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# Management of vegetation under electric distribution lines will affect the supply of multiple ecosystem services

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ABSTRACT

In this study, we estimated the impact of different management strategies on the ecosystem services provided by the vegetation under electric power lines in urban and rural areas. Two management scenarios were evaluated in urban areas: (a) complete removal of trees that interfere with power lines, and (b) pruning of these trees. Four management scenarios were evaluated in rural areas, where power lines cut through wood lots and forests: (1) clear-cutting with whole-tree removal, (2) clear-cutting with slash left on site, (3) selective logging with slash left on site, and (4) tree pruning only. Because it was not feasible to carry out field experiments to examine the effects of all of these management scenarios on fourteen ecosystem services, we used the Delphi method to solicit expert opinion and address testable predictions and preliminary management recommendations. According to this expert survey, pruning is expected to have little or no effect on a range of services provided by trees, woodlands and forests either in rural or urban areas. On the other hand, all other scenarios are expected to have similar effects on at least half the services evaluated. Based on these results, we recommend that pruning be prioritized over other management practices as much as possible in urban and rural settings.



## 1. Introduction

The links between biodiversity, ecosystem function and ecosystem services (ES) and between ES and human well-being has led to the development of a normative approach to conservation and natural resource management (Millennium Ecosystem Assessment, 2005). ES are the goods and services provided by ecosystems from which humans derive benefit. This concept aims to characterize ecosystems according to a series of attributes that make life possible for humans (Boyd and Banzhaf, 2007). The generally accepted reasoning is that ES arise from the ecological processes and interactions of the biotic and abiotic components of ecosystems (Millennium Ecosystem Assessment, 2005). Thus, considering ecosystems and natural capital as reserves of natural resources, ES are all the benefits (e.g., social, economic, health, spiritual) generated by this capital in both managed and unmanaged contexts (Millennium Ecosystem Assessment, 2005).

Trees, woodlands and forests provide multiple ES. For example, supporting ES include nutrient cycling, soil formation, and primary production of biomass (Millennium Ecosystem Assessment, 2005). These supporting services allow biodiversity and ecosystems to generate services that are useful to humans, namely provisioning, regulating and cultural services. Provisioning services include direct consumption by humans of natural resources such as wood, food, and fibre. Regulating services include processes that provide an environment conducive to human well-being, such as climate regulation, air quality regulation, pollination, and erosion control. Cultural services relate to intangible assets that humans get from ecosystems and biodiversity; these include cultural, aesthetic and recreational values.

Human infrastructures, like roads, buildings, and power lines directly or indirectly impact the quality and quantity of ES provided

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by trees. In this study we ask whether electric power distribution networks affect ES supply. In particular we asked whether a power line right-of-way (ROW), influences the production of ES. This information is important for public institutions like Quebec's power company, because it is required to inform decisions about best practices for ecosystem management.

Any activities during, before, and after construction of power lines affect landscapes differently. Maintenance of existing lines often involves the management of vegetation on the ROW, which requires complete or partial removal of trees and shrubs growing under power lines. As trees and other vegetation form habitat for many plant and animal species some disturbance types on ROWs could have negative consequences for biodiversity conservation (Berger, 1995; Goosem, 2004; Söderman, 2006).

In addition to these habitat functions, ROW vegetation generates many other ES: habitat for insects that pollinate agricultural fields (Russell et al., 2005) and potentially root systems that reduce soil erosion, woody material that store and sequester carbon, and beautiful structures that affect landscape aesthetics that eventually affect property prices. Although there are several studies reporting the negative impacts of power lines on local property prices (see Refs. Jackson and Pitts, 2010; Elliott and Wadley, 2002), many of those negative effects on landscape aesthetics can be reduced by effective management of vegetation and landscapes in and around ROWs. Earlier studies have found that many negative impacts of power lines, especially on wildlife, can be mitigated through effective ROW management, including leaving natural vegetation onsite, retaining rooted trees, snags, logs, and mid-seral vegetation, and protecting fruit and nut trees, which serve as a food source for wildlife (Berger, 1995; Clarke et al., 2007; Storm and Choate, 2012). Different strategies have been put forward to minimize the environmental impacts of transmission and distribution power line ROWs biodiversity and ES (Berger, 1995; Clarke and White, 2008; Young, 2010). The use of pruning techniques, selective cutting, retention of some structural elements, and other environmental practices can minimize the impacts of power line networks, by reducing landscape fragmentation and the loss of natural habitats (Clarke and White, 2008; Young, 2010).

Ideally, field studies and experiments could be carried out to investigate the effects of various land use policies and practices on biodiversity and ES. However, given the large number of ES that might be affected by various land use policies and practices, this approach would be complicated, time-consuming, and expensive. In the meantime, management decisions must be made. To tackle this problem, we used a qualitative assessment approach, the Delphi method, to evaluate the integrity of the natural environment and the production of ES by vegetation under electric power distribution lines. Group communication methods such as this have led to fairly good estimates in a number of studies (Young, 2010). Among the existing methods of group communication, the Delphi Method, based on expert opinion, has been the most widely recognized over the past 60 years (Okoli and Pawlowski, 2004). A quick search on March 2015, of the Web of Science for the words Delphi method indicate 835 publications in 2014 alone, the method being used for everything from studies on mental health issues (e.g., Ross et al., 2014) to environmental risk assessment (e.g., Saffarian et al., 2014). The use of this qualitative assessment approach can overcome a lack of scientific literature and/or an inability to do field studies and experiments.

