003	0,029	0,003	0,257
5	0,053	0,242	0	0,077	0	0,519
6	0,073	0,193	0	0,079	0,004	0,418
7	0,087	0,141	0,035	0,141	0,053	0,763
8	0	0	0	0	0	0
9	0,717	0,1	0,043	0,033	0,129	1,39
10	0,01	0,026	0,004	0,03	0	0,119
11	0,1	0,027	0,007	0,078	0,044	0,342
12	0,23	0,093	0,017	0,055	0,052	0,471
13	0,113	0,069	0,008	0,029	0,53	0,844
14	0,277	0,068	0,013	0,055	0,004	0,536
15	0,18	0,13	0,033	0,051	0,014	0,618
16	0,277	0,157	0,029	0,05	0,07	0,716
17	0,363	0,086	0	0,015	0	0,556
18	0,367	0,097	0,013	0,075	0,093	0,794
19	0,227	0,102	0,004	0,04	0,265	1,004
20	0,223	0,093	0,052	0,048	0	0,456
21	0,167	0,084	0,007	0,048	0,165	0,62
22	0,007	0	0,01	0	0	0,017
23	0,097	0,018	0,015	0,009	0,073	0,248
24	0,073	0,068	0,047	0,068	0,081	0,375
25	0,103	0,114	0,012	0,031	0,22	0,723
26	0,043	0,008	0,005	0	0	0,048
27	0	0	0	0	0	0
28	0,373	0,066	0,031	0,007	0,059	0,615
29	0,11	0,04	0,026	0	0,026	0,277
30	0,363	0,004	0,071	0	0	0,621
31	0,457	0,102	0,024	0,004	0,204	1,011
32	0,507	0,167	0,026	0,016	0,266	1,664
33	0,257	0,056	0,006	0,013	0,094	1,239
34	0,16	0,281	0,068	0,029	0,165	1,338
35	0,193	0	0,021	0	0,005	0,359
36	0,013	0,045	0	0,014	0	0,482
37	0	0	0	0,01	0	0,138
38	0,052	0,053	0,003	0,01	0,017	0,15
39	0,076	0,048	0,011	0,011	0,052	0,186
40	0	0,182	0,056	0	0,434	1,146
41	0,023	0,174	0,013	0	0,144	0,573

Tableau 8 : Densité cumulative (n·sec·m^{-3}) des six descripteurs de communauté pour les 41 emplacements.

Emplacements	Ouitouche	Crapet soleil	Achigan à petite bouche	Perchaude	Cyprins	Communauté
1	1274,682	58,423	32,752	10,622	59,308	1500,407
2	0	10,493	1,825	27,374	0	39,692
3	22,975	2434,513	12,371	136,969	59,206	2736,729
4	109,68	1734,827	0	205,207	45,995	2095,708
5	0	4225,45	34,027	8,725	0	4268,202
6	0	275,71	0	97,647	5,744	379,101
7	0	83,494	0	0	0	83,494
8	2,41	0	8,836	0	0	11,245
9	129,803	95,785	44,76	56,397	111,004	545,171
10	17,151	277,28	0	10,72	0	305,151
11	331,337	833,138	0	368,626	36,223	1605,548
12	101,931	488,723	30,943	123,773	0	776,315
13	647,074	239,887	11,507	60,193	5,311	963,973
14	280,063	190,067	45,67	0	0	515,799
15	1,031	273,861	8,252	23,724	13,925	368,242
16	244,033	647,032	14,608	43,823	0	949,496
17	353,533	3411,74	0	24,91	4,79	3823,717
18	410,989	37,222	55,833	10,081	151,213	670,765
19	0	5453,427	13,514	35,344	582,142	6093,783
20	165,871	68,98	0,797	33,094	0	268,743
21	69,617	46,037	0	45,475	273,414	604,092
22	540,95	0	376,938	0	0	917,888
23	1262,46	176,627	0	1,682	0	1440,769
24	330,929	99,582	3,036	92,903	0	526,45
25	496,613	249,213	0	19,031	13,593	778,449
26	1074,31	564,074	22,025	0	0	1660,409
27	0	0	16,044	0	0	16,044
28	0	95,068	0	0	18,641	113,709
29	15,421	0	59,868	0	0	75,289
30	159,557	0	48,52	0	18,662	226,739
31	226,128	875,09	0	34,328	220,68	1356,226
32	73,826	760,319	90,797	143,408	0	1068,35
33	147,77	175,286	24,459	105,987	1176,048	2805,599
34	916,092	206,891	49,076	1,925	0	1173,984
35	284,646	0	0	0	0	284,646
36	575,947	461,743	2,465	51,761	3324,224	7373,105
37	68,103	44,598	0	36,161	3,013	151,876
38	17,522	573,83	3,65	0	0	595,002
39	0	239,428	0	0	0	239,428
40	0	758,363	0	0	0	3260,83
41	0	0	0	0	24,498	7584,925

