University of Nevada, Reno

Analyzing the Importance of Coarse Woody Debris to Water Quality in a Temperate Lake

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by

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ABSTRACT

Coarse woody debris (CWD) in temperate lakes represents a nutrient-rich habitat for microscopic and macroscopic communities, communities that substantially contribute to the carbon flux of the lake (Czarnecka et al., 2014). Despite CWD's abundance in lakes, the degree to which it contributes to lake carbon dynamics and nutrient cycles remains understudied. The question asked in this study is the impact coarse woody debris has on water quality of a temperate, oligotrophic lake. I tested the hypothesis that in the presence of CWD lake algal and microbial productivity will increase due to the enrichment of lake water with higher nutrients and increased substrate for algal growth. This hypothesis was tested by measuring dissolved oxygen levels, chlorophyll-*a* and nitrogen and organic carbon content in treatments with various levels of CWD and littoral zone water from Donner Lake, CA. Woody treatments had significantly higher primary production and higher levels of algae growth compared to control treatments. This study illuminates the impact of CWD on aquatic ecosystems' productivity and overall quality, advocating for the need for more systematic studies as to how to conserve coarse woody habitat in temperate lakes.

KEYWORDS: Coarse woody debris (CWD), lake littoral zone, lake water quality

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INTRODUCTION

Inland watersheds are major components of the global carbon cycle: lakes receive near twice as much carbon from land compared to oceans. The intake of organic carbon in lakes is greater than carbon sequestration in the ocean floor (Tranvik 2009). Lake littoral zones, the near-shore areas, are especially influential because they can sequester as much as six times more carbon than the surrounding riparian area (Czarnecka 2016), making lake carbon productivity a crucial component to their region's ecosystem dynamics (Cole et al., 1994). Lakes' contributions to global carbon cycling are changing with climate change and human activities, due to urban development causing loss of biodiversity and species abundance (Twardochleb et al., 2016).

In forested (temperate) lakes, lifeless trees that fall into the water by various natural processes are termed coarse woody debris (CWD). Lake level changes driven by climate change along with human activity are causing levels of CWD in lakes to drastically decline (Gaeta et al., 2014). An analysis of northern temperate lakes estimated that lakes in developed areas have 500 less logs than undisturbed lakes; these changes in CWD habitat can affect littoral organisms for two hundred years after the removal (Christensen et al., 1996). A 2009 study done in Little Rock Lake showed that even with a drought-driven lake level decline of 1.1m, one fish population size fell below the level of recognition and the other prominent species showed a decrease in growth, both primarily due to the loss of CWD associated with lake level decline (Gaeta et al., 2014). The bottom sediments in temperate lakes are also extremely important to lake food webs (Francis et al., 2007) and are affected by the amounts of CWD present in the lake. This is because CWD has the potential to retain organic matter in littoral sediments.

With the loss of CWD in littoral zones, the sediments' value and thus the dynamics of the entire lake could show negative impacts (Francis et al., 2007). In the littoral zone, this woody debris builds up over hundreds of years (Guyette et al., 1999) and provides a complex habitat for floral and faunal species that is substantially more productive than ordinary sediments (Glaz et al., 2009). It has been shown that the presence of CWD can positively affect upper trophic levels' productivity such as fish, due to the microbes living in the wood providing food, as well as the wood providing shelter for spawning and predator-prey interactions (Gaeta et al., 2014).

Microscopic organisms that come to inhabit CWD generally belong to one of two main groups: heterotrophic bacteria or algae. Carrying out photosynthesis and respiration, these microbes play a key role in carbon and nutrient cycling in lakes. By providing a habitat for these productive organisms in the littoral zone, coarse woody debris may directly contribute to lake carbon flux, nutrient cycles and, thus, water quality. Studies also suggest that CWD nutrient concentrations increase as the wood pieces degrade, providing substrate and more bioavailable nutrients for more microbial growth (Czarnecka 2016). These microbes (including nitrogen-fixing species) colonize the wood and their respiration makes nutrients bioavailable to other species. As more nutrients like nitrogen become available to surrounding algae, algae benefit from both these nutrients and the carbon released from degrading wood. These processes feed back into the carbon cycle as the algae then produce more organic carbon (Czarnecka 2016). These carbon and nutrient cycles that CWD influences are essential processes of aquatic systems.

