Predictable Changes in Abundance, Composition, and Size Structure of Fish and Macroinvertebrates Along an Urbanization Gradient in the Ottawa-Gatineau Area

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Abstract

As land use transformations are the main driver of biological diversity loss at the global scale, it is essential to provide predictions and understanding of their impacts in order to improve the mitigation of ecosystem perturbations. The first objective of this project was to describe the response of biological assemblages along a gradient of urbanization and to compare metrics of watershed imperviousness in order to determine, as has been suggested in the literature, whether effective imperviousness, which represents the proportion of impervious area directly connected to the stream by storm sewers, is a better predictor of stream impairement than total imperviousness in the watershed. Decline in sensitive taxa abundance is initiated at 14% total imperviousness and 3% effective imperviousness in the Ottawa-Carleton region and, total and effective imperviousness have equivalent predictive power. The second objective of this project was to describe how the structure of metazoan assemblages in urban streams, as described by size spectra attributes (i.e. slopes, intercepts, number of logarithmic size classes occupied, and residual variance), varies with watershed size, land use and water quality. Streams size spectra of the Ottawa-Gatineau region have relatively shallow slopes, reflecting relatively higher densities of organisms in the larger size classes compared to other ecosystem types (e.g. lakes, oceans, soils, coastal waters). Size spectra slopes, density corrected for size, number of size classes, and residual variance vary predictably along gradients of watershed size, watershed proportion of natural land use and periphyton chlorophyll *a*. A systematic trend of declining spectra slopes with increasing periphyton biomass suggests that ecological efficiency declines in urban eutrophic streams.

Résumé

Puisque les changements d'utilisation des terres constituent le principal facteur responsable de la diminution de la diversité biologique à l'échelle mondiale, il est essentiel d'améliorer la prédiction et la compréhension de leurs impacts afin d'améliorer la mitigation des perturbations écologiques. Le premier objectif de ce projet était de décrire la réponse des assemblages biologiques soumis à un gradient d'urbanisation et de déterminer, tel qu'il a été démontré dans la littérature, si l'imperméabilité effective, qui représente la proportion de surface imperméable connectée directement aux ruisseaux par des égouts pluviaux, constitue un meilleur prédicteur des perturbations écologiques que l'imperméabilité totale. Le déclin des taxa les plus sensibles est amorcée à 14% d'imperméabilité totale et 3% d'imperméabilité effective, et l'imperméabilité totale et effective ont des puissances prédictives équivalentes. Le deuxième objectif de ce projet était de décrire comment la structure des assemblages de metazoaires, tel que décrits par les attributs des spectres de taille (c.-à-d. la pente, l'intercepte, le nombre de classes de taille logarithmique occupées et la variation résiduelle), varient avec l'utilisation des terres et les caractéristiques des sites. Les spectres de taille des ruisseaux de la région de Ottawa-Gatineau ont des pentes relativement peu négatives et reflètent une densité relative plus élevée des plus grosses classes de taille comparativement à d'autres types d'écosystèmes (p. ex. lacs, océans, sols, eaux côtières). La pente, la densité corrigée pour la taille, le nombre de classes de taille et la variance résiduelle des spectres de taille varient de manière prédictible avec la taille des bassins versants, la proportion de terres naturelles et la biomasse du périphyton (chlorophylle *a*). Une tendance systématique selon laquelle la pente des spectres de taille

diminue avec l'augmentation de la biomasse du périphyton suggère que l'efficacité écologique décline dans les ruisseaux eutrophes des millieux urbains.

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Chapter 1 — General Introduction

As a result of the tremendous human population growth (Cohen 2003), natural ecosystems are globally facing significant landscape alterations (Foley *et al.* 2005, Changhong *et al.* 2011). Lotic systems, in particular, are sensitive to land use transformations as they reflect intimately the characteristics of the catchment they draining and are therefore sensitive (Allan *et al.* 1997, Paul and Meyer 2001). Catchment alterations are associated with profound perturbations of a stream's hydrological regime (Leopold 1968, Hancock 2002), water quality (Cooper 1993, Bolstad and Swank 1997, Hatt *et al.* 2004), habitat (Richard *et al.* 1996, Bledsoe and Watson 2001) and biological assemblages (Schlosser 1991, Barton 1996, Sonneman *et al.* 2001, Huryn *et al.* 2002, Townsend *et al.* 2003, Pinto *et al.* 2006) of streams. Empirical assessments to identify the strongest correlate of ecological impacts are essential to generate the best predictions of ecological impairement induced by landuse transformations. In addition, the study of the changes in structure of multitrophic biological assemblages will help better understand the impacts of land use transformations at the ecosystem level.

Urbanization is often quantified using various physical, demographic and landscape variables such as road density, urban intensity index, dominant land cover, ratio of people per unit urban land cover and watershed imperviousness (Brabec *et al.* 2002, Walsh *et al.* 2005a, Cuffney *et al.* 2005, Hahs and McDonnell 2006, Steuer *et al.* 2009). Among those variables, watershed imperviousness is the most widely used and often strongest correlate of ecological impact of urbanization on running water ecosystems (Schueler 1994, Arnold and Gibbons 1996, Brabec *et al.* 2002). Defined as the proportion of impervious surfaces (e.g., building, roads, sidewalks) present in a catchment, watershed imperviousness constitutes a

reliable predictor of stream biological condition (Morse *et al.* 2003, Ourso and Frenzel 2003, Taylor *et al.* 2004, Morgan and Cushman 2005, Gresens *et al.* 2007). Watershed imperviousness has profound impacts on groundwater level and storm water runoff (Leopold 1968, Finkenbine *et al.* 2000, Rose and Peter 2001, Roy *et al.* 2005), which lead to important physical and biological perturbations at the ecosystem level (Wang *et al.* 2000, Paul and Meyer 2001, Wang *et al.* 2001, Hatt *et al.* 2004, Taylor *et al.* 2004, Walsh *et al.* 2005b, Bazinet *et al.* 2010, Davies *et al.* 2010). Although various sources of disturbance exist in urbanized areas (Paul and Meyer 2001, Walsh *et al.* 2005b, Dosskey *et al.* 2010), the increase in watershed imperviousness is considered the leading cause of stream impairment in urban areas (Brabec *et al.* 2002, Shuster *et al.* 2005). Recent findings suggest that effective imperviousness, the proportion of impervious area directly connected to the stream by storm sewer pipes, constitutes a better correlate of urban impairment than total watershed imperviousness (Taylor *et al.* 2004, Walsh *et al.* 2005a).

Many studies have documented non-linear responses of stream biological assemblages to increased imperviousness and have identified threshold values representing levels of imperviousness at which changes occur (Arnold and Gibbons 1996, Klein 1979, Schueler and Galli 1992, Horner *et al.* 1997, Morse *et al.* 2003, Ourso and Frenzel 2003, Fitzpatrick *et al.* 2004, Deacon *et al.* 2005, Snyder *et al.* 2005, Baker and King 2010). Two different types of thresholds have been described: the iniation-of-impact threshold representing the stage at which degradation first occurs, and the extirpation threshold at which the ecosystem experience an important shift of a vital structural or functional

component so that the degradation becomes unavoidable and permanent (Hilderbrand 2010, Klein 1979, Morse *et al.* 2003, Schueler *et al.* 2009).

The second chapter of my thesis describes the response of water quality and biological assemblages along a gradient of imperviousness and quantifies regional thresholds. I also investigated whether effective imperviousness is a better correlate of changes in abundance and composition of the biota than total imperviousness in the Ottawa region.

Improved knowledge of the effects of land use alterations on biological assemblages will help better manage our land and mitigate changes at the ecosystem level. Ecosystem descriptions based on size distributions have great potential for improving our comprehension of ecosystem trophic structure and underlying energetic transfers (Kerr and Dickie, 2001). As body size is correlated with many fundamental ecological traits (e.g., diet breadth, trophic status, abundance, richness, metabolic rate) (Peters 1986, Woodward *et al.* 2005), body size distributions correlate with underlying ecological processes of entire assemblages and many studies have focused on body size distributions to better understand the interactions between animal assemblages and their environment (Allen *et al.* 2006).

Sheldon *et al.* (1972, 1973) were the first to report evidence of uniform biomass distribution at all body size ranges; from bacteria to whales. The constant biomass within all size classes led them to suggest the existence of intrinsic structuring in ecosystems. Kerr (1974) speculated that size distribution was governed by energy transfers between trophic levels as predator-prey interactions are size dependent, with larger organisms being

constrained to feed on smaller preys. Platt and Denman (1977, 1978) strengthened the concept with mathematical analyses of energy transfer through aquatic food webs. Subsequent studies of size distributions on various different taxa and ecosystem types provided further evidence of similarity of size structure across ecosystems (e.g., Schwinghamer 1981, Sprules *et al.* 1983, Schwinghamer 1985, Sprules and Munawar 1986).

The size spectrum is remarkably consistent when quantified as a log-density versus log-body size linear relationship. The slope of the spectra was shown to approximate -1 in many different ecosystems (lakes: Sprules and Munawar 1986, Ahrens and Peters 1991; streams: Morin and Nadon 1991; oceans: Gaedke 1992, Jennings and Mackinson, 2003; soils: Mulder *et al.* 2009; coastal waters: Huete-Ortega *et al.* 2010). However, although the general shape of the size spectrum is similar among systems, size spectra parameters (i.e. slopes, intercepts, number of size classes, and residual variance) vary slightly with local environmental conditions (Rasmussen 1993, Bourassa and Morin 1995, Cyr *et al.* 1997a, Kerr and Dickie, 2001, Mulder *et al.* 2009, Huete-Ortega *et al.* 2010, DeNichola *et al.* 2006, Emmrich *et al.* 2011). Size spectra constitute descriptors of ecosystems that can be used to quantify structural changes. For instance, the observed variation in size spectra intercept in relation to nutrient availability suggests that size spectra could be used to quantify the influence of enrichment on ecosystems (Kerr and Dickie 2001). Size spectra constitute an alternative to traditional taxon-based methodologies by integrating many aspects of multi-trophic assemblages into a few parameters.

The third chapter of this thesis describes variations in size spectra attributes (i.e. slopes, intercepts, number of size classes and residual variance) as structural descriptors of stream multi-trophic assemblages collected on 129 sampling events to describe how these assemblages vary with watershed size, land use and water quality.

Chapter 2 — Comparing Total and Effective Imperviousness as Predictors of Stream Impairment

Abstract

Stormwater runoff is considered the leading cause of stream impairment in urban areas. Watershed imperviousness is commonly used as a predictor of urban impact, but it has been argued that effective imperviousness (EI), the proportion of impervious area directly connected to the stream by storm sewer pipes, constitutes a better correlate of urban impairment than total watershed imperviousness (TI). However, the superiority of EI over TI as a correlate of ecological impact remains to be demonstrated outside Australia. Twenty nine streams in the region of Ottawa-Carleton were selected to represent local ranges of total and effective imperviousness while minimizing their correlation. Regression tree models were used to calculate thresholds of imperviousness and compare the fit of the predictions obtained using the two metrics. Fish and macroinvertebrate assemblages from watersheds of low imperviousness were associated with a wide range of biological conditions which declined abruptly at 29% TI and 23% EI. The impact of imperviousness was however initiated at 14% TI and 3% EI. In contrast to previous studies conducted in Australia, effective imperviousness was not a better correlate of stream impairment in the region of Ottawa-Carleton. This difference was attributed to regional characteristics of runoff regime, geology and topography.

Introduction

Urbanization constitutes one of the critical global trends shaping humanity's impact on the environment (World Resources Institute 1996). Therefore, the success of efforts to maintain and improve ecosystem health is strongly bounded by our understanding of the ecological impacts associated with urban development. Streams are highly sensitive to landscape changes and constitute one of the ecological components most vulnerable to urbanization (Lenat and Crawford 1994). Several factors related to urban development can impair streams, but the increase in storm water runoff associated with the increase of impervious cover in urban developments is considered the leading cause of stream alterations in urban areas (Brabec *et al.* 2002).

Impervious structures such as rooftops, roads, sidewalks, pavements and parking lots increase surface runoff by decreasing water infiltration. Increased surface runoff has important altering effects on hydrological regimes and habitat quality. As a consequence of increased impervious structures, streams are exposed to a decrease in groundwater level coupled with an increased frequency and intensity of flood flow during storm events (Finkenbine *et al.* 2000, Rose and Peter 2001, Roy *et al.* 2005). These changes are associated with erosion of banks and channels, excessive streambed scour, increased suspended solids, temperature elevation and elevated pollutant concentration (Paul and Meyer 2001, Wang *et al.* 2001, Hatt *et al.* 2004, Walsh *et al.* 2005a, Stanfield and Kilgour 2006) leading to important impacts on biological assemblages (Wang *et al.* 2000, Taylor *et al.* 2004, Bazinet *et al.* 2010, Davies *et al.* 2010).

The proportion of imperviousness within the watershed of a stream, the **total imperviousness (TI)**, has been widely used as a correlate of the impact of urbanization on stream ecosystem quality (Paul and Meyer 2001). **Effective imperviousness (EI),** which represents the proportion of the total impervious area within a watershed that is directly connected to the stream by storm water drainage pipes, has been shown to be a stronger predictor of the changes experienced by the biological community in urbanized areas of Melbourne, Australia (Taylor *et al.* 2004, Walsh *et al.* 2005a). Effective imperviousness could constitute a better predictor because direct connections of impervious cover to stormsewer pipes prevent attenuation of physico-chemical and hydrological perburtations through ground infiltration (Walsh *et al.* 2005a, Walsh and Kunapo 2009). However, the superiority of EI over TI as a correlate of ecological impact remains to be demonstrated in other regions (Morgan and Cushman 2005, Cianfrani *et al.* 2006).

The objectives of the present study were 1) to describe the response of water quality and biological assemblages along a gradient of imperviousness and to quantify thresholds; and 2) to investigate whether effective imperviousness is a better correlate of changes in abundance and composition of the biota than total imperviousness in the Ottawa region.

Methods

Study area

The study was conducted within the municipality of Ottawa-Carleton (Canada). The region covers an area of approximately 2 800 km^2 and harbours a population of more than 800 000 people (as of 2006) with a population density of 292.3 per km^2 (Statistics Canada 2011). The municipality has a humid continental climate (*Dfb*) according to the Köppen-Geiger climate classification (Kottek *et al.* 2006), which is characterized by large seasonal temperature differences, with average daily temperatures of 20.9 ºC in July and -10.8 ºC in January. Annual average precipitation is 732.0 mm rainfall and 235.7 cm snowfall (Environment Canada 2011). The region of Ottawa is located in the northern part of mixedwood plains ecozone, near the boreal shield (Natural Resources Canada 2003). This ecozone is characterized by a flat topography including a few hilly areas. The vegetation is composed predominantly of deciduous trees such as sugar maple, yellow birch, basswood, American beech, butternut and white oak, and a few coniferous evergreen species (Natural Resources Canada 2012).

The 29 studied streams ranged from order 1 to 3 and had watershed areas ranging from 0.05 km^2 to 18 km^2. The urban portion of the studied watersheds comprised open areas, single and multi-family residential sectors, commercial and industrial sectors. Final site selection aimed to cover the local range in total imperviousness and to minimize the correlation between TI and EI. Consequently, sites of similar levels of total imperviousness but having different connectivity to storm water management facilities were selected.

Imperviousness estimation

The studied watersheds were delineated using digital topographic maps and 2009 digital orthophotos (City of Ottawa 2008) and were traced as polygon shapes with a geographic information system (GIS). The upstream area that drained into each sampling site was calculated.

The proportion of total imperviousness for each stream was determined by calculating the area covered by impervious structures within the limits of the natural watersheds delineated. The proportion of impervious structures within the watersheds was determined using an ArcGIS database representing all types of impervious structures encountered in the region of the City of Ottawa (Surveys and Mapping Division, City of Ottawa 2005). Buildings, roads, driveways, parking lots, laneways, pathways, runways and sidewalks were included. The total amount of impervious surface was divided by the area of the watershed to calculate the percentage of total imperviousness of every watershed.

To estimate the effective imperviousness of each site, the storm catchments connected to every sampled stream were considered. Storm catchments, also called sewersheds, represent areas where storm water from all connected impervious are carried by storm sewers to a single stream location. By using an ArcGIS database representing the storm catchments of the city of Ottawa (Infrastructure Management Group, City of Ottawa 2009) it was possible to detect all the impervious structures connected to a particular stream location. Therefore, the effective imperviousness was calculated by considering all the areas of impervious covers within the limits of a storm catchment connected to an outfall located

upstream of every sampling site. However, because connectivity varies among the different impervious structures, the connected area of every structure type was adjusted based on the proportions of connectivity obtained from a field survey conducted in Cincinnati, USA (Roy et al. 2009) (Table 2.1). The resulting connected areas calculated for every impervious structure type were added to obtain the overall connected impervious area of every storm catchment. Finally, in order to obtain a proportion of effective imperviousness, the cumulative area of connected imperviousness was adjusted for human alterations of drainage areas.

Table 2.1: The proportion of connectivity (%) based on impervious structure type, from a field survey conducted by Roy *et al.* (2009).

Impervious structure type	Proportion of connectivity (%)
Parking	61.6
Road	89.2
Driveway	39.9
Laneway	0
Pathway	0
Building	67.0
Runway	0
Sidewalk	0

Effective imperviousness estimates were adjusted when the size of the natural watershed had been modified. Some storm catchments were exceeding the topographical limits of the natural watersheds, allowing the drainage of areas that would naturally drain in an adjacent watercourse. In fact, in certain flat areas of the city of Ottawa, the storm sewer pipes were installed with a specific slope allowing the drainage of storm water into

watercourses corresponding to different watersheds; storm sewer pipes were buried deep underground and do not always conform to the topography. Therefore, watershed area was adjusted in order to account for these regions of connected impervious areas that are drained into streams that are not corresponding to the watershed in which they are located. This variable constitutes a precise representation of the actual area drained by these urban streams which have been modified by the implementation of sewer networks. However, the added and subtracted areas referred only to the proportions of connectivity, and only the connected proportion of an impervious structure type was considered in the procedure of watershed area adjustment.

GIS database update

Because the data used in the calculation of the values of total and effective imperviousness were for 2005, the information was updated to get values representative for 2009, the year of sampling. The 2009 lot distribution of the city of Ottawa (Surveys and Mapping Division, City of Ottawa, 2009) was used to detect the presence of new developments within the limits of the studied watersheds. The values of imperviousness of 7 sites were corrected by adding the area of newly implemented streets, houses and driveways. The area of streets has been calculated directly from the lot representation database, while the areas of houses and driveways were calculated by multiplying the number of added lots with the average area of a driveway and the average area of a house. Digital orthophotos for 2009 (City of Ottawa 2008) were used to confirm the presence of impervious structure on the new lots.

Sampling protocol

Field sampling was performed in July and August 2009. Every sampling site consisted of an approximately 10 m stream section including a pool and a riffle. Sampling sites were isolated using two seine nets of 5 mm mesh size to prevent the escape of fish and crayfish during sampling.

Macroinvertebrate assemblages were sampled using the cobble method. Six cobbles were randomly collected across the riffle segment of every site and preserved with 95% ethanol in a cool and dark location. Macroinvertebrates and material attached to the cobbles were scrubbed, sieved on a 1 mm mesh size and preserved. Cobbles were then wrapped with aluminum paper to estimate their surface area from the mass of the aluminum foil required to cover the entire surface of the rock. Once sorted, the macroinvertebrates were identified to the family level using identification keys from McCafferty (1998). An empirical sieve retention model (Morin *et al.* 2004) was used to account for the loss of small macroinvertebrates through the 1 mm mesh sieve. The model calculates the probability (p) that an organism is retained in a sieve as:

$$ln(p/(1-p)) = -2.84 + 5.81log_{10}(RL) - 3.181log_{10}(RL)log_{10}(MS)$$

where RL is the body length/mesh size and MS is the mesh size (mm). Length-dry mass regressions models (Benke *et al.* 1999) were used to determine the mass of each individual invertebrate. Density and biomass values were calculated by dividing the number of individuals and the dry mass of organisms collected on each cobble by the estimated surface area of the cobble.

A Smith-Root LR-24 backpack electrofisher was used to quantitatively sample the fish assemblage that inhabited the 10 m sampling reaches. A current of 150 V to 300 V was used depending on the stream conductivity. Repeated passes were made until the number of fish caught in a single pass dropped below 50% of the number of individuals caught in the first pass. Every captured individual was identified to the species level and measured for total length, standard length, and maximum body depth. A downstream net was installed to allow the capture of the individuals missed in the shocking process. Fish density was calculated by dividing the estimated site abundance by the reach's surface area. Abundance was calculated by attrition using an R program based on fisheries stock assessment methods (FSA) (Ogle 2011). The wet mass of each individual caught was determined according to Randall and Minns (2000) or Schneider *et al.* (2000) length-weight regression models. Fish biomass was established by calculating the total dry mass by site area, assuming that fish dry mass comprised 25% of fish wet mass (Brey 2001).

After a 24 hour period of extraction and prior to the cobble scrubbing (i.e. collecting macroinvertabrates and attached material), a subsample of the ethanol from the cobble field samples was extracted for chlorophyll *a* biomass determination using the spectrophotometric technique of Ostrofsky and Rigler 1987.

Three water samples were collected at each site over the summer of 2009; July 21st, August 5th and August 18th. The physico-chemical analyses were conducted by Robert O. Pickard Environmental Center (ROPEC) laboratories (Ottawa, Ontario, Canada).

Statistical analysis

Various biological dependent variables corresponding to periphyton biomass, abundance of the 24 dominant taxonomic groups (corresponding to the identification level) of fish and invertebrates, and seven assemblage metrics (Table 2.2) were used to describe stream ecological condition along gradients of connected and unconnected imperviousness proportions. Initial examination of scatterplots of the various dependent variables as a function of the two imperviousness metrics revealed triangular distributions of observations with large variability at low imperviousness value and much less variability at the highest imperviousness values. To model these response patterns, I used a nonparametric deviance reduction approach for threshold identification. Constituting the first split of a regression tree model, this method is useful for the identification of stages of rapid changes in a response variable and determine the fit of calculated threshold (based on Akaike information criterion [AIC]). This method was characterized as accurate by Brenden *et al.* (2008) and had better fit than generalized additive models (GAM) on the dataset. The r^2 value of a one way ANOVA comparing means above and below the estimated threshold values was used to quantify the fit of the threshold model to TI and EI. Bootstrapping with 5000 iterations was used to assess the uncertainty around the thresholds identified and the values obtained from variance analysis. These statistical analyses were computed using R programs for the regression trees method (rpart) (Therneau *et al.* 2012) and the bootstrap method (Canty and Ripley 2012).

Table 2.2: Macroinvertebrate and fish assemblage metrics

Macroinvertebrate	Fish
Richness	Richness
Biomass (g/m^2)	Biomass (g/m^2)
Density ($ind./m^2$)	Density ($ind./m^2$)
Percentage of density belonging to Ephemeroptera, Plecoptera and Trichoptera (EPT) orders (%)	

All biological dependent variables were used for threshold calculations. Because aggregate community metrics can hide nonlinear responses of multiple taxa, taxonomic groups corresponding to the identification level were tested individually in order to decompose community response as suggested by King and Baker (2010). The tolerance of macroinvertebrate families calculated by Hilsenhoff (1988), was considered in the interpretation of the responses of individual taxa. However, when a family-level tolerance value was not presented in the publication, species tolerance values presented in Bode *et al.* (1996, 2002) were used to calculate an averaged family tolerance. I distinguished between positive and negative thresholds based on whether the observed density was increasing (positive threshold) or decreasing (negative threshold) in sites with total or effective imperviousness superior to the thresholds.