This study aims to make predictions about the effects of different management practices to control vegetation under electric distribution lines on the production of ES in rural areas and at the tree scale in urban areas. It uses the Delphi method to explore the opinions of experts on the impact of six different management strategies.

## 2. Methodology

We used the Delphi method to quantify variation in the production of ES resulting from various vegetation management practices. This technique, based on iteration and feedback acquired from open questionnaires, is anonymous, and tends towards consensual answers (Okoli and Pawlowski, 2004). In practice, respondents are first asked to respond to an initial questionnaire. The results of this questionnaire, accompanied by a summary of the general trends, divergent opinions and supporting arguments, are then sent to each expert in a second round. Finally, the experts are invited to react and respond to this second questionnaire, reviewing their positions in light of this additional information. Although consensus is often reached after two or three rounds, iterations may continue until sufficiently convergent positions are acquired (Okoli and Pawlowski, 2004). The main advantages of the Delphi Method are the compilation of anonymous information within a group of experts, the flexibility in data entry (time and space), and controlled feedback that allows for credible consensus (Okoli and Pawlowski, 2004).

### 2.1. Experimental Design

Six different types of existing tree management of the electrical distribution network were defined by a team of experts and the power company's team to estimate the impacts these different management scenarios have on ES. These scenarios represent the current state of management and are applied to two settings: rural and urban areas. In rural areas, 14 ES were assessed under four different scenarios: (1) clear-cutting with whole-tree removal, (2) clear-cutting with slash left on site, (3) selective logging with slash left on site, and (4) tree pruning (Tables 1 and 2; Fig. 1). In urban areas, 10 services were evaluated based on two scenarios: whole-tree removal and single tree pruning (Tables 1 and 3; Fig. 1). Six of the ES examined in rural areas were considered irrelevant for urban areas (food production, timber resources, flood and drought control, biological control, nutrient cycle/soil formation and recreational activities), whereas two were only considered relevant for urban areas (local climate regulation and water runoff control) (Table 1). We chose these ES as being the most relevant based on a literature review of the ES provided by trees, woodlands, and forests in urban and rural areas (Nowak et al., 2006; Haines-Young and Potschin, 2008; De Groot et al., 2010; Dobbs et al., 2011) as well as well as on studies performed on forest-related ES in Quebec (Dupras et al., 2015; Dupras and Alam, 2015)

### 2.2. Selection of Experts

We selected experts based on three criteria: (1) they are experts in ES science (they held a Ph.D. and actively carried out research in this field); (2) they are familiar with forests and trees located in the urban and rural areas of southern Quebec (they published peer-reviewed studies on these types of ecosystems); and (3) they read and write French adequately since the questionnaire was in French.

After developing these criteria, we compiled a list of Quebec-based experts and invited them to participate in the study. The invitations included an overview of the process of the investigation and its objectives. Participant anonymity was preserved: the identity of each expert was known only to the researchers. Those experts who agreed to participate in the study were contacted anew and provided with the further details.

Thirty-six experts were invited to participate in the study. Of these, 19 agreed to take part but 2 did not access the questionnaire's website. In the end, a total of 16 experts completed the two rounds required to obtain adequate results. Of the 16, 15 were academics and 1 was a public service researcher. Expertise varied from