Little is known about CWD's nutrient load and habitat contribution to the carbon flux, nutrient cycles and productivity of the littoral zone (Czarnecka 2016). The responses of lake productivity to various levels of CWD complexity, or the effect of various decay status also remain understudied (Czarnecka 2016). The idea that CWD must be conserved due to its high density in some littoral habitats has been contemplated (Marburg et al., 2009), yet there is room for expansion as to exactly why CWD is a crucial component to temperate lake systems.

Even though there are studies advocating for the importance of CWD to lake ecosystems, the particular impact of CWD to microbial growth, primary productivity and nutrient flux in lake littoral zones is still a persisting question. The intent of this study is to understand the role of coarse woody debris to lake littoral zone water quality and content in a temperate, oligotrophic lake. The ultimate hypothesis is if coarse woody debris contributes a stable and complex substrate for microbial growth in the littoral zone of temperate lakes, then this debris substantially contributes to overall lake littoral zone productivity and water quality. By experimentally simulating environments with varying levels of CWD in Donner Lake littoral zone water and measuring levels of respiration, algae growth and nutrient concentrations, the effect on CWD in lake littoral zones is made clear, advocating for more management and conservation measures.

MATERIALS AND METHODS

Field Site

To conduct these studies, littoral zone water and coarse woody debris samples were collected from Donner Lake, California. Donner Lake is a temperate, oligotrophic lake (little amount of production), located in the eastern region of the Sierra Nevada

Mountains. The laboratory experiments were conducted at the University of Nevada, Reno in the Aquatic Ecosystems Analysis Laboratory.

Experimental Design

To quantify the role of CWD to a lake's primary productivity, algae growth and nutrient flux, studies must be done that quantify differences between aquatic environments with varying levels of woody debris. Following field sample collection from Donner Lake, all samples were prepared: water samples screened for zooplankton, CWD stripped of bark and measured 3 inches long and glass cuvette tubes of the same length were filled and sealed. The tubes were used as a positive control with the same surface area as the wood pieces for microbial growth. Biological oxygen demand (BOD) bottles were used for the 40 samples (ten of each of the four treatments: control, tubes, small wood and large wood), because of their small tops, which provided a small surface area for atmospheric exchange, minimizing evaporation during the experiment. Ten replicates of each treatment were used and assigned randomly: one control, one positive control (tubes), one small volume of CWD and one large volume of CWD. The control contained only lake water, the positive control had sealed glass tubes with the same surface area as the large wood pieces and the last two treatments had CWD, in small and large volumes. Samples were prepared by stripping the bark off of woody samples, measured three inches in length then divided into three pieces of wood for each replicate. Tube treatments also had three tubes per replicate. Small wood treatments contained wood with smaller diameter, one quarter of an inch, than that of large wood samples. The BOD bottles were filled with Donner Lake littoral zone water and their assigned samples (either small, large wood or tubes or none) and incubated in a controlled temperature incubator at 19 degrees C with a light schedule set at 10:00am to 8:00pm for 23 days.

Measurement Methods

As a primary indicator of photosynthesis and respiration, dissolved oxygen (DO) measurements were taken using a Yellow Springs Instrument Dissolved Oxygen Probe. DO measurements were recorded every day: morning (10:00am) and night (8:00am) for the first seventeen days of incubation. This length of time was chosen due to the time available. DO% morning and night measurements capture both the daily respiration level maximum (night measurement) and to differentiate respiration from photosynthesizers (morning measurement). The DO data was plotted every day along with gross primary production (GPP). GPP was formulated as the difference between night and morning absolute concentration measurements for each treatment. Periodically (days zero, seven, twelve, seventeen and twenty-three), one round of replicates from the experiment were shut down for chlorophyll *a* (chl-a) content measurement and nutrient analysis. Chlorophyll *a*, total nitrogen (TN) and total organic carbon (TOC) were measured on days 0, 7, 12, 17 and 23. Chlorophyll *a* was measured using a Turner 10 AU flourometer and Shimadzu TN/TOC measured using standard laboratory methods with a TN/TOC analyzer. There are ten replicates of the 4-sample design (n=40 total) allowing us to attain these physical and nutrient values at the days specified without skewing the ratio of water to CWD amounts. Average GPP values for each day and treatment were analyzed using a two-way ANOVA test of variance among the two predictor variables, day and treatment against the continuous response variable, average GPP. Tukey HSD tests were performed on each day that proved to be significant to establish where the significance was between treatments.

