Are we out of the woods?: Evaluating the impact of lakeshore development on coarse woody habitat in the littoral zone of a unique lake system

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ABSTRACT

Coarse woody habitat (CWH) remains a largely understudied yet an ecologically significant feature of lake ecosystems. Previous research has demonstrated its essential role in enhancing structural complexity in the littoral zone and providing critical habitat for a wide range of aquatic species. However, increasing lakeshore development poses a potential threat to the distribution and integrity of CWH. In this study, I examine how the composition of CWH may vary with lakeshore residential developments. Residential density was classified into three categories: high (12-24 buildings per km), low (1-11 buildings per km), and areas designated as protected (0 buildings per km) which is composed of either Frontenac Park or crown land on Devil Lake in South Frontenac, ON. Devil Lake is classified as a large, deep, cold-water lake on the Canadian Shield north of Kingston that drains into Lake Ontario. We measured randomized 100-meter transects, each at a depth of 2 meters, with equal representation from each residential density category with 20 transects per category. In these transects, the abundance and size of CWH was accounted for. There were two designations for coarse woody habitat: small (5-15cm) or large (>15cm) in diameter, as these diameters encompass opposing ecological functions and species associations. Past studies have suggested that lakeshore residential development decreases both the abundance and size of CWH due to the removal of riparian trees, installation of docks and seawalls, and physical removal of CWH for aesthetic or functional purposes. Anthropogenic alterations to CWH abundance due to lakeshore development may have significant ecological implications, including habitat modifications for aquatic species, such as fish and invertebrates that depend on these structures for shelter, spawning, and foraging. Understanding these dynamics can provide insights into how lakeshore developments are altering the ecosystems in the littoral zone of Devil Lake, ON. We found that the abundance of CWH was significantly higher in low and protected areas compared to high-density regions. Similarly, small CWH was significantly higher in low-density regions than in both protected and high-density areas, with protected areas also having higher small CWH than high-density regions. For large CWH, protected areas had significantly higher counts than high-density regions, while no significant differences were observed between low-density and protected areas or between low-density and high-density regions. These findings highlight the importance of limiting lakeshore development to no more than 12 houses per km in similar regions and show that low-density areas may provide ecological benefits comparable to protected zones.

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I also want to recognize that fieldwork was conducted on Devil Lake, ON which is situated on the traditional unceded territory of the Algonquin, Anishinaabe, and Haudenosaunee peoples. Additionally, Queen’s University is located on the traditional homeland of the Anishinabek, Haudenosaunee, and Huron-Wendat peoples.

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CWH	Coarse Woody Habitat
QUBS	Queen’s Biological Station
ArcGIS	Geographic Information System Software
CPUE	Catch Per Unit Effort

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INTRODUCTION AND LITERATURE REVIEW

Importance of Littoral Zones and CWH

Littoral zones are fundamental components of lake ecosystems, playing a key role in facilitating photosynthesis and supporting high levels of primary and secondary productivity, as well as biodiversity (Van Leeuwen *et al*., 2023; Wetzel, 2001). These zones are characterized by ample light penetration throughout the water column, making them more biologically productive than other regions of the lake (Perales and Zanden, 2023; Wetzel, 2001). However, littoral zones are particularly vulnerable to anthropogenic pressures, such as shoreline development, as they serve as the primary interface between land and water (Perales and Zanden, 2023; Marburg *et al*., 2006; Roth *et al*., 2007). Such developments often result in habitat alteration and loss, including significant reductions in coarse woody habitat (CWH) (Perales and Zanden, 2023; Schindler and Scheuerell, 2002; Theis *et al*., 2023; Francis and Schindler, 2006). CWH, which includes living or dead trees, tree fragments, and other woody debris within the littoral zone, is crucial for creating structural complexity and linking terrestrial and aquatic ecosystems (Preul-Stimetz *et al*., 2024; Roth *et al*., 2007). The main sources of CWH inputs consist of riparian tree mortality through wind disturbances (Harmon *et al*., 1986), mortality of trees by beavers and insects (Harmon *et al*., 1986; Marburg *et al*., 2006), and landowners clearing trees on their shoreline (Francis and Schindler, 2006; Marburg *et al*., 2006). A reduction in CWH has been shown to exacerbate negative impacts on littoral zones (Marburg *et al*., 2006). This is particularly evident in oligotrophic lakes, such as Devil Lake, where CWH constitutes the primary form of structural habitat (Preul-Stimetz *et al*., 2024).

CWH Effect on Lower Trophic Levels

CWH serves as a substrate for both algae and macroinvertebrates, providing secure refuge as well as supporting growth and development, while also supplying the lake system with lower trophic species that contribute energy to higher trophic species, thereby supporting the overall food web (Marburg *et al*., 2006). CWH is stable compared to other habitat structures such as macrophytes, as it offers reliable, all-year-round colonization opportunities for algal species (Vadeboncoeur *et al*., 2006). Submerged CWH demonstrates quick degradation, with integrity dropping significantly by the 12-month mark, eventually deteriorating to around 30% of the original mass after two years (Theis *et al*., 2023). Vadeboncoeur *et al*. (2006) found that the productivity of algae on CWH is greatly influenced by the decomposition rate of the wood, as more decayed wood provides favourable conditions for algal growth due to increased nutrient release including nitrogen and phosphorous through microbial processes during decay. These results highlight how CWH not only provides physical structure for lower trophic levels but also plays a key role in supporting algal productivity by enhancing nutrient availability in the aquatic system (Vadeboncoeur *et al*., 2006; Sinsabaugh *et al*., 1991; Harmon *et al*., 1986).

Studies examining the effects of CWH on zooplankton and macroinvertebrates remain limited (Detmer *et al*., 2021). While zooplankton abundance can be indirectly influenced by allochthonous inputs such as dissolved organic carbon and other nutrients from decaying wood, there remains considerable uncertainty in regards to whether CWH directly affects zooplankton populations (Francis *et al*., 2011). Previous studies suggest that benthic macroinvertebrate communities are highly sensitive to a loss in CWH and that macroinvertebrate density and productivity are highly influenced by the amount of CWH present in the littoral zone (Schindler and Scheuerell, 2002; Benke and Wallace, 2003). However, in contrast, Smokorowski *et al*.

(2006) found that removing approximately 50% of CWH from the littoral zone in three separate lakes within the Turkey Lakes Watershed did not significantly affect the overall abundance of macroinvertebrates. Instead, the level of decay in the wood had a significant influence on periphyton and invertebrate production (Smokorowski *et al*., 2006). Specifically, more decayed CWH supported higher concentrations of chlorophyll a, invertebrate biomass, and invertebrate density compared to non-decayed wood (Smokorowski *et al*., 2006). This suggests that the abundance of CWH may not matter but its condition and decay stage, are critical factors influencing lower trophic level production in aquatic ecosystems (Smokorowski *et al*., 2006). In a similar CWH removal study by Helmus and Sass (2008), removal of approximately 70% of the littoral CWH on Little Rock Lake in Wisconsin, USA, did not impact macroinvertebrate community composition and density. The authors suggested that even if anthropogenic disturbances on a lake are severe, different trophic groups will have different responses (Helmus and Sass, 2008). This suggests that macroinvertebrates might rely on other habitats or substrates such as sediments or macrophytes instead of CWH in response to this change (Helmus and Sass, 2008). Although macroinvertebrates did not show a significant increase in biomass or production with associated CWH in this case, there may still be influence from CWH decomposition over time as nutrients are added to the lake system, potentially increasing productivity (Fenstermacher *et al*., 2024; Francis *et al*., 2011).

CWH Effect on Higher Trophic Levels

When looking at the influence of CWH on higher trophic species, it is typically demonstrated found that CWH increases the productivity of fish communities (Smith *et al*., 2024; Mushet *et al*., 2023; Theis *et al*., 2023; Sass *et al*., 2012; Sass *et al*., 2023). Two separate boreal lakes in the Experimental Lakes Area were assessed using a habitat-specific mark-recapture method on fish found that woody habitats and extremely woody habitats (classified as beaver lodges), were associated with higher fish abundance and biomass (Mushet *et al*., 2023). Beaver lodges containing a vast amount of CWH possessed the highest Shannon Diversity Index (1.19) for fish in comparison to all other habitat types, with rocky, open, woody, and vegetated areas all being comparable (~1.00) (Mushet *et al*., 2023). The catch per unit effort (CPUE), a metric used to measure the relative abundance of fish populations, was significantly greater in beaver lodges and wooded habitats compared to open habitats, with smaller fish species such as northern redbelly dace and finescale dace dominating the woody habitats (Mushet *et al*., 2023). Larger fish such as lake trout and pike were found to occupy less complex open areas, while smaller fish were more commonly found in complex secluded woody areas, indicating that these woody habitats provide refuge from predators at a time when development is underway (Mushet *et al*., 2023). A study investigating the effects of CWH structures on fish populations in a boreal lake in Alberta, Canada, applied three treatments: CWH spaced 30m apart, CWH clustered 15m, and a control (Theis *et al*., 2023). Over a 2-year period, they measured CPUE and found that both clustered and spaced CWH treatments resulted in significantly higher CPUE compared to the control (Theis *et al*., 2023). The clustered CWH treatment produced the highest CPUE for northern pike, spottail shiner, and white sucker, while brook stickleback had consistently low CPUE across all treatments (Theis *et al*., 2023). Additionally, the clustered treatment demonstrated a greater increase in fish abundance and biomass, especially for northern pike and spottail shiner (Theis *et al*., 2023). This suggests that the configuration of CWH, particularly in clustered arrangements, has a more pronounced positive effect on fish communities by enhancing fish abundance, biomass, and overall productivity, particularly for certain species