Results

The sampling sites covered wide ranges of watershed total and effective imperviousness proportions (Figure 2.1). Total impervioness ranged from 2.3 to 53.7% among the 29 sites whereas the range for effective imperviousness was 0 to 74% (Figure 2.1). EI was lower than TI in most sites except in 4 sites where parts of adjacent watersheds are drained by storm sewers into the studied watersheds. Despite my attempt to reduce the correlation between total and effective imperviousness by sampling watersheds with varying levels of connectivity, EI and TI were still correlated at the sampled sites ($r = 0.6$, p-value < 0.0005).

Water quality varied considerably among sampling sites with total phosphorus varying over one order of magnitude between 0.01 and 0.12 mg/L and total nitrogen varying 7 folds between 0.8 and 5.8 mg/L (Table 2.3). Ions and nutrients correlated positively, or were uncorrelated with TI and EI (Table 2.4), except for total Kjeldahl nitrogen that was significantly negatively correlated with both measures of imperviousness.

Increases in both imperviousness metrics were associated with a triangular distribution of density, biomass, taxa richness of fish and macroinvertebrate assemblages, and percent EPT density (Figure 2.2). There was considerable variability in these variables in watersheds of low imperviousness. However, as the proportion of imperviousness increased, the observed range of biological metrics narrowed until they remained uniformly low. Similar responses of the macroinvertebrate and fish assemblage biological variables were observed along gradients of total and effective imperviousness.

Thresholds of EI and TI for assemblage metrics were positively but weakly correlated, and always inferior for EI than for TI (Figure 2.3a, Table 2.5). Precision of estimated thresholds for community metrics, as estimated by the width of bootstrap confidence intervals was similar for EI and TI (Figure 2.3b, Table 2.5) except for total invertebrate density that had a much narrower threshold confidence interval for EI than for TI. Fish density and percent EPT were the assemblage metrics that varied the most clearly with differences in imperviousness and consequently had the highest r^2 for the regression tree models (Figure 2.3c, Table 2.5).

Individual taxa thresholds were often at imperviousness levels lower than the values calculated for the assemblage metrics and always lower for EI than for TI. Thresholds for Chloroperlidae, Elmidae, Philopotomatidae, Psephenidae, Heptageniidae and Tipulidae macroinvertebrate taxa were observed at approximately 14% TI and between 3 and 12% EI (Figure 2.3a, Table 2.5). In most cases, the taxa associated with the lowest thresholds had the greatest r^2 and were characterized by low tolerance values. The tolerance values of the taxa were significantly correlated with their associated threshold of total imperviousness ($r= 0.58$, $p =0.01$) but not for effective imperviousness (Figure 2.4).

In contrast, algal biomass increased with increasing proportion of total or effective imperviousness. The estimated thresholds for the response of chlorophyll *a* to imperviousness were very different whether total (threshold 24.5%, 9.5% - 26.3%) or effective imperviousness (threshold 7.7%, = 4% - 7.9%) was used (Table 2.5). Effective

imperviousness was a better predictor of algal biomass than total imperviousness as it was associated with smaller confidence intervals.

Overall, considering the width of confidence intervals and the r^2 values associated with the threshold values calculated, effective imperviousness was not a better correlate of macroinvertebrate assemblage condition than total imperviousness in the municipality of Ottawa-Carleton. The threshold confidence intervals of four of the seven biological metrics tested in this study were smaller when total imperviousness was used as the independent variable (Figure 2.3b, Table 2.5). Individual taxa threshold confidence intervals and r^2 values did not show any indication that effective imperviousness was a stronger predictor as the values were distributed evenly between the two metrics of imperviousness (Figure 2.3a, b, Table 2.5). However, r^2 values associated with the thresholds calculated for the biological metrics were higher for total imperviousness than EI for six of the seven metrics (Figure 2.3c, Table 2.5).

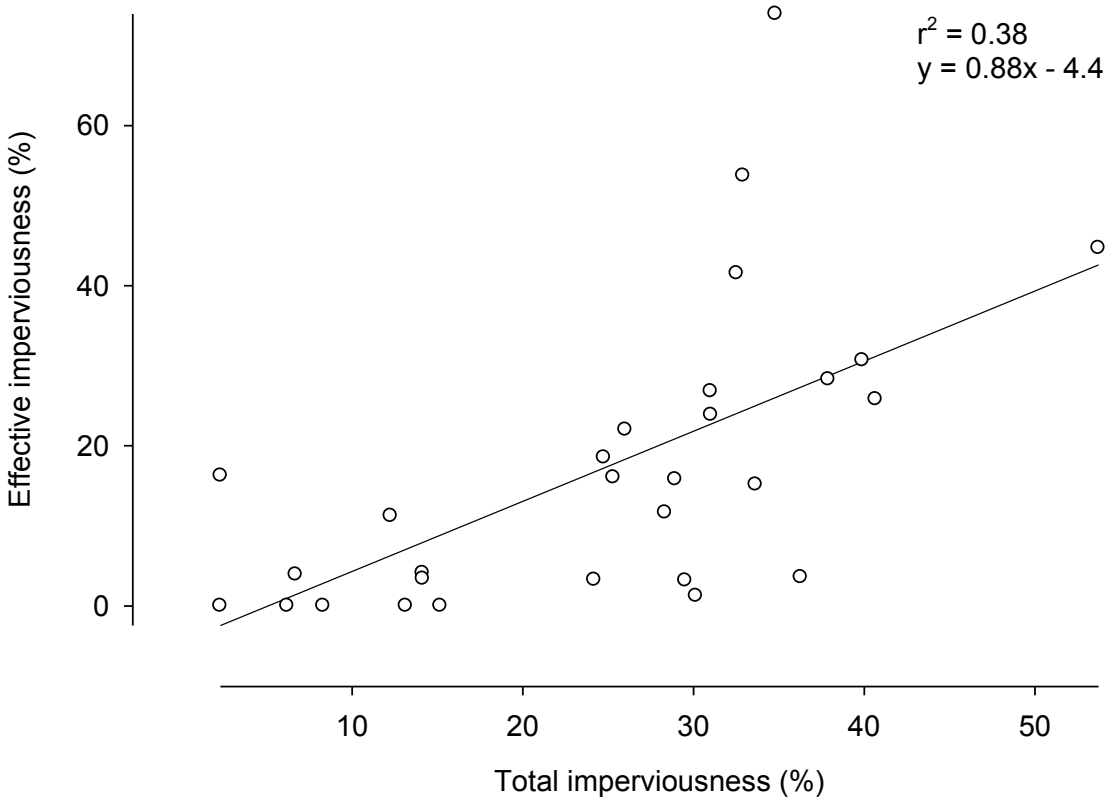

Figure 2.1: Relationship between total and effective imperviousness.

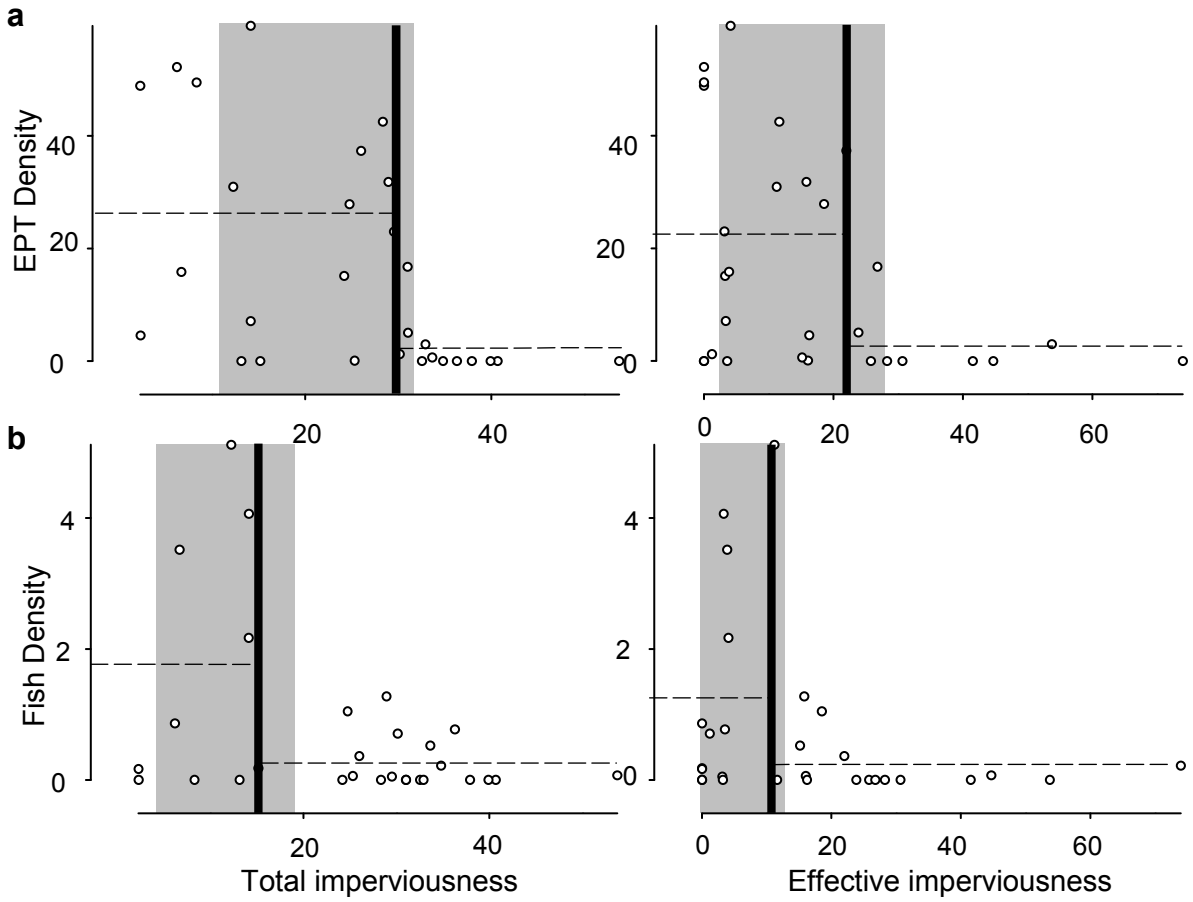

Figure 2.2: Response of a) fish density (ind./m^2) and b) macroinvertebrate density attributable to the EPT taxa along gradients of total and effective imperviousness. The threshold values estimated by regression trees (dark line), the confidence intervals estimated by bootstrap (gray zone) and the means below/above the threshold (dashed line) are presented.

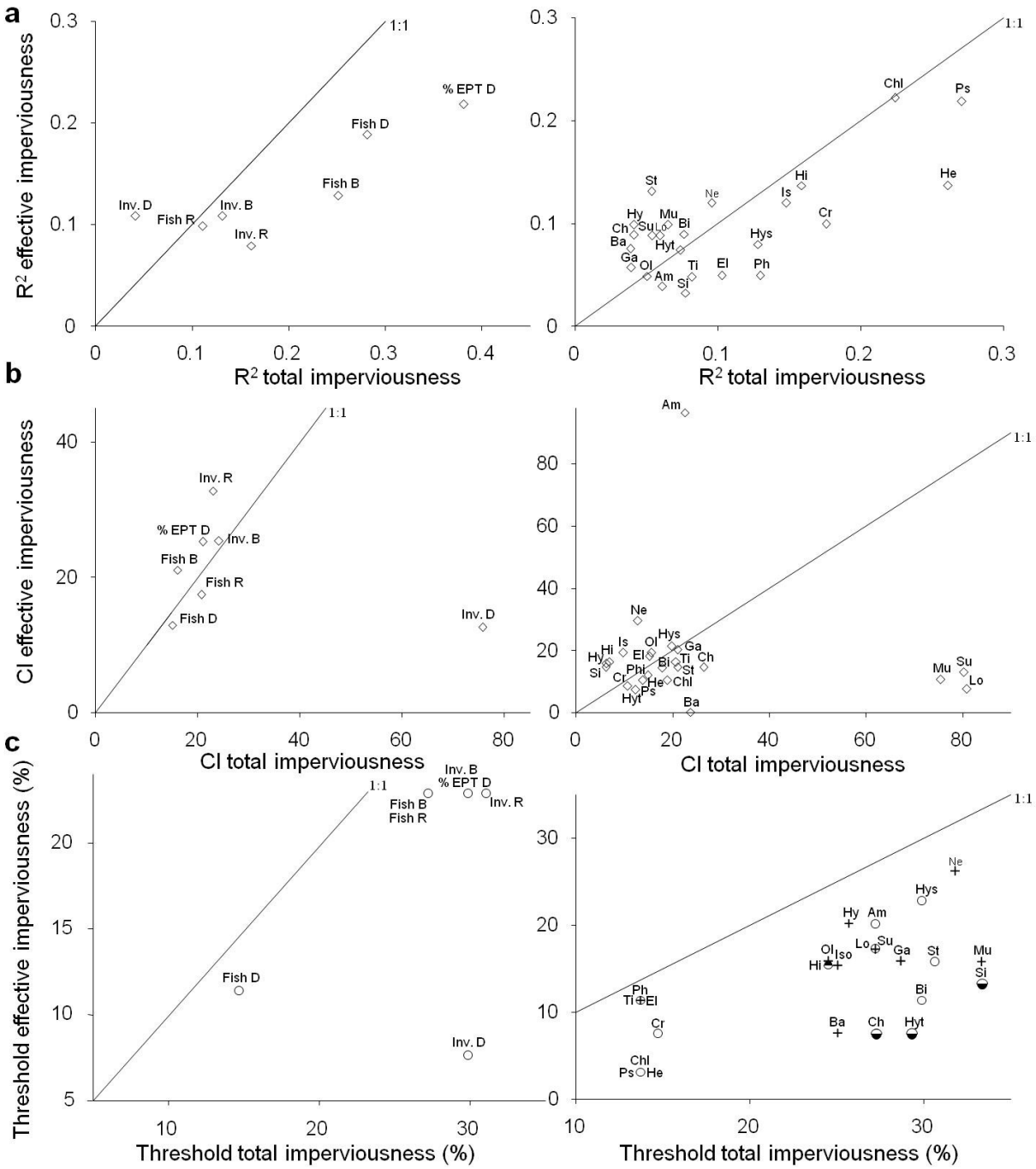

Figure 2.3: a) Threshold values for assemblage metrics and individual taxa density, b) width of confidence interval and c) r^2. Assemblage metric: fish density, Fish D; fish richness, Fish R; fish biomass, Fish B; percentage of the density attributed to the EPT taxa,% EPT D; invertebrate biomass, Inv B.; invertebrate biomass, Inv R.; invertebrate richness, Inv. R. Individual taxa: Chloroperlidae, Chl; Philopotomatidae, Ph; Psephenidae, Ps; Heptageniidae, He; Creek chub, Cr; Amphipoda, Am; Chironomidae, Ch; LongnoseDace, Lo; Hydroptilidae, Hyt; Hydropsychidae, Hys; Bivalvia, Bi; Brook stickleback, St; Simuliidae, Si; Elmidae, El; Tipulidae, Ti; Oligochaeta, Ol; Hirudinea, Hi; Rock bass, Ba; Isopoda, Is;

Hydrophiliadea, Hy; White sucker, Su; Gastropoda, Ga; Nematoda, Ne; Muscidae-Anthomyiidae, Mu. ⬭ Negative threshold (drop above threshold), ✚ positive threshold (increase above threshold), ◓ positive threshold TI / negative threshold EI, ◒ negative threshold TI / positive threshold EI.

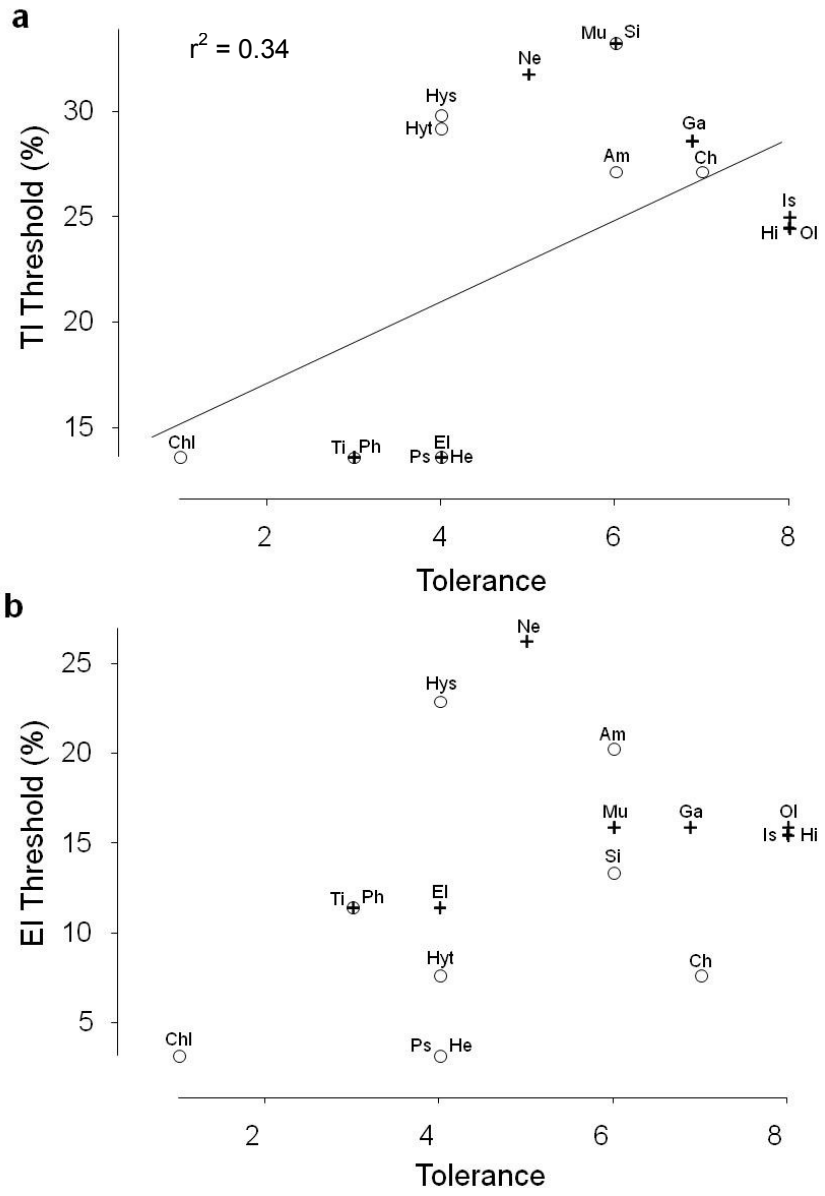

Figure 2.4: The tolerance value of the invertebrate taxa tested (Hilsenhoff *et al.* 1988, Bode *et al.* 1996, Bode *et al.* 2002) as a function of a) total imperviousness and b) effective imperviousness threshold. Positive (cross) and negative (circle) thresholds are presented. Fit to linear regression is illustrated in panel a).

Table 2.3: Watershed area, land use, total imperviousness (TI), effective imperviousness (EI), stream water chemistry (average of three measurements) and benthic chlorophyll *a*. Stream order is presented in brackets with the watershed area. The presence of industrial activity in the watershed is marked with an asterisk next to the site.

Sites	Coordinates (Latitude, longitude)	Watershed area (km2)	Natural (%)	Crop (%)	Urban (%)	TI (%)	EI (%)	Cond (µS/cm)	TP (mg/L)	TKN (mg/L)	TN (mg/L)	Chl *a* (mg/m^2)
09Gill	45°20'44.85"N, 75°41'16.27"W	6.10 (1)	29.7	0.3	70.0	30.1	1.2	893	0.03	0.47	1.4	7.73
09You*	45°27'55.47" N, 75°32'55.18" W	6.57 (3)	40.3		59.7	25.3	16.0	1536	0.03	0.48	3.0	91.96
09Ced1	45°15'44.68" N, 75°46'16.19" W	2.09 (2)	5.2	20.9	73.9	33.6	15.1	1603	0.02	0.51	4.2	36.04
09Ced2	45°16'29.80" N, 75°46'40.92" W	0.36 (1)			100.0	40.7	25.8	1913	0.01	0.26	5.8	123.52
09Watt1	45°18'50.95" N, 75°52'59.50" W	0.62 (1)	22.4	72.0	5.6	30.1	1.2	1376	0.01	0.21	3.5	17.82
09Crow	45°20'50.87" N, 75°41'39.79" W	5.37 (1)	29.9	0.2	69.8	32.5	41.5	800	0.06	0.62	1.4	19.15
09Watt2	45°18'40.76" N, 75°53'16.67" W	0.43 (1)			100.0	26.0	22.0	1453	0.02	0.40	5.7	89.86
09Watt3	45°19'37.30" N, 75°53'15.82" W	4.15 (2)	8.7	19.4	71.9	12.3	11.2	1876	0.02	0.36	2.9	113.85
09Bet1	45°19'57.22" N, 75°53'50.20" W	0.05 (1)			100.0	29.5	3.2	1696	0.04	0.43	4.3	73.49
09Bet2	45°19'57.69" N, 75°53'50.42" W	0.96 (2)	0.6		99.4	32.9	53.7	1676	0.07	0.62	3.7	75.89
09Bet3	45°19'59.34" N, 75°53'48.72" W	1.45 (2)	0.5		99.5	34.8	74.0	1483	0.09	0.72	3.3	23.42
09Mac1	45°20'55.78" N, 75°39'11.09" W	2.26 (1)	46.7		53.3	31.0	26.8	1046	0.05	0.31	1.4	1.32
09Mac2	45°20'54.39" N, 75°39'8.49" W	2.2 (1)	46.7		53.3	31.0	23.9	850	0.07	0.44	1.4	1.78
09POO1*	45°17'8.74" N, 75°54'59.92" W	18.03 (3)	58.7	6.1	35.2	14.1	4.1	923	0.03	0.80	1.4	117.40
09Blai	45°25'17.96" N, 75°35'45.72" W	0.23 (1)	12.2		87.8	14.1	3.4	2406	0.02	0.55	2.3	40.55
09Pri1	45°19'43.33" N, 75°42'3.42" W	0.56 (1)	5.6		94.4	36.3	3.6	1593	0.05	0.39	5.4	3.70
09Pri2*	45°19'59.63" N, 75°42'0.00" W	0.50 (1)	1.5		98.5	53.7	44.7	1846	0.05	0.43	2.9	43.65
09Ma*	45°19'15.16" N, 75°41'32.86" W	0.18 (1)	100.0			15.2		1420	0.12	0.57	2.9	2.36
09Jar*	45°19'6.53" N, 75°41'30.52" W	0.17 (1)	85.4	14.6		13.1		1206	0.06	0.60	1.4	6.04
09Rid*	45°18'44.72" N, 75°41'39.25" W	0.42 (2)	55.9	43.5	0.6	2.3		970	0.07	0.82	2.2	9.45
09Bil1*	45°27'41.75" N, 75°30'13.77" W	1.10 (2)	13.9	14.5	71.6	28.9	15.8	1220	0.05	0.71	1.7	99.13
09Bil2	45°27'44.44" N, 75°30'12.54" W	1.18 (2)	16.7	4.0	79.3	28.3	11.6	1710	0.05	0.64	2.3	46.21
09Her1	45°27'8.66" N, 75°32'11.81" W	0.39 (1)	2.3		97.7	37.9	28.3	1496	0.03	0.47	2.7	0.91
09Her2	45°27'18.73" N, 75°32'6.00" W	0.81 (1)	3.1		96.9	39.9	30.7	1563	0.03	0.49	3.4	66.26
09Fau	45°31'8.53" N, 75°24'23.01" W	0.32 (1)	25.2		74.8	24.2	3.2	2400	0.23	0.49	3.6	19.90
09Qui1	45°30'40.67" N, 75°25'28.57" W	2.41 (3)	44.6	22.1	33.2	6.2		820	0.10	0.68	1.2	9.71
09Qui2	45°30'39.72" N, 75°25'28.63" W	0.52 (2)	32.5	8.9	58.7	8.3		740	0.04	0.47	0.8	20.12
09Mer	45°25'32.55" N, 75°29'24.14" W	0.96 (2)	85.0	15.0		6.7	3.9	760	0.05	0.72	3.6	3.19
09SAWD	45°23'21.38" N, 75°40'29.72" W	19.98 (3)	35.5	1.2	63.3	24.8	18.5	1532	0.08	n/a	1.7	94.73

Table 2.4: Correlation coefficients between water quality variables and total or effective imperviousness (p≤ 0.05, * ; p≤ 0.01, ** ; p≤ 0.001, ***). P-value is presented in brackets.