**Table 1**
List and definition of ecosystem services assessed.

| Ecosystem Service | Definition |
|---|---|
| Food production[a] | Production of food products associated with forest ecosystems, e.g., berries, fruit, vegetables, mushrooms, and maple products. |
| Timber resources[a] | Production of wood and other resources through the ecosystem. Currently, when the timber is removed, it is mainly used as firewood. Non-commercial slash that is removed is also used for various purposes (mulch, compost, humus or soil application, bedding in animal enclosures, biomass cogeneration). |
| Air quality | The ability of an ecosystem to filter air pollutants. Trees and plants absorb gaseous and particulate pollutants and thus contribute to reducing odors and airborne particles. |
| Global climate regulation | Carbon storage in plant biomass and carbon sequestration by photosynthesis mechanism can prevent the release of a large amount of $CO_2$ present into the atmosphere and contribute to limiting climate changes. |
| Local climate regulation[b] | The ability of an ecosystem to regulate the local temperature. Here, we consider the main service to be heat reduction, particularly in urban areas (heat islands). Urban trees can serve as “natural air conditioning” thanks to their shading effect. |
| Flood and droughts control[a] | The presence of vegetation helps to regulate the flow of rivers, both during spring flooding, after a storm, or drier season. It thereby contributes to mitigating floods and droughts that can cause significant discomfort and damage. |
| Erosion control | The ability of an ecosystem to maintain soil structure and prevent leaching, the effects of which include road damage, siltation of spawning grounds, and muddy soil depletion. To counter this process, vegetation protects the soil against the impact of raindrops, slowing the flow of runoff, promoting the permeability of the soil and absorbing water. |
| Biological control[a] | Control of pests is crucial to ensure food safety and supply of certain other natural resources (e.g., wood). The majority of agricultural and forest pests that could affect supply are controlled by natural enemies in healthy ecosystems. |
| Water runoff control[b] | In urban areas, rainfall and snowmelt produce runoff water that are transported by sewers, drainage channels and streams and are eventually discharged into water bodies. During this transport, the quality of runoff water is deteriorating as a result of the contribution of various pollutants and they have a significant adverse effect on the environment. Trees in urban areas can control these waters and reduce the negative effects. |
| Pollination | An estimated 70% of global crops depend on pollinators, i.e., almost all fruits and several vegetables. It is in feeding on pollen or nectar in the flowers that bees, wasps, flies, beetles and other pollinators provide this service. |
| Water quality | The ability of an ecosystem to filter and metabolize pollutants. Forest cover is the first natural filter to improve the quality of surface water. In addition to this filtration capacity, trees also remove pollutants from water. |
| Nutrient cycle/soil formation[a] | Leaves, branches, dead animals, and even whole uprooted trees can be colonized by a community of organisms that transform them into humus. This activity is largely responsible for soil fertility, which is considered the service of soil formation and nutrient cycling. |
| Biodiversity habitat | The habitat service for biodiversity in forests refers to the ability of ecosystems to provide a conducive environment to the life and survival of native species. |
| Recreational activities[a] | People access woodlands and forests for various recreational activities. While many activities are carried out in forest environments, others, such as cross-country skiing, snowshoeing, snowmobiling, and all-terrain vehicle operation may also often be practiced in ROWs. |
| Landscape aesthetics | The landscape is a fundamental component of human life. Trees and forests provide elements of landscape diversity, which are prized by many for their aesthetic value. |
| Cultural values | Services of a cultural nature provide non-material benefits. Intangible, they include spiritual experiences and cultural and educational values of nature. These services also contribute to the optimal development of children. |

[a] Only assessed for rural areas.
[b] Only assessed for urban areas.

**Table 2**
Scenarios proposed to manage vegetation under power lines in rural areas.

| Scenario | Description |
|---|---|
| Clear-cutting with whole-tree removal | This practice involved removing trees and shrubs from under and around power lines. Although no soil disturbance is generally observed (herbaceous layer intact), all wood is removed from the site, except for small residues that are left. Slash is shredded and recycled in authorized sites and merchantable timber is reused or sold. Vegetation under power lines is cut when it reaches 7 m, i.e., every 12–15 years. These allowances are therefore occupied by stands that are in constant regeneration. The ROW is not cleared at any time, the continued growth ensures that we find the height of vegetation between 0 and 7 m. |
| Clear-cutting with slash left on site | This is the same as above except that slash (branches, trunks, leaves) is left on the site, scattered on the ground and piled in windrows on the edge of forests/woodlands or shredded. |
| Selective logging with slash left on site | Selective logging involves cutting only trees and shrubs that may interfere with the electrical distribution system (incompatible species) and leaving species that present no such risk of interference (compatible species). This technique aims to promote compatible species at the expense of incompatible species. The tree layer is completely removed, the shrub layer is kept at 90% compared to the original, and the herbaceous layer is not affected. Slash is left on the site after logging. In addition, snags are left in place. In the case of selective logging, it is again necessary to intervene every 12–15 years or when the vegetation has reached 7 m. |
| Pruning | Pruning helps to minimize the effects of intervention on vegetation, which largely preserves habitats, trees, and shrubs in their natural states. The visual impact and inconvenience to users are reduced. Generally, trees are preserved and some branches are cut every 3–years depending on the region. Observations show that the canopy is reduced by about 15%. The canopy gradually closes between each intervention. Pruning slash is shredded, removed, and recycled. |

**Table 3**
Scenarios proposed to manage vegetation under power lines in urban areas.

| Scenario | Description |
|---|---|
| Tree removal | This practice involves cutting down trees that are likely to come into contact with power lines. Slash is shredded and recycled in authorized sites and merchantable timber is reused or sold. |
| Pruning | Pruning involves cutting the branches of a tree that are likely to come into contact with medium-voltage wires to reduce the risk of a short circuit or electrocution. Pruning in landscaped areas (cities, suburbs, villages) is known to reduce tree crown volume by 1–30%. This operation must be repeated at regular intervals (between 3 and 6 years). Pruning slash is shredded, removed and recycled. |


**Fig. 1.** Pictures of the different practices in rural and urban areas.

**Table 4**
Field of expertise of respondents.

| Formation | Field of expertise | Number of experts |
|---|---|---|
| Ecologist/ Biologist | Landscape ecology | 2 |
| | Entomology | 1 |
| | Forest ecology | 4 |
| | Vegetation dynamics | 1 |
| | Wetlands ecology | 1 |
| | Silviculture | 2 |
| | Biodiversity evolution | 1 |
| Economist | Ecological economics | 1 |
| Pedologist | Biogeochemistry | 2 |
| Forest engineer | Forest ecology | 1 |
| Total | | 16 |


**Fig. 2.** Scale assessment of ecosystem services presented to respondents.

pedology and landscape ecology to environmental economics and forest ecology (Table 4).