RESULTS

Photosynthesis and Respiration

The dissolved oxygen measurements recorded at night indicate the photosynthesis occurring that day. Average DO levels for each treatment are shown in **Figure 1**. Small and large wood treatments had much lower DO% compared to the control and positive control throughout the duration of the experiment. Large wood treatments have the lowest DO%, reaching 5% on day 7, followed by small wood that had slightly higher levels of oxygen with its lowest point at 36% on day 6. DO measurements taken in the morning represent the respiration that occurred during the previous night. Average respiration levels can be found in **Figure 2** and show higher DO% for both controls than that of small and large wood treatments. Large wood treatments consistently had the lowest level of DO%, the lowest being 12% on day 5, throughout the time measured.

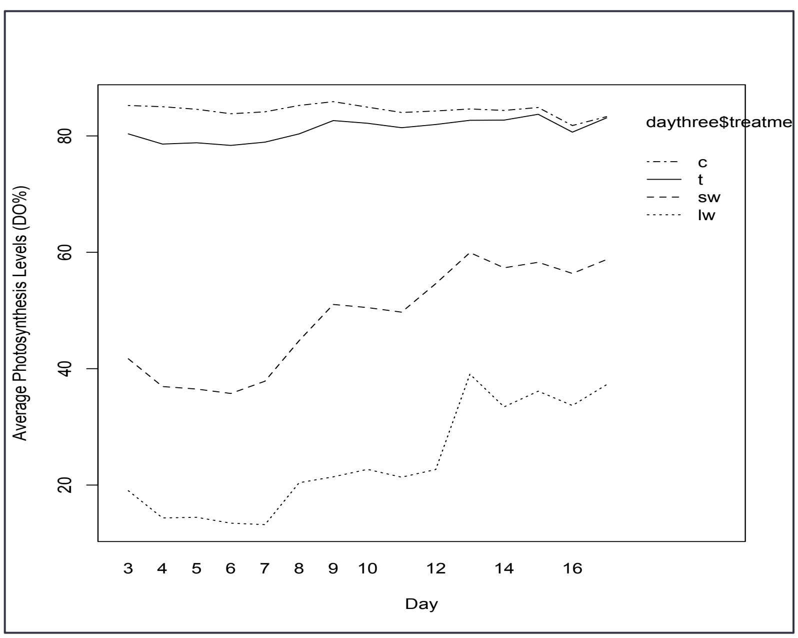

Figure 1. A plot of the average photosynthesis levels per day measured in percent dissolved oxygen for each treatment. Treatments are represented in the legend as follows: c = control, t = tubes (positive control), sw = small wood, lw = large wood.

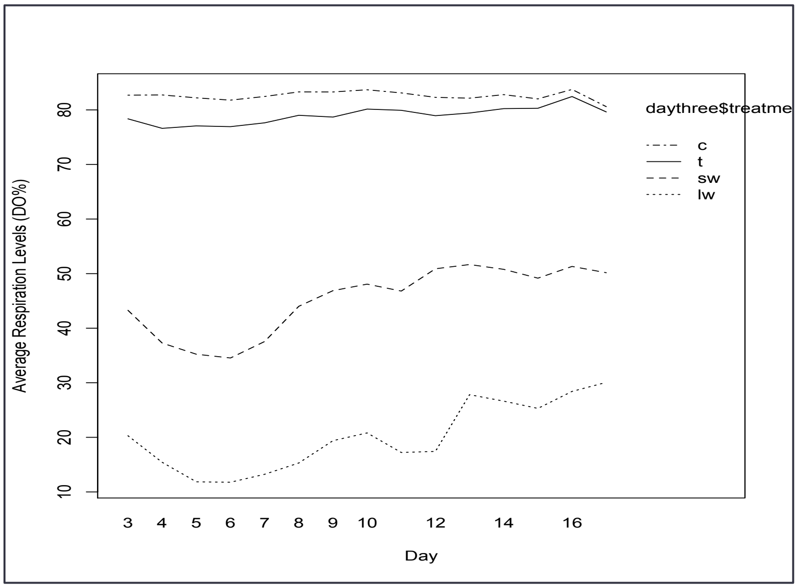

Figure 2. A plot of the average respiration levels per day measured in percent dissolved oxygen for each treatment. Treatments are represented in the legend as follows: c = control, t = tubes (positive control), sw = small wood, lw = large wood.