	Total imperviousness		Effective imperviousness	
	(%)	p-value	(%)	p-value
Alkalinity	0.68***	7.005e-05	0.47 **	0.01
Magnesium	0.63***	0.0003	0.40 *	0.04
Calcium	0.62 ***	0.0005	0.58 ***	0.001
Conductivity	0.60 ***	0.0008	0.57 **	0.002
Nitrite	0.58***	0.001	0.52 **	0.005
Sodium	0.51**	0.006	0.51 **	0.006
Chloride	0.51**	0.006	0.50 **	0.006
Nitrate	0.48 **	0.01	0.46 **	0.01
Total nitrogen	0.47 **	0.01	0.45 *	0.02
Total Kjeldahl nitrogen	-0.49 **	0.008	-0.55 **	0.002
Sulphate	0.37 *	0.05	0.43 *	0.02
Potassium	0.26	0.18	0.11	0.58
Silicon	0.22	0.27	0.2	0.31
Total phosphorus	-0.19	0.33	-0.35	0.068
Ammonia/ammonium	-0.19	0.34	-0.05	0.81
Reactive phosphorus	-0.13	0.49	-0.23	0.24
pH	0.01	0.95	-0.14	0.46

Table 2.5: The threshold values and their associated r^2 calculated for the biological metrics and individual taxa density (ind./m^2). Bold values are showing the smallest intervals of confidence when comparing between total and effective imperviousness.

	Total imperviousness (%)				Effective imperviousness (%)			
	Threshold	**I.C**	**r^2**	**I.C**	**Threshold**	**I.C**	**r^2**	**I.C**
Inv. Density (ind./m^2)	29.83	24.47, 100.00	0.04	**0.00, 0.07**	7.66	**0.61, 13.39**	0.11	0.03, 0.22
Inv. Biomass (g/m^2)	29.83	**10.29, 34.22**	0.13	0.03, 0.25	22.92	3.20, 28.73	0.11	**0.02, 0.18**
Inv. Richness	31.02	**9.48, 32.32**	0.16	0.04, 0.35	22.92	3.2, 36.1	0.08	**0.01, 0.17**
% EPT Density	29.83	**10.73, 31.58**	0.38	0.12, 0.58	22.92	3.31, 28.73	0.22	**0.03, 0.41**
Fish Density(ind./m^2)	14.66	4.25, 19.17	0.28	0.08, 0.63	11.43	**0.61, 13.63**	0.19	**0.07, 0.37**
Fish Biomass(g/m^2)	27.17	**14.66, 30.58**	0.25	0.06, 0.46	22.92	4.00, 25.14	0.13	**0.02, 0.24**
Fish Richness	27.17	12.71, 33.28	0.11	0.02, 0.26	22.92	**7.56, 25.14**	0.10	**0.02, 0.19**
Chlorophyll *a* (mg /m^2)	24.47	9.48, 26.26	0.22	**0.02, 0.48**	7.66	**4.00, 7.87**	0.52	0.19, 0.72
Amphipoda	27.17	**7.51, 29.83**	0.06	0.00, 0.12	20.26	3.20, 100	0.04	**0, 0.06**
Elmidae	14.66	**6.45, 19.17**	0.13	0.00, 0.35	3.47	0.61, 3.47	0.10	**0, 0.24**
Hydrophiliadea	25.66	**19.58, 25.66**	0.04	**0.00, 0.11**	20.26	10.07, 26.29	0.10	0, 0.26
Psephenidae	13.65	6.45, 19.96	0.27	**0.11, 0.83**	3.20	**0.61, 11.43**	0.22	0, 0.82
Chironomidae	27.17	12.71, 38.90	0.04	**0.00, 0.06**	7.66	**0.61, 15.60**	0.09	0.02, 0.17
Muscidae-Anthomyiidae	33.28	24.75, 100	0.06	**0.00, 0.15**	15.92	**7.87, 18.90**	0.10	0, 0.22
Heptageniidae	13.65	6.45, 19.96	0.26	0.09 0.65	3.20	**0.614, 11.43**	0.14	**0, 0.40**
Gastropoda	28.64	9.48, 30.27	0.04	0, 0.05	15.92	**2.19, 22.92**	0.06	**0.01, 0.1**
Hirudinea	24.47	**18.51, 25.10**	0.16	**0.07, 0.27**	15.48	0.61, 17.39	0.14	0.04, 0.32
Isopoda	25.03	**15.93, 25.38**	0.15	**0.05, 0.29**	15.48	0.61, 20.26	0.12	0.04, 0.29
Oligochaeta	24.47	**10.29, 25.66**	0.05	**0.03, 0.07**	15.92	0.61, 20.26	0.05	0, 0.09
Chloroperlidae	13.65	6.45, 25.10	0.22	**0, 0.65**	3.20	**0.61, 11.43**	0.22	0, 0.66
Bivalvia	29.83	12.71, 30.27	0.08	**0.03, 0.16**	11.43	**0.61, 15.48**	0.09	0.03, 0.22
Simuliidae	33.28	**29.83, 36.77**	0.07	0.04, 0.20	13.39	0.61, 15.92	0.03	**0.02, 0.03**
Hydropsychidae	29.83	**10.73, 30.26**	0.13	0.04, 0.24	22.92	3.31, 25.14	0.08	**0.01, 0.14**
Hydroptilidae	29.23	19.96, 31.96	0.07	**0.03, 0.14**	7.66	**2.19, 9.95**	0.08	0, 0.12
Philopotomatidae	13.65	10.73, 25.38	0.13	0, 0.50	11.43	**0.61, 13.19**	0.05	**0, 0.15**
Nematoda	31.78	**25.66, 38.09**	0.09	**0.01, 0.21**	26.29	7.66, 37.68	0.12	0.03, 0.41
Tipulidae	13.65	9.48, 29.83	0.08	0.04, 0.22	11.43	**0.61, 17.39**	0.05	**0, 0.09**
Creek chub	14.66	4.25, 14.66	0.18	0.06, 0.44	7.66	**0.61, 9.63**	0.10	**0.03, 0.26**
Brook stickleback	30.58	14.14, 34.96	0.05	**0.01, 0.08**	15.92	**2.19, 17.17**	0.13	0.05, 0.26
White sucker	27.17	19.96, 100	0.05	**0, 0.11**	17.39	**9.52, 22.92**	0.09	0, 0.25
Longnose Dace	27.17	19.45, 100	0.06	**0, 0.16**	17.39	**11.05, 19.02**	0.09	0, 0.26
Rock bass	25.03	9.23, 32.72	0.04	0, 0.08	7.66	**7.19, 7.66**	0.08	**0, 0.19**

Discussion

Storm sewers are designed and installed to control the risk of floods in regions with reduced ground water absorption because of impervious surfaces (Ellis and Marsalek 1996, Gomez-Valentin *et al.* 2009). It is therefore not surprising that I could not completely eliminate the correlation between TI and EI in my dataset as connectivity of impervious surfaces with storm sewers is constrained in urbanized sectors of the study region. Surprisingly, other studies on the impact of connected impervious covers in Australia (Taylor *et al.* 2004, Walsh *et al.* 2005a) did not report similar positive correlations between TI and EI. Connectivity of impervious surfaces therefore varies geographically.

However, as observed in many other geographical regions (Paul and Meyer 2001, Brabec *et al.* 2002, Shuster *et al.* 2005, Schueler *et al.* 2009), stream biological condition was clearly affected by watershed imperviousness. Based on macroinvertebrate and fish assemblages, sites draining watersheds of low imperviousness had biological conditions ranging from minimally altered to impacted (i.e. low values in dependent biological variables). However, with the increase of impervious cover proportion, the best attainable condition declined until only degraded conditions were observed. This triangular relationship was reported in several other studies and suggests that factors other than impervious cover explain variation in assemblage metrics at low levels of urbanization (Karr and Chu 2000, Wang *et al.* 2001, Booth *et al.* 2004, Stanfield and Kilgour 2006, Schueler *et al.* 2009).

Uniformly low biological condition was observed above 29% TI and 23% EI. These threshold values for assemblage metrics (fish and invertebrate density, biomass, and taxa

richness; percent EPT) correspond to extirpation thresholds as described by Hilderbrand *et al.* beyond which the taxa disappear. (2010). Sensitive taxa started to respond at lower levels of imperviousness with an observed decline around 13.7% TI and 3.2% EI. This biological response corresponds to an initiation-of-impact threshold representing the level at which degradation first occurs (Hilderbrand *et al.* 2010). Metrics representing the general condition of fish or macroinvertebrate assemblages did not respond to small changes of imperviousness as sensitive taxa did. This observation is in agreement with the findings of Baker and King (2010) that important changes in community structure can be difficult to detect using summary metrics.

Thresholds calculated for the municipality of Ottawa-Carleton are within the ranges of published threshold values. Reported extirpation thresholds vary between 20% and 33% of impervious cover (Arnold and Gibbons 1996, Klein 1979, Yoder *et al.* 1999, Morse *et al.* 2003, Schueler *et al.* 2009) while reported initiation-of-impact thresholds vary between 1% and 18% (Klein 1979, Schueler and Galli 1992, Horner *et al.* 1997, Kennen and Ayers 2002, Morse *et al.* 2003, Ourso and Frenzel 2003, Coles *et al.* 2004, Fitzpatrick *et al.* 2004, Deacon *et al.* 2005, Snyder *et al.* 2005, Walsh *et al.* 2005a, CT Department of Environmental Protection 2007, Baker and King 2010).

It is unlikely that the calculation of thresholds of imperviousness could have been considerably affected by confounding sources of disturbance. Although six of the studied watersheds had high proportions of agricultural lands (> 40%) that could have caused stream impairment (Appendix B), the addition of percentage of agricultural land to the models did

not improve the predictions significantly. Industrial zones were also found within the studied watersheds, pointing to the potential contribution of contaminated effluents to stream degradation (Appendix B). However, the examination of the biological condition of the sites that were identified has being potentially contaminated with industrial effluents did not show evidence of greater ecological alterations. These sites expressed conditions that were similar to those observed for similar levels of imperviousness, indicating that industrial effluents were not likely an important source of confounding variability.

Moreover, it is also unlikely that the use of proportions of connectivity from a field survey conducted in Ottawa rather than Cincinnati would have changed qualitatively our results. Cincinnati is subjected to similar levels of precipitations to those in the Ottawa-Carleton municipality during the summer, and the urban development of Shepherd creek watershed, the area where the land survey was conducted, also presents a configuration very similar to the developed areas of the city of Ottawa. Moreover, although the topography of the region of Ottawa is slightly flat compared to the Shepherd creek watershed, topography is not different enough to induce significant differences in storm sewer configuration. Therefore, based on similarities of precipitation, configuration of developed areas and topography, it is unlikely that the proportions of connectivity differ significantly between the two cities.

Effective imperviousness was a better predictor of the increase in algal biomass than total imperviousness, as reported by Taylor *et al.* (2004). Urban runoff is associated with increased levels of conductivity and nutrients (Griffin *et al.* 1980, Carpenter *et al.* 1998,

Ometo *et al.* 2000, Winter and Duthie 2000, Brabec *et al.* 2002, Bedan and Clausen 2009, Cunningham *et al.* 2009) and storm sewers connecting impervious surfaces directly to streams prevent attenuation of nutrients or pollutant concentration through ground infiltration (Taylor *et al.* 2004, Walsh and Kanupo 2009).

Contrastingly, total and effective imperviousness constituted similar correlates of the variation in macroinvertebrate and fish assemblages in the municipality of Ottawa-Carleton (Canada). These results differ from those Walsh *et al.* (2005a) obtained in the temperate region of Victoria, Australia (the city of Melbourne and the sub-urban region of Dandenong ranges). Walsh *et al.* (2005a) showed that, in their study region, EI was a much stronger correlate of urban impact on macroinvertebrate assemblages and other ecological indicators (i.e. water-quality, algal biomass, diatoms). It seems unlikely that the correlation observed between total and effective imperviousness in the region of Ottawa would completely account for the contrast between the two regions. Differences in 1) runoff regime; 2) geology; and, 3) topography, between the area studied by Walsh *et al.* (2005a) and Ottawa, explain why the predictive value of EI varies between the two regions.

Climatic and vegetation differences could explain why EI is a much better correlate than TI in Australia around Melbourne but not in Ottawa. Australia has higher annual runoff variability than other continents within the same Köppen climate zones, due to the high regional potential evapotranspiration and variability in annual precipitation (McMahon *et al.* 1992, Peel *et al.* 2001, Peel *et al.* 2004). Temporal variability in water availability has also favored the emergence of traits allowing native plants to maximize capture of water when

available and decreasing considerably the runoff following rainfall (McMahon *et al.* 1992). For instance, the most species rich taxa of Australia, *Eucalyptus* and *Acacia* (Groves 1994), have developed root configurations and/or water potentials which allow adaptive use of the water resources as it fluctuates (Tunscall and Connor 1981, Calder *et al.* 1997, Whitehead and Beadle 2004). Moreover, evergreen tree forests present in the temperate regions of the Southern hemisphere are associated with higher evapotranspiration rates which also contribute to the decrease of runoff compared to temperate deciduous forests of the Northern hemisphere (Peel *et al.* 2001, Peel *et al.* 2004) receiving similar amounts of rainfall. Australian native vegetation is likely able to retain a higher proportion of rainfall (and hence reduce runoff) compared to the vegetation in the region of Ottawa where such plant adaptations are absent (McMahon *et al.* 1992). Therefore, the runoff coefficient of Australian catchments is only 40% of catchments in other regions of the world due to the combined effects of evapotranspiration, precipitation variability and vegetation (McMahon *et al.* 1992). Hydraulic and water-quality effects of urban runoff from unconnected impervious surfaces are likely more mitigated by higher rates of infiltration and retention in Australia than in Ottawa. On the other hand, hydrological and water quality effects of urban runoff from connected impervious surfaces which are conveyed through storm sewer pipes are less influenced by inherent properties of natural hydrological regimes (Walsh and Kunapo 2009).

Geological characteristics of the Ottawa-Carleton municipality contribute to high runoff and may also explain why EI is not superior to TI as a correlate of biological condition. The soil of the Ottawa-Carleton region is naturally poorly drained as a high

proportion of the surficial material is Paleozoic bedrock and marine clay deposits; especially in the suburban area (Schut and Wilson 1987). Because of this, even when covered by native vegetation, a large fraction of rainfall on land runs off into streams. Therefore, as storm water runoff is exposed to low levels of ground infiltration and retention, impacts from unconnected impervious covers are less likely to be attenuated.

Difference in the topographical characteristics between the two regions of study could also explain why effective imperviousness does not constitute a better predictor of stream impairment around Ottawa relative to the Melbourne urban area and Dandenong ranges sub-urban area of Victoria, Australia (Walsh *et al.* 2005a). It has been shown that the impact of impervious surfaces on stream hydrological regime is lower when unconnected impervious covers are created on hillslope landscapes (Sung and Li 2010). This topographic setting is characteristic of the Dandenong ranges, a sub-urban area including 12 of the 15 watersheds sampled by Walsh and his colleagues. The development of urban area in hillslope settings is associated with land grading to allow the construction of buildings and paths on steep topographical settings. Urban development is therefore associated with the conversion to stair-stepped landscapes as impervious structures are implemented. Since runoff penetrates more easily the exposed ground of the tread portion of the stairs as opposed to the steep natural slope, this topographical change has the effect of increasing rates of stormwater infiltration (Sung and Li 2010). On the other hand, stormwater impact from connected imperviousness does not differ between topographical settings as runoff is carried directly to the streams without any ground attenuation. Therefore, in steep topographical settings, the effect of adding impervious cover is counteracted by the landscape changes with

which it is associated. As this effect is absent on the flat watersheds of the city of Ottawa, this could explain the why EI is not superior to TI as a correlate of biological condition.

In addition to the similarity of total and effective imperviousness as predictors of stream impairment, unexplained variability observed in the present study is much higher than what was reported by Walsh *et al.* (2005a). Large ranges of biological conditions are observed for fixed levels of watershed TI and EI in the region of Ottawa, especially at low levels of urbanization, and thresholds are associated with low r^2 values. This high variability could be explained by the size of sampled watersheds and pre-development land use.

Size of sampled watersheds may have contributed to the high variability of the biological conditions observed as spatial variability of hydrological regimes is known to decrease with watershed size. Published studies have reported large ranges of hydrological conditions in watersheds smaller than 1 km^2 (approximately) as differences in topography, soil and rainfall have a larger impact on hydrological regimes at such small scales (Wood *et al.* 1988, Asano and Uchida 2010). Fifty five percent of the sites sampled in this study had a watershed smaller than 1 km^2. Therefore, hydrological variability among sites with similar EI or TI could have partially obscured the signal of imperviousness in small watersheds. In contrast, using CPCe software, I calculated approximate areas from visual representations, of the watersheds sampled in Walsh *et al.* (2005a); all larger than 1 km^2 (i.e. 1.9 - 16.3 km^2)

The high variability of the biological conditions observed in the region of Ottawa in relation to watershed imperviousness could also be attributed in part to the pre-development

land use of the region as 23.8% of the total area covered by the studied watersheds was previously used for agriculture, as compared to 6% in 2009. The presence of agricultural activities prior to urbanization in some of the studied watersheds could be responsible for biological conditions lower than the level expected for a given proportion of watershed imperviousness. As these ecosystems were already altered before the implementation of urban development, urban ecological impacts are confounded with the effect of agricultural activities (Wenger 2009). This type of additional impairment from historical land use was also reported by Fitzpatrick *et al.* (2004) and Brown *et al.* (2009).

In summary, this study revealed that effective imperviousness is not superior to total imperviousness as a predictor of biological condition in the Ottawa-Carleton municipality. The laborious calculation of effective imperviousness is therefore avoidable in this region because EI and TI have similar predictive power. However, similar studies should be conducted in other geographic areas before considering total imperviousness as the best proxy of catchment urbanization. Regions with different runoff regime, geology and topography should be targeted as further investigations of the effects of these regional factors are necessary to better understand how geographical difference in the relative predictive power of total and effective imperviousness are induced.

Chapter 3 — Effects of Watershed Size, Land Use, Water Quality, and Periphyton Biomass on Size Spectra of Stream Macroinvertebrate and Fish Assemblages

Abstract

Stream ecosystems are sensitive to characteristics of their catchments. To describe how the structure of stream metazoan assemblages vary with land use perturbations and site characteristics, size spectra attributes (i.e. slopes, intercepts, number of logarithmic size classes occupied, and residual variance) were used as descriptors of macroinvertebrate and fish assemblages. The size spectrum of stream macroinvertebrate and fish collected on 129 sampling events in the Ottawa-Gatineau region were analyzed in relation to site benthic chlorophyll *a*, total phosphorus, total nitrogen, conductivity, watershed area and watershed land use. Stream size spectra were characterized by: 1) higher densities in the larger size classes mostly occupied by fish compared to abundance-body size distributions of other ecosystem types (e.g. lakes, oceans, soils, coastal waters); 2) a larger increase of small organisms' density than of larger organisms in response to an increase in periphyton biomass (chlorophyll *a*); and, 3) an increase in overall size corrected densities and number of size classes with increasing watershed area and periphyton biomass. Moreover, linear size spectra of undisturbed watersheds were associated with statistically significant, but small, reduction in residual variation. This study showed how macroinvertebrate and fish assemblages vary along naturally and human generated environmental gradients and help better understand ecosystems structural changes resulting from land use perturbations.

Introduction

Current understanding of ecological assemblages relies greatly on traditional taxon-based methodologies focusing on specific taxonomic groups and is therefore restricted to the study of a limited portion of the organisms present in a system (Cyr *et al.* 1997a). In order to better understand how local environmental conditions affect structure of ecological systems as a whole, there is a need for a multi-trophic approach integrating many aspects of assemblages' ecological properties. As body size is correlated with many fundamental ecological traits (e.g., diet breadth, trophic status, abundance, richness) (Woodward *et al.* 2005), ecosystem descriptions based on size distributions have great potential for improving our comprehension of ecosystem trophic structure and underlying energetic transfers (Kerr and Dickie, 2001). Size spectra provide useful quantitative descriptions of communities and biological assemblages by plotting density (or biomass) of individuals, irrespective of their taxonomy, as a function of their body size.

Size spectra quantified as log-density versus log-body size relationships are remarkably similar among systems (Kerr and Dickie, 2001). The slope of the spectra approximate -1 in many different ecosystems (lakes: Sprules and Munawar 1986, Ahrens and Peters 1991; streams: Morin and Nadon 1991; oceans: Gaedke 1992, Jennings and Mackinson, 2003; soils: Mulder *et al.* 2009; coastal waters: Huete-Ortega *et al.* 2010). However, although the general shape of the size spectrum is similar among systems, size spectra parameters (i.e. slopes, intercepts, number of size classes and residual variance) vary slightly with local environmental conditions (Rasmussen 1993, Bourassa and Morin 1995, Cyr *et al.* 1997a, Kerr and Dickie, 2001, Mulder *et al.* 2009, Huete-Ortega *et al.* 2010,

DeNichola *et al.* 2006, Emmrich *et al.* 2011). Several studies showed that shifts in the structure of perturbed ecosystems are reflected in size spectra attributes (Sprules and Munawar 1986, Cyr and Peters 1996, Rice and Gislason 1996, Cottingham 1999, deBruyn *et al.* 2002, Quintana *et al.* 2002, Yvon-Durocher *et al.* 2008). For instance, size spectra slopes reflect declining energy transfer efficiency of a system as perturbations increase; intercepts of spectra with equivalent slopes provide an estimate of relative abundance; and, the residual variability around the linear spectra is proportional to system perturbation (Sprules and Munawar 1986, Sprules *et al.* 1988).