Graphique 1 : Distribution de la densité instantanée, pour six descripteurs de la communauté, dans les 41 emplacements.



Graphique 2 : Distribution de la densité cumulative, pour six descripteurs de la communauté, dans les 41 emplacements.

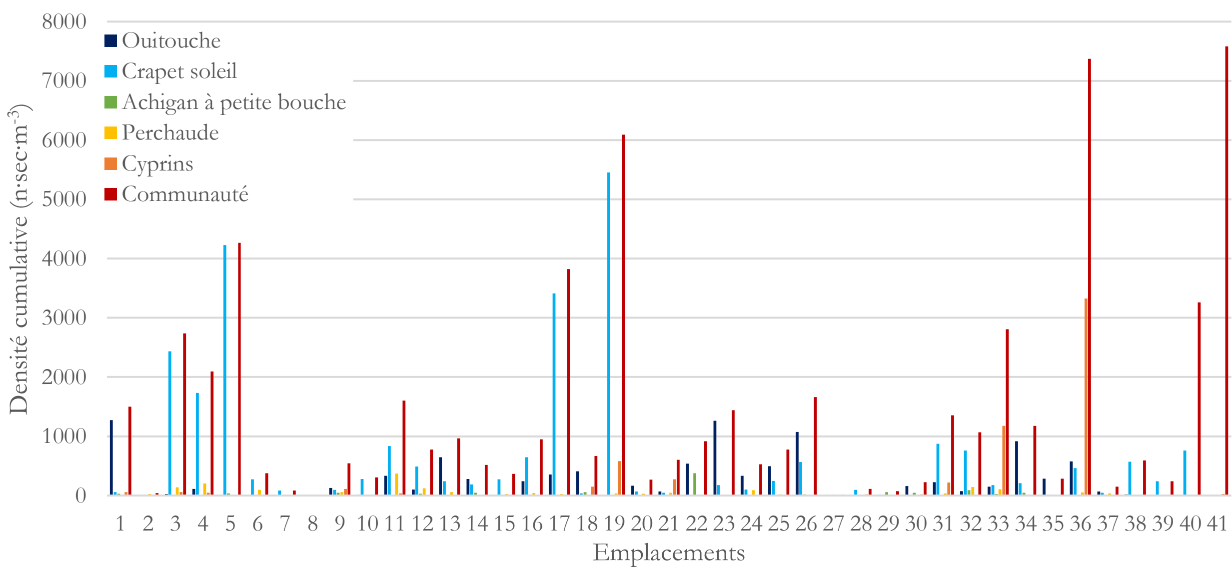


Tableau 9 : Valeurs des conditions environnementales dans les 41 emplacements, estimées ou mesurées en transect en plongée en apnée (TPA).

