# *Forest Harvesting Impacts on Forested Wetland Ecosystem Functions in North America*


by

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# CONTENT

## List of Figures

## List of Tables

# *Forest Harvesting Impacts on Forested Wetland Ecosystem Functions in North America*

## ABSTRACT

Wetlands provide various ecosystem services and values such as hydrology regulation, wildlife habitat and carbon sequestration. Harvesting activities can alter wetland functions and cause tremendous changes to the ecosystem but the magnitude and direction of the effects depend upon the intensity of the harvest and associated activities (Wigley et al., 1994). Harvesting methods which are well-developed in the size, timing and spacing can minimize impacts or even bring positive effects to wetland habitats.  Clear-cut, for instance, may eliminate the ability of a wetland to reduce flood peaks. Forest retention, on the other hand, can help retain water capacity of soil and thus reducing peak flood flows. To maintain wetland functions and thus protect their ecosystem values, wetlands must be properly identified and well managed. This article provides an understanding of some of the ecosystem functions and societal values of and some possible timber harvesting impacts on temperate forested wetlands. Potential operation suggestions during harvesting are given in the discussion part such as use shelter wood instead of clear cutting. BMPs that are effective to protect forested wetland ecosystem functions need to be considered by forest management operators.

*Key words: Temperate Forested Wetland, Logging Impacts, Wetland Ecosystem Functions, Wetland Habitat*

# INTRODUCTION

Wetland has diverse definitions in different regions and for varied audiences. A simply but broadly applied definition states wetland as “an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes, which, in turn, forces the biota, particularly rooted plants, to adapt to flooding” (Keddy, 2010). Wetlands provide wildlife, fisheries, biodiversity, water quality, and aesthetic values that are disproportionately large compared with their limited extent in the landscape (Gregory et al., 1991; Mitsch and Gosselink, 1993; Decamps et al., 1990; Forman and Godron, 1981; Malanson, 1993). E.g. Wetlands can regulate water flow by detaining storm flows and thus reducing flood peaks; Wetlands improve downstream water quality by retaining excess nutrients and by trapping sediment and heavy metals; Wetlands also provide many wildlife habitat components such as breeding grounds, nesting sites for a variety of fish and wildlife species, some of which are unique for many threatened and endangered plants and animals (Welsch et al, 1995). However, long-term loss of wetlands resulted from human activities has been reported from all regions of the world. A literature review of 189 reports on change in wetland area (Davidson, 2014) indicate a loss of world’s wetland averages between 54–57% but loss may have been as high as 87% since 1700 AD. Figure 1 shows his result of percentage remaining of natural wetland area since the start of the 18th century (Davidson, 2014). The largest overall losses occurred in Europe (56.3%) and North America (56%), followed by Asia (45.1%), Africa (43.0%) and Oceania (44.3%). Davidson (2004) also announced that while the rate of wetland loss in Europe and North America have either slowed or remained low since the 1980s, the rate has remained high in Asia. Besides, there is a need to improve the knowledge of the change in wetland areas worldwide, particularly for Africa, the Neotropics and Oceania where the amount of published reports of wetland area changes is limited (Davidson, 2004).

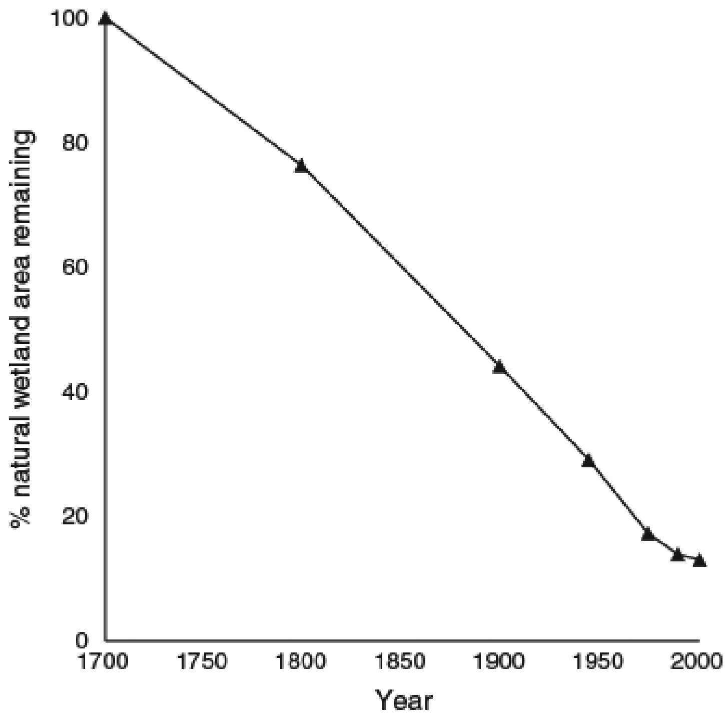


*Figure 1. The percentage remaining of the global natural wetland area (all types) since 18th century (Davidson, 2014).*