Slight systematic variations of stream size spectra attributes in relation to environmental conditions, such as season, enrichment, periphyton, substrate, and predation, have been detected in previous studies (Morin and Nadon 1991, Morin *et al.* 1995, Bourassa and Morin 1995, Solimini *et al.* 2001, Knouft 2002, Cattaneo 1993). However, most of these results were observed over relatively small numbers of sites and as data accumulate, it becomes now possible to describe more general patterns. In this study, variations in size spectra attributes (i.e. slopes, intercepts, number of size classes and residual variance) were used as structural descriptors of stream multi-trophic assemblages collected on 129 sampling events to describe how these assemblages vary with watershed size, land use, water quality, and periphyton biomass.

Methods

Study area

Data were gathered from five studies (Morin [unpublished data 2003], Stephenson 2007, Lento 2010, Hamilton 2010, Duhaime 2012 [chapter 2]) conducted between 2001 and 2009 in Ottawa (Ontario, Canada), Gatineau (Quebec, Canada), and the surrounding area. In total, there were 89 sampling sites that represented a wide range of land cover proportions from natural land cover in Gatineau Park to mostly urbanized and agricultural catchments (Appendix A). Some of these sampling locations were visited on multiple occasions, resulting in a total of 129 sampling events where periphyton, macroinvertebrates and fish were sampled.

Sampling protocol

Sampling sites consisted of approximately 10 m stream segments including a pool and a riffle. Sampling sites were isolated using two seine nets of 5 mm mesh size to prevent the escape of fish during sampling.

Macroinvertebrate assemblages were sampled by randomly collecting six cobbles across the riffle segment of every site. Cobbles were preserved with 95% ethanol and kept in a cool and dark location. Macroinvertebrates and material attached to the cobbles were scrubbed, sieved on a 1 mm mesh and preserved for later sorting. Cobbles were then wrapped with aluminum paper without overlapping in order to measure the surface area of each cobble, which was estimated from the mass of the aluminum foil required to cover its entire surface. Once sorted, the macroinvertebrates were identified to the family level using

identification keys from McCafferty (1998). A sieve retention model (Morin *et al.* 2004) was used to account for the loss of small macroinvertebrates through the 1 mm mesh sieve. The model calculates the probability (p) that an organism is retained in a sieve as:

$$ln(p/(1-p)) = -2.84 + 5.81log_{10}(RL) - 3.181log_{10}(RL)log_{10}(MS) \quad (1)$$

Where *RL* is the body length/mesh size and *MS* is the mesh size (mm). Length-dry mass regressions models (Benke *et al.* 1999) were used to determine the mass of each individual invertebrate. Density and biomass values were calculated by dividing the number of individuals and the dry mass of organisms collected on each cobble by the estimated surface area of the cobble.

A Smith-Root LR-24 backpack electrofisher was used to quantitatively sample fish assemblages that inhabited the 10 m sampling reaches. Current of 150 V to 300 V was used depending on stream conductivity. Repeated passes were made until the number of fish caught in a single pass dropped below 50% of the number of individuals caught in the first pass. A downstream net was installed to allow the capture of the individuals missed in the shocking process. Fish were identified to the species level and measured for total length, standard length, and maximum body depth. Fish density was calculated by dividing the estimated site abundance by the reach's surface area. Abundance was calculated by attrition using an R program based on fisheries stock assessment methods (FSA) (Ogle 2011).

After a 24 hours period of extraction and prior to the cobble scrubbing (i.e. collecting macroinvertabrates and attached material), a subset of the ethanol from the cobble field samples was extracted for benthic chlorophyll *a* biomass determination. A

spectrophotometric technique was used to obtain an index of periphyton standing stock (Ostrofsky and Rigler 1987).

To allow the comparison of algal, macroinvertebrate and fish density among sites for the planar area of the 10 m sampling transects, algal and macroinvertebrate density were adjusted to account for the average amount of cobble area per stream area unit. This correction consisted of multiplying macroinvertebrate density and biomass, and periphyton chl *a* by a correction factor (3.3) representing the average ratio of cobble total surface area per planar area of stream bottom (SD=1.2). This correction factor was obtained by averaging the ratio calculated for 27 sampling events.

Statistical analysis

A size spectrum was constructed for each sampling event by grouping collected organisms into $\log_2$ size classes based on dry mass. The size spectra were plotted as $\log_{10}$ density (ind./m^2) against $\log_{10}$ average mass (μg) for each size class.

Special consideration had to me made for empty size classes (density equal to zero) given our use of log transformations. Empty size classes for a given sampling event could result from true absences, but it is likely that some organisms were missed in the sampling process because their density was below our detection imit. Blind elimination of all empty size classes for the statistical analyses would have led to biased models. To account for the detection limits of the study design, size class density was adjusted by adding density value corresponding to half the detection limit for each size class before log transformation.

Detection limits for areal density were calculated as 1 individual for the average area sampled at each sampling event to collect macroinvertebrates and fish. Macroinvertebrate detection limits were further adjusted to account for sieve retention probability. This additional correction accounted for the higher probability of retaining larger individuals through a sieve. Small macroinvertebrates therefore had higher overall detection limit compared to larger individuals. Fish and macroinvertebrates detection limits were calculated as:

Fish detection limit: $1 / A_f$ (2)

Macroinvertebrates detection limit: $1 / (p^* A_m)$ (3)

Where A_f is the sampled reach area, A_m is the mean area sampled for macroinvertebrates at every sampling event and p the average sieve retention probability of the size class.

Statistical comparisons of size spectra among sites were made using mixed effects modeling techniques as implemented in the nlme R package (Pinheiro *et al.* 2009) following the model selection approach advocated by Zuur *et al.* (2009). Mixed models tested included various physicochemical variables and watershed characteristics used as covariates of size-corrected density. The log density in each *i* size class in each *j* site was the dependent variable. A saturated model including the fixed effect of log body mass, log covariates and interactions was first fitted tentatively to allow selection of the appropriate random terms represented by random effects intercepts and slopes and appropriate variance structure for the residuals. Saturated models were of the form:

$$Log\ (Density)_{ij} = \alpha + b_j + \beta\, log(M) + c_j\, (logM) + \Sigma\gamma_k\, log(covariates) + \Sigma\phi_k\, log(M)\, log(covariates) + \varepsilon_{ij} \quad (3)$$

where $\varepsilon_{ij} \sim N(0, \sigma^2_{group})$.

In these models, α represents the average intercept; β represents the fixed effect coefficients for mass, γ_k the fixed effect coefficients for each of the k covariates, ϕ_k the fixed effect coefficients for each of the k first order interactions between mass and the covariates (allowing me to detect linear changes of the size spectra slope with a change in the covariates) respectively, b_j represents the random intercept and c_j the random slope of the size spectra for the each of the j sampling events, and σ^2_{group} allowed residual variance to vary among streams draining mostly pristine and developed watersheds. The best mixed model predicting variation in size class density corrected for size was determined using MuMin R package (Bartòn 2012). This R function, based on multi-model inference, allows model selection and model averaging based on information criteria (AIC). An additional multi-model inference analysis was used to assess interactions between covariates.

The number of size classes containing organisms at each sampling event (n= 129) was used to determine whether the number of non-empty size classes (equivalent to size class richness) was varying with the covariates. The variables explaining most of the variation in number of size classes among sampling events were determined using MuMin R package (Bartòn 2012).

Total phosphorus (TP, mg/L), total nitrogen (TN, mg/L), and conductivity (COND, µS/cm) were the water quality variables used as covariates. Two to three water samples were generally collected at each site over the summer on years when the biological assemblages were sampled and averaged to get more accurate estimates of the average water chemistry conditions throughout the sampling season. Water samples were analyzed at the Robert O. Pickard Environmental Center (ROPEC) laboratories (Ottawa, Ontario, Canada) using standard protocols. In cases where data were missing for a site at a particular sampling event, the data corresponding to the closest sampling period were used.

The determination of the watershed characteristics, used as potential predicting factors, required the use of a digitized land cover map (Government of Canada 2009) which was reorganized into 3 major land use classes; natural, agricultural and developed lands. Land use proportions of every watershed were calculated by dividing the area of each major land use class present within the watershed by its total area. The watersheds were delineated using 2009 digital orthophotos (City of Ottawa 2008), digital elevation models (DEM) (City of Ottawa 1988) and/or geospatial database representing the boundaries of the major watersheds of the region (Ontario Ministry of Natural Resources 2002). A geographic information system (GIS) was used to trace watersheds as polygon shapes for each studied stream (GIS Branch, IT services, Corporate Services, City of Ottawa. 2002), and to compute its area.

Results

The size spectra, as described by simple linear regressions for each sampling event, were visually similar although intercepts and slopes varied (Figure 3.1 and 3.2a). Intercepts ranged from 2.8 to 5.8 (mean= 3.82, SD= 0.58) and slopes from -1.05 to -0.34 (mean= -0.66, SD= 0.11) (Figure 3.2b). r^2 values ranged between 0.48 and 0.93; with 85% of r^2 values being equal to or larger than 0.75 (Figure 3.2c).

The detection limits were clearly apparent on the scatter plot of all observations (Figure 3.2d). The concentration of points at the minimum density value for each size class reflected adjusted densities for empty size classes. Densities were also more variable in size classes with $\log_{10}$ Mass ranging between 5.6 and 7.7 (µg), which contained fish, compared to smaller size classes with $\log_{10}$ Mass ranging between -0.7 and 5.3 (µg).

Among the covariate values quantified (Table 3.1), the regression model including mass, watershed area and periphyton biomass (benthic chlorophyll *a*) best fitted observed densities per size class. These three variables were the only covariates having significant effects (confidence intervals of weighted coefficients excluding zero) on density per size class when considering the subset of models within 4 AIC units of the best model (Table 3.2). Mass, watershed area and chlorophyll *a* were also the only variables with 100% relative variable importance (i.e. always included in the subset of models likely to include the best one; Table 3.2). When every possible interaction term between size class mass, watershed area and chlorophyll *a* was added, the interaction between mass and chlorophyll *a* constituted the only one improving significantly the fit of the model (Table 3.3). When

allowing the residual variance to vary between disturbed and undisturbed watersheds, the AIC of the model decreased substantially (ΔAIC= 23). Residual variability (i.e. sd of the residuals) around the linear size spectra in watersheds with complete natural cover was 86% of that in watersheds with anthropogenic land uses.

Final model parameters are presented in Table 3.4. The negative interaction between mass and chlorophyll *a* indicated that the size spectra slopes became more negative with increasing benthic chlorophyll *a* concentration reflecting a steeper decrease in relative density of larger size classes with increasing periphyton biomass. Watershed area and chlorophyll *a* had a positive effect on size class density corrected for size. These two variables were weakly correlated in the data set (r= 0.24, p-value= $2.2e^{-16}$).

Based on multi-model inference, the best model predicting number of size class included watershed area and benthic chlorophyll *a* as independent variables (Table 3.5). Average parameter values showed these two variables as the only variables having a significant effect on the number of size class (confidence intervals excluding zero) (Table 3.6). Watershed area and chlorophyll *a* were also the only two variables with 100% relative variable importance (Table 3.6). The combined effect of watershed area and chlorophyll *a* accounted for 38% of the variation in size class number. In simple regression models, watershed area and chlorophyll *a* explained 13 and 33% of the variation on size class number respectively (Figure 3.3).

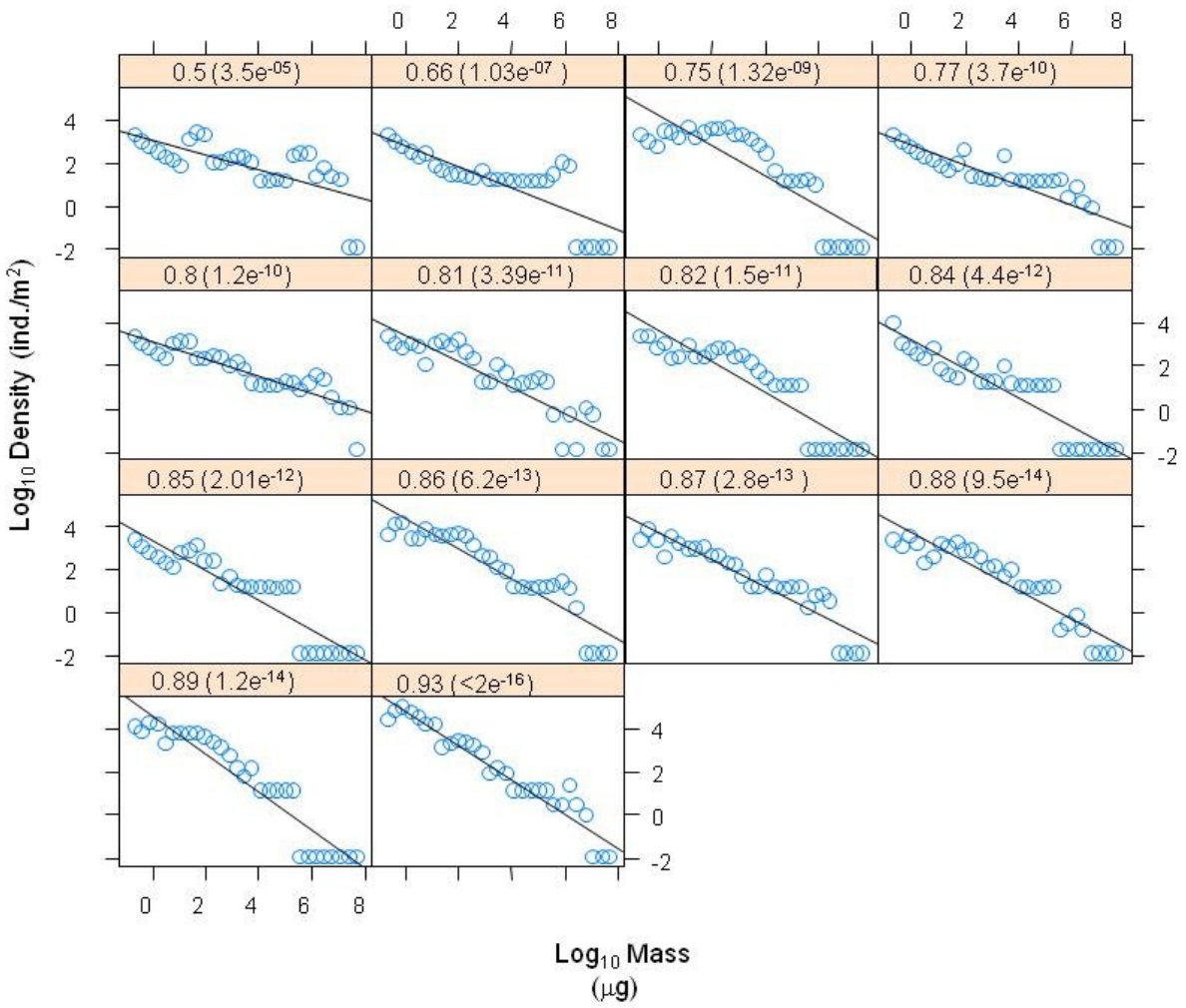

Figure 3.1: Size spectra at 14 sampling sites and selected to illustrate the range from the worst to the best fit to a linear regression. The selection was made by organizing size spectra r^2 in ascending order and selecting the first, the last, and every tenth size spectrum in between these 2 extremes. R^2 are shown at the top of each size spectrum, and p-values are presented in brackets.

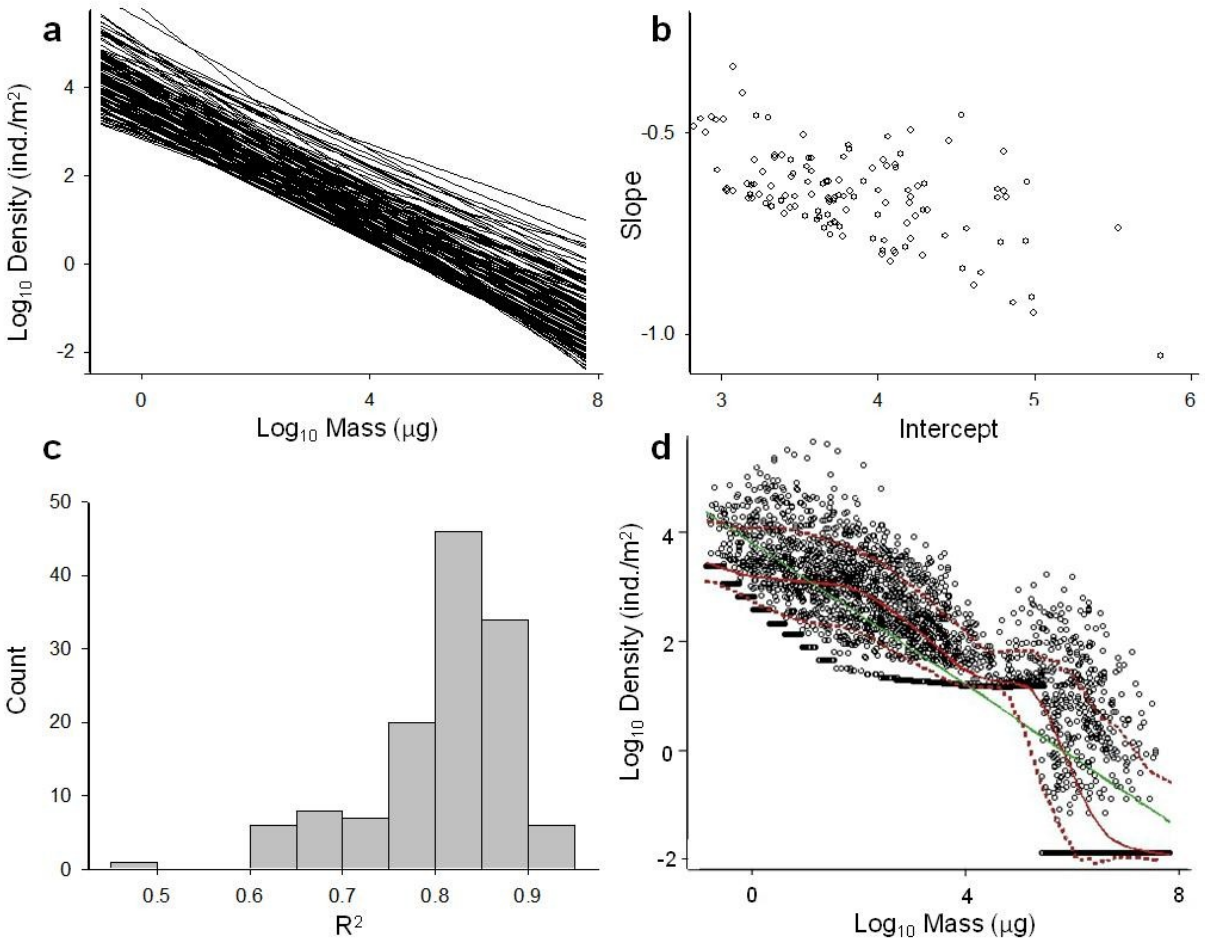

Figure 3.2: Representation of the 129 size spectra a) regression lines, b) intercepts and slopes, c) r^2 distribution, and d) size class density (ind./m^2) and mass (µg) with regression (green line), loess smoother (red line) and smoother applied to the root-mean-square positive and negative residuals from the loess line to display conditional spread (dashed lines) loess conditional spread (dashed lines). A jitter effect was used in panel d to allow the visualization of superposed data.

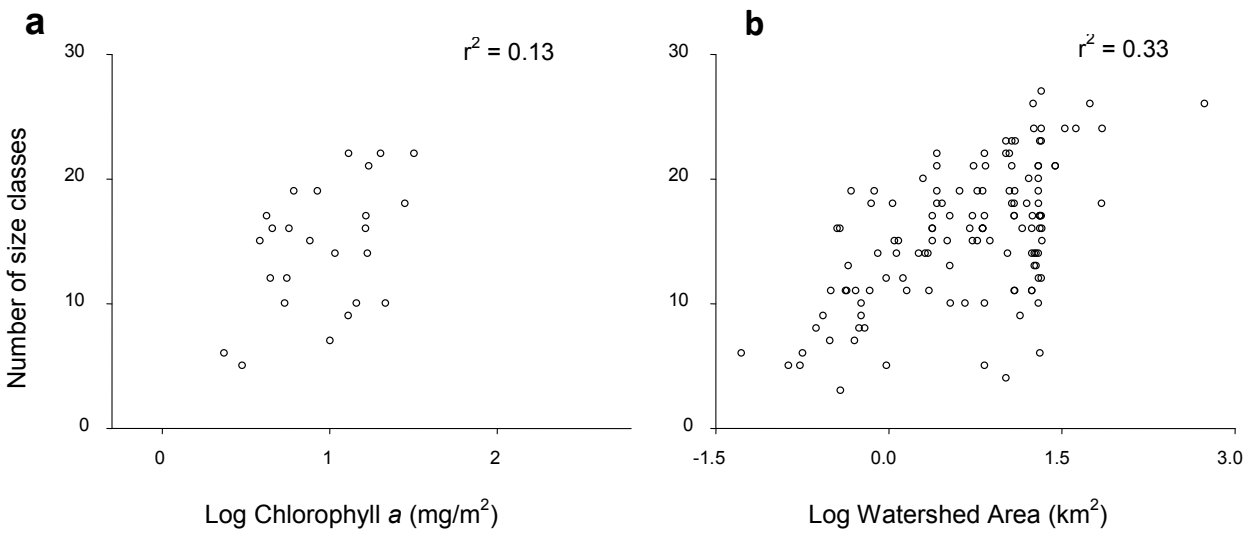

Figure 3.3: The number of size class occupied as a function of c) chlorophyll *a* concentration (mg/m^2), and b) watershed area (km^2).

Table 3.1: Description of the range of covariate values quantified among sampling events (n=129).

	Average	Minimum	Maximum
Total Phosphorus (mg/L)	0.05	0.01	0.60
Total Nitrogen (mg/L)	1.32	0.18	5.78
Conductivity (µS/cm)	736.00	53.00	2406.00
Chlorophyll *a* (mg/m^2)	35. 80	0.90	293.00
Watershed Area (km^2)	15.00	0.05	550.00
Natural (%)	67.00	0.00	100.00
Agriculture (%)	7.00	0.00	79.00
Developed (%)	26.30	0.00	100.00

Table 3.2: Average parameters for models predicting density per size class and relative variable importance of covariates in predicting abundance per size class.

	Coefficient	Adjusted SE	I.C.	Relative importance
Intercept	3.14	0.11	2.93, 3.35	
logArea	0.31	0.05	0.21, 0.41	1.00
logChla	0.36	0.07	0.22, 0.49	1.00
logM	-0.65	0.01	-0.67, -0.64	1.00
logTN	0.00	0.03	-0.06, 0.06	0.08
logTP	0.00	0.03	-0.05, 0.05	0.07

Table 3.3: Average parameters for models predicting density per size class and relative variable importance of every possible interaction between size class mass, watershed area and chlorophyll *a*.

	Coefficient	SE	Adjusted SE	I.C	Relative importance
Intercept	2.99	0.14	0.14	2.71, 3.27	
logArea	0.15	0.17	0.17	-0.19, 0.48	1.00
logChla	0.49	0.11	0.11	0.27, 0.71	1.00
logM	-0.58	0.03	0.03	-0.64, -0.52	1.00
logArea:logChla	0.09	0.11	0.11	-0.13, 0.32	0.47
logArea:logM	0.02	0.02	0.02	-0.03, 0.06	0.42
logChla:logM	-0.07	0.02	0.02	-0.12, -0.02	0.96

Table 3.4: Summary of final mixed effects model predicting the density per size class fitted to 129 size spectra including macroinvertebrate and fish taxa.