Gross Primary Production

The photosynthesis and respiration values become significant when the difference is taken between the two values. The difference between the night respiration value and the day's photosynthesis value gives an assessment of Gross Primary Production (GPP). These primary production values of the seventeen-day testing period were analyzed using a two-way ANOVA test of variance to assess the significance of predictor variables, day and treatment to the response variable of average GPP. Significance of these factors was found on days 3, 5, 8, 14, 15, 16 and 17 and can be found in **Table 1**. Corresponding p values are: 1.32e-04, 1.68e-04, 2.37e-02, 9.03e-04, 7.58e-05, 3.4e-04, and 2.87e-03

(Table 1). Following the two-way ANOVA, a Tukey HSD analysis was performed to find the exact area of significance. The Tukey HSD test showed that the significance was between both the control and positive control to each experimental small wood and large wood treatment.

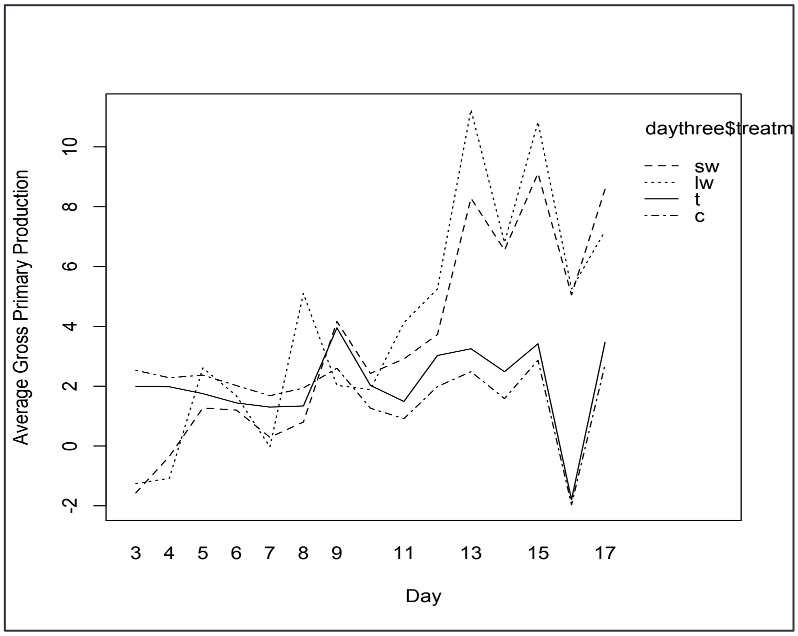

Figure 3. An interaction plot of average gross primary production values per day for each treatment. Treatments are represented in the legend as follows: sw = small wood, lw = large wood, t = tubes (positive control), c = control.

Day	P-value
3	1.32e-04***
5	1.68e-04***
8	2.37e-02*
14	9.03e-04***
15	7.58e-05***
16	3.4e-04***
17	2.87e-03**

Table 1. Days of the experiment that showed significant p values from the two-way ANOVA tests for the difference between both positive controls and experimental treatments.

Chlorophyll-a

Chlorophyll *a* (chl-a) content in water serves as a surrogate for algal biomass in the sample. Chl-a measurements from each treatment show differences over time; experimental small wood and large wood treatments have much higher amounts of chlorophyll *a* over time compared to both controls (**Figure 4**). Control and positive control (tubes) remain constant at a low level of chlorophyll *a*, the highest level only 1.74 µg/L on day 7. Small wood samples increase in chl-a much faster than that of the large wood samples, reaching 8.3µg/L on day 17, and large wood samples have an increase in chl-a, but later in the experiment, 5.9 µg/L on day 23.

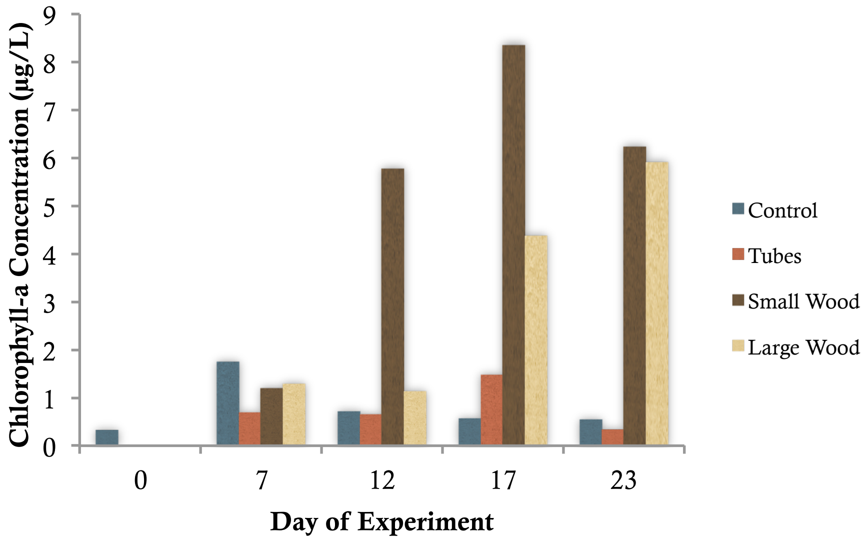

Figure 4. A graph of chlorophyll *a* content (µg /L) of each treatment on periodic days throughout the experiment.