Harvesting activities can compromised or enhanced wetland functions and therefore shift the forested wetland ecosystem. The magnitude and direction of these effects depend upon the intensity of the harvest and associated activities (Wigley et al., 1994). Harvesting methods which are well-developed in the size, timing and spacing can minimize impacts or even bring positive effects to wetland habitats. Clear-cut, for instance, may eliminate the ability of a wetland to reduce flood peaks. Forest retention, on the other hand, can help retain water capacity of soil and thus reducing peak flood flows.

The purpose of this review is to call strong attention for forest management professionals and operators in North America to recognize environmental values of forested wetland and the potential forestry activity impacts on the ecosystem. Incorporating these values into management decisions by the professionals would contribute greatly to better development of sustainable forestry management plans with minimized impacts on the wetland ecosystem.

## Wetland classification

It is easier to avoid detrimental impacts on forested wetlands if the management area is recognized as wetland prior to the planning process. There are abundant classification schemes for wetlands vary by geographic region or by intended use of the classification results, and the scale at which classification is undertaken (Keddy, 2010). Canada, for example, sorted the variety of wetlands across Canada into five wetland classes: bog, fen, swamp, marsh and shallow open water. Here I summarized some main characteristics of the five types of wetlands in Table 1:

| ***Type*** / ***Feature*** | ***Bog*** | ***Fen*** | ***Swamp*** | ***Marsh*** | ***Shallow open water*** |
|---|---|---|---|---|---|
| ***Peat Accumulation*** | Deep peat accumulation | Peat accumulation | No peat accumulation | No peat accumulation | No peat accumulation |
| ***Water Occurrence*** | High water table；Very little water flow | High water table; Slow internal drainage | Water table usually below soil surface; Standing or gently moving water occurs seasonally | Periodically or permanently inundated by standing or slowly moving water | Shallow bodies of standing or flowing water (commonly representing a transitional stage between lakes and marshes) |
| ***Nutrients*** | Lack of nutrients | Low to moderate nutrient | Nutrient rich | Nutrient rich | Nutrient rich |
| ***PH*** | Strongly acidic | neutral pH | Low acidity | Low acidity | Low acidit1y |
| ***Vegetation*** | Dominated by sphagnum moss, shrubs, black spruce | Dominated by sedges, mosses, and many wild flowers; Shrubs and trees may be present | Presence of trees and shrubs | Emergent, submergent, and floating vegetation | Truly aquatic plants growing in and covered by at least 25 cm of water |
| ***Productivity*** | Least productive | Productive | productive | Most productive | Productive |
| ***Distribution in Canada*** | More common in the north | More common in the north | Most common in temperate areas | Most common wetland type in North America | |

*Table 1. Summary of the main characteristics of the five types of wetlands (Keddy, 2010)*

# Forested wetland

Forested wetlands are defined as the wetland where a closed canopy tree cover (>5 m) forms the dominant vegetation or if immature, the trees have the potential of becoming closed-canopy forests (Dahl et al., 1997). Figure 2 is a cross section of different wetland types, forested wetland showed as the second type from right. An estimate of 60% of the global wetland is forested (Matthews and Fung, 1987). Forested wetlands have many unique values, for example, more shading offered by trees maintains a low soil and water temperature that is critical to the survival of cold water fish in streams fed by or within such forested wetlands (Sharitz and Gibbons, 1989). Forested wetlands offer vital food, habitat, shelter resources for many wetland-dependent species such as amphibians and water birds. In America, although wetlands make up only about 3.5 percent of the land area, more than one-third of the United States' threatened and endangered species live only in wetlands (Mitsch and Gosselink, 1993) and an additional 20% of the threatened and endangered species use or inhabit wetlands at some time in their life. Moreover, more structural complexity (the vertical component of the plants) induces increased bird diversity (e.g. MacArthur and MacArthur, 1961; Huston, 1994) in forested wetland than other wetlands. According to the Census reports of breeding birds (Adamus, 1992), forested wetlands have a median of 27 bird species whereas freshwater marshes have only 9.5 (see appendix A).