Fixed	**Coefficient**	**SE**	**DF**	**p-value**
Intercept	2.91	0.12	3610	0
logM	-0.57	0.03	3610	$<1e^{-10}$
logArea	0.31	0.05	126	$7.4e^{-09}$
logChla	0.53	0.08	126	$9.1e^{-10}$
LogM:logChla	-0.07	0.02	3610	0.0005
Random	**SD**			
Intercept	0.40			
logM	0.09			
Residual	0.84			
Undisturbed	0.72			

Table 3.5: Summary of regression model between watershed area, chlorophyll *a* and number of non-empty size classes.

	Estimate	**Std.Error**	**p-value**
Intercept	9.454	1.0535	$3.38e^{-15}$
logArea	3.931	0.5483	$5.63e^{-11}$
logChla	2.614	0.7683	$8.96e^{-04}$

Table 3.6: Average model parameters and relative variable importance of covariates to predict number of non-empty size classes.

	Coefficient	**SE**	**Adjusted SE**	**I.C**	**Relative importance**
Intercept	13.10	78.70	79.50	-143.00, 169.00	
agriculture	-0.01	0.79	0.79	-1.57, 1.55	0.39
developed	-0.03	0.79	0.79	-1.58, 1.53	0.26
logArea	3.51	0.63	0.64	2.26, 4.76	1.00
logChla	3.09	0.91	0.92	1.29, 4.90	1.00
logCOND	-0.28	0.85	0.85	-1.96, 1.39	0.29
logTN	-2.20	2.01	2.02	-6.16, 1.76	0.72
logTP	0.17	0.66	0.66	-1.13, 1.47	0.23
natural	-0.03	0.79	0.80	-1.59, 1.52	0.31

Discussion

Consistent with previous descriptions of size spectra, assemblages in streams of the Ottawa-Gatineau region were characterized by a generally linear decline in density with increasing body mass. However, decline in density was not directly proportional with the increase in individual mass. Size spectra slopes (mean = -0.66) were shallower than -1, the value usually observed for size spectra (Sprules and Munawar 1986, Ahrens and Peters 1991, Morin and Nadon 1991, Gaedke 1992, Kerr and Dickie 2001, Jennings and Mackinson 2003, Huete-Ortega *et al.* 2010).

Shallow slopes reflect relatively high densities of large organisms compared to small ones. This can result from high ratios of predator:prey masses. In resource limited systems, organismal abundance is dependent on available energy and the efficiency of energy transfers between trophic levels (Cyr 2000); consequently the rate of decreasing abundance with increasing body size is related to the predator:prey mass ratios (Jennings and Mackinson 2003). When predator:prey size ratios are high, size spectra cover few trophic levels and a larger proportion of available energy can be used by the larger organisms. Therefore, when predator:prey size ratios are high, the density of large size classes can represent a higher proportion of the density of small organisms, resulting in shallower size spectra slopes. Accordingly, Brose *et al.* (2006) reported higher predator:prey mass ratios in freshwater ecosystems when compared to marine and terrestrial habitats. As the relationship between $\delta^{15}N$ and body mass can be used to quantify predator:prey size ratios (Jennings *et al.* 2002, Jennings and Mackinson 2003), nitrogen stable isotopes analyses of organisms

pooled into the same size class would allow one to assess whether they can explain the relatively shallow size spectra slopes in stream ecosystems.

Shallow size spectra slopes could also result from allochtonous resource inputs benefitting more the larger organisms. The energetic contribution of terrestrial insects constitutes a significant portion of the diet of many stream fish (Garman 1991, Cloe and Garman 1996, Nakano *et al.* 1999), and the incorporation of biomass produced outside the stream can explain the observation of high fish density relative to the biomass available from the smaller size classes. Accordingly, Cyr *et al.* (1997b) observed a higher density of organisms of comparable body size in aquatic than terrestrial systems and the difference in size class density, between the two types of ecosystems, tended to increase in larger size classes. Fish are known to attain higher densities compared to terrestrial endotherms of similar body size (Cyr *et al.* 1997b). This could be explained by the contribution of biomass originating from riparian environments and by higher proportions of allochtonous biomass incorporation by the larger size classes. The use of carbon stable isotopes would allow the determination of the source of the carbon incorporated by stream biota. Finlay (2001) studied $\delta^{13}C$ of stream assemblages and observed that higher trophic levels in streams with watershed smaller than 10 km^2 (corresponding to 53% of the sites included in the present study) were relying greatly on terrestrial biomass. In larger streams, although consumers were incorporating greater proportions of carbon from algal sources in general, terrestrial biomass inputs varied notably among functional feeding groups and sites. The use of similar methodology in size distribution studies would help better understand the link between terrestrial biomass contributions and streams size spectra slopes. Despite the importance of

the interactions between streams and riparian ecosystems (Naiman and Decamps 1997), terrestrial energetic contributions are absent from aquatic size spectra theories.

Size spectra slopes were also negatively correlated with periphyton chlorophyll *a*, which is a strong correlate of primary productivity (Morin et *al.* 1999). This negative trend reflects a larger increase in small organisms' density, with increasing system productivity, than of larger organisms. A negative effect of primary productivity on size spectra slopes has been reported in three publications on size spectra (Cyr *et al.* 1997a, Rasmussen 1993, Emmrich *et al.* 2011). However, other authors also reported the opposite trend (i.e. flatter slope with increasing primary productivity) (Sprules and Munawar 1986, Ahrens and Peters 1991, Cottingham 1999, deBryun *et al.* 2002, Mulder *et al.* 2009, Huete-Ortega *et al.* 2010), and DeNichola (2006) reported positive and negative variations in slope, in relation to primary productivity, depending on sampling location. Quintana *et al.* (2002) studied the size distribution of coastal marshes, in Aiguamolls de l'Empordà Natural Park, exposed to frequent inundation pulses and showed that the variation in the size spectra slope in relation to primary productivity depended on the mechanism responsible for nutrient inputs. When the system was under steady state conditions, the size spectra slope expressed a positive relation with primary productivity. However, when the nutrient input originated from inundation pulses also associated with hydrological perturbations, size spectra slopes decreased with primary productivity. A possible explanation for a decrease in size spectra slope with increasing productivity is a decreased efficiency of energy transfer with increasing productivity if this gradient of productivity is collinear with ecosystem stress. In the present study, system eutrophication in urban areas was correlated with other potential

stressors such as hydrological perturbations, increased conductivity, loss of riparian vegetation (see Chapter 2).

Accordingly, an ANCOVA revealed the presence of a significant positive interaction between benthic chlorophyll *a* concentration and the percentage of natural land use on the slopes of size spectra (Table 3.7). The positive interaction indicates that the chlorophyll *a* concentration is positively correlated with the size spectrum slopes at sites characterized by high proportions of natural watershed land use and low levels of perturbation. In these mostly undisturbed watersheds, as trophy increases, the increase in density of larger organisms becomes greater than that of smaller organisms whereas the opposite happens in developed watersheds. The negative effect of chlorophyll *a* concentration on size spectra slopes is shifting to a positive effect when the percentage of natural land increases above 95 percent. Therefore, the observation of negative trend in disturbed watershed is likely associated with collinear land use stress.

Table 3.7: Summary of ANCOVA model testing the effect of chlorophyll *a* and the percentage of natural land on the slopes of the size spectra.

	Estimate	**Std.Error**	**p-value**
Intercept	-0.52	0.06	$1.94e^{-13}$
logChla	-0.12	0.04	$2.42\ e^{-3}$
Natural	$-1.02\ e^{-3}$	$7.92\ e^{-4}$	0.2
logChla:Natural	$1.26\ e^{-3}$	$5.72\ e^{-4}$	0.03

Decreased efficiency of energy transfer is a predictable response to external stress. In his famous paper "*Trends Expected in Stressed Ecosystems*", Odum (1985) describes

functional and structural changes generally observed in stressed systems. He explains that impacted systems are subjected to an important increase in community respiration as organisms require more energy to cope with external perturbations (Odum 1985, 1967). As a result, a lower proportion of energy is available for production and a decreased efficiency of converting energy to biomass is observed (Odum 1985). Systems under perturbation become more leaky and higher proportions of nutrients and primary productivity is exported or unused (Odum 1985). Therefore, stressed systems also tend to be dominated by small organisms which have high turnover rates (Woodwell 1983, Odum 1985, Gaedke 1992, Quintana *et al.* 2002). Size spectra are good descriptors of the changes operated in stressed ecosystems as they provide valuable information on energy transfer efficiency and size structure.

Watershed size was positively correlated with size corrected densities. The relation between density and watershed size has been reported in several previous studies (Foltz 1982, Lotrich 1973, Grubaugh *et al.* 1996, Magalhaes *et al.* 2002, Anjos and Zuanon 2007, Yun-Zhi 2010). Increase in fish abundance with stream size is attributed to an increase in living space and environmental stability (Magalhaes *et al.* 2002). Larger streams also contain deeper pools providing refugia habitat beneficial for fish (Foltz 1982, Magalhaes *et al.* 2002). Macroinvertebrate assemblages on cobble substrate are also known to increase with watershed area (Grubaugh *et al.* 1996).

Benthic chlorophyll *a* concentration, which is a strong correlate of primary productivity (Morin et *al.* 1999), had a positive effect on size corrected densities as reported

in studies on streams (Morin *et al.* 1995, Bourassa and Morin 1995) and on other aquatic systems (Rasmussen 1993, Cyr and Peters 1996, Cyr *et al.* 1997a, deBryun *et al.* 2002, DeEyto and Irvine 2007). The increase of density of consumers with primary productivity is typical of a bottom-up effect where abundance is resource limited. The positive effect of primary productivity on growth, density and biomass of consumers is widely recognized (Huntsman 1948, Rosemond *et al.*1993, Biggs and Lowe 1994, Lamberti 1996, Wallace *et al.* 1997, Sabater *et al.* 2005). The significant effect of chlorophyll *a* on density indicates an increase in density (or biomass) of consumers with increasing system productivity.

Benthic chlorophyll *a* concentration and watershed area explained 38% of the variation in the number of size classes collected. This increase in total number of size classes with chlorophyll *a* concentration and watershed area are consistent with the predictions of the River Continuum Concept (RCC), as number the of size classes and the number of taxa were highly correlated (r= 0.76) in the dataset; but could also be a sampling artifact related to our ability to detect presence of organisms in size classes given my sampling effort. Vannote *et al.* (1980) predicted the increase of community diversity from headwater streams to medium-size streams, with highest diversity being observed in streams of third to fifth order. Since then, richness pattern with stream order has been confirmed in several publications (Foltz 1982, Minshall *et al.* 1985, Grubaugh *et al.* 1996, Roper and Scarnecchia 2001, Anjos and Zuanon. 2007, Yun-Zhi *et al.* 2010). Because my study included small to medium streams, it would also be expected to observe an increase in assemblage diversity with watershed size. Given the high correlation between the number of size classes and the number of taxa , the increase in size class number with chlorophyll *a* and watershed area is

in agreement with the predictions of the RCC. Accordingly, Emmrich *et al.* (2011) reported that watershed size was significantly correlated with the number of size classes and taxa richness of lowland lakes in northern Germany. However, given that overall density was positively correlated with chlorophyll *a* standing stock ($r= 0.42$, $p=8.6x10^{-07}$) and with watershed size ($r= 0.56$, $p= 6.6\ x10^{-12}$), it is possible that the positive relationship between the number of size classes and these two variables simply reflected higher detectability of size classes resulting from a larger number of organisms collected. Indeed number of size classes was highly correlated with overall density ($r=0.89$) at the sampling sites.

Size spectra of undisturbed watersheds had statistically significant, but small, reductions in residual variation. This result is in agreement with other studies reporting greater residual variation of size spectra subjected to environmental stress (Sprules and Munawar 1986, Gaedke 1992, Quintana *et al.* 2002). Sprules and Munawar (1986) speculated that the increase in residual variation could potentially be used to quantify ecosystem perturbation from steady state. The results of the present study support this concept as sites exposed to land use perturbation were associated with higher residual variation than natural sites. However, the difference in residual standard deviation, between pristine and disturbed sites, was smaller in the present study compared to the effect reported by Sprules and Munawar (1986). Residual standard deviation decreased by 80% in pristine sites studied by Sprules and Munawar (1986), but residual standard deviation decreased by only 24% in the present study. Moreover, the residual variation was not increasing in a predictable way along the gradient of proportion of developed land ($r= 0.16$, $p= 0.072$). Considering the relatively small differences in residual variation around the linear size

spectra between pristine and developed watershed, and the absence of a consistent trend with percent developed land, it remains uncertain whether ecosystem perturbation results in higher variability.

Size spectra, providing synthetic descriptions of stream assemblages' structure, allow assessment of ecological changes related to environmental conditions. Differences in slopes, intercepts, number of size classes and residual variance were significantly correlated with land use, watershed size and chlorophyll *a* concentration. Size spectra revealed that stream ecosystems of the Ottawa-Gatineau region are characterized by higher densities in the larger size class range compared to other ecosystems types (e.g. lakes, oceans, soils, coastal waters). Stable isotopes analyses would help better understand whether shallow slopes result from high predator:prey size ratios or allochtonous resource inputs. In addition, size spectra also helped differentiate between the changes initiated along naturally and human generated gradients. Size class density corrected for size and the number of size classes varied naturally with watershed size, however the response of those size spectra attributes to variations in chlorophyll *a* concentration is indirectly related to land use perturbations as nutrient enrichment is one of the principal mechanisms by which land use influence lotic ecosystems (Allan 2004). Moreover, collinear increase of primary production and proportion of developed land was identified as a possible reason for the observation of positive and negative trends between size spectra slopes and primary productivity in different studies. Steeper slopes could result from environmental stress altering energy flow from the small size classes to the larger ones. Further studies of size spectra along disturbance gradients,

coupled with stable isotope analyses would allow quantification of altered ecological efficiencies.

Chapter 4 — General Conclusion

As land use transformations constitute the main driver of biological diversity loss at the global scale (Meyer and Turner 1992, Vitousek 1997), it is important to generate strong predictions of the ecological impacts before land use transformations are initiated. Morevover, improved comprehension of the effects of land use alterations on biological assemblages will help better manage our land and mitigate changes at the ecosystem level. Results presented in chapters two and three allow to better quantify and understand ecological impacts associated with urbanization.

In Chapter 2, I showed that the predictive power of total and effective imperviousness were similar in the studied region, in contrast to what was suggested in previous studies in Australia (Taylor *et al.* 2004, Walsh *et al.* 2005a). The geographical differences are likely due to differences in regional runoff regime, geology and/or topography. Prediction of the impact of imperviousness can be made without accounting for storm sewer connections in the Ottawa-Carleton municipality. Moreover, the data I collected suggest that imperviousness should be kept under 14% TI and 3% EI in order to maintain undisturbed stream conditions. Those findings are valuable to urban land use planners as they help better predict (and hopefully minimize) the ecological impacts of urban development. However, comparison of the predictions obtained using total and effective imperviousness must be performed in many different environmental settings in order to validate the effects of regional factors on the relative predictive power of the metrics. Moreover, as it has been demonstrated that very precise quantification of the connectivity of impervious structures could provide stronger predictions of stream hydrological alteration (Lee and Heaney 2003, Meierdiercks *et al.* 2010) it would be informative to integrate

hydrological measures in studies on the ecological impact of watershed imperviousness. It is still unclear how much of the increase in the reliability of the prediction in hydrological changes obtained when using effective instead of total imperviousness is also translated in an increased reliability in the prediction of biological impairment.

In Chapter 3, I showed that streams of the Ottawa-Gatineau region have relatively high densities in the larger size class range compared to other ecosystems types (e.g. lakes, oceans, soils, coastal waters). Morevover, I showed that multitrophic stream size spectra attributes are significantly correlated with watershed size, proportion of natural land in the watershed and site primary productivity. Land use transformations were associated with statistically significant, but small, increase in size spectra residual variation. Moreover, collinear increases of productivity and ecosystem stress caused by land use alteration was also identified as a possible explanation for the observation of a decrease in energy transfer efficiency affecting energy flow between the small size classes and the larger ones. Landscape alteration also had an indirect effect on density per size class and the number of size classes which are both correlated with primary productivity. The results of this study showed how macroinvertebrate and fish assemblages vary along naturally and human generated environmental gradients and help better understand ecosystems structural changes resulting from land use perturbations. Size spectra constitute valuable tools allowing the assessment of ecological changes induced by local environmental conditions by integrating many aspects of assemblages' ecological properties. Further investigations based on stable isotopes analyses would help better understand the factors responsible for the observation of shallow size spectra slopes in streams of the Ottawa-Gatineau region. Moreover, for future

studies of ecological stress, size spectra slopes can be used to estimate the energy transfer efficiency and to determine ecosystem functional disturbances along gradients of anthropogenic perturbations.

The results of this thesis will help developing efficient practices to mitigate ecological impairment from land-use changes in the Ottawa-Carleton region by providing information on regional thresholds, correlates of urbanization impact and changes in stream ecosystems structure. As the impact of land-use changes is increasing globally with growing humanity footprint (Foley *et al.* 2005, Hu *et al* 2008, Changhong *et al.* 2011), these findings will also be conducive to stream conservation in other geographic regions. Thorough information allowing good prediction and comprehension of land use ecological impacts, as provided in this thesis, should be integrated in every land-use planning decisions. Stream protection is crucial to the conservation of healthy freshwater networks, as larger watercourses (e.g. rivers, tributaries) rely greatly on organic material from upstream (Vannote et al. 1980).

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Appendix I — Water quality, watershed properties and researcher for each sampling event (chapter 3)

Year	Site	TP (mg/L)	TN (mg/L)	Cond (µS/cm)	Chl*a* (mg/m^2)	Watershed area (km^2)	Natural (%)	Agriculture (%)	Developed (%)	Park	Author
2001	20017BEA	0.084	1.87	741.1	293.0	34.0	63.2	35.9	1.0		Stephenson
2001	20017BRA	0.016	0.57	414.0	27.1	42.4	86.5	13.5	0.0		Stephenson
2001	20017GRE	0.065	1.42	1395.0	74.1	18.3	46.3	29.8	23.8		Stephenson
2001	20017JR-01	0.036	1.36	646.0	84.3	550.4	64.0	32.0	3.3		Stephenson
2001	20017MOS	0.075	0.83	636.7	58.3	21.2	58.5	34.2	7.3		Stephenson
2001	20017NCR	0.042	1.43	995.6	68.6	71.4	63.0	28.5	8.4		Stephenson
2001	20017SAWD	0.085	1.36	1327.8	92.5	20.0	35.5	1.2	63.3		Stephenson
2001	20017TAYD	0.070	3.14	562.5	28.7	16.5	20.2	79.3	0.5		Stephenson
2001	20017You	0.057	2.13	1434.0	63.4	6.6	40.3	0.0	59.7		Stephenson
2001	20018BLA	0.011	0.35	67.9	3.8	19.1	99.9	0.0	0.1		Stephenson
2001	20018CHE	0.020	0.50	285.0	16.6	20.6	95.8	0.0	4.2	P	Stephenson
2001	20018COR	0.010	0.31	71.6	13.1	6.8	100.0	0.0	0.0		Stephenson
2001	20018DESF	0.038	1.66	960.0	13.0	13.9	70.3	6.3	23.4		Stephenson
2001	20018DEST	0.085	1.07	920.0	97.2	11.2	71.5	8.7	19.8		Stephenson
2001	20018LAP	0.033	0.48	72.8	16.5	17.5	100.0	0.0	0.0	P	Stephenson
2001	20018Mine1	0.042	0.84	290.0	32.1	2.6	99.6		0.4	P	Stephenson
2001	20018UNA	0.104	1.80	1340.0	39.5	1.8	9.5	0.0	90.5		Stephenson
2002	20025COR	0.010	0.31	71.6	13.1	6.8	100.0	0.0	0.0		Stephenson
2002	20025LAP	0.033	0.48	72.8	16.5	17.5	100.0	0.0	0.0	P	Stephenson
2002	20025LMS	0.034	0.35	590.0	62.5	10.5	62.1	0.0	37.9		Stephenson
2002	20025MOS	0.040	0.84	585.0	40.0	21.2	58.5	34.2	7.3		Stephenson
2002	20025POO2	0.017	1.37	821.1	62.5	18.5	69.3	8.0	22.7		Stephenson
2002	20025SAWD	0.082	1.66	1532.0	21.7	20.0	35.5	1.2	63.3		Stephenson
2002	20027COR	0.010	0.31	71.6	4.2	6.8	100.0	0.0	0.0		Stephenson
2002	20027Crow	0.076	1.95	1117.5	42.6	5.4	29.9	0.2	69.8		Stephenson
2002	20027SAWD	0.082	1.66	1532.0	21.7	20.0	35.5	1.2	63.3		Stephenson
2002	20027STI	0.056	1.58	1055.7	31.5	21.4	61.9	18.7	19.4		Stephenson
2002	20027You	0.043	2.65	1574.4	94.2	6.6	40.3	0.0	59.7		Stephenson
2002	20028BLA	0.011	0.35	67.9	1.4	19.1	99.9	0.0	0.1		Stephenson
2002	20028CHE	0.020	0.50	285.0	11.3	20.6	95.8	0.0	4.2	P	Stephenson
2002	20028FOR	0.005	0.44	320.0	8.5	5.9	99.7	0.0	0.3	P	Stephenson
2002	20028HAR	0.017	0.78	820.0	129.7	12.5	70.3	29.7	0.0		Stephenson
2002	20028Kingsmere	0.055	0.64	200.0	9.8	3.4	98.1	0.0	1.9	P	Stephenson
2002	20028LAP	0.033	0.48	72.8	16.9	17.5	100.0	0.0	0.0	P	Stephenson