Total Nitrogen

Measurements of average total nitrogen content are higher in woody treatments versus both controls, as shown in **Figure 5**. Control samples show a slight decrease over time first reaching 257µg/L on day 7 then leveling out around 100µg/L, whereas small wood treatments increase from initial readings (180.1µg/L on day 0) to approximately 350µg/L. Large wood treatments increase from initial to over 450µg/L by day 23.

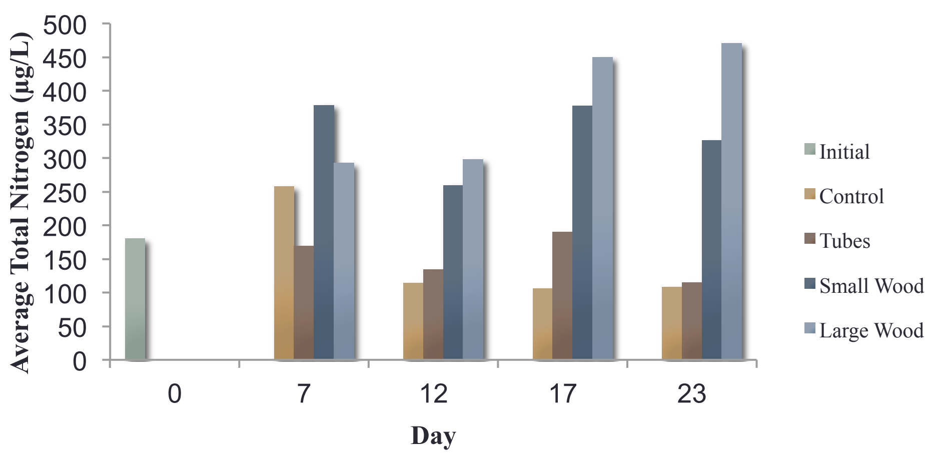

Figure 5. A graph of average total nitrogen content (µg/L) of each treatment measured during periodic days of experiment.

Total Organic Carbon

Total organic carbon (TOC) measurements show the amount of organic carbon in the sample, due to photosynthesis outputs and the wood being decomposed by microbes. Average TOC levels for all treatments are shown in **Figure 6** and have a stable value of approximately 2.5 mg/L for both controls, while small wood treatments are similar across time at around 10mg/L. Large wood treatments show slightly more variation in organic carbon levels, ranging from 18mg/L to 28mg/L.

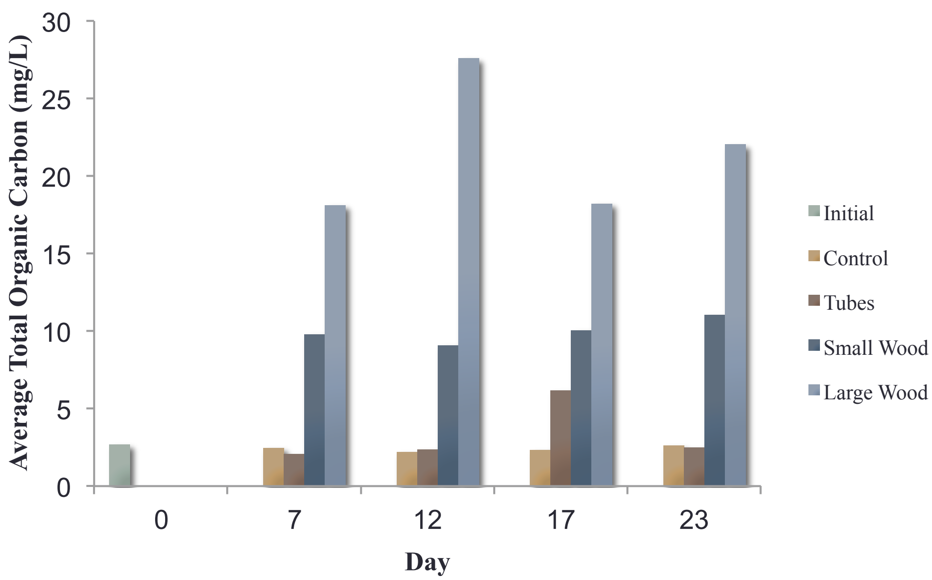

Figure 6. A graph of average total organic carbon (mg/L) measured for each treatment throughout periodic days of the experiment.