Forested wetlands represent a significant source of timber supply for forestry operations in Canada (Smith, 2007) and America (McLaughlin et al., 2000). Evidence from the U.S. Wetland Status and Trends study suggests that while the rate of wetland loss is declining overall, the rate of loss of forested wetlands has accelerated. Harvest activities are strongly associated with the loss and modification of forested habitat in most regions of the world (Putz et al., 2008). Land management activities which affect these attributes will impact the use of the site by wildlife, amphibians and waterfowl. Some features that may influence a wetland’s habitat value are water, structural diversity and cover, abundant forage and high prey densities. With the desire for forest management professionals to better understand the effects of industrial timber operation on forested wetland ecosystems, this article is mainly focused on the shifted ecosystem functions of forested wetland by forestry operations.

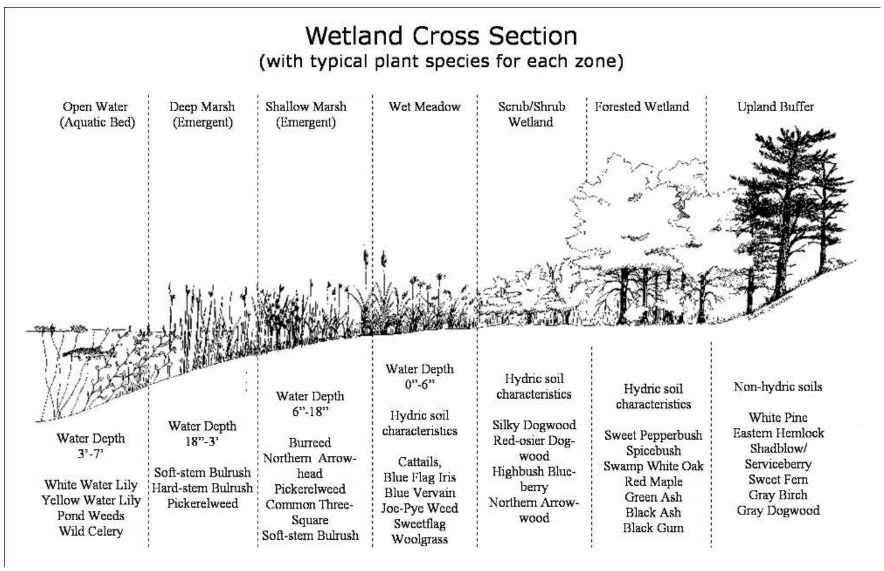


*Figure 2. Cross section of wetland types (Shirari, 2011), Forested wetland showed as the second type from right*

## Definition of Terms

*Ecosystem services* are defined as the benefits people obtain from ecosystems (Board, 2005). Wetlands provide a wide range of ecosystem services which are distinguished to four main categories according to Millennium Ecosystem Assessment: 1) Regulating services, which describes the capacity of ecosystems to regulate essential ecological processes and life support systems on Earth; 2) Supporting services, which includes the space or suitable substrate needed for the conduct of human activities such as living, cultivation, and recreation; 3）Provisioning services, which incorporates the resources provided by nature, including food, raw materials for industrial use, and genetic raw material; 4) Culture services, which refers to the role played by natural ecosystems in the maintenance of mental health by providing cognitive development, spiritual inspiration, and scientific appreciation of the world (Keddy, 2010).

*Ecosystem functions* are the biological, geochemical and physical processes and components that take place or occur within an ecosystem (e.g. vegetation, water, soil, atmosphere and biota) and how they interact with each other, within ecosystems and across ecosystems (ecosystem services SEQ, 2012). Examples include: nutrient source or sink on the landscape, water storage reservoir and regulator, habitat for species (unique and endangered) and carbon sequestration. Richardson (1994) summarized some attributes generally given as functions of wetland ecosystems (see Appendix B).

*Ecosystem values* arisen from functions desirable or useful to humans and are measures of how important ecosystem services are to people. To name some of the values a wetland ecosystem offer can include providing habitats for fishing, hunting, waterfowl, timber harvesting, wastewater assimilation, and flood control. These values can be subjective to different interest groups. For example, timber productivity (a function) is of primary concern to the forest industry. Environmentalists on the other hand, place other values related to endangered species or recreation to more critical concern than timber productivity.