2002	20028LDS	0.142	1.14	774.1	115.6	12.4	52.8	0.0	47.2		Stephenson
2002	20028MEE	0.013	0.25	98.0	40.8	11.8	92.5	0.0	7.5	P	Stephenson
2002	20028MOS	0.040	0.84	585.0	40.0	21.2	58.5	34.2	7.3		Stephenson
2002	20029SAWD	0.082	1.66	1532.0	21.7	20.0	35.5	1.2	63.3		Stephenson
2002	20029You	0.043	2.65	1574.4	94.2	6.6	40.3	0.0	59.7		Stephenson
2002	200210CHE	0.020	0.50	285.0	16.6	20.6	95.8	0.0	4.2	P	Stephenson
2002	200210COR	0.010	0.31	71.6	13.1	6.8	100.0	0.0	0.0		Stephenson
2002	200210HAR	0.017	0.78	820.0	129.7	12.5	70.3	29.7	0.0		Stephenson
2002	200210LAP	0.033	0.48	72.8	16.5	17.5	100.0	0.0	0.0	P	Stephenson
2002	200210LDS	0.142	1.14	774.1	115.6	12.4	52.8	0.0	47.2		Stephenson
2002	200210MOS	0.040	0.84	585.0	40.0	21.2	58.5	34.2	7.3		Stephenson
2002	200210POO2	0.017	1.37	821.1	62.5	18.5	69.3	8.0	22.7		Stephenson
2003	03C12	0.073	0.45	603.3	35.3	0.7	25.5	0.0	74.5		Morin
2003	03C2	0.023	0.53	500.0	9.0	20.0	96.4	0.0	3.6	P	Morin
2003	03C6	0.005	0.64	410.0	18.9	2.4	98.0	0.0	2.0	P	Morin
2003	03C9	0.012	0.43	550.0	21.9	28.1	93.1	2.2	4.7	P	Morin
2003	03CHE	0.011	0.50	533.3	22.0	20.6	95.8	0.0	4.2	P	Morin
2003	03FOR	0.016	0.52	350.0	22.5	5.9	99.7	0.0	0.3	P	Morin
2003	03LDS	0.126	1.23	1456.7	22.3	12.4	52.8	0.0	47.2		Morin
2003	03LDS2	0.104	1.80	1340.0	68.3	0.6	1.2	0.0	98.8		Morin
2003	03LMS	0.033	0.58	1400.0	20.3	10.5	62.1	0.0	37.9		Morin
2003	03M10	0.014	0.32	95.0	17.2	7.0	100.0	0.0	0.0	P	Morin
2003	03M12	0.033	0.39	106.7	19.0	15.8	91.9	8.1	0.0	P	Morin
2003	03M14	0.057	0.42	114.0	23.3	17.8	90.2	9.7	0.1	P	Morin
2003	03MEE	0.014	0.30	94.7	24.2	11.8	92.5	0.0	7.5	P	Morin
2003	03Mine1	0.042	0.84	290.0	26.7	2.6	99.6		0.4	P	Morin
2005	05C2	0.018	0.50	380.0	5.6	20.0	96.4	0.0	3.6	P	Lento
2005	05CHE	0.021	0.50	365.0	7.1	20.6	95.8	0.0	4.2	P	Lento
2005	05DEST	0.085	1.07	920.0	20.3	11.2	71.5	8.7	19.8		Lento
2005	05DT2	0.072	1.09	890.0	40.4	12.6	70.7	7.9	21.4		Lento
2005	05BEC	0.080	1.06	564.3	71.9	56.0	40.0	60.0	0.0		Lento
2005	05DT0	0.042	0.49	985.0	12.1	0.4	79.5	13.6	6.9		Lento
2005	05LDS	0.145	1.46	1110.0	55.2	12.4	52.8	0.0	47.2		Lento
2005	05LDS2	0.204	3.00	1685.0	20.2	0.6	1.2	0.0	98.8		Lento
2005	05LMS	0.600	5.23	1130.0	62.5	10.5	62.1	0.0	37.9		Lento
2005	05MEE	0.015	0.29	95.5	23.5	11.8	92.5	0.0	7.5	P	Lento
2005	05MO	0.015	0.36	90.0	6.2	0.5	100.0	0.0	0.0	P	Lento
2005	05MOS	0.075	0.83	636.7	46.6	21.2	58.5	34.2	7.3		Lento
2005	05SAWD	0.082	1.66	1532.0	10.8	20.0	35.5	1.2	63.3		Lento
2008	08Gat1	0.027	0.37	257.0	4.0	0.3	100.0	0.0	0.0	P	Hamilton
2008	08Notch	0.017	0.57	125.0	3.9	3.2	98.7	0.0	1.3	P	Hamilton
2008	08C6	0.012	0.35	79.0	13.9	2.4	98.0	0.0	2.0	P	Hamilton
2008	08C6b	0.008	0.49	360.0	7.7	1.1	98.8	0.0	1.2	P	Hamilton

2008	08CHE	0.021	0.50	365.0	7.1	20.6	95.8	0.0	4.2	P	Hamilton
2008	08DesFeesO	0.170	0.46	137.0	28.3	0.4	95.5	0.0	4.5	P	Hamilton
2008	08Eardley1	0.019	0.37	90.0	5.8	14.5	100.0	0.0	0.0	P	Hamilton
2008	08Fortune1	0.036	0.35	136.0	4.5	1.3	99.4	0.0	0.6	P	Hamilton
2008	08Fortune2	0.019	0.39	69.0	5.4	4.6	100.0	0.0	0.0	P	Hamilton
2008	08Fortune3	0.017	0.29	53.0	7.9	2.0	100.0	0.0	0.0	P	Hamilton
2008	08Kingsmere	0.011	0.41	110.0	9.4	3.4	98.1	0.0	1.9	P	Hamilton
2008	08Meech1	0.019	0.53	72.0	28.3	2.6	100.0	0.0	0.0	P	Hamilton
2008	08Meech2	0.023	0.67	297.0	32.0	1.2	100.0	0.0	0.0	P	Hamilton
2008	08Meech3	0.005	0.45	287.0	14.6	3.4	100.0	0.0	0.0	P	Hamilton
2008	08Meech4	0.014	0.46	155.0	3.0	0.1	100.0	0.0	0.0	P	Hamilton
2008	08Mine1	0.020	0.44	85.0	20.6	2.6	99.6		0.4	P	Hamilton
2008	08Renaud1	0.017	0.55	66.0	4.6	10.8	100.0	0.0	0.0	P	Hamilton
2008	08Renaud2	0.008	0.32	189.0	4.6	2.4	100.0	0.0	0.0	P	Hamilton
2008	08Taylor	0.012	0.46	367.0	5.6	5.5	100.0	0.0	0.0	P	Hamilton
2008	08C9	0.015	0.18	240.0	21.5	28.1	94.8	0.8	4.3	P	Hamilton
2008	08DesLoups	0.010	0.87	270.0	9.8	7.6	100.0	0.0	0.0	P	Hamilton
2008	08Eardley2	0.020	1.19	103.0	5.4	0.8	100.0	0.0	0.0	P	Hamilton
2008	08LaPeche	0.014	0.20	89.0	12.1	2.9	100.0	0.0	0.0	P	Hamilton
2008	08LaPeche2	0.012	0.32	353.0	1.3	21.5	100.0	0.0	0.0	P	Hamilton
2008	08Loutre	0.016	0.37	74.0	25.3	70.5	99.2	0.2	0.6	P	Hamilton
2008	08LUS2	0.023	0.30	247.0	10.1	0.3	100.0	0.0	0.0	P	Hamilton
2008	08Mine3	0.061	0.67	293.0	10.8	0.7	100.0	0.0	0.0	P	Hamilton
2009	09Bet1	0.040	4.32	1696.7	73.5	0.1	0.0	0.0	100.0		Duhaime
2009	09Bet2	0.068	3.66	1676.7	75.9	1.0	0.6	0.0	99.4		Duhaime
2009	09Bet3	0.091	3.28	1483.3	23.4	1.4	0.5	0.0	99.5		Duhaime
2009	09Blai	0.020	2.28	2406.7	40.5	0.2	12.2	0.0	87.8		Duhaime
2009	09Ced1	0.024	4.23	1603.3	36.0	2.1	5.2	20.9	73.9		Duhaime
2009	09Ced2	0.013	5.78	1913.3	123.5	0.4	0.0	0.0	100.0		Duhaime
2009	09Crow	0.057	1.35	800.0	19.2	5.4	29.9	0.2	69.8		Duhaime
2009	09Gill	0.034	1.44	893.3	7.7	5.1	29.7	0.3	70.0		Duhaime
2009	09Her1	0.025	2.70	1496.7	0.9	0.4	2.3	0.0	97.7		Duhaime
2009	09Her2	0.034	3.45	1563.3	66.3	0.8	3.1	0.0	96.9		Duhaime
2009	09Watt1	0.007	3.45	1376.7	17.8	0.6	22.4	72.0	5.6		Duhaime
2009	09Watt2	0.019	5.70	1453.3	89.9	0.4	0.0	0.0	100.0		Duhaime
2009	09Watt3	0.019	2.89	1876.7	113.8	4.2	8.7	19.4	71.9		Duhaime
2009	09You	0.028	3.04	1536.7	92.0	6.6	40.3	0.0	59.7		Duhaime
2009	09Bil1	0.050	1.71	1220.0	99.1	1.1	13.9	14.5	71.6		Duhaime
2009	09Bil2	0.046	2.35	1710.0	46.2	1.2	16.7	4.0	79.3		Duhaime
2009	09Fau	0.234	3.57	2400.0	19.9	0.3	25.2	0.0	74.8		Duhaime
2009	09Jar	0.057	1.45	1206.7	6.0	0.2	85.4	14.6	0.0		Duhaime
2009	09Ma	0.124	2.86	1420.0	2.4	0.2	100.0	0.0	0.0		Duhaime
2009	09Mac1	0.049	1.40	1046.7	1.3	2.3	46.7	0.0	53.3		Duhaime

2009	09Mac2	0.068	1.41	850.0	1.8	2.2	46.7	0.0	53.3	Duhaime
2009	09Mer	0.054	3.59	760.0	3.2	1.0	85.0	15.0	0.0	Duhaime
2009	09POO1	0.028	1.38	923.3	117.4	18.0	58.7	6.1	35.2	Duhaime
2009	09Pri1	0.052	5.36	1593.3	3.7	0.6	5.6	0.0	94.4	Duhaime
2009	09Pri2	0.052	2.93	1846.7	43.6	0.5	1.5	0.0	98.5	Duhaime
2009	09Qui1	0.102	1.21	820.0	9.7	2.4	44.6	22.1	33.2	Duhaime
2009	09Qui2	0.039	0.84	740.0	20.1	0.5	32.5	8.9	58.7	Duhaime
2009	09Rid	0.073	2.22	970.0	9.5	0.4	55.9	43.5	0.6	Duhaime
2009	09SAWD	0.082	1.66	1532.0	94.7	20.0	35.5	1.2	63.3	Duhaime

Appendix II — Raw data (chapter 2)

Table 1: Total imperviousness, effective imperviousness, invertebrate density, invertebrate biomass, percent EPT density and invertebrate richness for all sites.

Sites	Density (ind./m^2)	Biomass (g/m^2)	EPT Density (%)	Richness
09Bet1	1070.60	0.05		1
09Bet2	2163.05	0.74	16.73	10
09Bet3	842.02	0.54	5.03	5
09Bil1	10601.98	5.63	31.83	11
09Bil2	1940.03	0.53	42.51	9
09Blai	576.58	0.06	2.94	5
09Ced1	9073.05	1.90	0.61	7
09Ced2	28694.05	1.09		6
09Crow	26650.30	4.53	22.99	16
09Fau	398.68	0.55	15.12	5
09Gill	4364.66	0.42	1.20	10
09Her1	107.03	0.01		3
09Her2	10365.17	0.43		10
09Jar	89.46	0.09		3
09Ma	76.77	0.02		2
09Mac1	86.02	0.01	59.57	2
09Mac2	408.78	0.32	7.08	7
09Mer	53.70	0.00	15.85	2
09POO1	90778.33	4.48	30.96	23
09Pri1	332.21	0.11		2
09Pri2	339.70	0.04		4
09Qui1	2748.34	1.02	52.25	13
09Qui2	2825.17	0.91	49.50	14
09Rid	339.53	0.23	48.90	6
09SAWD	10982.84	2.19	27.87	12
09Watt1	661.38	0.16	4.56	4
09Watt2	19147.54	0.12		5
09Watt3	35017.96	5.23	37.36	18
09You	78166.61	2.10	0.06	9

Table 2: Invertebrate taxa density (ind./m^2) for all sites. Amphipoda, Am; Elmidae, El; Hydrophiliadea, Hy; Psephenidae, Ps; Chironomidae, Ch; Muscidae-Anthomyiidae, Mu; Heptageniidae, He; Gastropoda, Ga; Hirudinea, Hi; Isopoda, Is; Nematoda, Ne; Oligochaeta, Ol; Chloroperlidae, Chl; Bivalvia, Bi; Simuliidae, Si; Hydropsychidae, Hys; Hydroptilidae, Hyt; Philopotomatidae, Ph; Tipulidae, Ti.

Sites	Am	El	Hy	Ps	Ch	Mu	He	Ga	Hi	Is	Ne	Ol	Chl	Bi	Si	Hys	Hyt	Ph	Ti
09Bet1					1070.6														
09Bet2					1116.0			60.5	18.6	430.7	26.2				111.9	291.6	53.1		
09Bet3					106.4					559.6		113.4			20.3	42.3			
09Bil1					1686.4			1925.6	63.8	2838.2	588.6			64.1		2773.4	156.9		
09Bil2					732.5			36.2		113.6		105.7		15.5	7.1	824.7			
09Blai					432.4					63.3					11.5		17.0		
09Ced1					2123.2			204.3		49.5					4085.7	55.0			
09Ced2					18051.6	124.1			7.4	9597.0	800.2	113.8							
09Crow	42.6				12987.11			301.1	28.1	2889.8	772.6	1643.3		764.4	546.4	5936.9	17.7		97.1
09Fau					9.4			163.8				138.4		26.8		60.3			
09Gill					1846.2			42.1	11.5	1442.3	504.6	386.2			58.6	25.8			20.8
09Her1					35.9					37.4									
09Her2			10.9		5578.2			159.5		2577.9	1568.1	190.1							
09Jar								6.5		70.3									
09Ma										63.2									
09Mac1					34.8											51.3			
09Mac2		191.3			119.6							6.1				29.0			
09Mer					45.2											8.5			
09POO1	84.9	20.0		87.7	43397.0		73.1	475.07		758.2	670.0	64.5		646.1	193.1	5089.4	385.6	97.04	462.8
09Pri1					41.5					290.7									
09Pri2					103.4					26.6		154.3							
09Qui1		32.3		541.2	572.4					8.6			77.9	41.4	56.0	1300.5			
09Qui2				581.7	321.8		211.9						52.1	48.9	273.5	984.8		7.01	11.4
09Rid	58.2				46.9		64.6	10.9		57.5									
09SAWD					5056.1				15.0	175.9		2048.4		77.6	221.0	2774.3	237.8		42.3
09Watt1					571.2					38.1						30.2			
09Watt2					7230.8				9.7		11870.1				19.6				
09Watt3	465.6		42.00		14065.0	29.1		92.9	57.4	3660.4	286.6	20.78			651.3	11964.0	994.8		73.8
09You					60927.4	46.6			49.4	8480.6		8132.4			246.5	21.9	23.1		

Table 3: Total imperviousness, effective imperviousness, fish density, fish biomass, percent EPT density and fish richness for all sites.

Sites	SiteDensity (ind./m^2)	SiteBiomass (g/m^2)	Richness
09Bet1	0.22	0.64	1
09Bil1	1.28	0.58	1
09Ced1	0.52	0.25	3
09Crow	0.05	0.04	1
09Gill	0.71	0.38	1
09Ma	0.18	0.17	2
09Mac1	2.17	1.01	1
09Mac2	4.06	5.12	1
09Mer	3.52	3.10	2
09POO1	5.12	2.69	11
09Pri1	0.77	0.18	1
09Pri2	0.07	0.04	2
09Qui1	0.86	2.97	1
09Rid	0.16	0.13	2
09SAWD	1.05	2.28	7
09Watt3	0.36	1.89	3
09You	0.06	0.18	1

Table 4: Fish taxa density (ind./m^2) for all sites. Brook stickleback, St; Creek chub, Cr; Longnose Dace, Lo; Rock bass, Ba; White sucker, Su.

Sites	St	Cr	Lo	Ba	Su
09Bet1		0.22			
09Bil1	1.28				
09Ced1	0.34	0.15			0.04
09Crow	0.05				
09Gill	0.71				
09Ma	0.12				
09Mac1		2.17			
09Mac2		4.06			
09Mer	0.55				
09POO1	0.12	0.06		0.03	
09Pri1					
09Pri2				0.03	
09Qui1		0.86			
09Rid	0.08				
09SAWD		0.30	0.34	0.05	0.19
09Watt3		0.18	0.09		0.09
09You		0.06			

Appendix III — Raw data (chapter 3)

Table 1: Log_{10} mass (μ) and log_{10} density (ind./m^2) per size class for macroinvertebrates and fish for all sites. Size class mass, M; size class density, D.