Emplacemen	**Couvert nuageux (%)**	**Canopée (%)**	**Largeur de la rivière (m)**	**Distance à la berge (m)**	**Profondeur (m)**	**Transparence (m)**	**Température (°C)**	**Conductivité ajustée (µS)**	**Vélocité (m/s)**	**Argile (%)**	**Limon (%)**	**Sable (%)**	**Gravier (%)**	**Caillou (%)**	**Galet (%)**	**Bloc (%)**	**Matière ligneuse (%)**	**Macrophyte (%)**	**Émergente (%)**
1	25	15,5	44	0	0,655	2,8	20,8	33,6	1,088	4,5	65	30,5	0	0	0	0	10	15,0	1
2	60	15,0	48	0	0,645	2,8	20,8	33,5	0,000	9,5	70,5	20	0	0	0	0	25	1,0	3
3	60	1,0	45	0	0,593	2,8	21,0	33,8	0,000	0	93,5	6,5	0	0	0	0	4	25,5	1,5
4	10	0,0	52	12	1,168	2,5	20,6	33,7	0,198	0	83	17	0	0	0	0	0	47,0	0
5	5	1,0	33	0	0,565	2,5	20,8	33,7	0,058	20,5	76,5	3	0	0	0	0	2,5	31,0	0
6	5	13,0	58	0	0,758	2,5	20,6	33,9	-0,020	19	81	0	0	0	0	0	12,5	46,0	0
7	70	8,5	41	0	0,568	3,0	20,6	33,6	0,058	2,5	88,5	9	0	0	0	0	9	11,0	0
8	40	0,0	54	15	1,014	3,0	20,6	33,4	0,497	0	0	22	22	29	27	0	0	5,0	0
9	50	10,5	42	0	0,698	3,0	20,7	33,6	0,079	1	92,5	6,5	0	0	0	0	8,5	26,0	0
10	60	11,0	41	0	0,783	2,2	21,3	33,9	0,019	4,5	95	0,5	0	0	0	0	4,5	14,0	1,5
11	50	0,0	48	9	0,983	2,2	21,3	33,9	0,022	0	75	25	0	0	0	0	0	50,0	0,5
12	50	1,0	50	0	0,969	2,2	21,3	33,8	0,012	2	97	1	0	0	0	0	16,5	9,0	3
13	0	4,5	40	0	0,818	2,8	19,9	33,6	1,350	3,5	95,5	1	0	0	0	0	2	39,0	0
14	0	18,5	43	0	0,790	2,8	20,0	33,5	0,500	20	79,5	0,5	0	0	0	0	3	34,5	0
15	10	10,5	45	0	0,717	2,6	19,7	33,7	0,005	0	92	8	0	0	0	0	11,5	23,5	1,5
16	10	8,5	52	0	0,805	2,6	20,1	33,6	0,050	3	92	5	0	0	0	0	7,5	40,5	0
17	15	10,0	39	0	0,887	2,6	20,0	33,6	0,000	2,5	97	0,5	0	0	0	0	7,5	12,5	12
18	30	1,5	41	0	0,756	2,2	20,3	34,1	0,061	0	96,5	3,5	0	0	0	0	10	45,0	0
19	30	0,5	42	0	0,754	2,2	20,4	33,8	-0,040	0	100	0	0	0	0	0	7	46,5	1,5
20	40	3,5	29	0	0,900	2,2	20,6	33,1	0,088	0	72	4,5	0,5	16,5	6,5	0	7	31,5	0
21	100	6,0	38	0	0,909	3,2	20,2	33,5	0,046	0	98,5	0,5	0	0	1	0	10	29,0	0
22	100	0,0	40	9	0,988	3,2	20,2	33,5	0,399	0	0	13,5	2	0,5	61,5	22,5	1	0,5	0

Tableau 9 (suite) : Valeurs des conditions environnementales dans les 41 emplacements, estimées ou mesurées en transect en plongée en apnée (TPA).