# AFFECTED WETLAND FUNCTIONS

Extraction for natural resources, timber as a big one, can cause alternations to wetland functions. For example, forest harvest activities (e.g. clear cutting, selective cutting, commercial thinning, etc.) would influence wetland ecosystems in various ways such as rise in water table due to a decreased transpiration and interception, soil disturbance and compaction by heavy equipment, drainage and altered hydrology from ditching, draining, and road construction, etc. (Shepard, 1994). Besides, forest harvesting typically produce at least minimal temperature increases on the forest floor by increasing solar radiation input to the surface of soils. Decreased transpiration rates and interception by forest canopy removal would also increase the amounts of precipitation reaching the forest floor (Nieminen, 1998). Many of these shifts are detrimental to wetland habitat. For example, according to Veny (1986), increase in water table can last a long time and it takes as long as 15 years for watershed to return to its pre-harvest hydrologic conditions. The elevated water table and therefore more moisturized soil and higher water depth, clearly altered habitat conditions for wetland plant and animal species. Hoover, (2006) found that rates of prothonotary warblers (*Protonotaria citrea*) nest predation decreased with increasing water depth as a result of nest predation by raccoons.

The recognition of the special nature of these forested wetland by researchers and managers is essential for wetland management and conservation.  In Table 2, I summarized some of the functions of a wetland ecosystem which would possibly be affected under forest harvest activities. In the following paragraphs, wetland function shifts in hydrology, nutrient, leaf litter and habitat after harvesting have been evaluated by reviewing case studies.

| ***Affected Components*** | ***Function*** | ***Forest Operation Effects*** |
|---|---|---|
| ***Soil*** | Recycling system for nutrients and organic waste; Habitat for soil organisms; System for water supply and purification | Harvest roads/heavy machine increase soil compaction; create impermeable surfaces of lower water storage capacity and therefore increase water runoff |
| ***Leaf Litter*** | Important source of energy and nutrition to heterotrophic communities in forested aquatic system (99% Dissolved Organic Carbon (DOC) input) | Timber removal activities change leaf litter input quantity (usually reduce) and quality, both of which alter habitat conditions to many wetland-dependent organisms. |
| ***LW and Forest Canopy*** | Offer shading and cover, source of leaf litter; important to nutrient cycling; contribute to hydraulic diversity and habitat complexity | Removed as part of site clean-up; Less cooling and less food input; Decrease in habitat complexity; Exposed amphibians, birds, and invertebrates to higher temperature. |
| ***Sediment*** | Improve downstream water quality by trapping suspended sediment from adjacent waterways. | Rapid movement of large amounts of sediment (E.g., rock, soil, organic debris); affect downstream water quality |
| ***Hydrology*** | Regulate flood, discharge and recharge streams, | Forest harvest can increase water table, alter water temperature, decrease water quality etc. |

*Table 2. Affected wetland components under forest operation activities*

# Hydrology

Recognised as lands transitional between terrestrial and aquatic systems (Cowardin, 1979), wetlands have crucial hydrologic functions including flood storage and flood-peak desynchronization, groundwater recharge and discharge and water-quality regulation (Carter, 1986). Forest harvesting can affect many of these functions by influencing radiation, temperature, wind, moisture and nutrient cycle.