## 2.3. Data Collection

An online format of the survey was created for data collection, integration, and communication with the experts. Data collection was accomplished in two stages. First, the experts who agreed to participate in the survey were asked to complete the questionnaire. Specifically, they were asked to give a score (in%) to the magnitude of potential changes in ES caused by the various management scenarios (Figs. 2 and 3), and they were also asked to include their justifications associated with these assigned scores. A score of 100% meant no change in ES; a score of 200% meant a doubling. Survey Monkey (https://www.surveymonkey.com/) was used to create the questionnaire and collect the responses. Participants were requested to submit responses to the first round questionnaire in early November, 2013. Once all the answers from the first round had been collected, a mean of the answers was calculated. All comments of the first round presenting a difference of opinion with the average value were presented to experts in the second round.

In the second round, the experts were asked to review their answers from the first round in light of the responses and comments of the other experts. Three options were available to them: they could agree with the average of the majority, maintain their position, or otherwise modify their response from the first round. They were also asked to justify their answers. The second round of the survey was conducted in late November, 2013.

## 2.4. Data analysis

To examine whether the two-step Delphi process resulted in (1) changes in scores or (2) increased consensus, we compared first the mean scores given by experts during the first round of questions to mean scores given by experts during the second round of questions and second the variation (standard error) around these mean scores during the two rounds. Since the data did not meet the assumptions of parametric statistics, we used a paired Wilcoxon signed rank test on the means calculated per service for each treatment during each round and on the standard errors of these means. We analyzed urban and rural data separately. Analyses were done in R version 3.0.2. Effects were considered significant at $\alpha = 0.05$.

To determine if consensus had been reached and if there was a strong or weak agreement, the percentages were translated into broad categories: ES lost (0%), ES decreased significantly (11–49%), ES slightly decreased (50–89%), no change (90–110%), ES slightly increased (111–149%) and ES increased significantly (≥150%). A lack of consensus meant that 4 respondents disagreed with the category of the average of the majority, a low consensus with 2 or 3 respondents in disagreement, and a strong consensus with 1 or no experts in disagreement.

The last step was to examine whether the treatments were expected to differ in terms of the services provided. To address this question, we performed Kendall's tau analyses. This is a non-parametric statistical analysis, necessary because our data did not meet the assumptions of parametric statistics. For this analysis, we first calculated the mean score assigned to each treatment and service, then ranked these means to see whether the rankings were consistent across treatments. Although we merged data from the

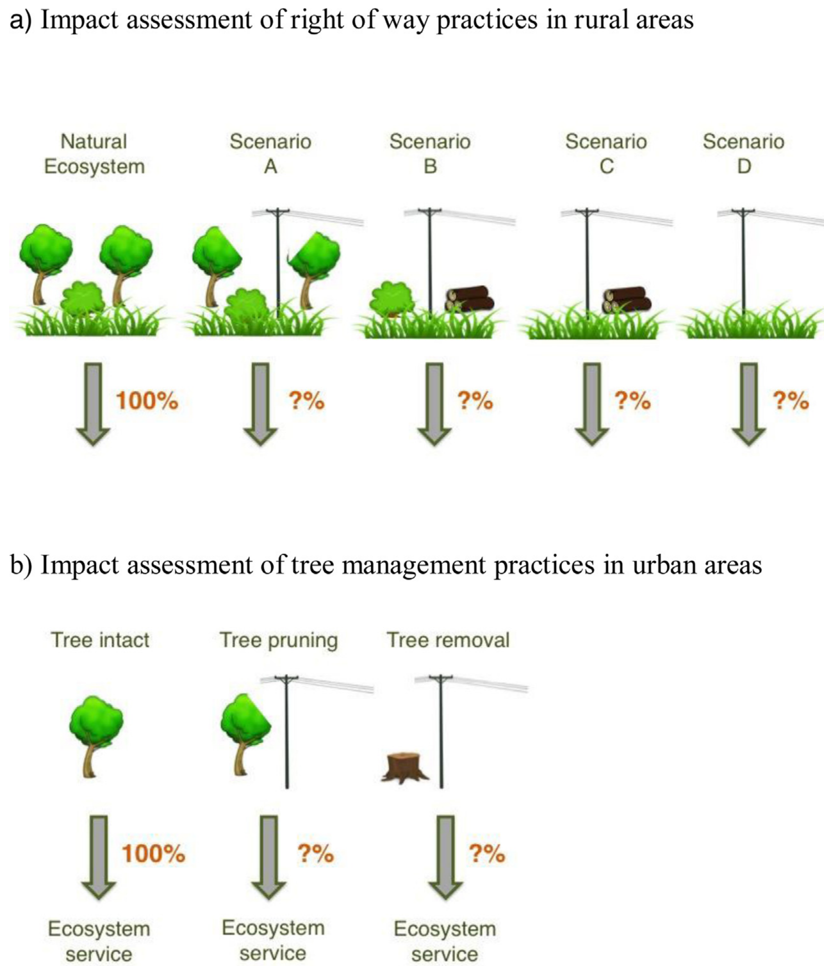


**Fig. 3.** Diagrams showing the study objectives for rural areas (a) and urban areas (b).

two rounds of questions here, we analyzed urban and rural data separately.