	03C12		03C2		03C6		03C9		03CHE		03FOR		03LDS		03LDS2		03LMS		03M10		03M12	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.81	-0.39	3.98	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.58	-0.39	3.06	-0.39	3.06
0	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.95	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.71	-0.11	3.58	-0.11	2.82
1	0.18	3.04	0.18	2.96	0.18	2.58	0.18	2.58	0.18	4.31	0.18	3.12	0.18	3.38	0.18	2.58	0.18	4.29	0.18	2.58	0.18	2.58
2	0.46	2.91	0.46	2.33	0.46	3.46	0.46	3.66	0.46	4.07	0.46	3.38	0.46	3.26	0.46	2.71	0.46	4.25	0.46	3.28	0.46	2.33
3	0.77	2.12	0.77	2.86	0.77	3.05	0.77	3.50	0.77	3.99	0.77	3.46	0.77	2.92	0.77	3.20	0.77	4.13	0.77	2.69	0.77	3.21
4	1.07	3.08	1.07	3.15	1.07	2.58	1.07	3.50	1.07	3.80	1.07	3.47	1.07	3.06	1.07	3.30	1.07	3.66	1.07	1.88	1.07	3.08
5	1.38	3.17	1.38	3.10	1.38	3.23	1.38	3.66	1.38	3.78	1.38	3.32	1.38	3.01	1.38	3.52	1.38	3.49	1.38	2.72	1.38	3.64
6	1.68	3.03	1.68	3.16	1.68	3.21	1.68	3.61	1.68	3.52	1.68	3.24	1.68	3.20	1.68	3.33	1.68	3.45	1.68	3.17	1.68	3.75
7	1.95	3.21	1.95	3.15	1.95	3.01	1.95	3.43	1.95	3.45	1.95	3.04	1.95	2.87	1.95	3.24	1.95	3.40	1.95	3.17	1.95	3.53
8	2.26	2.71	2.26	2.78	2.26	2.17	2.26	3.07	2.26	3.26	2.26	1.72	2.26	2.65	2.26	2.42	2.26	2.98	2.26	3.27	2.26	3.55
9	2.56	2.33	2.56	2.28	2.56	1.33	2.56	3.12	2.56	3.03	2.56	1.92	2.56	2.30	2.56	1.33	2.56	2.76	2.56	2.60	2.56	3.62
10	2.86	1.30	2.86	2.76	2.86	2.12	2.86	2.95	2.86	2.27	2.86	2.28	2.86	2.17	2.86	1.81	2.86	2.40	2.86	2.38	2.86	2.91
11	3.16	1.27	3.16	2.50	3.16	1.27	3.16	2.84	3.16	1.82	3.16	1.89	3.16	1.91	3.16	1.27	3.16	2.08	3.16	2.19	3.16	2.74
12	3.46	2.13	3.46	2.09	3.46	1.77	3.46	2.38	3.46	2.40	3.46	1.23	3.46	1.86	3.46	1.64	3.46	2.12	3.46	1.87	3.46	2.07
13	3.74	1.73	3.74	1.22	3.74	1.22	3.74	1.90	3.74	1.62	3.74	1.22	3.74	1.57	3.74	1.22	3.74	1.22	3.74	1.69	3.74	1.74
14	4.06	1.18	4.06	1.58	4.06	1.18	4.06	1.66	4.06	1.57	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18
15	4.36	1.23	4.36	1.17	4.36	1.72	4.36	1.17	4.36	1.90	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.75	4.36	1.68	4.36	1.17
16	4.69	1.32	4.69	1.58	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.75	4.69	1.27	4.69	1.67
17	4.99	1.44	4.99	1.18	4.99	1.18	4.99	1.75	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.68	4.99	1.69
18	5.31	1.34	5.31	1.97	5.31	1.18	5.31	1.35	5.31	1.18	5.31	1.20	5.31	1.19	5.31	1.18	5.31	1.42	5.31	1.65	5.31	1.48
19	5.58	-0.21	5.58	2.48	5.58	-0.13	5.58	1.46	5.58	0.91	5.58	-0.11	5.58	0.83	5.58	-1.87	5.58	1.19	5.58	1.45	5.58	1.98
20	5.87	-1.87	5.87	2.37	5.87	0.77	5.87	0.73	5.87	1.21	5.87	0.89	5.87	-0.24	5.87	-1.00	5.87	1.19	5.87	0.38	5.87	1.77
21	6.18	-0.21	6.18	1.76	6.18	0.47	6.18	0.99	6.18	0.95	6.18	0.36	6.18	0.23	6.18	-1.87	6.18	0.79	6.18	0.92	6.18	1.01
22	6.44	-1.87	6.44	1.22	6.44	-1.87	6.44	0.93	6.44	0.61	6.44	-1.87	6.44	0.05	6.44	-1.87	6.44	0.02	6.44	0.92	6.44	0.93
23	6.75	0.09	6.75	-1.87	6.75	0.35	6.75	0.04	6.75	0.21	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	0.02	6.75	-1.87	6.75	-1.87
24	7.05	-0.21	7.05	-1.87	7.05	-0.13	7.05	-1.87	7.05	-0.09	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	03M14		03MEE		03Mine1		05BEC		05C2		05CHE		05DEST		05DT0		05DT2		05LDS		05LDS2	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.29	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.69	-0.70	4.21
-1	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	4.20	-0.39	3.06	-0.39	3.88	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.98
0	-0.11	3.53	-0.11	3.47	-0.11	2.82	-0.11	3.91	-0.11	2.82	-0.11	3.40	-0.11	2.82	-0.11	2.82	-0.11	3.71	-0.11	3.23	-0.11	4.10
1	0.18	3.23	0.18	3.75	0.18	3.49	0.18	4.32	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	3.65	0.18	2.98	0.18	2.58
2	0.46	2.33	0.46	3.41	0.46	3.51	0.46	4.13	0.46	2.33	0.46	3.55	0.46	2.33	0.46	2.33	0.46	4.03	0.46	2.33	0.46	2.33
3	0.77	2.55	0.77	3.47	0.77	3.03	0.77	4.27	0.77	3.49	0.77	3.18	0.77	2.50	0.77	2.12	0.77	3.82	0.77	3.20	0.77	2.12
4	1.07	3.24	1.07	3.17	1.07	3.64	1.07	4.13	1.07	3.08	1.07	2.99	1.07	3.06	1.07	1.88	1.07	3.65	1.07	3.40	1.07	2.73
5	1.38	3.06	1.38	2.82	1.38	3.69	1.38	4.07	1.38	2.91	1.38	2.95	1.38	2.99	1.38	2.28	1.38	3.66	1.38	3.05	1.38	2.98
6	1.68	3.29	1.68	3.08	1.68	3.51	1.68	4.19	1.68	3.31	1.68	3.06	1.68	2.93	1.68	1.96	1.68	3.42	1.68	3.04	1.68	3.13
7	1.95	2.88	1.95	3.39	1.95	3.34	1.95	4.09	1.95	2.90	1.95	2.66	1.95	3.12	1.95	2.27	1.95	3.37	1.95	3.04	1.95	3.04
8	2.26	2.85	2.26	3.23	2.26	3.12	2.26	3.91	2.26	2.51	2.26	2.67	2.26	2.78	2.26	2.25	2.26	3.12	2.26	2.99	2.26	2.31
9	2.56	2.57	2.56	2.81	2.56	3.33	2.56	3.48	2.56	1.74	2.56	2.32	2.56	2.47	2.56	1.73	2.56	2.84	2.56	2.56	2.56	1.33
10	2.86	2.10	2.86	2.37	2.86	3.33	2.86	3.23	2.86	1.30	2.86	2.22	2.86	1.68	2.86	1.98	2.86	2.39	2.86	2.17	2.86	1.98
11	3.16	2.17	3.16	2.48	3.16	3.19	3.16	3.22	3.16	1.79	3.16	1.72	3.16	1.27	3.16	1.74	3.16	2.86	3.16	2.41	3.16	1.27
12	3.46	1.64	3.46	2.07	3.46	2.74	3.46	3.16	3.46	1.23	3.46	1.23	3.46	1.66	3.46	1.74	3.46	2.98	3.46	1.23	3.46	1.23
13	3.74	1.98	3.74	1.81	3.74	2.05	3.74	2.84	3.74	1.22	3.74	1.22	3.74	1.28	3.74	1.22	3.74	2.49	3.74	1.22	3.74	1.22
14	4.06	1.18	4.06	1.30	4.06	2.32	4.06	2.07	4.06	1.18	4.06	1.74	4.06	1.68	4.06	1.18	4.06	1.67	4.06	1.18	4.06	1.18
15	4.36	1.17	4.36	1.48	4.36	1.90	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.36	4.36	1.17	4.36	1.52	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.57	4.69	1.15	4.69	1.79	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.24	4.69	1.40	4.69	1.17	4.69	1.15
17	4.99	1.18	4.99	1.28	4.99	1.20	4.99	1.95	4.99	1.18	4.99	1.18	4.99	1.25	4.99	1.23	4.99	1.36	4.99	1.18	4.99	1.18
18	5.31	1.18	5.31	1.61	5.31	1.25	5.31	1.67	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.43	5.31	1.23	5.31	1.18	5.31	1.18
19	5.58	-0.78	5.58	0.38	5.58	0.90	5.58	2.01	5.58	-1.87	5.58	0.22	5.58	0.14	5.58	0.54	5.58	-1.87	5.58	0.76	5.58	-1.87
20	5.87	-0.50	5.87	0.93	5.87	-0.26	5.87	2.22	5.87	1.08	5.87	0.78	5.87	1.21	5.87	0.71	5.87	1.18	5.87	-0.19	5.87	-1.87
21	6.18	-0.11	6.18	1.34	6.18	-1.87	6.18	1.97	6.18	1.18	6.18	0.86	6.18	1.56	6.18	1.38	6.18	1.31	6.18	0.41	6.18	-1.87
22	6.44	-0.78	6.44	0.68	6.44	-1.87	6.44	0.51	6.44	0.75	6.44	0.52	6.44	1.41	6.44	0.24	6.44	1.31	6.44	-1.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-0.09	6.75	-1.87	6.75	0.14	6.75	0.24	6.75	-1.87	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	0.14	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	0.51	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	05LMS		05MEE		05MO		05MOS		05SAWD		08C6		08C6b		08C9		08CHE		08DesFeesO		08DesLoups	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	4.13	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	4.34	-0.39	3.56	-0.39	3.06	-0.39	3.67	-0.39	3.5
0	-0.11	3.32	-0.11	3.58	-0.11	2.82	-0.11	3.26	-0.11	2.82	-0.11	3.46	-0.11	2.82	-0.11	3.76	-0.11	2.82	-0.11	3.38	-0.11	3.33
1	0.18	2.58	0.18	3.37	0.18	2.58	0.18	3.12	0.18	3.76	0.18	3.25	0.18	4.05	0.18	4.10	0.18	3.31	0.18	3.87	0.18	2.58
2	0.46	3.32	0.46	2.33	0.46	2.33	0.46	3.90	0.46	2.33	0.46	3.33	0.46	3.92	0.46	3.48	0.46	3.52	0.46	3.35	0.46	3.40
3	0.77	3.50	0.77	2.55	0.77	3.10	0.77	3.78	0.77	2.12	0.77	3.32	0.77	2.12	0.77	3.70	0.77	2.98	0.77	2.94	0.77	3.41
4	1.07	3.51	1.07	2.73	1.07	3.16	1.07	3.39	1.07	2.8	1.07	2.98	1.07	2.48	1.07	3.43	1.07	3.10	1.07	3.48	1.07	2.84
5	1.38	3.85	1.38	2.43	1.38	3.14	1.38	3.47	1.38	2.56	1.38	2.98	1.38	1.66	1.38	3.1	1.38	2.88	1.38	3.33	1.38	3.12
6	1.68	4.07	1.68	2.54	1.68	2.38	1.68	3.63	1.68	2.95	1.68	2.07	1.68	2.81	1.68	3.47	1.68	3.21	1.68	3.30	1.68	3.22
7	1.95	3.61	1.95	2.92	1.95	2.36	1.95	3.46	1.95	2.93	1.95	2.25	1.95	2.45	1.95	3.37	1.95	3.18	1.95	3.25	1.95	3.42
8	2.26	3.41	2.26	3.00	2.26	2.5	2.26	3.56	2.26	2.73	2.26	1.87	2.26	2.32	2.26	3.58	2.26	2.59	2.26	2.85	2.26	3.33
9	2.56	2.95	2.56	2.54	2.56	2.42	2.56	3.49	2.56	2.21	2.56	2.14	2.56	2.01	2.56	3.38	2.56	3.14	2.56	1.84	2.56	3.10
10	2.86	2.79	2.86	2.37	2.86	2.03	2.86	3.14	2.86	1.30	2.86	2.40	2.86	1.85	2.86	3.07	2.86	2.87	2.86	2.73	2.86	2.79
11	3.16	2.47	3.16	2.42	3.16	2.17	3.16	3.02	3.16	1.27	3.16	2.12	3.16	1.97	3.16	2.84	3.16	2.48	3.16	2.34	3.16	2.20
12	3.46	2.53	3.46	2.40	3.46	1.91	3.46	3.02	3.46	1.23	3.46	1.96	3.46	1.23	3.46	2.42	3.46	2.27	3.46	1.23	3.46	2.40
13	3.74	1.95	3.74	2.08	3.74	1.22	3.74	2.70	3.74	1.68	3.74	1.74	3.74	1.22	3.74	1.94	3.74	1.22	3.74	1.22	3.74	2.08
14	4.06	1.43	4.06	1.76	4.06	1.18	4.06	2.07	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.23	4.06	1.18	4.06	1.18	4.06	2.07
15	4.36	1.31	4.36	1.21	4.36	1.17	4.36	1.36	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	2.17	4.69	1.29	4.69	1.15	4.69	2.38	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	2.52	4.99	1.22	4.99	1.31	4.99	1.91	4.99	1.27	4.99	1.18	4.99	1.26	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	2.62	5.31	1.18	5.31	1.25	5.31	2.69	5.31	1.26	5.31	1.18	5.31	1.37	5.31	1.33	5.31	1.18	5.31	1.18	5.31	1.18
19	5.58	2.53	5.58	0.18	5.58	0.90	5.58	2.08	5.58	0.39	5.58	-0.67	5.58	0.68	5.58	1.42	5.58	-0.05	5.58	-1.87	5.58	-1.87
20	5.87	1.66	5.87	0.92	5.87	1.20	5.87	1.89	5.87	0.22	5.87	-0.38	5.87	-1.87	5.87	1.86	5.87	0.94	5.87	-1.87	5.87	-1.87
21	6.18	1.71	6.18	2.09	6.18	1.67	6.18	1.56	6.18	0.99	6.18	-1.87	6.18	-0.02	6.18	1.72	6.18	1.28	6.18	-1.87	6.18	-1.87
22	6.44	1.06	6.44	0.48	6.44	1.35	6.44	1.49	6.44	1.12	6.44	-1.87	6.44	-1.87	6.44	0.80	6.44	0.24	6.44	-1.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	0.60	6.75	1.49	6.75	-1.87	6.75	-1.87	6.75	-0.02	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	0.13	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	0.13	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	08Eardley1		08Eardley2		08Fortune1		08Fortune2		08Fortune3		08Gat1		08Kingsmere		08LaPeche		08LaPeche2		08Loutre		08LUS2	
	M	D	M	D	M	D	M	D	M	D	M	D	D	D	D	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.52	-0.70	3.61	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	4.11	-0.39	3.06	-0.39	3.06	-0.39	4.12	-0.39	3.06	-0.39	3.06	-0.39	3.06
0	-0.11	3.80	-0.11	3.51	-0.11	3.81	-0.11	2.82	-0.11	4.14	-0.11	3.44	-0.11	2.82	-0.11	4.01	-0.11	2.82	-0.11	2.82	-0.11	2.82
1	0.18	4.46	0.18	3.81	0.18	4.08	0.18	3.61	0.18	3.48	0.18	2.58	0.18	3.23	0.18	4.16	0.18	2.58	0.18	2.58	0.18	2.58
2	0.46	4.02	0.46	3.54	0.46	3.57	0.46	3.32	0.46	3.41	0.46	2.93	0.46	2.33	0.46	4.33	0.46	2.81	0.46	3.07	0.46	3.62
3	0.77	3.87	0.77	3.33	0.77	2.80	0.77	2.91	0.77	3.88	0.77	3.42	0.77	2.82	0.77	3.55	0.77	2.87	0.77	3.02	0.77	2.12
4	1.07	3.16	1.07	2.93	1.07	2.74	1.07	1.88	1.07	3.62	1.07	2.47	1.07	2.53	1.07	3.13	1.07	1.88	1.07	3.11	1.07	1.88
5	1.38	3.18	1.38	2.94	1.38	2.48	1.38	1.66	1.38	3.53	1.38	2.31	1.38	2.70	1.38	2.75	1.38	1.66	1.38	2.97	1.38	2.83
6	1.68	3.37	1.68	2.58	1.68	2.36	1.68	2.41	1.68	3.59	1.68	2.06	1.68	1.50	1.68	3.04	1.68	2.40	1.68	3.34	1.68	2.42
7	1.95	3.20	1.95	2.85	1.95	2.47	1.95	2.54	1.95	3.69	1.95	2.07	1.95	2.55	1.95	2.57	1.95	2.05	1.95	2.99	1.95	2.35
8	2.26	3.09	2.26	2.72	2.26	2.43	2.26	2.24	2.26	3.56	2.26	2.36	2.26	2.23	2.26	2.82	2.26	2.02	2.26	3.01	2.26	1.99
9	2.56	2.83	2.56	2.65	2.56	2.75	2.56	2.32	2.56	3.14	2.56	1.33	2.56	2.63	2.56	3.07	2.56	2.42	2.56	2.94	2.56	1.86
10	2.86	2.59	2.86	2.70	2.86	2.25	2.86	1.30	2.86	2.66	2.86	2.12	2.86	2.25	2.86	2.81	2.86	2.36	2.86	2.60	2.86	1.30
11	3.16	2.55	3.16	2.5	3.16	1.27	3.16	1.27	3.16	2.59	3.16	1.27	3.16	1.78	3.16	2.66	3.16	2.17	3.16	2.74	3.16	2.00
12	3.46	1.91	3.46	2.22	3.46	1.71	3.46	1.23	3.46	2.09	3.46	1.23	3.46	1.23	3.46	2.23	3.46	1.81	3.46	2.40	3.46	1.23
13	3.74	1.22	3.74	1.22	3.74	1.22	3.74	1.22	3.74	1.94	3.74	1.22	3.74	1.22	3.74	1.65	3.74	1.22	3.74	2.48	3.74	1.22
14	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.59	4.06	1.60	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.77	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.20	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.36	5.31	1.29	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.19	5.31	1.18	5.31	1.18
19	5.58	0.35	5.58	0.64	5.58	-1.87	5.58	-1.87	5.58	1.28	5.58	-1.87	5.58	-1.87	5.58	-0.86	5.58	-0.18	5.58	-0.07	5.58	-1.87
20	5.87	-1.87	5.87	0.10	5.87	-1.87	5.87	-1.87	5.87	1.46	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	0.29	5.87	-0.59	5.87	-1.87
21	6.18	0.42	6.18	0.58	6.18	-1.87	6.18	-0.39	6.18	1.08	6.18	-1.87	6.18	-1.87	6.18	-0.86	6.18	-0.18	6.18	-0.3	6.18	-1.87
22	6.44	-1.87	6.44	0.28	6.44	-1.87	6.44	-0.56	6.44	0.24	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-0.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-0.89	6.75	-1.87	6.75	-0.18	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-0.89	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-0.89	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	08Meech1		08Meech2		08Meech3		08Meech4		08Mine1		08Mine3		08Notch		08Renaud1		08Renaud2		08Taylor		09Bet1	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.7	3.37	-0.70	4.06	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	3.78	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06
0	-0.11	2.82	-0.11	3.42	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.94	-0.11	2.82	-0.11	2.82
1	0.18	3.98	0.18	3.46	0.18	2.58	0.18	2.58	0.18	3.27	0.18	3.14	0.18	3.18	0.18	3.23	0.18	3.02	0.18	2.58	0.18	2.58
2	0.46	3.96	0.46	4.01	0.46	2.33	0.46	2.33	0.46	4.04	0.46	2.33	0.46	3.72	0.46	3.37	0.46	3.12	0.46	3.71	0.46	2.33
3	0.77	3.70	0.77	3.67	0.77	3.21	0.77	2.80	0.77	3.75	0.77	2.94	0.77	2.87	0.77	2.99	0.77	3.21	0.77	3.42	0.77	2.12
4	1.07	3.19	1.07	3.15	1.07	1.88	1.07	1.88	1.07	3.15	1.07	1.88	1.07	2.49	1.07	2.56	1.07	2.82	1.07	3.11	1.07	2.52
5	1.38	2.45	1.38	2.76	1.38	1.66	1.38	1.66	1.38	3.31	1.38	2.89	1.38	1.66	1.38	2.91	1.38	2.60	1.38	3.06	1.38	2.81
6	1.68	2.68	1.68	2.77	1.68	1.50	1.68	1.50	1.68	3.16	1.68	2.07	1.68	2.65	1.68	2.85	1.68	3.12	1.68	3.03	1.68	3.33
7	1.95	2.86	1.95	2.28	1.95	2.51	1.95	2.38	1.95	3.10	1.95	2.02	1.95	2.67	1.95	2.82	1.95	2.85	1.95	3.24	1.95	2.76
8	2.26	2.75	2.26	2.96	2.26	2.10	2.26	2.13	2.26	3.50	2.26	2.22	2.26	2.74	2.26	2.42	2.26	2.51	2.26	3.57	2.26	1.40
9	2.56	1.73	2.56	2.40	2.56	1.80	2.56	1.33	2.56	3.47	2.56	2.16	2.56	2.3	2.56	1.97	2.56	2.24	2.56	3.62	2.56	1.33
10	2.86	1.69	2.86	2.16	2.86	1.30	2.86	1.30	2.86	3.57	2.86	2.50	2.86	2.38	2.86	2.23	2.86	2.19	2.86	3.55	2.86	1.30
11	3.16	1.79	3.16	2.48	3.16	1.27	3.16	1.27	3.16	3.29	3.16	2.32	3.16	2.00	3.16	2.29	3.16	1.70	3.16	3.27	3.16	1.27
12	3.46	1.23	3.46	1.81	3.46	1.88	3.46	2.04	3.46	2.68	3.46	2.28	3.46	1.23	3.46	1.23	3.46	1.66	3.46	2.93	3.46	1.23
13	3.74	1.65	3.74	1.22	3.74	1.22	3.74	1.22	3.74	2.50	3.74	1.77	3.74	1.22	3.74	1.22	3.74	1.22	3.74	2.43	3.74	1.22
14	4.06	1.63	4.06	1.18	4.06	1.18	4.06	1.18	4.06	2.32	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	2.22	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.66	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.26	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.42	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.22	5.31	1.18
19	5.58	-0.66	5.58	-1.87	5.58	0.94	5.58	-1.87	5.58	1.72	5.58	-1.87	5.58	-0.46	5.58	-0.47	5.58	-0.29	5.58	0.85	5.58	-1.87
20	5.87	-0.37	5.87	-1.87	5.87	1.44	5.87	-1.87	5.87	2.04	5.87	-1.87	5.87	-0.46	5.87	-0.47	5.87	0.95	5.87	-0.14	5.87	-1.87
21	6.18	-0.66	6.18	-0.21	6.18	0.70	6.18	-1.87	6.18	1.61	6.18	-1.87	6.18	-0.17	6.18	-1.87	6.18	-0.29	6.18	0.69	6.18	-0.64
22	6.44	-0.66	6.44	-1.87	6.44	0.70	6.44	-1.87	6.44	1.42	6.44	-1.87	6.44	-0.46	6.44	-1.87	6.44	-1.87	6.44	0.33	6.44	-0.18
23	6.75	-0.66	6.75	-1.87	6.75	0.40	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-0.46	6.75	-1.87	6.75	-1.87	6.75	-0.14	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-0.14	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-0.14	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	09Bet2		09Bet3		09Bil1		09Bil2		09Blai		09Ced1		09Ced2		09Crow		09Fau		09Gill		09Her1	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.14	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.43	-0.39	3.06	-0.39	3.06	-0.39	3.89	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06
0	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	4.27	-0.11	4.05	-0.11	2.82	-0.11	3.32	-0.11	2.82
1	0.18	2.58	0.18	2.58	0.18	3.48	0.18	3.05	0.18	2.58	0.18	2.58	0.18	4.20	0.18	4.14	0.18	2.83	0.18	3.55	0.18	2.58
2	0.46	2.81	0.46	2.33	0.46	3.46	0.46	2.33	0.46	2.33	0.46	2.75	0.46	3.33	0.46	4.05	0.46	2.33	0.46	3.49	0.46	2.33
3	0.77	2.88	0.77	2.12	0.77	3.17	0.77	2.46	0.77	2.55	0.77	2.54	0.77	3.85	0.77	3.88	0.77	2.35	0.77	3.40	0.77	2.12
4	1.07	2.90	1.07	2.16	1.07	3.67	1.07	3.02	1.07	2.42	1.07	1.88	1.07	3.81	1.07	3.87	1.07	1.88	1.07	3.04	1.07	2.27
5	1.38	2.95	1.38	2.02	1.38	3.16	1.38	2.41	1.38	2.35	1.38	3.15	1.38	3.80	1.38	3.76	1.38	1.66	1.38	2.72	1.38	1.66
6	1.68	3.10	1.68	2.33	1.68	3.39	1.68	2.44	1.68	2.91	1.68	3.78	1.68	3.81	1.68	3.75	1.68	1.81	1.68	2.97	1.68	2.07
7	1.95	2.71	1.95	2.96	1.95	3.63	1.95	2.66	1.95	2.59	1.95	3.94	1.95	3.67	1.95	3.64	1.95	2.41	1.95	2.87	1.95	2.26
8	2.26	2.95	2.26	2.89	2.26	3.62	2.26	2.85	2.26	1.91	2.26	3.70	2.26	3.42	2.26	3.70	2.26	2.31	2.26	2.26	2.26	1.40
9	2.56	2.88	2.56	2.55	2.56	3.65	2.56	2.81	2.56	1.33	2.56	3.71	2.56	3.17	2.56	3.66	2.56	2.12	2.56	2.40	2.56	1.33
10	2.86	2.77	2.86	2.25	2.86	3.39	2.86	2.42	2.86	1.92	2.86	3.45	2.86	2.78	2.86	3.39	2.86	1.90	2.86	2.09	2.86	1.30
11	3.16	2.49	3.16	2.30	3.16	3.33	3.16	2.48	3.16	1.72	3.16	2.22	3.16	2.24	3.16	3.08	3.16	2.24	3.16	1.85	3.16	1.27
12	3.46	2.45	3.46	1.23	3.46	3.07	3.46	2.15	3.46	1.23	3.46	1.23	3.46	1.84	3.46	2.88	3.46	1.98	3.46	2.11	3.46	1.23
13	3.74	1.22	3.74	1.98	3.74	2.83	3.74	1.79	3.74	1.22	3.74	1.69	3.74	2.18	3.74	2.40	3.74	1.62	3.74	1.22	3.74	1.22
14	4.06	1.68	4.06	1.71	4.06	2.43	4.06	1.50	4.06	1.18	4.06	1.18	4.06	1.18	4.06	2.13	4.06	1.18	4.06	1.87	4.06	1.18
15	4.36	1.17	4.36	1.52	4.36	1.64	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.77	4.36	1.81	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.70	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.18	5.31	1.18	5.31	1.21	5.31	1.18	5.31	1.18	5.31	1.21	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18
19	5.58	-1.87	5.58	-1.87	5.58	1.28	5.58	-1.87	5.58	-1.87	5.58	0.67	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	0.70	5.58	-1.87
20	5.87	-1.87	5.87	-1.87	5.87	1.01	5.87	-1.87	5.87	-1.87	5.87	0.02	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	0.80	5.87	-1.87
21	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-0.27	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87
22	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	09Her2		09Jar		09Ma		09Mac1		09Mac2		09Mer		09POO1		09Pri1		09Pri2		09Qui1		09Qui2	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.6	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	4.13	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06
0	-0.11	3.02	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	4.59	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82
1	0.18	3.94	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	4.59	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58
2	0.46	3.75	0.46	2.33	0.46	2.33	0.46	2.33	0.46	2.33	0.46	2.33	0.46	4.65	0.46	2.33	0.46	2.33	0.46	2.6	0.46	2.95
3	0.77	3.72	0.77	2.12	0.77	2.12	0.77	2.12	0.77	2.12	0.77	2.44	0.77	4.44	0.77	2.12	0.77	2.12	0.77	2.92	0.77	2.42
4	1.07	3.66	1.07	1.88	1.07	1.88	1.07	2.28	1.07	1.88	1.07	1.88	1.07	4.26	1.07	1.88	1.07	2.48	1.07	2.78	1.07	2.82
5	1.38	3.69	1.38	2.22	1.38	1.66	1.38	1.66	1.38	2.29	1.38	1.66	1.38	4.35	1.38	1.66	1.38	2.14	1.38	2.59	1.38	2.85
6	1.68	3.27	1.68	1.96	1.68	2.03	1.68	1.50	1.68	2.48	1.68	1.50	1.68	3.94	1.68	1.77	1.68	1.96	1.68	3.18	1.68	2.88
7	1.95	3.18	1.95	1.46	1.95	1.94	1.95	1.98	1.95	1.94	1.95	1.46	1.95	3.76	1.95	2.43	1.95	2.67	1.95	3.06	1.95	3.12
8	2.26	2.94	2.26	1.82	2.26	1.40	2.26	1.80	2.26	1.73	2.26	1.40	2.26	3.77	2.26	2.39	2.26	2.21	2.26	3.18	2.26	3.36
9	2.56	2.89	2.56	1.33	2.56	2.14	2.56	1.72	2.56	2.22	2.56	1.33	2.56	3.69	2.56	2.61	2.56	2.26	2.56	3.28	2.56	3.2
10	2.86	1.62	2.86	1.84	2.86	1.30	2.86	1.71	2.86	2.11	2.86	1.68	2.86	3.66	2.86	2.29	2.86	1.30	2.86	2.83	2.86	2.79
11	3.16	2.34	3.16	1.27	3.16	1.27	3.16	1.27	3.16	2.75	3.16	1.27	3.16	3.11	3.16	1.80	3.16	1.27	3.16	2.52	3.16	2.73
12	3.46	1.76	3.46	1.23	3.46	1.23	3.46	1.23	3.46	1.71	3.46	1.23	3.46	3.12	3.46	1.23	3.46	1.23	3.46	2.47	3.46	2.36
13	3.74	1.69	3.74	1.22	3.74	1.22	3.74	1.22	3.74	1.22	3.74	1.22	3.74	2.04	3.74	1.22	3.74	1.22	3.74	1.55	3.74	1.22
14	4.06	1.18	4.06	1.56	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.67	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.71	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.38	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.31	4.99	1.25	4.99	1.18	4.99	2.02	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.70	5.31	1.68	5.31	1.18	5.31	2.51	5.31	1.29	5.31	1.18	5.31	1.18	5.31	1.18
19	5.58	-1.87	5.58	-1.87	5.58	-0.72	5.58	0.95	5.58	1.48	5.58	1.51	5.58	2.24	5.58	0.19	5.58	-1.87	5.58	-1.87	5.58	-1.87
20	5.87	-1.87	5.87	-1.87	5.87	-0.72	5.87	0.25	5.87	-1.87	5.87	2.05	5.87	2.2	5.87	-1.87	5.87	-1.09	5.87	-1.87	5.87	-1.87
21	6.18	-1.87	6.18	-1.87	6.18	-0.72	6.18	0.55	6.18	1.92	6.18	1.92	6.18	1.95	6.18	-1.87	6.18	-1.87	6.18	0.54	6.18	-1.87
22	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	0.55	6.44	0.70	6.44	-1.87	6.44	1.30	6.44	-1.87	6.44	-1.87	6.44	0.72	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	0.88	6.75	-1.87	6.75	0.70	6.75	-1.87	6.75	-1.87	6.75	0.72	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	09Rid		09SAWD		09Watt1		09Watt2		09Watt3		09You		20017BEA		20017BRA		20017GRE		20017JR-01		20017MOS	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.3	-0.70	3.37	-0.70	3.37	-0.70	4.43	-0.70	4.30	-0.70	4.83
-1	-0.39	3.06	-0.39	3.78	-0.39	3.06	-0.39	4.05	-0.39	3.06	-0.39	3.98	-0.39	3.06	-0.39	4.46	-0.39	4.5	-0.39	4.40	-0.39	4.64
0	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.64	-0.11	3.66	-0.11	4.16	-0.11	2.82	-0.11	4.24	-0.11	3.95	-0.11	4.55	-0.11	4.87
1	0.18	2.58	0.18	3.73	0.18	3.01	0.18	4.27	0.18	4.13	0.18	4.79	0.18	4.54	0.18	4.76	0.18	4.22	0.18	4.58	0.18	5.18
2	0.46	2.33	0.46	3.58	0.46	3.05	0.46	4.01	0.46	4.14	0.46	4.67	0.46	4.61	0.46	4.83	0.46	4.33	0.46	4.59	0.46	5.35
3	0.77	2.12	0.77	3.58	0.77	2.12	0.77	3.84	0.77	4.18	0.77	4.48	0.77	4.39	0.77	4.80	0.77	3.98	0.77	4.77	0.77	5.41
4	1.07	1.88	1.07	3.33	1.07	2.22	1.07	3.66	1.07	4.23	1.07	4.26	1.07	4.61	1.07	4.62	1.07	4.09	1.07	4.64	1.07	5.35
5	1.38	2.41	1.38	3.38	1.38	2.03	1.38	3.35	1.38	4.21	1.38	4.05	1.38	4.30	1.38	4.25	1.38	4.22	1.38	4.53	1.38	5.05
6	1.68	2.09	1.68	3.43	1.68	2.55	1.68	3.25	1.68	3.95	1.68	4.06	1.68	4.20	1.68	3.98	1.68	4.13	1.68	4.34	1.68	4.78
7	1.95	2.23	1.95	3.58	1.95	1.46	1.95	2.18	1.95	3.96	1.95	4.05	1.95	4.06	1.95	3.69	1.95	4.00	1.95	4.10	1.95	4.51
8	2.26	2.22	2.26	3.45	2.26	1.40	2.26	2.46	2.26	3.73	2.26	3.73	2.26	3.93	2.26	3.46	2.26	3.84	2.26	4.03	2.26	4.13
9	2.56	1.67	2.56	3.39	2.56	1.33	2.56	1.33	2.56	3.66	2.56	3.39	2.56	3.91	2.56	3.52	2.56	3.54	2.56	3.66	2.56	3.83
10	2.86	2.36	2.86	3.12	2.86	1.3	2.86	1.30	2.86	3.55	2.86	3.04	2.86	3.90	2.86	3.22	2.86	3.40	2.86	3.47	2.86	3.50
11	3.16	2.39	3.16	2.90	3.16	1.72	3.16	1.70	3.16	3.39	3.16	2.63	3.16	3.92	3.16	3.17	3.16	3.41	3.16	3.38	3.16	3.52
12	3.46	1.76	3.46	2.74	3.46	1.70	3.46	1.23	3.46	2.96	3.46	2.31	3.46	3.55	3.46	3.08	3.46	3.35	3.46	3.09	3.46	3.45
13	3.74	1.56	3.74	2.45	3.74	1.90	3.74	1.22	3.74	2.60	3.74	1.22	3.74	3.05	3.74	3.01	3.74	3.36	3.74	2.81	3.74	3.30
14	4.06	1.18	4.06	1.80	4.06	1.18	4.06	1.18	4.06	2.17	4.06	1.94	4.06	2.71	4.06	2.35	4.06	2.50	4.06	2.29	4.06	2.17
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.65	4.36	1.17	4.36	1.91
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.25	4.69	1.98
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.98	4.99	1.18	4.99	1.18	4.99	1.18	4.99	2.34
18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.96	5.31	2.78	5.31	1.18	5.31	1.27	5.31	1.97
19	5.58	-0.75	5.58	0.62	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	0.83	5.58	3.23	5.58	1.03	5.58	2.46	5.58	1.95
20	5.87	-1.87	5.87	1.02	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.15	5.87	1.24	5.87	3.17	5.87	0.78	5.87	2.94	5.87	1.80
21	6.18	-0.75	6.18	1.32	6.18	-1.87	6.18	-1.87	6.18	0.26	6.18	-1.15	6.18	1.29	6.18	2.79	6.18	1.68	6.18	2.26	6.18	1.80
22	6.44	-1.87	6.44	1.48	6.44	-1.87	6.44	-1.87	6.44	0.17	6.44	-1.87	6.44	0.29	6.44	2.22	6.44	1.62	6.44	2.52	6.44	0.57
23	6.75	-1.87	6.75	0.03	6.75	-1.87	6.75	-1.87	6.75	0.04	6.75	-1.15	6.75	0.83	6.75	2.13	6.75	1.48	6.75	1.70	6.75	1.35
24	7.05	-1.87	7.05	0.03	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	0.46	7.05	1.80	7.05	0.56	7.05	1.03	7.05	0.57
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-0.42	7.38	-1.87	7.38	0.69	7.38	1.02	7.38	-1.87	7.38	0.86	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-0.01	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	20017NCR		20017SAWD		20017TAYD		20017You		20018BLA		20018CHE		20018COR		20018DESF		20018DEST		20018LAP		20018Mine1	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.50	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	4.43	-0.70	3.37
-1	-0.39	4.13	-0.39	4.25	-0.39	3.06	-0.39	4.35	-0.39	4.4	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	4.85	-0.39	3.06
0	-0.11	4.22	-0.11	4.56	-0.11	2.82	-0.11	4.60	-0.11	4.48	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	5.01	-0.11	2.82
1	0.18	5.01	0.18	4.57	0.18	2.97	0.18	5.07	0.18	4.88	0.18	3.73	0.18	3.94	0.18	2.58	0.18	3.81	0.18	4.82	0.18	2.58
2	0.46	4.95	0.46	4.53	0.46	2.33	0.46	5.32	0.46	4.95	0.46	3.42	0.46	4.77	0.46	2.33	0.46	4.31	0.46	4.58	0.46	2.33
3	0.77	4.90	0.77	4.54	0.77	3.76	0.77	5.50	0.77	4.67	0.77	2.12	0.77	4.53	0.77	3.13	0.77	3.39	0.77	4.22	0.77	2.12
4	1.07	4.62	1.07	4.38	1.07	3.57	1.07	5.66	1.07	4.54	1.07	3.21	1.07	4.39	1.07	3.01	1.07	3.76	1.07	4.24	1.07	1.88
5	1.38	4.45	1.38	4.50	1.38	3.79	1.38	5.61	1.38	4.33	1.38	2.96	1.38	3.85	1.38	3.05	1.38	2.92	1.38	3.17	1.38	1.66
6	1.68	4.36	1.68	4.36	1.68	4.02	1.68	5.48	1.68	4.07	1.68	3.29	1.68	4.00	1.68	2.72	1.68	3.09	1.68	3.35	1.68	2.01
7	1.95	4.14	1.95	4.26	1.95	3.93	1.95	5.23	1.95	3.69	1.95	1.46	1.95	3.68	1.95	2.61	1.95	3.24	1.95	3.46	1.95	2.63
8	2.26	4.14	2.26	3.87	2.26	3.78	2.26	4.80	2.26	3.51	2.26	1.98	2.26	3.56	2.26	2.36	2.26	2.65	2.26	3.42	2.26	1.40
9	2.56	4.03	2.56	3.47	2.56	3.51	2.56	4.12	2.56	3.33	2.56	2.35	2.56	3.6	2.56	2.27	2.56	2.81	2.56	3.23	2.56	1.33
10	2.86	3.78	2.86	3.47	2.86	3.56	2.86	3.24	2.86	3.16	2.86	1.30	2.86	3.48	2.86	2.11	2.86	2.84	2.86	2.96	2.86	1.30
11	3.16	3.76	3.16	3.23	3.16	3.40	3.16	3.11	3.16	3.15	3.16	1.27	3.16	3.09	3.16	1.27	3.16	2.25	3.16	1.98	3.16	1.27
12	3.46	3.62	3.46	2.84	3.46	3.43	3.46	2.50	3.46	3.04	3.46	1.23	3.46	2.71	3.46	1.89	3.46	1.23	3.46	2.22	3.46	2.41
13	3.74	3.21	3.74	2.15	3.74	2.71	3.74	1.22	3.74	2.61	3.74	1.87	3.74	2.59	3.74	1.82	3.74	1.22	3.74	1.99	3.74	1.22
14	4.06	2.49	4.06	1.18	4.06	2.06	4.06	1.18	4.06	1.18	4.06	2.11	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	2.13	4.36	1.17	4.36	1.90	4.36	1.74	4.36	1.17	4.36	1.17
16	4.69	1.25	4.69	1.15	4.69	1.25	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.29	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.26	4.99	1.42	4.99	1.18	4.99	1.47	4.99	1.22	4.99	1.31	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.28	5.31	1.69	5.31	1.71	5.31	1.18	5.31	2.11	5.31	1.24	5.31	1.31	5.31	1.18	5.31	2.25	5.31	1.18	5.31	1.20
19	5.58	1.58	5.58	0.84	5.58	2.24	5.58	-1.87	5.58	2.20	5.58	1.03	5.58	2.23	5.58	-1.87	5.58	2.49	5.58	0.48	5.58	1.22
20	5.87	2.00	5.87	1.25	5.87	1.91	5.87	-1.87	5.87	2.65	5.87	0.55	5.87	2.02	5.87	-1.87	5.87	2.59	5.87	0.48	5.87	0.42
21	6.18	2.50	6.18	1.25	6.18	1.17	6.18	-0.79	6.18	2.55	6.18	0.08	6.18	2.71	6.18	-1.87	6.18	2.59	6.18	1.39	6.18	0.90
22	6.44	2.55	6.44	1.37	6.44	0.87	6.44	-1.87	6.44	2.59	6.44	1.25	6.44	2.28	6.44	-1.87	6.44	1.95	6.44	0.48	6.44	0.25
23	6.75	1.43	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	0.85	6.75	-1.87	6.75	1.56	6.75	-0.71	6.75	-1.87	6.75	0.01	6.75	-0.05
24	7.05	0.58	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	1.56	7.05	-0.71	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	20018UNA		200210CHE		200210COR		200210HAR		200210LAP		200210LDS		200210MOS		200210POO2		20025COR		20025LAP		20025LMS	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	4.23	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.48
0	-0.11	4.48	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.16	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.30
1	0.18	4.75	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	2.58	0.18	3.46	0.18	2.58	0.18	3.37	0.18	3.40
2	0.46	4.84	0.46	2.33	0.46	2.33	0.46	3.34	0.46	2.33	0.46	3.05	0.46	2.33	0.46	3.66	0.46	3.02	0.46	2.33	0.46	3.41
3	0.77	4.79	0.77	2.12	0.77	2.48	0.77	2.52	0.77	2.12	0.77	2.12	0.77	2.12	0.77	3.20	0.77	2.45	0.77	3.02	0.77	3.08
4	1.07	4.67	1.07	2.83	1.07	1.88	1.07	2.95	1.07	1.88	1.07	2.79	1.07	2.21	1.07	3.09	1.07	1.88	1.07	2.76	1.07	3.51
5	1.38	4.65	1.38	2.88	1.38	1.66	1.38	2.59	1.38	2.12	1.38	3.00	1.38	2.22	1.38	3.04	1.38	1.66	1.38	3.23	1.38	3.62
6	1.68	4.64	1.68	3.11	1.68	2.38	1.68	2.83	1.68	2.43	1.68	3.14	1.68	2.10	1.68	2.89	1.68	2.16	1.68	3.33	1.68	3.45
7	1.95	4.63	1.95	2.42	1.95	2.4	1.95	3.24	1.95	1.93	1.95	2.55	1.95	1.79	1.95	2.14	1.95	2.61	1.95	3.23	1.95	3.23
8	2.26	2.60	2.26	2.42	2.26	2.68	2.26	3.16	2.26	1.69	2.26	2.43	2.26	1.40	2.26	1.91	2.26	2.26	2.26	2.85	2.26	3.09
9	2.56	2.68	2.56	1.33	2.56	2.04	2.56	3.44	2.56	1.33	2.56	2.29	2.56	1.33	2.56	1.33	2.56	2.55	2.56	2.39	2.56	2.98
10	2.86	2.60	2.86	1.67	2.86	2.40	2.86	2.42	2.86	1.30	2.86	1.73	2.86	1.30	2.86	1.96	2.86	2.23	2.86	2.16	2.86	2.74
11	3.16	2.03	3.16	1.27	3.16	2.15	3.16	1.94	3.16	1.27	3.16	1.27	3.16	1.27	3.16	1.92	3.16	1.93	3.16	1.71	3.16	2.34
12	3.46	1.23	3.46	1.23	3.46	2.09	3.46	1.23	3.46	1.23	3.46	1.72	3.46	1.23	3.46	1.91	3.46	1.90	3.46	2.91	3.46	1.99
13	3.74	1.22	3.74	1.22	3.74	1.67	3.74	1.82	3.74	1.94	3.74	2.11	3.74	1.22	3.74	1.22	3.74	2.61	3.74	1.72	3.74	1.22
14	4.06	2.23	4.06	1.18	4.06	1.66	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	2.01	4.06	1.18	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18
19	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87
20	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87	5.87	-1.87
21	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87	6.18	-1.87
22	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	20025MOS		20025POO2		20025SAWD		20027COR		20027Crow		20027SAWD		20027STl		20027You		20028BLA		20028CHE		20028FOR	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.49	-0.39	3.50	-0.39	3.49	-0.39	3.55	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.57	-0.39	3.06	-0.39	3.06	-0.39	4.47
0	-0.11	4.00	-0.11	3.75	-0.11	3.50	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	2.82	-0.11	3.10	-0.11	2.82	-0.11	2.82	-0.11	4.28
1	0.18	4.03	0.18	4.27	0.18	3.40	0.18	3.91	0.18	2.58	0.18	2.58	0.18	4.41	0.18	3.43	0.18	2.58	0.18	3.08	0.18	4.82
2	0.46	4.47	0.46	3.85	0.46	3.71	0.46	4.00	0.46	2.33	0.46	2.94	0.46	4.63	0.46	4.14	0.46	3.05	0.46	3.56	0.46	4.81
3	0.77	4.14	0.77	3.73	0.77	3.83	0.77	3.50	0.77	2.93	0.77	2.56	0.77	3.99	0.77	3.38	0.77	2.91	0.77	3.30	0.77	4.53
4	1.07	4.12	1.07	3.03	1.07	3.51	1.07	3.31	1.07	2.99	1.07	2.42	1.07	4.12	1.07	3.56	1.07	3.24	1.07	3.38	1.07	4.50
5	1.38	3.84	1.38	2.99	1.38	3.25	1.38	3.26	1.38	2.66	1.38	2.55	1.38	3.97	1.38	3.92	1.38	3.41	1.38	3.60	1.38	4.23
6	1.68	3.61	1.68	3.11	1.68	3.16	1.68	2.88	1.68	2.44	1.68	3.15	1.68	3.77	1.68	3.97	1.68	3.65	1.68	3.55	1.68	3.99
7	1.95	3.55	1.95	2.85	1.95	2.99	1.95	2.96	1.95	2.34	1.95	3.02	1.95	3.72	1.95	4.02	1.95	1.97	1.95	3.26	1.95	3.49
8	2.26	3.39	2.26	2.57	2.26	2.97	2.26	2.66	2.26	1.99	2.26	2.63	2.26	3.53	2.26	3.94	2.26	1.40	2.26	1.40	2.26	3.13
9	2.56	2.69	2.56	2.23	2.56	1.93	2.56	2.43	2.56	1.33	2.56	2.53	2.56	3.05	2.56	4.01	2.56	1.97	2.56	2.85	2.56	2.82
10	2.86	2.47	2.86	1.30	2.86	2.52	2.86	2.10	2.86	1.74	2.86	2.48	2.86	2.2	2.86	3.59	2.86	1.30	2.86	1.30	2.86	2.30
11	3.16	2.81	3.16	1.27	3.16	2.17	3.16	2.29	3.16	2.26	3.16	2.08	3.16	2.07	3.16	3.10	3.16	1.27	3.16	1.27	3.16	2.17
12	3.46	2.78	3.46	1.75	3.46	1.23	3.46	1.68	3.46	1.23	3.46	1.85	3.46	2.05	3.46	2.91	3.46	1.23	3.46	1.23	3.46	2.16
13	3.74	2.64	3.74	1.55	3.74	2.45	3.74	1.22	3.74	1.80	3.74	1.22	3.74	1.22	3.74	2.35	3.74	1.22	3.74	1.22	3.74	1.59
14	4.06	1.8	4.06	1.18	4.06	2.25	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.22	4.06	1.18
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.78	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.53	4.36	1.17
16	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.49	4.69	1.15
17	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	2.60	4.99	1.18	4.99	1.18	4.99	1.42	4.99	1.18
18	5.31	1.20	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.18	5.31	1.75	5.31	3.04	5.31	1.18	5.31	1.18	5.31	1.44	5.31	1.18
19	5.58	0.54	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	-1.87	5.58	1.85	5.58	2.59	5.58	-1.87	5.58	-1.87	5.58	1.44	5.58	-1.27
20	5.87	1.19	5.87	-1.87	5.87	-0.67	5.87	-0.15	5.87	-0.57	5.87	1.31	5.87	2.41	5.87	-1.87	5.87	-1.87	5.87	1.29	5.87	-1.87
21	6.18	0.84	6.18	-1.87	6.18	-0.67	6.18	0.80	6.18	-0.57	6.18	1.97	6.18	1.88	6.18	-1.87	6.18	-0.45	6.18	1.22	6.18	-1.87
22	6.44	0.42	6.44	-1.87	6.44	0.21	6.44	0.33	6.44	-1.87	6.44	1.39	6.44	1.23	6.44	-1.87	6.44	-0.89	6.44	-1.87	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-0.67	6.75	-0.15	6.75	-0.57	6.75	0.61	6.75	0.93	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-0.57	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87	7.05	-1.87
25	7.38	0.42	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-0.89	7.38	-1.87	7.38	-1.87
26	7.67	-0.05	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87