(Theis *et al*., 2023). Another study adding ~160 pieces of large CWH to enhance the complexity of the littoral zone in an undeveloped lake in Wisconsin, USA tracked certain fish species such as muskellunge, smallmouth bass, and walleye before and after the addition using radio telemetry and analyzed their behaviour (Smith *et al*., 2022). They found that muskellunge had a significantly greater home range size post-CWH addition, with both smallmouth bass and walleye increasing their home range but not significantly compared to pre-CWH addition (Smith *et al*., 2022). This indicated that the addition of CWH for muskellunge specifically may have altered the availability of resources and shifted their foraging behaviours, potentially leading to larger home ranges as the fish expanded their search areas to find prey (Smith *et al*., 2022). Therefore, these studies demonstrate that CWH promotes the growth and abundance of most fish species, but not uniformly across all species (Mushet *et al*., 2023). While the abundance and biomass of fish species generally increase with higher CWH density (e.g., clustered or woody habitats), the effects are species-dependent and influenced by factors like habitat complexity and CWH configuration (Mushet *et al*., 2023; Theis *et al*., 2023; Smith *et al*., 2022). The size of CWH also plays a significant role in enhancing fish populations, particularly in clustered arrangements, which seem to offer the greatest benefits for most fish species (Theis *et al*., 2023).

Sedimentation and Organic Matter

The removal of CWH from the littoral zone has been associated with an increased flow of organic sediments, which can reduce organic content and disrupt ecosystem functions such as nutrient cycling, sediment stabilization, and habitat provision for aquatic organisms (Francis *et al*., 2007). Conversely, the addition of CWH is thought to mitigate these disturbances by promoting sediment retention and facilitating organic matter cycling (Francis *et al*., 2007). Additionally, eutrophic conditions, commonly associated with development and driven by increased microbial degradation as seen with decaying wood, may enhance detritivore macroinvertebrate activity, potentially contributing to the observed loss of sediment in the littoral zone (Kashian and Barnes, 2000). A study by Francis *et al*. (2007) that spanned over 15 lakes aimed to understand how development affects organic detritus in sediments, an important component of food webs, as the impact of urbanization on this is widely understudied in this system (Francis *et al*., 2007). They found a 10-fold decline in the proportion of detritus in littoral sediments in developed lakes (95% shoreline altered) compared to undeveloped (0% shoreline altered) (Francis *et al*., 2007). A positive correlation was seen between sediment organic matter and CWH basal area, indicating that a higher density of riparian trees that may become CWH had significantly more organic matter (Francis *et al*., 2007). Focusing on size, large CWH has been shown to influence sedimentation and organic matter deposition within lake ecosystems (Gennaretti *et al*., 2014). However, the inputs of large CWH are exceptionally slow, with only 5.8 pieces added to the littoral zone per 100 m of shoreline per century (Gennaretti *et al*., 2014). A study conducted in northern Québec on a minimally developed lake, with development occurring only 40 years ago, found that approximately 46% of large CWH categorized as unexposed (covered within the lake sediment) eventually became buried in the sediment, while the remaining 54% exposed (directly in contact with the water column) decayed before burial (Gennaretti *et al*., 2014). This burial process is crucial for long-term carbon storage and the deposition of organic matter into the sediment, which increases the residence time of organic matter (Gennaretti *et al*., 2014). The residence time of buried CWH was found to be significantly higher than that of exposed CWH, with an average of ~794 years for buried CWH compared to ~386 years for exposed CWH (Gennaretti *et al*., 2014). This extended residence time within sediments enhances the long-term storage of carbon and organic matter within the aquatic ecosystem (Gennaretti *et al*., 2014). This is crucial as it demonstrates that large CWH, particularly those that remain unexposed, provide lake systems with a longer-lasting store of organic carbon, contributing to the ecosystem's carbon sequestration over extended periods (Gennaretti *et al*., 2014; Francis *et al*., 2007). Thus, the preservation of CWH, especially large, unexposed pieces, is vital not only for maintaining sediment stability and organic matter cycling but also for supporting long-term carbon storage in lake ecosystems.

Lakeshore Residential Development

Residential development is increasing at a rapid rate, especially around the Great Lakes region and these developments are commonly concentrated directly surrounding lakes (Radeloff *et al*., 2001). Landowners modifying their lakeshore through the construction of seawalls, docks, removal of riparian trees near the shore, and direct removal of logs and plants from the water is a common practice (Pearles and Zanden 2023; Amato *et al*., 2015). In a comprehensive study covering 45 lakes in Wisconsin, USA, representing both developed and undeveloped lakes, lakeshore residential density was measured by counting the buildings within 100 meters of each lake (Marburg *et al*., 2006). The findings showed that lakes with more than 9 buildings per km never had more than 200 total pieces of CWH (Marburg *et al*., 2006). Additionally, CWH in the littoral zone was positively correlated with trees in the riparian zone and a higher abundance of riparian trees was seen with less development (<9 houses per km) (Marburg *et al*., 2006). Another large study in a nearby region in Wisconsin, USA, covering 57 lakes demonstrated a significant negative effect of lakeshore residential development on CWH when the development was over 10 buildings per km (Pearles and Zanden 2023). There were around 700 pieces of CWH per km in undeveloped lakes compared to around 200 pieces of CWH per km in developed lakes on average (Pearles and Zanden 2023). The authors suggest that the contributing factor to the discrepancy is a lower density of riparian forests in highly developed lakes (Pearles and Zanden 2023). In support of this, a study looking at 16 northern temperate lakes to assess the relationship between CWH abundance and shoreline residential development found a positive correlation between both riparian tree density, basal area to CWH density (Christensen *et al.*, 1996). A negative correlation was also found between lakeshore development and CWH abundance, consistent with the results from the previous studies above (Christensen *et al.*, 1996). Specifically, undeveloped lakes had 555 pieces of CWH per km, developed lakes had 379 pieces per km and, cabin-occupied sites with direct access to the lake had only 57 pieces of CWH per km of shoreline (Christensen *et al.*, 1996). Lakeshore development is particularly harmful, as the natural recruitment of CWH is slow, about 2.52 logs per ha per year, resulting in at least 200 years to replace CWH to match the levels of 500 pieces per km seen in old-growth forests (Christensen *et al.*, 1996). Looking at a different approach, a whole lake removal of CWH was conducted to simulate a developed lake and compared it to a reference basin acting as an undeveloped lake (Sass *et al.*, 2006). This study demonstrated that when 73% of large CWH (>10cm) was reduced, perch populations declined rapidly from 141 perch per ha to 60 perch per ha (Sass *et al.*, 2006). This led to a shift in the food web dynamics, as perch, which had previously made up 93% of the largemouth bass's diet, dropped to only 14% (Sass *et al.*, 2006). As a result, the primary dietary component for largemouth bass shifted to terrestrial invertebrates (Sass *et al.*, 2006). In this case, the addition of CWH may be suggested to offset the impacts seen by lakeshore development; Sass et al. (2011) did exactly this by conducting a whole lake addition of CWH by adding ~300 pieces of large CWH (>10 diameter) to the littoral zone of a treatment lake increasing CWH from 41 to 141 large CWH per km and compared the results to a control lake where there was ~40 pieces of CWH per km. When looking at the body condition and growth rate of largemouth bass and bluegill sunfish the authors found a slight increase of ~6% in body condition in largemouth bass and bluegill showing no significant increase in body condition (Sass *et al*., 2012). Growth rates demonstrated no significant change in bluegill, while largemouth bass exhibited size-specific growth patterns (Sass *et al*., 2012). Specifically, bass at 100m and 200m declined in the treatment basin but showed a slight increase in the reference basin (Sass et al., 2012). Another paper found different results with bluegill sunfish growth rate on average being 2.6 times lower in heavily developed (17-24 houses per km) lakes than in undeveloped lakes (0 houses per km) (Schindler *et al*., 2000). The loss of CWH due to development likely reduced the availability of vital resources such as foraging habitat and refuge, both critical for supporting fish populations (Schindler *et al*., 2000). This highlights the importance of maintaining CWH to support fish growth and biodiversity, especially in habitats that are subject to anthropogenic pressures like development (Schindler *et al*., 2000). Therefore, while the addition of CWH can help mitigate some of the negative impacts of lakeshore development by restoring habitat complexity and improving body condition in fish like largemouth bass, the overall effects on fish growth may be more complex. The results from the studies presented above underline how the loss of CWH often associated with lakeshore development can lead to cascading effects on fish populations, species interactions, and food web dynamics. Additionally, the slow natural replacement of CWH suggests that the loss of such habitat can have long-term, irreversible impacts on lake ecosystems, further supporting the need for CWH preservation and restrictions on lakeshore development to mitigate these negative effects.