DISCUSSION

Photosynthesis and Respiration

In the photosynthesis and respiration data, the dissolved oxygen levels of experimental treatments being consistently lower than controls suggest that microbes are more productive in treatments with woody debris. Large wood treatments have the lowest DO%, which corresponds with more microbes in these treatments using the woody habitat and respiring (thus using oxygen). The slight increases in photosynthesis of the experimental treatments towards the end of the experiment suggest that there was a new algal species dominating, first responders are coming to the end of their life cycle and new ones are taking their place. The fact that respiration results have much lower dissolved oxygen content for experimental treatments shows that these microbes are respiring over night and using the available oxygen in the water from primary production earlier that day. These findings support the notion that woody debris supports microbial communities.

Gross Primary Production

Treatments containing CWD have significantly higher gross primary production (GPP) than both controls over a short period of time **(Figure 3).** The seven statistically significant days during the experiment show that GPP is notably different for experimental woody treatments compared to both controls. Gross primary production is crucial to carbon cycling in aquatic systems and the significance of CWD to primary productivity is illustrated in this study.

Chlorophyll-a

Chlorophyll *a* (chl-a) is an indicator of algal growth and the chl-a results here were especially interesting because the large wood treatments showed a later response of growth than that of small wood samples **(Figure 4).** Due to the nature of the small and large wood samples having different surface area and volumes, they have different amounts of biologically available nutrients. Age and decay rate of woody debris are recognized as potentially important factors to the wood's role in microbial growth in previous studies (Czarnecka 2016). Since the small and large wood volumes serve as various amounts of spatial complexity, decay statuses and levels of spatial complexity, the differences in chlorophyll *a* responses from small and large wood treatments advocates for the importance of these factors, not only the presence of CWD.

Total Nitrogen

When nitrogen-fixing microbes inhabit the wood, they degrade the wood and release bioavailable nutrients. Increases in total nitrogen concentration in both woody treatments allude to the fact that microbial respiration (from microbes inhabiting the wood) increases nutrient content. These results show that CWD is contributing immensely to the nutrient flux of the littoral zone lake water.

Total Organic Carbon

The interactions from the microbes inhabiting the wood have been shown to increase concentrations of organic carbon (Czarnecka 2016). In this study, total organic carbon concentration increases over time in small and large wood treatments. This demonstrates that microbes are decomposing the organic carbon the wood is composed of and releasing organic carbon into the water. Another source of organic carbon in water is the photosynthesis sugar product. The fact that organic carbon levels were higher in experimental treatments than controls shows microbes are decomposing the wood and photosynthesizers are more productive in woody environments.

Implications and Future Directions

Some previous studies argue that chlorophyll *a* content is much lower on wood than from normal sediments, possibly due to the fact that these algae cannot derive nutrients directly from wood (Czarnecka 2016). Since CWD provides a complex habitat for other microbes that can make those nutrients available, these algae can then be productive in a woody habitat. The higher chlorophyll levels, organic carbon and nitrogen concentrations with woody treatments advocate for wood's contribution to this particular aspect nutrient cycling and primary productivity.

These results emphasize the importance of coarse woody debris in aquatic systems because in experimental treatments with wood, there was significantly more primary productivity, algae growth and nutrient concentration than littoral lake water alone.

Sometimes as much as 50% higher invertebrate biomass is found on older, more decayed wood than compared to new wood (Czarnecka 2016), adding to the importance of more systematic studies involving decay rates of CWD in littoral zones.
Algae abundance is also greater in spring and lower in summer, due to senescence and predator grazing upon them, shows possibility for conducting study at a different time (Czarnecka 2016).

The demand for conserving CWD densities in temperate watersheds has been noted before (Marburg et al., 2009), and this study emphasizes the importance of this notion. If densities of CWD in lakes continue to decrease, this keystone contributor to lakes could be lost and all the organisms, nutrient cycles and overall water quality involved with it could see drastic changes. This study emphasizes the importance of CWD to temperate lake littoral zones and the microbial communities within it, underlining the need for more in-depth analyses on the interactions between coarse woody habitat and aquatic systems in a changing climate.

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