Table 1 (cont.)

	20028HAR		20028Kingsme		20028LAP		20028LDS		20028MEE		20028MOS		20029SAWD		20029You	
	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
-2	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37	-0.70	3.37
-1	-0.39	3.06	-0.39	4.69	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.06	-0.39	3.42	-0.39	3.36
0	-0.11	3.6	-0.11	2.82	-0.11	2.82	-0.11	3.38	-0.11	3.69	-0.11	2.82	-0.11	3.40	-0.11	2.82
1	0.18	3.23	0.18	4.36	0.18	2.58	0.18	2.58	0.18	3.53	0.18	2.58	0.18	3.51	0.18	3.83
2	0.46	2.99	0.46	4.23	0.46	3.55	0.46	2.98	0.46	3.50	0.46	2.33	0.46	3.38	0.46	3.71
3	0.77	3.83	0.77	4.09	0.77	3.32	0.77	3.44	0.77	3.55	0.77	2.12	0.77	3.34	0.77	3.54
4	1.07	3.69	1.07	3.90	1.07	3.67	1.07	2.52	1.07	3.22	1.07	1.88	1.07	3.29	1.07	3.55
5	1.38	4.06	1.38	3.41	1.38	3.13	1.38	2.98	1.38	3.58	1.38	3.08	1.38	3.30	1.38	3.46
6	1.68	3.77	1.68	3.79	1.68	2.72	1.68	3.38	1.68	3.05	1.68	3.40	1.68	3.13	1.68	3.81
7	1.95	4.04	1.95	3.31	1.95	2.70	1.95	2.82	1.95	3.13	1.95	3.33	1.95	3.31	1.95	3.34
8	2.26	3.85	2.26	3.41	2.26	2.38	2.26	2.57	2.26	3.15	2.26	2.05	2.26	3.33	2.26	2.83
9	2.56	3.16	2.56	3.17	2.56	2.50	2.56	2.27	2.56	2.95	2.56	2.06	2.56	3.24	2.56	2.54
10	2.86	2.95	2.86	3.20	2.86	1.30	2.86	1.30	2.86	2.91	2.86	2.23	2.86	3.08	2.86	2.57
11	3.16	2.63	3.16	3.16	3.16	1.89	3.16	1.83	3.16	2.56	3.16	2.37	3.16	2.47	3.16	2.81
12	3.46	2.24	3.46	2.41	3.46	1.23	3.46	2.32	3.46	2.45	3.46	2.27	3.46	2.48	3.46	2.52
13	3.74	2.50	3.74	1.22	3.74	1.22	3.74	1.22	3.74	1.78	3.74	2.04	3.74	2.19	3.74	1.60
14	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.77	4.06	1.18	4.06	1.18	4.06	1.18	4.06	1.58
15	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17	4.36	1.17
16	4.69	1.33	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.15	4.69	1.29	4.69	1.15	4.69	1.15
17	4.99	2.94	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18	4.99	1.18
18	5.31	2.66	5.31	1.18	5.31	1.22	5.31	1.21	5.31	1.18	5.31	2.35	5.31	1.19	5.31	1.18
19	5.58	1.98	5.58	-0.07	5.58	0.43	5.58	1.54	5.58	0.96	5.58	2.47	5.58	-0.30	5.58	-1.87
20	5.87	1.64	5.87	-0.07	5.87	0.21	5.87	0.13	5.87	0.80	5.87	2.50	5.87	0.29	5.87	-0.67
21	6.18	-1.87	6.18	-1.87	6.18	0.21	6.18	1.08	6.18	1.32	6.18	1.44	6.18	0.59	6.18	-1.87
22	6.44	-1.87	6.44	-1.87	6.44	-1.87	6.44	0.43	6.44	0.43	6.44	1.82	6.44	0.38	6.44	-1.87
23	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	-1.87	6.75	1.44	6.75	-1.87	6.75	-1.87
24	7.05	-1.87	7.05	-0.36	7.05	-0.26	7.05	-1.87	7.05	-1.87	7.05	1.22	7.05	-1.87	7.05	-1.87
25	7.38	-1.87	7.38	-0.07	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87	7.38	-1.87
26	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87	7.67	-1.87