Devil Lake as a Case Study

Devil Lake, ON is a unique lake system due to its relatively undeveloped nature, with vast regions of protected land provided by Frontenac Provincial Park and various crown land, alongside areas of both high and low residential densities. This diversity in land use offers a rare opportunity to compare and assess how CWH may vary with different development densities. Research into CWH has gained momentum in recent years as human pressure on littoral zones continues to rapidly accelerate (Radeloff *et al*., 2001). However, there are still notable research gaps regarding CWH abundance and size in relation to lakeshore development, particularly in Canada as most studies on CWH have focused on north temperate lakes in the United States Pacific Northwest, such as those in northern Wisconsin and Washington, USA, and are the primary reference points in the field (Marburg *et al*., 2006; Smith *et al*., 2022; Perales and Zaden, 2023; Helmus and Sass, 2008). These studies often overlook the juxtaposition of residential developments at varying densities: high, low, and protected, such as those present in the unique landscape of Devil Lake and split their categories into ‘developed’ and ‘undeveloped’ lakes instead. The lack of such comparisons in current research highlights a critical gap in understanding how differing levels of lakeshore development affect CWH dynamics and the associated ecological functions. As lakes like Devil Lake continue to experience increased development, the findings from this study could fill an important niche in understanding the impacts of land use on aquatic ecosystems in this region.

Study Objectives and Predictions

As the literature indicates, CWH is typically reduced in areas with a high density of developments, supporting my hypothesis that high-density lakeshore development will decrease both the abundance and size of CWH due to reduced tree density associated with residential development (Perales and Zanden, 2023). This study aims to systematically assess the impact of lakeshore development on CWH abundance, providing essential data for lake associations and informing ecological conservation strategies. With the rapid increase in lakeshore development, particularly in areas such as Frontenac, ON, where the population has grown by approximately 750% in just over 100 years (Statistics Canada, 2021), this research is more relevant than ever. Based on the literature, I expect to find that high-density development areas have reduced CWH abundance and reduced levels of both smaller (5-15 cm) and larger (>15 cm) CWH, while low-density and protected areas will have greater total and larger CWH. If lakeshore development (e.g., tree clearing or habitat alteration) reduces CWH abundance, it could limit essential resources for aquatic species. By analyzing both CWH abundance and size, this study will help us infer patterns related to how CWH influences habitat quality, resource availability, and the overall ecological health of the littoral zone. It will also help us understand how lakeshore development, through its effects on CWH, could alter these ecological functions, potentially causing cascading impacts on aquatic ecosystems. This may adversely affect the distribution and biodiversity of aquatic species in Devil Lake that rely on CWH for habitat, foraging, and spawning. The results of this study will inform management practices, highlighting the need for protective measures against tree clearing and development along shorelines. Previous research suggests that individual landowner decisions on land alteration significantly impact CWH inputs, indicating that local land-use intensity may be a more effective management strategy (Marburg *et al*., 2006). The outcomes of this study will engage stakeholders such as landowners on Devil Lake, the Devil Lake Association, Frontenac Provincial Park, and conservation authorities, helping to shape management practices and catalyze further research in aquatic ecology.

METHODS

Study Site

We assessed CWH coverage along multiple transects spanning 57.9 km of shoreline and various islands on Devil Lake (44.5811, -76.4532) in South Frontenac, ON. In total, 60 transects were surveyed, covering 6 km of shoreline, with 20 transects from each of the three density categories: protected, low, and high. The protected category included areas such as Frontenac Park and various crown land regions. Low-density transects were located in areas such as Buce Bay, Parkers Bay, Pine Haven Campground, various islands, and Hardwood Bay, while high-density transects were found in Bedford Mills, Green Bay Campground, and Goose Bay. Devil Lake is a natural, deep, cold-water lake located within the Cataraqui River Watershed, which drains into Lake Ontario (Devil Lake Association, 2017). It is one of the larger lakes in the area, spanning over 10 square km with a circumference of more than 58 km (Devil Lake Association, 2017). The lake contains over 250 cottages and lies within the Frontenac Arch Biosphere. A sawmill, which operated for nearly 100 years from 1831 to 1920, was located at Bedford Mills on the northern end of the lake (Devil Lake Association, 2017).

Sampling Design

Observational snorkelling surveys were conducted between June and August of 2024 along 100-meter transects, extending 1 meter on either side at a depth of approximately 2 meters and oriented perpendicular to the shoreline. If any transects had a steep incline (~45-90°) or consisted of particularly rocky terrain, a new randomized transect was selected. Only one building per plot of land was considered, and each building had to be located within 0-2 km of the shoreline, with direct access to the lake. Transects were categorized into three distinct housing density groups based on the number of residential buildings along the shoreline: protected (0 houses per km), low (1-11 houses per km), and high (12-24 houses per km). These density categories were based on the hotspot layer in ArcGIS, which assigns a 90%-99% confidence level to the distribution of housing density across the lake; Devil Lake has a total of ~293 houses and one house per plot of land was counted (Figure 1).

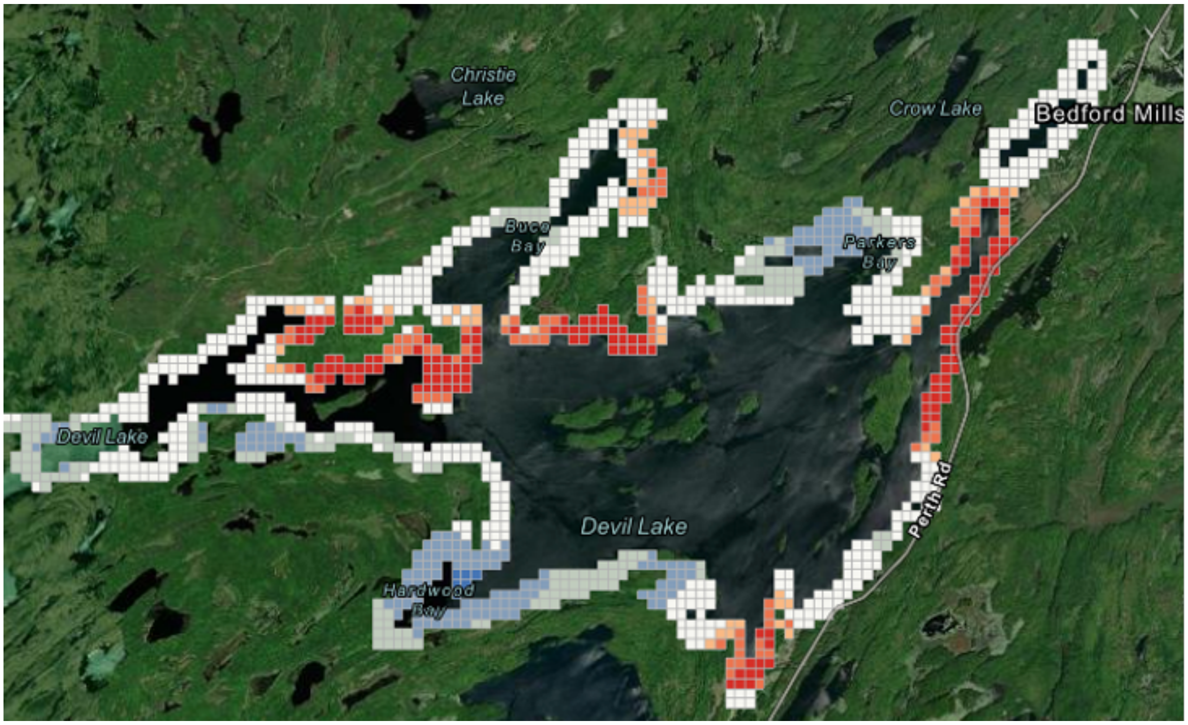

Figure 1. Map of Devil Lake using ArcGIS Hotspot Layer. The hotspot layer in ArcGIS assigns a 90%-99% confidence level to the distribution of housing density across Devil Lake, with red indicating high-density development, blue indicating protected land, and white indicating low-density or non-significant development.

The entire shoreline was assigned a density category and divided into 100-meter transects, each with an index number. Twenty transects were randomly selected from each density category. In some cases, transects were selected based on recommendations from the Devil Lake Association, including specific sites such as the boat launch and Pine Haven Campground. To ensure broad spatial representation, transects were also distributed across various wind exposures, representing different compass directions along the shoreline with 27 sites facing leeward and 33 sites facing westward (Figure 2).

Figure 2. Map of Devil Lake, ON, indicating the locations of our sampled transects. 20 transects from each category was sampled with blue points indicating the protected land (0 houses per km) transects, pink denotes the low-density (1-11 houses per km) transects, and red indicates the high-density (12-24 houses per km) development transects.

For each selected transect, a series of environmental and habitat variables were recorded. Cottage density was determined before conducting the transect. Daily weather conditions, including temperature and cloud cover, were also recorded during the survey. The substrate type at each transect was classified into one of the following categories: open, rocky, vegetated, woody, beaver dam, or other. CWH was assessed based on both size and abundance. CWH was categorized into two size groups: small CWH, defined as logs or branches with a diameter between 5-15 cm, and large CWH, defined as logs or branches with a diameter greater than 15 cm. These size distributions were based on Theis *et al*. (2023), Gregory *et al*. (2003), and Rutherfurd *et al*. (2002). Only submerged or partially submerged CWH was enumerated and recorded. The size of each piece of CWH was measured directly using a ruler to determine its diameter. Small and large CWH were counted separately within each transect. Each transect was surveyed only once during the field season.