A number of studies have shown that timber harvesting in wetlands can result in increases in water table height across a range of climate and site types (Bliss and Comerford, 2002; Xu et al., 2002; Marcotte et al., 2008; Pothier et al., 2003; Renou and Farrell, 2005). The rise of the water table in forested wetlands after logging activities, referred to as 'watering up', was mainly caused by reduced evapotranspiration and interception caused by over-story removal. The increased water availability in the site may have considerable consequences in forested wetlands such as delayed regeneration, reduced productivity and altered habitat. A study conducted in the Beaurivage forest, 50 km southwest of Quebec City, Canada from 1990 to 1992 was designed to evaluate the effect of clear-cutting on water table elevation (Dubé et al., 1995). They encompassed five forest types and four soil subgroups where water levels were measured during the summers of 1990 and 1991 prior to logging (calibration) and in 1992 after logging (treatment). The results indicate that watering up occurred after clearcutting on seven out of the eight forested wetlands. The magnitude of the rise of water table increased with the depth of the precut water table. The mean and maximum rises were 20 cm and 52 cm, respectively, on a poorly drained mineral soil which had the lowest precut water table levels. The smallest rises, with mean around 7 cm, were associated with high precut water table on bogs and on fens. Lowering of the water table after cutting was observed in the 8th forested wetland where the water level before clear-cutting was usually within the top 10 cm. Similarly, another study carried out in Minnesota, USA (Slesak et al., 2014) also found significant increases in water table height following forest harvesting. They applied four treatment (Control, Girdling, Group selection and Clear-cut harvest) during the winter of year 2011–2012 under frozen ground conditions. The girdling treatment is intended to mimic the effect of emerald ash borer (EAB) mortality, and the two forest harvesting treatments (Group selection and Clear-cut) represent alternative management strategies that could be used to maintain a forest ecosystem following EAB infestation. Both clear cut and group selection sites appeared to have significantly higher water table than that of the control treatment site predominantly when water table depth was below 30 cm. Notably, the study also reported that the effect of the group selection treatment on water table response was much subdued compared to that of clear-cutting. The same finding was announced by Pothier et al. (2003), when a linear relationship has been found between the water table rise following thinning of lowland spruce-fir forests and the amount of basal area removed, which I would discuss further in the discussion part. High water tables can lead to low infiltration rate of the soil and high surface runoff rates (Gburek and Sharpley, 1998), and will increase the loss of nutrients located at or near the soil surface (Madramootoo et. al., 1997) as well as restrict crop growth and nitrogen uptake by roots (Williams et al., 1989).

Beside, timber harvesting can also cause unacceptable changes to surface water quality (Binkley and Brown 1993) through soil disturbance by heavy equipment and sediment production from logging trails, roads, and ditches. Increased water temperature resulted from an increase in direct solar radiation reaching the water surface following forest removing activities is also well documented. For example, maximum summer temperatures may increase more than 10°C and weekly temperature range may be tripled or quadrupled (Keenan and Kimmins, 1993). Higher temperature would cause a series of shifts in water attributes such as decreased oxygen holding capacity and accelerated rates of chemical processes. Moreover, decreased interception and retention of precipitation by vegetation, combined with lower infiltration rates in disturbed soils, can result in a greater potential for overland flow in harvested catchments (Elliot et al., 1998). As a combined result of increased surface runoff, water movement through the soil profile, and reduced evapotranspiration, it is well established that clearing forest vegetation can also be responsible for increased streamflow (Hornbeck et al., 1986; Troendle and King, 1987).

## Soil Nutrient

Timber harvest can alter biogeochemical processes, and thus, surface and ground-water concentrations of compounds such as Nitrogen (N), phosphorus (P) and kalium (K), which are the three nutrient elements most commonly limiting forest production (Binkley 1986), may be affected.

Nitrogen (N) is required by plants in the largest quantity and is an essential nutrient for all living organisms in forested wetland ecosystem. Meanwhile N is also a very dynamic element and thus can easily be lost from the soil system. Forest harvesting can lead to N loss in various ways including denitrification, volatilization (Peterjohn and Correll, 1984) as well as soil run-off and leaching (Tiedemann et al., 1988). Denitrification refers to the conversion of nitrate to atmospheric forms of nitrogen, it can be a major loss mechanism of NO3--N when soils are saturated with water for 2 or 3 days (Tamm et al., 1974; Gundersen et al., 2006). Alkaline soil (pH higher than 7.3), high air temperature and moist soil surface can cause high volatilization occurrence, where significant amount of N lost as ammonia ($NH_3$) gas from some surface-applied N sources

(Peterjohn and Correll, 1984). Besides, the increase in soil temperature boosts the activity of soil microbes, which elevates the production of ammonium and nitrate (Nieminen, 1998). Consequently, it is possible that the available nitrogen become greater than that can be used by the few remaining trees. The combination of increased soil water and oversupply of nitrate creates favorable conditions for nitrate runoff to streams. As a result, the nitrate stored in shallow soil water may be transported from the soil to down streams by under or over surface flows following harvest. Nitrate input from upstream wetland can be harmful to the aquatic life stages of amphibians, even at relatively low concentrations (Baker and Waights, 1993, 1994; Hecnar, 1995; Marco et al., 1999). Nitrate concentrations resulting from forest harvest can even exceed drinking water standards and threaten potable water supplies according to past studies (e.g. Likens et al., 1970).