## 3. Results

In general, experts predicted that all treatments would result in a lower level of ecosystem service provision than untreated trees or forests both in the rural and in the urban context. The exceptions were food provision, recreation, and pollination services, the provision of which was expected to be higher than for untreated trees and forests in the case of some treatments in the rural context. In the urban context, all treatments were predicted to result in a lower level of ecosystem service provision than untreated trees (Fig. 4).

The two-step Delphi method did result in changes in how experts predicted the different ES would respond to the various treatments. There were significant changes in mean scores between the two rounds of questions in the rural context ($V = 92$, $P = 0.014$). Although for many services there was no change in mean score, overall, there was a decline in score between rounds 1 and 2 (an average difference of 1%), largely driven by changes in the food provision service (Fig. 4a and d). In the urban context, there was an even stronger change (an average difference of 7%; $V = 171$, $P = 0.0002$). The changes in the urban context were due to lower estimates in terms of almost all services examined in the pruning treatment (Fig. 4e) and a large decline in the scores given to the local climate regulation service in the tree removal treatment (Fig. 4f).

The two-step Delphi method also does not seem to have led to increased consensus. In the rural context, there was no significant change in standard error around the mean scores (Wilcoxon signed rank $V = 31$, $P = 0.19$; Fig. 4a–d), thus no change in consensus. There was a significant change in the urban context (Wilcoxon signed rank $V = 36$, $P = 0.03$), but this was in the opposite direction from that expected: on average, there was more variation around the mean in the second round than in the first round of questions (Fig. 4e and f).

Fig. 4a–d shows results of trends in ES variations that was reached for rural contexts. The most important reductions were predicted for the services of air purification, landscape aesthetics, and cultural values for the clear-cutting strategy with whole-tree removal and/or clear-cutting with slash left on site. There were no differences amongst the other management scenarios for the following services: food production, climate regulation, flood control, erosion control, biological control and pollination. Overall, if we only compare the scenarios of clear-cutting with whole-tree removal and slash left on site, there is very little difference except that clear-cutting with slash provides more habitat for biodiversity, contributes less to air purification, and provides fewer recreational opportunities. The selective harvesting scenario seems to affect the water quality service, nutrient cycling/soil formation, aesthetics of landscape, and cultural values less than the two scenarios of total clear-cutting.

In the vast majority of situations, weak consensus was reached because 2 or 3 respondents strongly disagreed with the proposed score. There was strong consensus about the expected results of the pruning scenario for most of the services, with the exceptions of food production service recreational activities, where a weak