Statistical Analyses

Data was analyzed using R (Version 2024.12.1+563) to examine how lakeshore development impacts the abundance and size of CWH (R Development Core Team, 2024). Abundance was measured by counting the total number of small (5-15 cm) and large (>15 cm) CWH within each transect. To assess the effects of residential density on CWH, a negative binomial GLM was conducted, as this model was the best fit for the data for both the total count of CWH and both size categories. The GLM tested the impact of density category (High, Low, and Protected) on CWH abundance and size separately. The assumptions of normality and homogeneity of variance were checked using Shapiro-Wilk and Bartlett tests, respectively. Diagnostic plots, including residuals versus fitted values, were created using the autoplot function (from the ggfortify package) to assess model fit and likelihood ratio tests from the null model were used to see the best model fit. The MASS package was used for residual analysis and to check for overdispersion. Post-hoc pairwise comparisons were conducted using Tukey's test to explore differences across density categories. To see significance between the density categories on the plots, ggsignif was utilized. Data manipulation and visualization were performed using the tidyverse, dplyr, and ggplot2 packages.

RESULTS

We found that total CWH abundance varied significantly across the three residential density categories (negative binomial GLM; $p < 0.001$, Figure 3). High-density residential transects had significantly fewer total CWH compared to protected areas (Post-hoc Tukey's HSD test: $z = 3.785$, $p < 0.001$, Table 1) and high-density areas had significantly lower total CWH than low-density areas ($z=2.525$, $p = 0.031$, Table 1). No significant difference was found between low-density and protected areas ($z = 1.264$, $p = 0.416$, Table 1). The average number of total CWH per transect was 23.70 in high-density areas, 45.25 in low-density areas, and 62.35 in protected areas. This means when using protected as a baseline for the total CWH, protected areas hosted 27.40% more than low-density areas, and protected areas hosted 61.98% more total CWH than high-density regions. When looking at low density compared to high, with high as the baseline, a high density of housing is seen to decrease the total CWH by 47.7% compared to a low density of housing.

For small CWH, similar patterns emerged; no significant interaction between large and small ($p=1.000$) CWH but significant differences in the abundance of small CWH across density categories ($F = 9.749$, $p < 0.001$, Figure 4). High-density areas exhibited significantly fewer small CWH than both low-density (Post-hoc Tukey's HSD test: $z = 2.392$, $p = 0.044$, Table 2) and protected areas ($z = 3.345$, $p < 0.001$, Table 2). However, no significant difference was found between low-density and protected areas ($z = 0.956$, $p = 0.604$, Table 2). The average number of small CWH per 100m transect was 17.95 in high-density areas, 35.45 in low-density areas, and 46.40 in protected areas. This means when using protected as a baseline for the small CWH, protected areas hosted 61.33% more than low-density areas, and protected areas hosted 23.59% more small CWH than high-density regions. When looking at low density compared to high, with high as the baseline, a high density of housing is seen to decrease small CWH by 49.35% compared to a low density of housing.

For large CWH, there were significant differences of large CWH across density categories ($F = 9.749$, $p < 0.001$, Figure 5). A significant difference was found between high-density and protected areas, with protected areas hosting larger CWH ($z = 3.626$, $p = p < 0.001$, Table 3). No significant differences were found between low-density and high-density areas ($z = 1.889$, $p = 0.141$, Table 3), or between low-density and protected areas ($z = 1.754$, $p = 0.185$, Table 3). The average number of large CWH per 100m transect was 5.75 in high-density areas, 9.80 in low-density areas, and 15.80 in protected areas. This means when using protected as a baseline for the large CWH, protected areas hosted 63.66% more than low-density areas, and protected areas hosted 37.97% more large CWH than high-density regions. When looking at low density compared to high, with high as the baseline, a high density of housing is seen to decrease large CWH by 41.43% compared to a low density of housing.

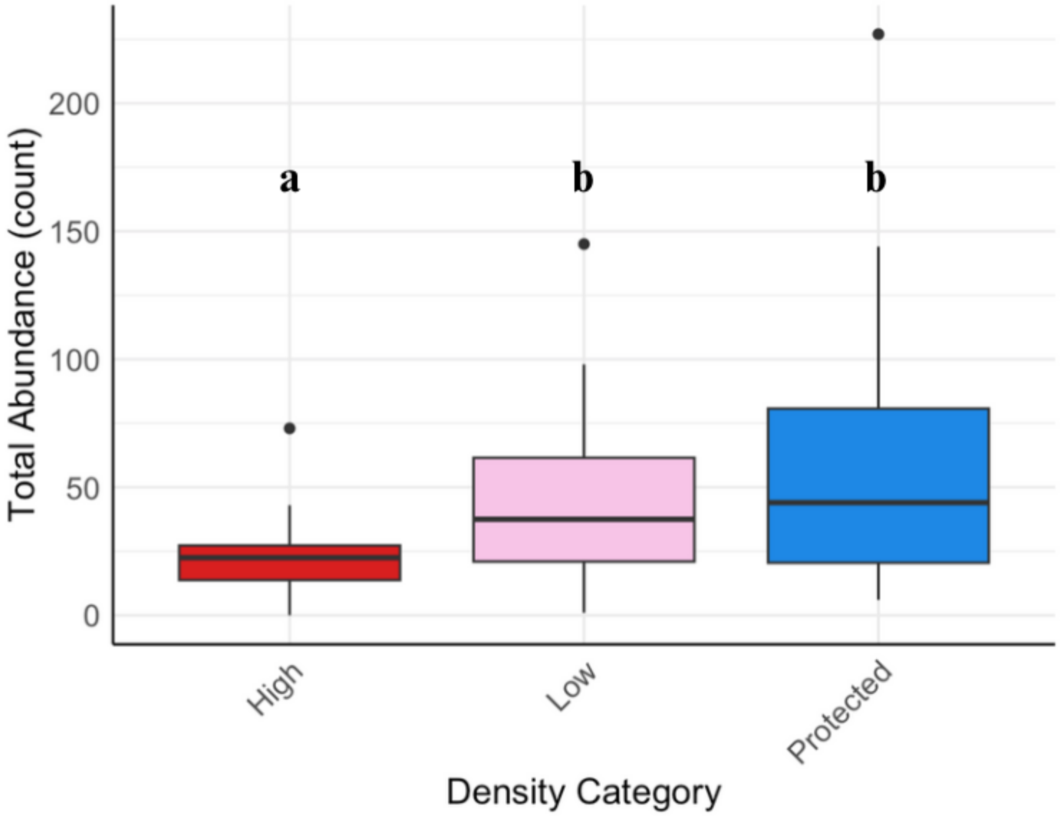

Figure 3. Total Abundance of Coarse Woody Habitat (CWH) across Density Categories. Boxplot displaying the total CWH counts for each of the three density categories. Residential density was classified into three categories: high (red) (12-24 buildings per km), low (pink) (1-11 buildings per km), and areas designated as protected (blue) (0 buildings per km). The data is presented as raw counts of total CWH, with the x-axis representing the density categories, and the y-axis showing the total CWH abundance. Letters above plot representing different categories of significance, a being significantly different than b.

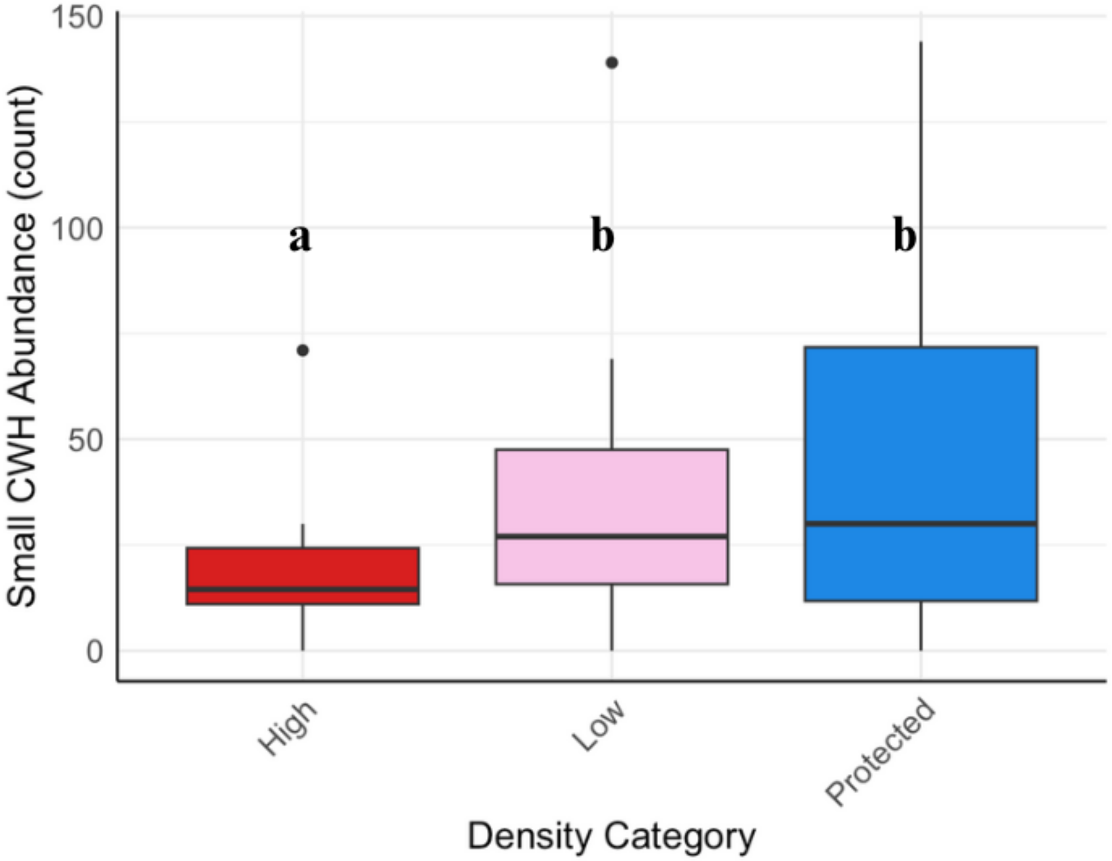

Figure 4. Count of Small Coarse Woody Habitat (CWH) Across Density Categories. Boxplot displaying the counts of large CWH (5-15cm) for each of the three density categories. Residential density was classified into three categories: high (red) (12-24 buildings per km), low (pink) (1-11 buildings per km), and areas designated as protected (blue) (0 buildings per km). The data is presented as raw counts of small CWH, with the x-axis representing the density categories, and the y-axis showing the small CWH abundance (count). Letters above plot representing different categories of significance, a being significantly different than b.