Phosphorus (P) has a much lower mobility in most soils and is less susceptible to leaching than N because it can be strongly bound to mineral particles and that it has no important gas phase therefore no lost in gaseous forms (Keenan and Kimmins, 1993). Several studies observed that there is no significant change in Phosphorus concentrations in a solution of mineral soil before and after logging (e.g., McColl 1978; Evans et al., 2000). Evans et al. (2000) studied the Phosphorus dynamics in shallow subsurface waters (<2.5 m depth) in harvested and unharvested sub-catchments of a Boreal Plain lake and the effects of forest. The uncut and cut sites were chosen with similar aspect, vegetation, and mean slope prior to winter (1996–1997) logging. Their findings are consistent with previous studies, which indicate that the variations in soil P concentration was less likely influenced by forest logging but due to amount of clay and Ca content in soils of the management site as P react with Ca, Fe and clay particles to form relatively insoluble compounds (Cresser et al., 1993). However, forest harvesting contributed to the rise in the water table of the cut site (as explained before in Hydrology section). The rise of water table after the logging activity, together with more P accumulated during low runoff would increase P export from soils to adjacent watersheds during high runoff after logging and contributing to eutrophication.

Moreover, studies have also found rapidly loss of Potassium (K) after forest harvesting. For example, Martin et al. (1984) reported higher K concentrations in catchments where at least 20% of the area was clear-cut. The increase in K may originate from logging residues, especially decomposition of needles. Palviainen et al. (2004) found that 90% of the initial amount of K was lost in three years from logging residue.

Forested wetlands are important sources of nutrients for the species within the ecosystem as well as downstream watersheds. Nutrients in water are vital for production, but nutrient loading can be regarded as a form of water pollution once natural concentrations are exceeded. Therefore the understanding of water and soil biochemistry shifts during forestry managements is essential for maintaining health functions of these ecosystems in future practices.

## Leaf litter

Leaf litter inputs are a dominant energy and nutrient resource in forested wetlands and they also play an important role in nutrient cycle of the wetland ecosystem. Leaf litter is the most important food resource for many wetland organisms including aquatic invertebrates. The loss of input of leaf litter through remover of vegetation may result in significant changes to wetland habitat. Batzer and Palik (2007) found that invertebrates were sensitive to changes in leaf litter input, but interactions may not be consistent. They quantified the influence of leaf litter inputs on aquatic invertebrates in two seasonal woodland ponds using an interception experiment (excluded leaf litter from parts of two seasonal woodland ponds). In one wetland pond, overall invertebrate biomass and the biomass declined in the excluded half-pond and then rapidly recovered after litter inputs were restored, which is consistent with assumption that leaf litter was a crucial resource to invertebrates. However, invertebrate benefited rather than harmed from litter exclusion in the other pond (Batzer and Palik, 2007).

Besides serving as food, leaf litter can also effect environment conditions in wetlands. Low litter may provide structure and refuge to invertebrates while high litter may displace vegetation and decrease oxygen concentration and supressed invertebrate communities (Christensen and Crumpton, 2010). Forest harvesting activities can have various impacts on leaf litter attributes. For example, according to Ash (1988a; 1995), significant decreases in litter dry mass， depth and moisture were reported after clear-cutting. Ash (1995) found that such alternation can significantly influence amphibians such as terrestrial salamanders, which depend on moisture environment for dermal respiration and use litter as their primary foraging area. Reductions in litter mass, depth and moisture may contribute to salamander disappearance from clear-cuts after timber harvest, which explain the disappearance of salamanders from clear-cuts within two years of cutting (Ash 1988a).