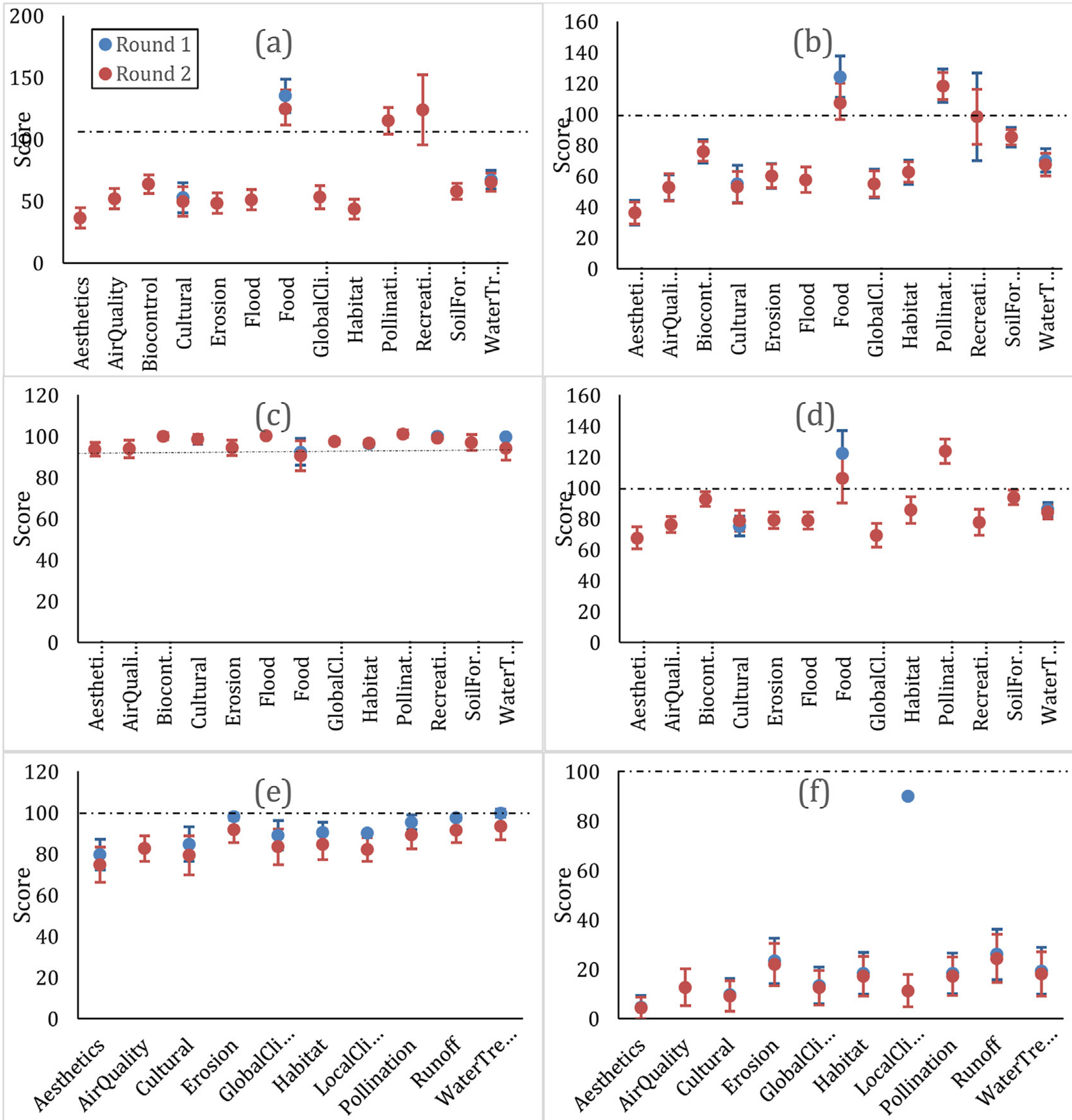


**Fig. 4.** Mean ± standard errors of scores assigned by experts to the different ecosystem services provided by (a) clearcut, (b) clearcut with slash, (c) pruned, and (d) selectively logged power line rights of way in a rural context and (e) pruned and (f) trees removed under power lines in an urban context.

consensus was reached; and timber resources, global climate regulation, recreation, and cultural values, for which no consensus was reached. For these services, contrasting views were expressed mainly regarding the clear-cutting with whole-tree removal scenario.

In urban areas, the tree-removal scenario was associated with a loss of all services, except erosion control, which was predicted to decline strongly (Fig. 4e and f). The pruning scenario was predicted to generate only slight losses in terms of air purification, local climate regulation, and aesthetics, the other ES being unaffected (Fig. 4). A strong consensus was generally reached for all services, with a few exceptions. Weak consensus was reached on the effects of whole-tree removal on water runoff control, pollination, erosion control and water treatment. Similarly, only weak consensus was reached for the effects of the pruning scenario on aesthetic and cultural values.

When ranked, there was a significant effect of treatment on the production of the different ES expected to be provided under the different treatments (Fig. 5). For example, in rural areas, in comparison to unmanaged forest, clearcuts were expected to provide very little habitat (ranked 2nd out of 14 services, with low ratings indicative of low scores, i.e., low service provision), whereas selective cutting was expected to provide substantially more (ranked 10th out of 14 services) (Fig. 5a). In urban areas, there were less extreme differences between treatments, the largest difference being for the local climate service, given a very low rank of 3 under a pruning treatment and a higher rank of 5 under a whole-tree removal treatment (Fig. 5b).

## 4. Discussion

### 4.1. Rural areas

#### 4.1.1. Total Harvesting

Of all the scenarios examined, the clear-cut scenario was predicted to differ the most from the natural forest in terms of provision of ES. According to the experts, total harvesting is likely to cause a large change (Fig. 4) in the amount of light that reaches the ground, leading to significant changes in the composition of the vegetation. This change may have both positive and negative effects on the provision of ES.

The more open conditions created by clear-cutting are predicted to have a positive effect on the provision of food, pollination, and, according to some, global climate and air purification services. It