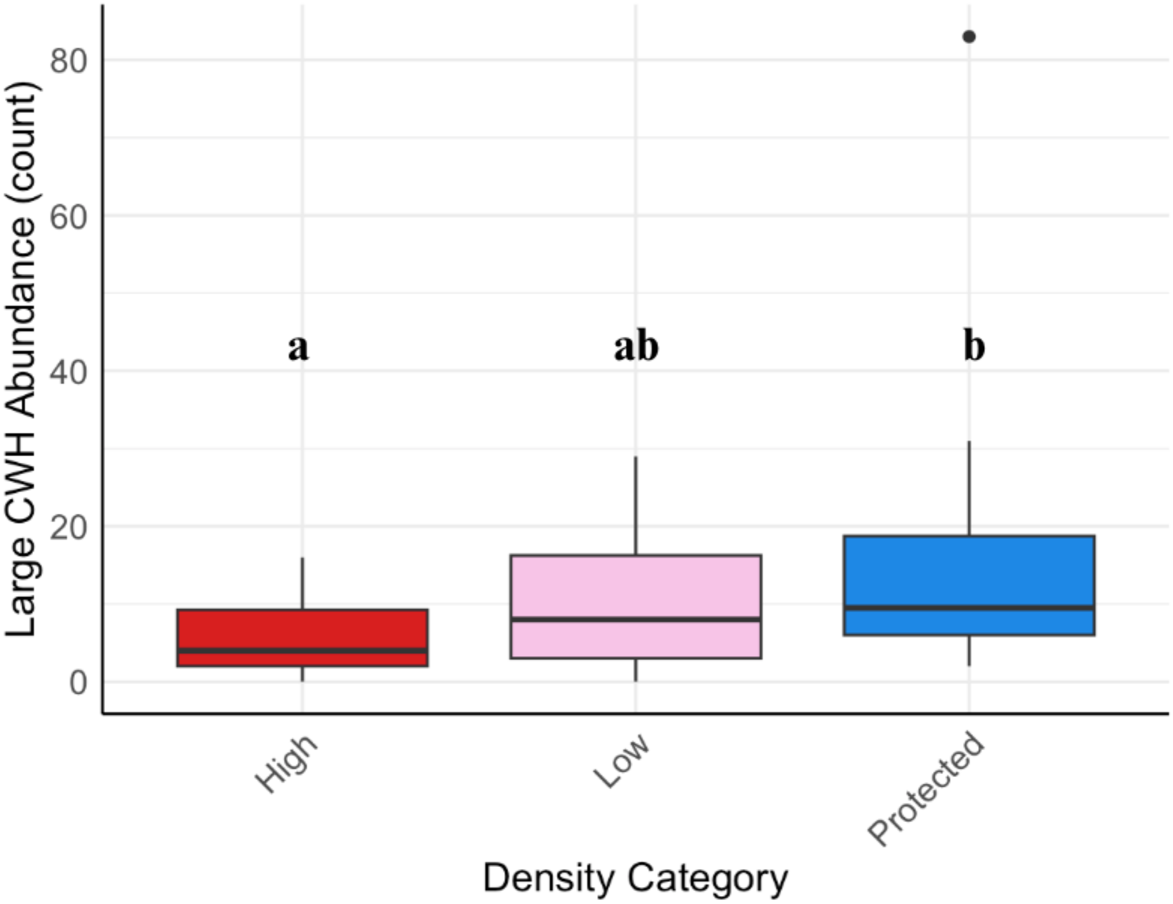

Figure 5. Count of Large Coarse Woody Habitat (CWH) Across Density Categories. Boxplot displaying the counts of large CWH (>15cm) for each of the three density categories. Residential density was classified into three categories: high (red) (12-24 buildings per km), low (pink) (1-11 buildings per km), and areas designated as protected (blue) (0 buildings per km). The data is presented as raw counts of large CWH, with the x-axis representing the density categories, and the y-axis showing the large CWH abundance (count). Letters above plot representing different categories of significance, a being significantly different than b, ab representing non significantly different from both a and b.

DISCUSSION

CWH Abundance

My first hypothesis suggested that the total abundance of CWH would vary across high-density, low-density, and protected areas, with high-density reducing CWH and the results supported this expectation. The data revealed that only high levels of residential development (12-24 houses per km) significantly decreased CWH availability. This decline is likely due to the physical alterations associated with development, such as the removal of riparian trees, the installation of docks and seawalls, and the physical removal of CWH for aesthetic or functional purposes (Pearles and Zanden, 2023; Amato *et al*., 2015; Marburg *et al*., 2006). Christensen *et al*. (1996) supported our results by demonstrating that riparian tree density was significantly lower in areas with direct cabin-occupied sites or high density of housing, ranging from 1-24 houses per km (mean of 809 stems per ha), compared to undeveloped lake sites with no houses (mean of 1381 stems per ha). Similarly, snags or standing dead trees, which serve as a precursor to CWH, were also less abundant on cabin sites, which may contribute to the lower CWH abundance in high-density developments observed in our study (Christensen *et al*., 1996).

CWH numbers can vary, with undeveloped lakes ranging from 42-638 logs per km and developed lakes with more than 10 houses per km ranging from 17-128 logs per km (Marburg *et al*., 2006; Lawson *et al*., 2011; Marburg *et al*., 2009; Christensen *et al*., 1996; Francis and Schindler, 2006). Residential densities from 12-20 houses per km are generally associated with the lowest levels of CWH (Marburg *et al*., 2006; Christensen *et al*., 1996). Our findings align with these trends, as we observed approximately 237 pieces of CWH per km in high-density regions (more than 12 houses per km). Although this number is relatively high compared to other studies, it still shows a marked decline compared to protected regions with no houses, where we found about 623 pieces per km. This indicates a significant decrease of CWH in areas of high residential development.

These findings suggest that there may be a certain threshold of residential development (e.g., at least 12 houses per km in high-density areas) at which a decrease in CWH abundance becomes correlated. In contrast, low-density development, while still affecting CWH abundance, does not seem to reach the threshold where the impacts are as severe as in high-density areas. The lack of significant differences between low-density and protected areas may indicate that the disturbances in low-density zones are not yet intense enough to cause substantial changes in CWH abundance, allowing natural processes that create and maintain CWH to persist. Previous studies have identified similar thresholds, generally around 10 houses per km. For instance, Francis and Schindler (2006) and Christensen et al. (1996) found that residential development with more than 10 houses per km significantly reduced CWH abundance and basal area in high-density areas. Likewise, Marburg et al. (2006) observed a threshold of 9 houses per km, beyond which the number of CWH never exceeded 200 pieces per km^2.

CWH Size

I found that the size of CWH varies across different development categories, but there is no interaction between large and small CWH. This means that the decrease in CWH abundance in high-density residential areas compared to low-density or protected areas is consistent for both small and large CWH. There is no evidence to suggest that residential development impacts small and large CWH differently, indicating that development affects both size classes similarly, with high-density areas showing the greatest decrease in CWH, while low-density and protected areas are similar.

Although research on CWH size is limited, particularly regarding the distribution of small and large CWH, existing studies support our finding that high-density development negatively impacts both size classes. This effect is less pronounced in areas with lower development levels, where riparian tree size remains intact and the natural processes of CWH accumulation are less disturbed. For example, Francis and Schindler (2006) found a significant negative effect of high residential development (more than 10 houses per km) on large CWH (>10 cm). They observed that riparian trees were significantly larger in undeveloped areas, likely contributing to the accumulation of larger CWH pieces. In these less disturbed forests, the presence of larger trees supports the accumulation of larger CWH due to fewer disturbances. This aligns with our findings that large CWH (>15cm in our case) decrease in high density developments when comparing it to protected areas.

A study that informed our classification of small and large CWH size categories highlighted the ecological importance of both, demonstrating that small CWH bundles and whole large trees each contribute to increased structural richness. (Theis *et al*., 2023). Our findings align with these studies, as we observed a clear reduction in large CWH abundance in high-density development areas. One possible explanation is that in high-density areas (12-24 houses per km), riparian trees are often removed for development, reducing the availability of large CWH. In contrast, low-density areas experience less intense disturbance, allowing for the persistence of larger CWH pieces. In high-density areas, the lack of large CWH could significantly impact the nutrient cycling process and organic matter retention, as larger pieces decompose more slowly than smaller ones (Francis et al., 2007). Without this slow-decomposing organic matter, nutrient cycling may be disrupted, which could alter the ecological balance of the aquatic ecosystem in these regions. Additionally, the absence of large CWH could reduce habitat complexity, which is essential for supporting a diverse range of species, particularly larger fish, like muskellunge and walleye, which depend on these structures for foraging and shelter (Sass et al., 2023). This loss of habitat complexity may lead to a decline in species richness, particularly in high-density areas where large CWH pieces are scarce. Thus, the reduction of large CWH in high-density development zones not only threatens immediate biodiversity but also has potential long-term implications for carbon storage and ecosystem health.