# DISCUSSION

As discussed above, timber harvesting activities in forested wetlands can cause major shifts to the ecosystem and habitat in multiple ways, many of which harms wetland organisms. The intensity of these changes, however, is largely regulated by the type of harvesting operation being conducted and the management system that is applied. To give a simple example, clear cutting removes all mature trees from a forest stand, which leads to immediate reduction in forest cover, soil retention and nutrient input. Selective logging, on the other hand, involves selectively removing a percentage of stems and leaving residual crop trees, minimizes changes in these processes. In an experimental study conducted in the United States to identify responses by pond-breeding amphibians during the first four years following experimental harvests (Semlitsch et al., 2009), they compared the effects of four kinds of forest management treatments (clear-cut-removed, clear-cut-retained, partial harvest and control) on life history stages and multiple response variables affecting both behavioral and demographic traits to nine species in three regions of the United States. The average net effect of timber harvest treatments relative to the control for all 33 responses was negative on amphibian population (Semlitsch et al., 2009). The partial harvest treatment had the smallest effect size (–7.2%), followed by the clear-cut-removed (–18.9%) and clear-cut-retained (–32.2%) treatments. The most consistent negative effects occurred in clear-cut treatments, which is explained as clearcutting altered the fundamental structure of forests by removing the canopy and exposing the forest floor to more sunlight and wind, leading to a warmer, drier surface microclimate (Keenan and Kimmins, 1993; Chen et al., 1999; Zheng et al. 2000), eventually reducing leaf litter (Hughes and Fahey, 1994; Ash, 1995) and food resources (Seastedt and Crossley, 1981).

Past studies have approved that appropriate forest management operations can not only reduce the negative impacts of timber harvesting but also benefit the wetlands ecosystem. The highlight here is that pre-management conditions of the wetlands need to be carefully evaluated because every wetland ecosystems are different. For example, drainage is widely used in forestry to compensate wetland watering up. In the boreal and temperate zones about 15 million hectares of peatlands and wetlands have been drained for forestry purposes (Paivanen, 1997). However, some studies indicate that drainage ditches do not reduce the water table rise after cutting on mineral (e.g. Pyatt et al., 1985) or organic soils (Berry and Jeglum, 1988). It is proposed that watering up can be minimized by the careful layout of skid trails, the use of low pressure wide-tired skidders, and harvesting on frozen soil to prevent ponding of surface water (Dubé et al., 1995).

Pothier et al. (2002) designed an experiment in eastern part of the sugar maple, known as the St. Lawrence lowland ecological region 2b (Saucier et al., 1998), near Villeroy, Quebec, Canada, to access the rise of the groundwater table produced by five cutting intensities and to determine the pattern of changes in water tables during the first 5 years following cutting. Ground water level of five levels of cutting (0, 40, 50, 60, and 100% of basal area removed) were measured. The values for groundwater level prior to the cutting of all plots are very similar. The three partial cutting treatments were applied following the principles of low thinning, but with the seed cutting objectives of the shelter wood method. Their results showed a linear relationship between the water table rise and the percentage of cutting during the first growing season after harvest. The shelter wood system not only mitigates water table rise after the first cut but also promotes a vigorous regeneration stratum which could potentially mitigates water table rise after the final cut. Pothier et al. (2002) gave the suggestion that the shelter wood method (e.g., 50% and 60% cuttings) should be considered as a better alternative of clear cutting and final cut 10 years after the seed cut in order to maximize the positive impact of regeneration leaf biomass on future water table rise for forest management of wetlands.

To prevent large nitrogen losses to stream water after forest harvesting activities, management need to ensure advanced regeneration (the presence of tree stems before harvest and young age classes of trees) and maintaining soil quality and stability during and after the harvest. Besides, a minimum intensity harvesting system that maintains stream buffers and allows for efficient, rapid vegetative regrowth will regulate the effects associated with nitrogen delivery to streams (SUNY College of Environmental Science and Forestry, 2016).

Best Management Practices (BMP), which are procedures considered and used as necessary to protect the environmental functions and societal values of wetlands during harvesting and other forest management operations have been established in many states and provinces in the US and Canada.

# CONCLUSION

Best Management Practices (BMPs) for wetland, which are procedures considered and used as necessary to protect the environmental functions and societal values of wetlands during harvesting and other forest management operations have been established in most states and provinces in the US and Canada. These BMPs need to be adopted on a wider basis and followed by forestry operators. Short-term changes in the forested wetlands caused by harvest activities should be within the range of natural variations and therefore not result in negative long term concerns in wildlife habitats and plant regeneration. An example can be draw forth from the study of Pothier et al. (2002), where the rise of water table is the most significant in the first growing season after logging and the magnitude decreases gradually. 5 years later, the water table recovered to near pre-harvest levels in all partial cut treatments.

Besides, it is difficult to generalize with data from different regions and site requirements vary greatly. Moreover, the responses of forested wetland ecosystem to forest harvesting need long term observation. Therefore, more long-term, regional studies considering specific site requirements of individual species and forest type is needed in order to understand the complex interactions between wetland ecosystem function and forestry practices.