Emplacemen	Couvert nuageux (%)	Canopée (%)	Largeur de la rivière (m)	Distance à la berge (m)	Profondeur (m)	Transparence (m)	Température (°C)	Conductivité ajustée (µS)	Vélocité (m/s)	Argile (%)	Limon (%)	Sable (%)	Gravier (%)	Caillou (%)	Galet (%)	Bloc (%)	Matière ligneuse (%)	Macrophyte (%)	Émergente (%)
23	100	15,5	38	0	1,101	3,2	20,1	33,5	0,059	0	81	17	0	0	0	2	21	12,0	0
24	20	10,0	43	0	0,782	3,4	20,4	33,8	0,032	0,5	91	1	0	0	5,5	2	14	6,0	0
25	30	6,5	42	0	0,848	3,4	20,6	33,8	0,011	0	97	3	0	0	0	0	8,5	14,0	0
26	25	0,0	42	10	1,252	3,4	20,8	33,8	0,143	0	6,5	52,5	1,5	0	31	8,5	1	3,0	0
27	60	0,0	41	0	1,080	2,8	20,6	33,6	0,368	0	0	39	5,5	0,5	28,5	26,5	0,5	0,5	0
28	60	2,0	33	0	0,964	2,4	20,6	33,6	0,077	0	79	21	0	0	0	0	4	15,5	0
29	60	24,0	44	0	0,759	2,8	20,5	33,7	0,078	8	6	59	0	0	14	13	4,5	11,0	0
30	40	5,0	27	0	0,620	2,1	20,3	33,8	0,163	0	2	38	4	2,5	16	37,5	10,5	0,5	0
31	30	2,0	49	0	0,794	2,1	20,3	33,8	-0,024	0	94,5	0	0	0,5	3	2	9	9,0	1,5
32	30	0,0	39	0	0,851	2,1	20,4	33,7	0,057	5,5	69	4	1	0	16,5	4	5	6,5	0
33	20	0,0	31	0	0,639	2,3	20,2	33,5	0,116	0	24,5	32	2,5	0	31	10	2	10,0	0
34	40	0,0	30	0	0,655	2,3	20,2	33,4	0,123	0	8,25	21	21,75	4	33,25	11,75	2,5	2,5	0
35	40	1,5	35	0	0,641	2,3	20,3	33,5	0,413	0	2,5	10	36	4,5	40,5	6,5	6,5	0,5	0
36	5	0,0	109	25	0,954	2,2	20,6	32,4	0,226	12	3,5	84	0,5	0	0	0	0,5	25,5	0
37	5	0,0	114	3	1,036	2,2	20,8	32,4	0,279	2	20,5	77	0,5	0	0	0	0	22,5	0
38	30	5,0	120	0	0,998	2,2	21,0	32,4	0,175	0	69	20	0	11	0	0	2,5	55,5	0
39	40	0,0	86	0	0,896	2,2	21,0	32,4	0,147	2	56	42	0	0	0	0	0,5	31,5	0
40	50	1,0	58	0	0,660	2,2	20,2	32,5	0,038	0	39	32,5	27	1,5	0	0	6,5	15,5	2
41	30	4,5	46	0	0,786	2,2	20,2	32,5	0,023	1	60,5	38,5	0	0	0	0	2	13,0	0

Tableau 10 : Valeurs des conditions environnementales dans les 41 emplacements, estimées ou mesurées par caméra-vidéo en stéréo (CVS).

Emplacement	Couvert nuageux (%)	Canopée (%)	Largeur de la rivière (m)	Distance à la berge (m)	Profondeur (m)	Transparence (m)	Température (°C)	Conductivité ajustée (µS)	Vélocité (m/s)	Argile (%)	Limon (%)	Sable (%)	Gravier (%)	Caillou (%)	Galet (%)	Bloc (%)	Matière ligneuse (%)	Macrophyte (%)	Émergente (%)
1	5	0	46	0	0,740	2,5	20,4	33,6	0,100	5	70	25	0	0	0	0	20	60	0
2	5	10	42	0	0,740	2,5	20,4	33,5	0,000	10	80	10	0	0	0	0	5	40	5
3	5	0	41	0	0,660	2,5	20,9	33,8	0,000	0	95	5	0	0	0	0	5	30	0
4	20	0	52	12	0,930	2,8	20,4	33,7	0,000	0	85	15	0	0	0	0	0	30	0
5	20	0	33	0	0,450	2,8	20,7	33,7	0,000	20	80	0	0	0	0	0	5	30	10
6	20	5	58	0	0,700	2,8	20,5	33,9	0,000	0	100	0	0	0	0	0	5	90	0
7	65	0	54	0	0,450	2,2	21,0	33,6	0,473	0	100	0	0	0	0	0	15	5	0
8	40	0	54	15	1,000	2,2	21,0	33,4	0,540	0	0	10	20	30	40	0	0	0	0
9	70	0	42	0	0,680	2,2	21,1	33,6	0,107	0	90	5	5	0	0	0	5	20	0
10	90	0	41	0	0,750	3,0	20,4	33,9	0,013	0	100	0	0	0	0	0	0	60	0
11	75	0	48	9	0,730	3,0	20,5	33,9	0,013	0	75	25	0	0	0	0	0	95	0
12	50	0	50	0	0,760	3,0	20,5	33,8	0,023	2	97	1	0	0	0	0	25	60	0
13	15	0	43	0	0,620	2,6	19,5	33,6	0,083	0	100	0	0	0	0	0	5	25	0
14	15	95	45	0	0,460	2,6	19,5	33,5	0,000	10	85	5	0	0	0	0	5	5	0
15	0	0	45	0	0,720	2,8	19,9	33,7	0,000	0	95	5	0	0	0	0	0	50	15
16	0	0	52	0	0,840	2,8	20,0	33,6	0,007	3	92	5	0	0	0	0	10	50	0
17	0	30	39	0	0,720	2,8	19,9	33,6	0,000	2	98	0	0	0	0	0	5	15	5
18	100	0	41	0	0,720	3,2	20,1	34,1	0,043	0	95	5	0	0	0	0	10	85	0
19	100	0	42	0	0,720	3,2	20,1	33,8	-0,037	0	100	0	0	0	0	0	0	85	0
20	100	0	29	0	0,700	3,2	20,1	33,1	0,010	0	100	0	0	0	0	0	10	95	5
21	10	0	38	0	0,680	2,2	20,2	33,5	0,083	0	100	0	0	0	0	0	5	40	0