Limitations and Assumptions

While this study provides valuable insights into the effects residential density has on CWH, there are several assumptions and limitations that need to be addressed for future studies in this field. Firstly, this study was carried out through July-August 2024, which can provide a snapshot of CWH abundance and size across density categories, but this does not allow us to see changes over time. Since natural inputs of CWH are slow with decomposition rates lasting decades and even centuries (Marburg *et al*., 2006), the accumulation and replenishment of CWH can be significantly affected by ongoing human disturbance. A longer-term study would be valuable to assess how CWH abundance and size change over time, particularly as urban development around lakes intensifies. Specifically, it could help determine whether the ongoing lack of natural recruitment of CWH due to human impacts leads to a gradual reduction in CWH availability, even in the absence of rapid degradation.

Additionally, Frontenac Provincial Park was established in 1974, 50 years before our study was completed, and there was severe logging on the forests immediately adjacent to Devil Lake in the mid to late 1800s (Devil Lake Association, 2017). Therefore, treating the protected area as a baseline for the appropriate levels of CWH may be inaccurate as forests need anywhere from 50-300 years to recover from logging and obtain large CWH (Reid and Hassan, 2020; Saeki *et al*., 2024). Despite historical logging, the amount of CWH observed in the protected areas of Devil Lake (~623 total CWH) was comparable to levels reported in undeveloped lakes in other studies, which ranged from 42 to 638 logs (>10 cm diameter) per km. Additionally, the high-density development category in our study exhibited higher CWH levels (~237 total CWH) than those typically reported in other developed lakes, which ranged from 17 to 128 logs per km. Having a baseline of an undeveloped lake in the region that has not been altered by logging may provide further insights into appropriate baseline levels in this area with old-growth forests that are undisturbed by humans, including an absence of logging (Reid and Hassan, 2020).

Recommendations for Future Research

There are several important avenues for future research based on the limitations of this study. One critical direction would be to investigate additional habitat variables, such as the number of trees along the riparian buffer (number of trees per 100km^2), basal area of riparian trees, along with macrophyte cover, rock, and sand score together (Perales and Zanden, 2023; Christensen *et al*., 1996; Francis *et al*., 2007). Including these variables would provide a more comprehensive understanding of the factors influencing CWH abundance and size. The number of trees along the riparian buffer and basal area of the trees on the riparian zone can help determine how much natural woody material is available since they have been shown to be positively correlated with CWH abundance (Christensen *et al*., 1996; Francis *et al*., 2007). Macrophyte cover may also play a role by influencing water quality, and sediment deposition, which could affect the stability and accumulation of CWH over time (Madsen *et al*., 2001). Similarly, the presence of rock and sand in the riparian zone may influence CWH retention, with rocks potentially providing a stable substrate for CWH to accumulate, while sandy areas might allow CWH to be more easily displaced (Pearles and Zanden, 2023). By assessing these additional variables, future studies could better isolate the mechanisms behind changes in CWH across different residential densities and further explore how environmental factors interact with human development to affect CWH dynamics.

Additionally, examining the role of shoreline vegetation and riparian buffers in supporting CWH may provide insights into how natural features can mitigate the effects of development. This topic is severely understudied, and the studies present today are typically in the Midwestern United States (Marburg *et al*., 2006; Smith *et al*., 2021; Perales and Zanden, 2023). The various types of residential developments are also a key aspect that is often overlooked in other limited studies on CWH as many studies that look at residential density and CWH categorize them into ‘developed lakes’ and ‘undeveloped lakes’ without having a gradient of development on one specific lake (Christensen *et al*., 1996; Sass *et al*., 2011). Expanding this research to include a broader range of locations and development types, from protected areas to high-density developments, will help to fill this gap. Although this may be challenging with undeveloped lakes becoming exceedingly rare; Frontenac does not have statistics to show percentages of undeveloped lakes vs developed in this region. A study in 2012 covering over 332 lakes found there was only 8% of lakes categorized as undeveloped (0 houses per km), 23% considered having low levels of development (0-10 houses per km), and the majority of lakes at 69% being categorized as highly developed (>10 houses per km) in the Michigan, USA, region (Wehrly *et al*., 2012).

Moreover, research on the spatial distribution of CWH could reveal how fragmentation affects the function and sustainability of these habitats. Fragmented CWH areas may be less effective in supporting aquatic biodiversity, as they may not allow for the movement of organic material between connected water bodies (Harmon *et al*., 1986). Investigating how fragmented versus continuous CWH regions impact ecosystem services, such as nutrient cycling and habitat connectivity, could provide valuable guidance for conservation efforts. This may be a more important indicator of structural complexity than analyzing size classes, as counting one small CWH is not as important as counting a bundle of small CWH; a bundle of small CWH might provide more significant ecological benefits by creating a denser, more structurally complex habitat compared to a single piece of CWH (Harmon *et al*., 1986). By focusing on the spatial continuity of CWH rather than just the individual pieces or size classes, we could gain a better understanding of how these habitats contribute to broader ecosystem functions, including supporting biodiversity and nutrient cycling.

Although this study surveyed a large section of Devil Lake, covering 60 transects and 6 km of shoreline, it was limited to just one lake. Having a sample size of more than one lake could provide a broader perspective on how residential development impacts CWH across different ecosystems. Expanding the study to include multiple lakes, especially those with varying levels of development, would help determine if the trends observed in Devil Lake are consistent or if they vary across different geographic regions, lake types, and development pressures. Additionally, including lakes with varying ecological characteristics could highlight potential regional or site-specific factors that could either mitigate or exacerbate the effects of development on CWH, further informing conservation strategies tailored to specific locations. Most studies in the literature cover a broader range of lakes, with the studies referenced here spanning from around 1-57 lakes, and most studies examining more than 15 lakes (Sass *et al*., 2011; Mushet *et al*., 2023; Francis *et al*., 2007; Christensen *et al*., 1996; Marburg *et al*., 2006; Pearles and Zanden, 2023). Expanding the sample size in future research would help confirm the findings observed in this study and provide a more robust understanding of the relationship between residential development and CWH abundance and size. Additionally, the size of the lake itself can influence CWH dynamics. Larger lakes tend to have more shoreline armouring (e.g., seawalls) to prevent erosion, and they also have greater fetch, making the wave action on larger lakes more powerful. This increased wave energy can move CWH more efficiently, leading to the potential loss of CWH in these areas (Wehrly *et al*., 2012). While Devil Lake is considered large for the region, covering a circumference of 58km (Devil Lake Association, 2017), it is important to note that it is still smaller compared to the vast number and size of lakes considered in many other studies. For example, although no studies have been conducted on the Great Lakes with regards to CWH, with these lakes being much larger, may experience significantly different CWH movement due to more substantial wave energy (Gabe*l et al.,* 2008). Thus, while the findings from Devil Lake provide valuable insights, they may not fully represent the trends in larger lakes with more intensive wave driven CWH movement.

Broader Ecological Implications and Significance

The results from this study have broader ecological implications for how we understand the relationship between residential development and aquatic ecosystems. The reduction in both the abundance and size of CWH in high-density areas having less could severely impact the lake's ecological functions. Large CWH serves as a vital habitat for aquatic species, promotes water quality through sediment retention, and contributes to carbon sequestration (Matern *et al*., 2023). Consequently, limiting high-density development around sensitive aquatic environments such as Devil Lake could help preserve the ecological integrity of these areas, ensuring the long-term health of CWH and associated ecosystems. These findings point to a potential ecological cost of human development that may not be immediately apparent but could have lasting effects on the lake's ecosystem. As smaller and larger CWH pieces are removed or never form due to disturbances in riparian zones, aquatic species that rely on these structures may be negatively affected. For example, species that use CWH for spawning may have fewer opportunities to breed, while fish and invertebrates that use CWH for shelter may experience higher predation rates or reduced access to food sources (Mushet *et al*., 2023). The reduction in CWH also limits the physical complexity of the habitat. Larger CWH pieces are often essential for certain species, as they provide more extensive habitats that support greater species richness (Theis *et al*., 2023). In high-density areas, the decreased availability of both small and large CWH could cause cascading effects through the food web, potentially leading to reduced biodiversity in these aquatic ecosystems. As Smith *et al*. (2022) and Theis *et al*. (2023) confirmed that higher trophic species such as northern pike, spottail shiner, and muskellunge were especially affected by the removal and disturbance of CWH, Devil Lake may increasingly see decreased growth sizes and abundance of these fish in high-density regions. Additionally, these high-density development areas may also witness a decline in detrital littoral sediments, as the removal of CWH disrupts the accumulation of organic matter and detritus that are critical for the food web. This observation aligns with the findings of Francis *et al*. (2007), who highlighted that CWH removal could lead to a decrease in nutrient cycling and sediment deposition, further contributing to the degradation of aquatic habitats in developed regions.