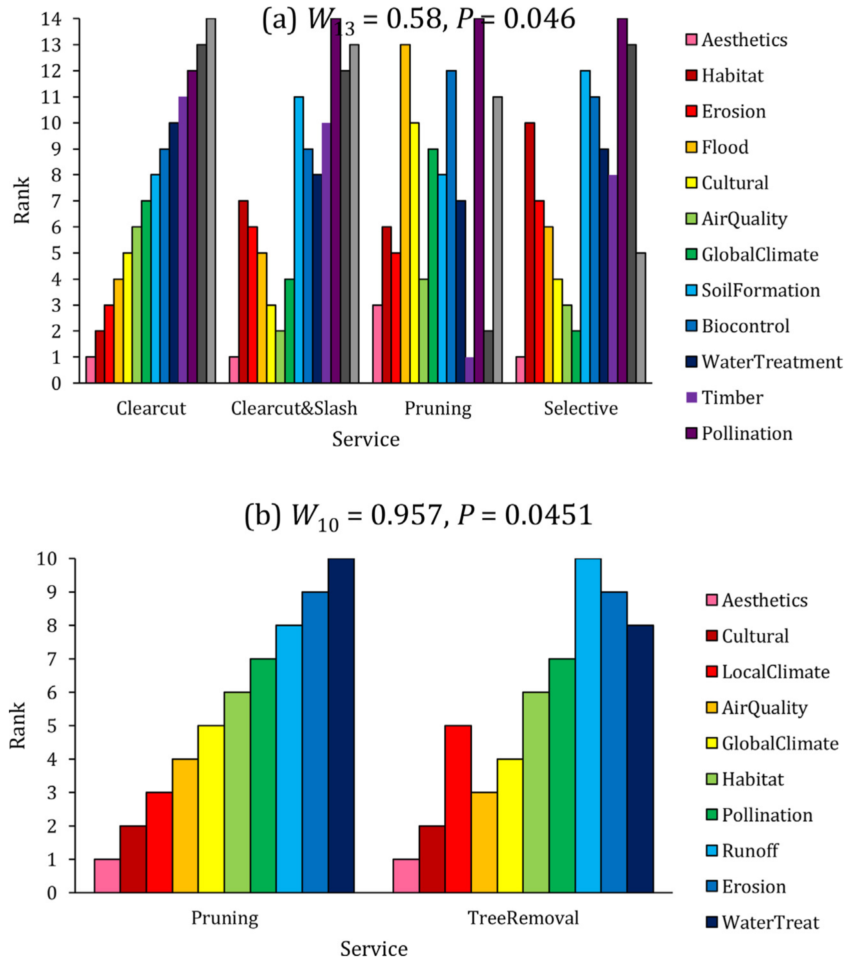


**Fig. 5.** Mean scores ranked from lowest to highest for the different treatments examined in (a) rural and (b) urban contexts.

is common to see diversity and species richness increase after clear-cutting (Haeussler et al., 2004). In terms of food production, species that require direct sunlight, such as berry-bearing shrubs like raspberries, will be favored. Indeed, these species, mainly pioneer species, need a great amount of light and are favored by clear cutting (Heinrichs and Schmidt, 2009). In terms of pollination, clear-cut conditions will also favor herbaceous plants characteristic of open areas, which generally produce more flowers than their closed-forest counterparts, thus providing more food for pollinators (even if many pollinators species would lose habitats). In terms of carbon sequestration and air purification, some argue that the sudden regrowth of vegetation following clear-cutting will have a positive effect. It is well known that young forest acts as a carbon sink due to the rapid growth of vegetation (Ter-Mikaelian et al., 2008).

On the other hand, more open conditions may have negative effects on the biodiversity habitat, biological control, and, some argue, global climate regulation and air purification services. In terms of diversity of habitats, the success of open-area species comes at the expense of species more characteristic of closed forest habitats, causing some experts to predict a sharp decline in this service. Indeed, pioneer species posses functional traits (abundant seeds, small seeds, wind dispersed, etc.) that make them more prone to colonize disturbed areas (Patry, 2013). In terms of disease regulatory and biological control services, more open conditions may also reduce certain pests. Finally, although some argued for a positive effect on carbon sequestration and air purification, other experts commented that rapidly growing young plants resulting from clear-cuts actually produce less of these services than the trees that were in place before cutting. No consensus could be reached on the service of global climate regulation.

The abundance of light will also affect soil warming and thereby stimulate decomposition and nutrient recycling by promoting greater diversity and abundance of organisms in the soil, such as beetles. Soil temperature mediates soil productivity (Kreutzweiser et al., 2008), but this may be counterbalanced by drying of soil resulting in reduced decomposition rates in the absence of adequate moisture. Soil formation and nutrient cycling, however, is still expected to decline with management as the action of tree removal significantly alters the soil structure with the passage of machinery, which compacts the soil and causes senescence of large roots and the export of stems from the site. Grigal (2000) reviewed the effects of forest management on soil productivity and concluded that soil runoff, change in soil biological community, and soil structure were frequently mentioned as consequences of conventional forestry. It should be noted that it is incorrect to think that the use of the machinery will impact the ground, because harvesting is generally done manually (see Table 2). Some experts believed that the role of the roots in water penetration into the soil is maintained, even if the roots are dead. This opinion was not shared by all. Some stated that the absence of trees and roots (soil structure) would increase leaching and reduce the filtering capacity of the ecosystem, which would decrease flood control, erosion control, and water quality services. In a review of logging impacts on water quality, Kreutzweiser et al. (2008) mentioned that nutrients leaching and erosion were higher after clear-cutting than partial harvesting.

Although clear-cutting provides income from timber resources in the first year, afterwards, the cycle of harvesting is too short, according to some, to allow for a sustained income. Comments for this service were very contradictory and a consensus could not be reached.

According to some experts, linear corridors, such as completely deforested power line ROWs, are perceived very negatively by people. In addition, cutting induces a sense of shock and destruction of nature, leading experts to suggest a sharp decline in aesthetic landscape and cultural services. Clear-cuts are less acceptable by users than partial cuts mainly for emotional and aesthetic reasons (Yelle et al., 2008). However, for recreational purposes, ROWs can be valued because they allow for the movement of hikers and snowmobilers, for example. There was a lack of consensus for aesthetic and cultural services because some believed that vacationers will flee these places and it is not possible to give a value to a cultural environment. Cultural and aesthetic values are known to be very difficult to quantify (Millennium Ecosystem Assessment, 2005).

#### 4.1.2. Clear cutting with slash left on site

The presence of slash in the second clear-cut scenario was predicted to have many positive effects that slightly mitigate the negative impacts of clear-cutting on ES. The differences between the two scenarios were of the order of 2–15% for most services, except for the soil formation, nutrient cycling, biological control, and timber production services, where the differences were in the range of 22–35%.