Tableau 10 (suite) : Valeurs des conditions environnementales dans les 41 emplacements, estimées ou mesurées par caméra-vidéo en stéréo (CVS).

Emplacement	Couvert nuageux (%)	Canopée (%)	Largeur de la rivière (m)	Distance à la berge (m)	Profondeur (m)	Transparence (m)	Température (°C)	Conductivité ajustée (µS)	Vélocité (m/s)	Argile (%)	Limon (%)	Sable (%)	Gravier (%)	Caillou (%)	Galet (%)	Bloc (%)	Matière ligneuse (%)	Macrophyte (%)	Émergente (%)
22	30	0	40	9	0,900	2,2	20,1	33,5	0,403	0	0	10	0	0	70	20	0	0	0
23	40	0	38	0	0,800	2,2	20,1	33,5	0,023	0	100	0	0	0	0	2	15	50	5
24	85	5	43	0	0,800	2,4	20,5	33,8	-0,030	1	93	1	0	0	5	0	20	5	0
25	50	25	42	0	0,710	2,4	20,6	33,8	0,027	0	100	0	0	0	0	0	5	30	0
26	60	0	42	10	1,360	2,4	20,4	33,8	0,123	0	5	70	10	0	5	10	5	5	0
27	5	0	41	0	1,280	3,0	20,0	33,6	0,330	0	0	30	5	5	20	40	0	0	0
28	10	5	33	0	0,600	3,0	20,1	33,6	0,150	0	100	0	0	0	0	0	0	90	0
29	30	95	44	0	0,760	3,0	20,3	33,7	-0,020	0	0	60	0	0	15	25	5	5	0
30	50	5	27	0	0,700	2,4	19,7	33,8	0,087	0	0	20	0	0	15	65	5	5	0
31	50	5	49	0	0,720	2,3	19,6	33,8	-0,017	0	95	0	0	0	5	0	20	15	5
32	30	0	39	0	1,100	2,3	19,9	33,7	0.130	0	95	5	0	0	0	0	10	30	0
33	40	0	31	0	0,890	2,1	20,2	33,5	-0,023	0	20	10	0	5	30	35	0	0	0
34	40	15	30	0	0,920	2,1	20,3	33,4	0,113	0	5	10	15	30	30	10	0	0	0
35	50	0	35	0	0,660	2,1	20,3	33,5	0,410	0	0	10	45	30	15	0	0	0	0
36	50	0	99	25	1,010	2,4	20,5	32,4	0,030	10	5	84	1	0	0	0	0	100	0
37	30	0	81	34	0,890	2,4	20,4	32,4	0,220	3	20	75	2	0	0	0	0	80	0
38	60	0	105	0	0,950	2,4	20,6	32,4	0,100	0	70	20	0	10	0	0	5	80	0
39	70	0	52	0	0,720	2,4	20,5	32,4	0,140	5	55	40	0	0	0	0	10	10	0
40	60	0	45	0	0,780	2,4	20,2	32,5	0,010	0	40	35	24	1	0	0	0	5	0
41	35	0	54	0	0,810	2,4	20,0	32,5	-0,060	1	60	39	0	0	0	0	5	90	0