Based on these results, I will be able to make recommendations to the Devil Lake Association, potentially advising cottagers and homeowners to avoid altering tree abundance on their land or to actively add wood to their shoreline. Future shoreline residential development may need to be limited to fewer than 12 houses per km to maintain CWH levels similar to those in undeveloped lakes, where a minimum of 30 pieces of CWH per km is observed (Marburg *et al*., 2006). For developed lakes, a stricter threshold may be necessary to match the CWH abundance found in less developed areas to match the baseline levels of ~500 CWH per km (Marburg *et al*., 2006). Additionally, as the Devil Lake Association is proposing a fish sanctuary on the lake to provide a haven for undisturbed fish populations, I recommend that the best locations for this sanctuary be areas away from high-density development. This would help promote healthier growth rates and higher fish population abundance by minimizing the ecological impacts of residential development. These findings underscore the importance of mindful land-use planning that prioritizes the conservation of natural habitats. Conservation recommendations for Devil Lake should focus on reducing human impact by promoting sustainable, low-density development (1-11 houses per km), and preserving the integrity of shoreline habitats by not allowing extensive riparian tree removal. By protecting CWH, we can support biodiversity, enhance ecosystem services, and contribute to the overall resilience of aquatic ecosystems.

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SUMMARY

1. Residential development around lakes often results in habitat alteration and loss, including significant reductions in coarse woody habitat (CWH). CWH, which includes living or dead trees, tree fragments, and other woody debris in the littoral zone, is crucial for creating structural complexity and linking terrestrial and aquatic ecosystems, however, the relationship between development and the abundance and size of CWH is severely understudied.
2. I conducted observational snorkelling surveys along 60 transects covering 6km of shoreline on Devil Lake, ON in South Frontenac, Ontario, to analyze how different residential development densities: protected (0 houses per km), low (1-11 houses per km), and high (12-24 houses per km), affected the abundance (count of total CWH) and size (small 5-15cm and large >15cm) of CWH.
3. Analyzes revealed that residential density plays a critical role in both the abundance and size of CWH, with protected and low-density areas consistently supporting more total CWH, small CWH, and large CWH than high-density residential areas. Notably, low-density, and protected areas consistently exhibited similar patterns across both total CWH and size categories.
4. There may be a threshold of development, particularly around 12 houses km^{-1}, beyond which significant declines in CWH abundance and size occur.
5. This study provides insights into the relationship between residential development and CWH dynamics, offering valuable information for conservation efforts. By identifying the impacts of different development densities on CWH, the findings can inform land-use policies aimed at preserving aquatic habitats and maintaining ecosystem functions

associated with CWH in the Frontenac region. The Devil Lake Association can play a key role in applying these findings, helping to guide responsible development practices and conservation efforts to protect the health and biodiversity of Devil Lake.

APPENDIX

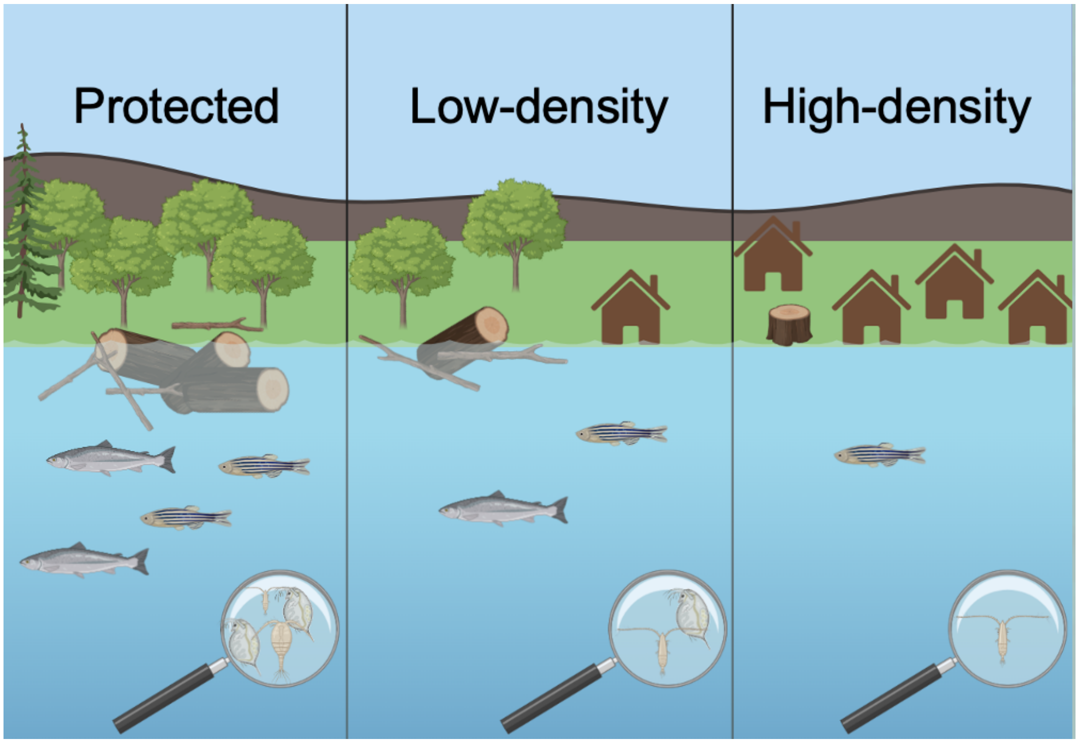

Figure 6. Visual hypothesis of CWH and associated biota affected by residential development (protected, low-density, high-density).

Table 1. Tukey test output of total CWH comparing across the density categories. P-values are flagged with one asterisk (* < 0.05), two asterisks (** < 0.01), or three asterisks (*** < 0.001).

Total CWH	Density Category	Estimate	Std. Error	Z-value	P-value
	Low - High	0.6497	0.2562	2.525	0.0311*
	Protected - High	0.9573	0.2556	3.785	<0.001***
	Protected - Low	0.3206	0.2536	1.264	0.4156

Table 2. Tukey test output of small CWH comparing across the density categories. P-values are flagged with one asterisk (* < 0.05), two asterisks (** < 0.01), or three asterisks (*** < 0.001).

Small CWH	Density Category	Estimate	Std. Error	Z-value	P-value
	Low - High	0.6805	0.2845	2.392	0.04425*
	Protected - High	0.9497	0.2839	3.345	0.00234**
	Protected - Low	0.2692	0.2815	0.956	0.60461

Table 3. Tukey test output of large CWH comparing across the density categories. P-values are flagged with one asterisk (* < 0.05), two asterisks (** < 0.01), or three asterisks (*** < 0.001).

Large CWH	Density Category	Estimate	Std. Error	Z-value	P-value
	Low - High	0.5332	0.2822	1.889	0.141694
	Protected - High	1.0108	0.2788	3.626	0.000879***
	Protected - Low	0.4766	0.2722	1.754	0.185145

Table 4. Raw Data

Transect ID	Density Category	Sediment type	Date	Site Description	Weather	Coordinates	Small (5cm-15cm)	Large (15cm-30cm)	Total CWH
#6	High	Rocky and sandy	03-Jul	rocky shoreline, some trees	27¡C and windy	44.583886¡N, 76.422261¡W	18	8	26
#102	Low	Sandy and weedy	05-Jul	clear water, loose sediment, nearshore rocks, vegetation and trees, east side of Miller island, not directly in front of cottage	26¡C, sunny	44.58363¡N, 76.42568¡W	16	16	32
#166	Protected	Weedy and muddy	05-Jul	crown land of lost bay, shoreline rocky, lots of trees,murky water, loose sed.	29¡C, slightly cloudy	44.59496¡N, 76.43090¡W	8	9	17
#11	High	Rocky	08-Jul	Perth road (bedford mills), rocky shoreline	24¡C, sunny	44.588218¡N, 76.420343¡W	12	2	14
#59	Low	Sandy	08-Jul	parkers bay inlet, narrow bay, rocky,	24¡C sunny, slight wind	44.58788¡N, 76.42734¡W	11	7	18

				murky bottom, algae abundant					
#3	Protected	Weedy	09-Jul	head of the lake (west end), shoreline a bit rocky, most of littoral zone was wetland, had to switch transect location away from dense wetland for swimming ability	30¡C, sunny	44.57844¡N, 76.51206¡W	0	6	6
#19	High	Sandy	09-Jul	lots of trees, bushes, a floating dock, site bedford mills (spot before parkers point, loose sed	28¡C, windy, mostly sunny	44.59421¡N, 76.41626¡W	11	2	13
#18	Low	Sandy and rocky	12-Jul	Buce bay , shoreline is rocky with lots of trees	27¡C, sunny	44.60037¡N, 76.45648¡W	0	1	1
#151	Protected	Weedy and rocky	12-Jul	buce bay,crown land, lots of macrophytes on bottom	25¡C,mostly sunny	44.59323¡N, 76.46922¡W	12	6	19

#62	High	Weedy and rocky	16-Jul	Goose bay, transect moved because too steep (west Devil)	24¡C and cloudy	44.58390¡N, 76.49198¡W	14	5	19
#207	Low	Weedy and rocky	15-Jul	Along perth road, very rocky shoreline, scattered trees, open space	28 ¡C , partly cloudy and windy	44.57762¡N, 76.42494¡W	4	0	4
#158	Protected	Weedy and rocky	15-Jul	Lost bay crown land, rocky shoreline, very steep drop sometimes, moved transect a bit over, many trees	25 ¡C and sunny	44.59172¡N, 76.44001¡W	17	15	32
#31	High	Loose	16-Jul	rocky shoreline, lots of macrophytes and wood on bottom	26¡C and cloudy/rainy	44.59737¡N, 76.41665¡W	21	6	27
#7	Low	Weedy and rocky	17-Jul	shoreline has lots of trees and fallen trees, some cottages, murky	25¡C and a bit windy	44.59618¡N, 76.46074¡W	26	13	39
#99	Protected	Loose	17-Jul	shoreline is rocky and there are lots of big trees	24¡C and cloudy	44.57644¡N, 76.51043¡W	5	10	15