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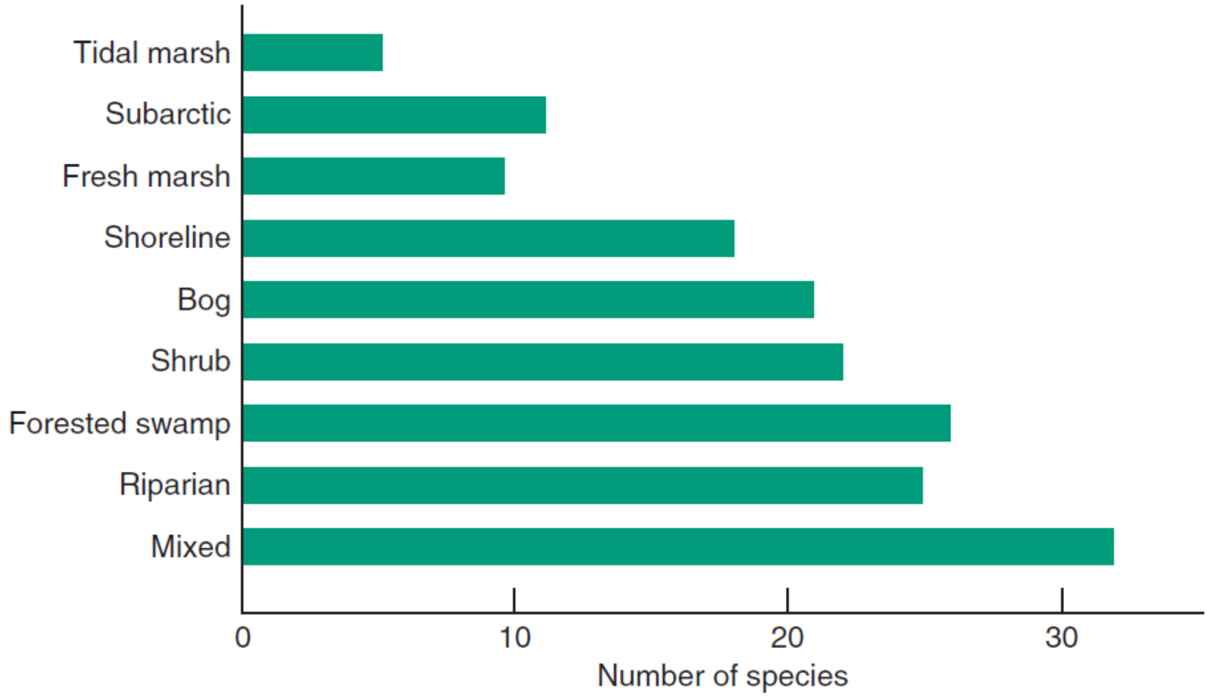


*Figure 3. Median number of species of birds occupying different wetland vegetation types in North America (Adamus, 1992).*

# APPENDIX B

| *Wetland functions* | *Attributes under each function* |
|---|---|
| ***1. Hydrologic flux and storage*** | a. Aquifer (ground water) recharge to wetland and/or discharge from the ecosystem<br>b. Water storage reservoir and regulator<br>c. Regional stream hydrology (discharge and recharge)<br>d. Regional climate control (evapotranspiration export = large scale atmospheric losses of $H_20$) |
| ***2. Biological productivity*** | a. Net primary productivity<br>b. Carbon storage<br>c. Carbon fixation<br>d. Secondary productivity |
| ***3. Biogeochemical cycling and storage*** | a. Nutrient source or sink on the landscape<br>b. C, N, S, P, etc. transformations (oxidation/reduction reactions)<br>c. Denitrification<br>d. Sediment and organic matter reservoir |
| ***4. Decomposition*** | a. Carbon release (global climate impacts)<br>b. Detritus output for aquatic organisms (downstream energy source)<br>c. Mineralization and release of N, S, C, etc. |
| ***5.Community/ wildlife habitat*** | a. Habitat for species (unique and endangered)<br>b. Habitat for algae, bacteria, fungi, fish, shellfish, wildlife, and wetland plants<br>c. Biodiversity |

Table 3. *Attributes generally given as functions of wetland ecosystems (Richardson, 1994)*