Tableau 11 : Proportion des classes de tailles pour chaque descripteurs de la communauté

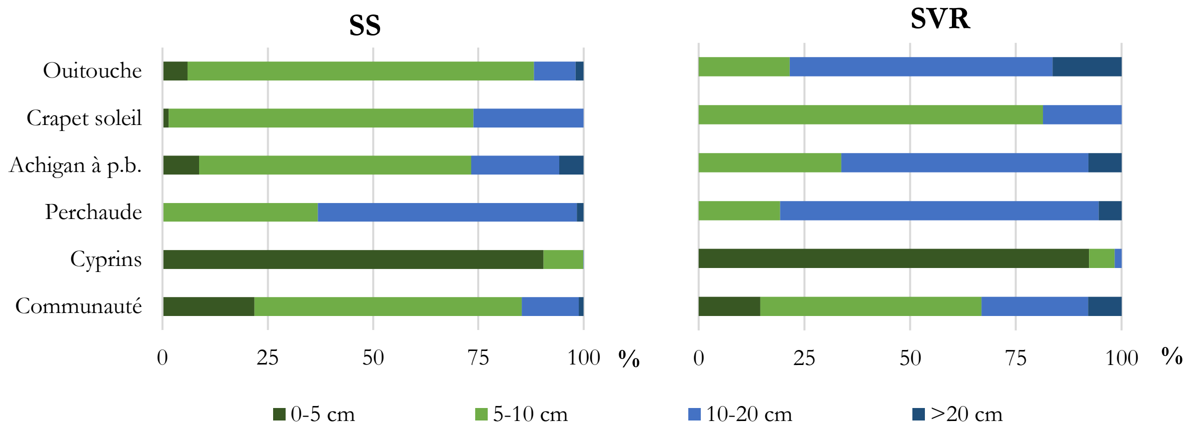


Tableau 12: Formules des modèles de qualité des habitats (MQH) basés sur la densité instantanée.

Descripteurs de la communauté	Formules de régression linéaire multiple – densité instantanée
Ouitouche	*f*(x) = – 2.968 – 0.183 (Transp.) – 0.150 (Temp.) + 0.202 (Cond. Aj.) + 0.002 (Limon)
Crapet soleil	*f*(x) = 0.587 – 0.006 (Dist. berge) – 0.003 (Prof.) – 0.008 (Bloc)
Achigan à petite bouche	*f*(x) = 0.136 – 0.005 (Dist. berge) – 0.004 (Argile)
Perchaude	*f*(x) = 0.158 – 0.001 (Prof.) + 0.002 (Limon)
Cyprins	*f*(x) = 3.798 – 0.008 (Dist. berge) – 0.171 (Temp.) – 0.011 (Argile) + 0.009 (Bloc)
Communauté	*f*(x) = 8.299 – 0.025 (Canopée) – 0.013 (Prof.) – 0.329 (Temp.) + 0.003 (Limon)

Tableau 13: Formules des modèles de qualité des habitats (MQH) basés sur la densité cumulative.

Descripteurs de la communauté	Formules de régression linéaire multiple – densité cumulative
Ouitouche	*f*(x) = – 65.641 + 0.123 (Dist. berge) – 3.307 (Transp.) + 2.326 (Cond. Aj.) – 5.668 (Vélocité)
Crapet soleil	*f*(x) = 3.427 – 5.725 (Vélocité) + 0.027 (Limon)
Achigan à petite bouche	*f*(x) = – 38.174 + 1.177 (Cond. Aj.) + 0.120 (Argile) + 0.063 (Galet)
Perchaude	*f*(x) = – 150.665 – 0.074 (Canopée) + 0.283 (Dist. berge) + 4.681 (Cond. Aj.) – 18.076 (Vélocité)
Cyprins	*f*(x) = 1.037 + 0.024 (Macrophyte)
Communauté	*f*(x) = 36.948 – 65.826 (Vélocité)