#79	High	Rocky	19-Jul	West end devil lake, many docks, very deep, steep slope, many macrophytes, many trees	23¡C and partly cloudy	44.58363¡N, 76.47935¡W	14	11	25
#189	Low	Loose and rocky and sandy	19-Jul	Cedar Island, rocky shoreline, some macrophytes	19¡C and sunny	44.58248¡N, 76.44746¡W	15	2	17
#77	Protected	Loose and rocky	22-Jul	Frontenac park, rocky shoreline, lots of CWH, some lily pads	25¡C, partly cloudy	NA	83	21	104
#44	High	Rocky	22-Jul	Green bay campground area, few scattered trees on shoreline	23¡C, sunny	44.33563N, 76.26359W	11	12	23
#50	Low	Rocky	23-Jul	Parkers Bay, rocky shoreline with some trees, first 5m is steep	22¡C and partly cloudy	44.59120¡N, 76.42757¡W	34	7	41
#62	Protected	Muddy and rocky and loose	23-Jul	Frontenac park, shoreline is steep, rocky, lots of trees, and some macrophytes	22¡C, partly cloudy and windy	44.57904¡N, 76.48608¡W	144	83	227

#9	High	Loose and rocky	23-Jul	Perth road by bridge (bedford mills)	25¡C and sunny	44.58482¡N, 76.42150¡W	25	3	28
#185	Low	Weedy and loose	24-Jul	Island 6	24¡C, hot and sunny	44.58026¡N, 76.45578¡W	29	17	46
#173	Protected	Rocky	25-Jul	Parkers bay crown land, shoreline rocky and a bit steep, some trees poking through rock	20¡C, windy, cloudy	44.59211¡N, 76.43226¡W	11	2	13
#78	High	Rocky	25-Jul	West end devil lake, few cottages, many trees	26¡C, partly closure, windy, waves strong	44.58557¡N, 76.47570¡W	26	10	36
#143	Low	Weedy and rocky	25-Jul	island 1, rocky and steep shoreline, lots of woody debris/macros, lots of trees, one dock	21¡C, cloudy	44.58035¡N, 76.44636¡W	47	17	64
#146	Protected	Rocky	25-Jul	Buce bay crown land, lots of trees , steep rock cliff and drop off in areas	20¡C, cloudy	44.59025¡N, 76.47289¡W	30	6	36
#56	High	Sandy and weedy	29-Jul	West end Devil - by Erin's Bluff,	22¡C and sunny	44.58807¡N, 76.48406¡W	17	3	20

				many cottages, some trees, rocky shoreline, loose sed					
#48	Low	Sandy and loose	29-Jul	Parker's bay, coast is marsh wetlands, some cattails, tall grasses and other shrubbery, some trees, mostly flat ground	26¡C, cloudy, still water	44.59400¡N, 76.42643¡W	19	3	22
#55	Protected	Weedy and loose	29-Jul	Frontenac park by Gibson lake, steep rocky shoreline, lots of trees, very clear water, very dense macrophytes	25¡C, partly sunny	44.57759¡N, 76.49169¡W	21	30	51
#15	High	Rocky and weedy and sandy	29-Jul	Along Perth road - by fish lodge, rocky shoreline, some trees	27¡C, cloudy	44.58871¡N, 76.41997¡W	15	7	22
#153	Low	Sandy and weedy	30-Jul	Loon Song Island, rocky shoreline under water, not steep, lots of fallen trees	NA	44.58073¡N, 76.45401¡W	27	9	36
#68	Protected	Rocky and weedy	30-Jul	Frontenac -west end, shoreline has	24¡C, sunny	44.57901¡N, 76.47909¡	107	31	138

				lots of trees and is slightly steep					
#5	High	Loose and sandy and weedy	30-Jul	bedford mills by Jims, few trees, stable slope, two docks, fairly deep	NA	44.58199¡N, 76.42349¡W	11	9	20
#198	Low	Rocky	30-Jul	Along perth, near boat launch, lots of trees, mini island w rocks and a few trees beside transect	29¡C, sunny	44.57127¡N, 76.42979¡W	54	7	61
#19	Protected	Weedy and loose	01-Aug	Frontenac, many trees on shoreline, rocky, a little steep	26¡C, sunny	44.57686¡N, 76.50890¡W	9	12	21
#17	High	Rocky and sandy	31-Jul	developed and rocky shoreline, some trees	25¡C and sunny	44.59116¡N, 76.41782¡W	71	2	73
#136	Low	Weedy and rocky	01-Aug	Loon song island (island 1), shallow alcove, not steep, lots of trees	27¡C , sunny	44.58169¡N, 76.45266¡W	43	20	63
#154	Protected	Rocky	01-Aug	Lost bay, lots of trees and rocky shoreline, not steep and deep	29¡C and sunny	44.59087¡N, 76.43617¡W	56	13	69

#4	High	Sandy and rocky	31-Jul	By tims, lots of trees, minimal slope	25¡C and sunny	44.58093¡N, 76.42390¡W	24	2	26
#155	Low	Muddy and loose	01-Aug	James island (Island 3), lots of trees, little bit steep	28¡C and sunny	44.57945¡N, 76.45076¡W	69	29	98
#37	Protected	Rocky	02-Aug	Frontenac, lots pf trees, little bit steep, deep undewater	24¡C and cloudy	44.58067¡N, 76.49717¡W	68	5	73
#52	High	Weedy and sandy	02-Aug	Campground Pinehaven, developed shoreline, almost no trees, many boats and docks	24¡C and cloudy	44.56580¡N, 76.43763¡W	0	0	0
#124	Low	Weedy and loose	07-Aug	Vanderbilts island, shoreline is a bit steep, many trees	24¡C and sunny	44.57660¡N, 76.42978¡W	139	6	145
#79	Protected	Rocky and loose	07-Aug	frontenac park, rocky shoreline, many trees, stable slope	19¡C, sunny and windy	44.57803¡N, 76.46857¡W	42	6	50
#85	High	Weedy and loose	07-Aug	west end by big house near micheaks lane steady shoreline,	23¡C and sunny	44.58334¡N,76.50052¡W	8	3	11

				not many trees (highly developed), a bit rocky					
#66	Low	Rocky	08-Aug	Near hardwood bay, steep shoreline that's rocky, many trees	23¡C and partly cloudy	44.56768¡N, 76.46427¡W	27	1	28
#150	Protected	Weedy and rocky	08-Aug	Crown land Bruce Bay, rocky shoreline, steep, many trees on shore	22¡C, partly cloudy, windy	44.59406¡N, 76.46696¡W	52	2	54
#49	High	Loose and sandy	08-Aug	Near Green Bay campground, lots of docks, some trees	22¡C and a bit rainy	44.56160¡N, 76.44173¡W	3	1	4
#252	Low	Weedy and loose	14-Aug	Fish santuary, shoreline is stable, many trees, some rocks	28¡C, sunny and windy	44.58888¡N, 76.41260¡W	12	3	15
#111	Protected	Weedy and loose	12-Aug	Frontenac in hardwood bay, lots of trees, some dead ones hanging over the water	20¡C, cool, overcast	44.56624¡N, 76.47115¡W	117	27	144
#86	High	Muddy and weedy	12-Aug	Boat ramp,few trees and	18¡C, cool, overcast	44.57438¡N, 76.42330¡W	26	16	42

				sloped shoreline, guard rail along roadside					
#216	Low	Weedy and muddy	14-Aug	North of bedford mills (by bedford cottages), beside cottage and 2 docks, slightly steep and lots of trees	27¡C and sunny	44.60170¡N, 76.40919¡W	49	9	58
#83	Protected	Rocky and weedy and sany	14-Aug	Hardwood bay Frontenac, steep shoreline, rock hill w flat surface, scattered trees	24¡C and sunny	44.57032¡N, 76.46752¡W	30	8	38
#30	High	Weedy and sandy	15-Aug	Bedford mills by bridge, shoreline developed, few trees, stable slope, by a couple cottages	27¡C , sunny	44.59589¡N, 76.41804¡W	2	0	2
#102	Low	Rocky and sandy	15-Aug	Miller Island, many trees, rocky shoreline and slight hills	25 ¡C and sunny	44.58304¡N, 76.42958¡W	65	17	82
NA	Protected	Weedy and loose	14-Aug	Hardwood bay Frontenac, a bit	26¡C, sunny	44.57028¡N, 76.47195¡W	87	18	105

				steep, many trees, rocky					
#74	High	Rocky and weedy and muddy	19-Aug	West end Devil, shoreline is deep, lots of trees, a few docks and cottages in transect	15¡C, rainy and cold and windy	44.58349¡N, 76.48307¡W	30	13	43
#236	Low	Rocky and weedy	19-Aug	House in between frontenac park, shoreline stable, rocky, lots of trees	16¡C, rainy and cold and windy	44.57611¡N, 76.46718¡W	23	12	35
#89	Protected	Rocky and sandy	15-Aug	Hardwood Bay frontenac, shoreline is rocky, many trees	23¡C and sunny	44.57115¡N, 76.46606¡W	29	6	35