The experts justified their responses to this scenario in several ways. Firstly, the presence of slash limits the space available for the development of fruiting shrubs and abundant flowering herbaceous plants, thus having a negative impact on the food production and pollination services. On the other hand, fertilizing the soil with dead wood stimulates flowering, fruiting, and mushroom production. Surprisingly, a synthesis study on the contribution of nutrients (NPK) through coarse woody debris in boreal forests concluded that this component has less influence on nutrient enrichment on the ground than expected (Laiho and Prescott, 2004). The loss of surface area may have a potential impact on the ability of plants to filter the air because plant biomass occupies a reduced space, thus there may be a reduction in air purification. In addition, deadwood keeps more moisture in the soil and limits soil compaction and deterioration of soil structure while providing more forest litter types. In fact, woody debris ensures the retention of a significant amount of moisture because it is very porous, especially in the advanced stages of decomposition (Harmon et al., 1986; Cornett et al., 2000; Robert, 2010). Therefore, it is suggested that there is lower loss of soil formation and nutrient cycling services in the presence of slash than in the absence of slash. It is also suggested that slash prevents runoff and thereby limits leaching, which may have a slightly positive effect on the provision of water quality, soil erosion, and flood control services. On the other hand, some experts suggested that slash decomposition incorporates free organic molecules in water and affects its quality. The process of slash decomposition also releases carbon, thus negatively affecting the provision of the global climate service. Dead wood plays a vital role in the carbon cycle (Harmon et al., 1986; Brais et al., 1995).

Decomposing slash fosters the creation of new habitats (e.g., rodents, reptiles, and insects) and increases biodiversity, thus reducing the impact of the cut. Many studies show the necessity of dead wood for wildlife (Darveau and Desrochers, 2001; Clipp and Anderson, 2014) mainly for saproxylic insects (Hammond, 1997; Ehnstrom, 2001; Jonsson et al., 2005; Jonsell and Schroeder, 2014) and cavity nesting birds (Flag and Imbeau, 2006; Drapeau et al., 2003; Nappi et al., 2004). However, slash can negatively affect the movement of large organisms. According to some experts, slash may also have a negative effect on the aesthetic appreciation people have of ROWs because the residue is seen as wasteful and makes traveling more difficult; thus, there may be a slightly negative effect on the provision of recreation and landscape aesthetics services. Finally, experts predicted this scenario would provide less timber than the clear-cut scenario because slash left behind represents a loss of income.

#### 4.1.3. Selective Logging with Slash Left on Site

Unlike other scenarios, the selective logging scenario with slash promotes the maintenance and development of shrubs that compete with and limit the development of tree seedlings. Some experts named this layer the recalcitrant layer because no other species can persist. This recalcitrant layer is mainly composed of ruderal species (Royo and Carlson, 2006). The increased presence of shrubs (companion species) has several implications for ES and it is why experts estimate an improvement in the provision of several services under this scenario compared to the total harvest scenario with slash. The difference is greater for the services of air purification, flood control, water quality, habitat for biodiversity, landscape aesthetic and cultural values. Provision of these services is expected to be improved by 20–40%.

The following reasons are given by experts to explain why they predict that provision of ES will be generally improved compared to the other scenarios of total harvest. Shrubs do not purify air or filter water as well as trees (Nowak et al., 2006). They have a limited ability to sequester carbon and consequently reduce the intake of organic matter. However, the presence of continuous evapotranspiration by vegetation is still better than no vegetation after clear-cutting. Furthermore, although the roots of shrubs are shallower than those of trees, and they therefore have less effect on soil structure and water penetration, they still participate in structuring the soil and reducing erosion. Indeed, shrubs are commonly used to limit erosion and retain nutrients on-site, which has a positive effect on water quality (Kort et al., 1998). Shrubs typically generate more flowers than trees, but less than herbs which are in competition with shrubs. Shrubs are more attractive to pests, but they also provide shelter to the predators of pests. Indeed, the presence of a variety of shrubs provides greater habitat diversity than do clear-cuts.

However, some experts believe that it is more difficult for people to move in this type of vegetation, which has an impact on recreational activities. Furthermore, the presence of shrubs limits the development of trees and therefore reduces the possibility of obtaining monetary value from this resource.

#### 4.1.4. Pruning

The pruning scenario was predicted to produce conditions most similar to those of the untreated forests. The experts predicted the changes brought about by pruning would have no effect on ES, except for the service of food provision, which may be slightly diminished. Experts point out that there is little difference in light, little impact on the ground, and little habitat loss caused by pruning. In addition, a pruned forest may visually resemble the natural forest, thus reducing the impression of destruction. However, pruning can open up the canopy and allow for the growth of more undergrowth, including shrubs, which can restrict human movement. The openings created will also allow better growth of trees along with an increase in the value of the stems. However, experts apparently did not consider these changes to be sufficiently important to justify a significant change in service provision.

### 4.2. Urban areas

#### 4.2.1. Tree removal

In urban areas, the removal of a tree usually involves the loss of all the services it provides at a local scale. The erosion control service may be the exception; on average, our experts gave this service a 10% instead of a 0% because they thought the loss of a single tree would generally not affect the general situation of the whole street. Despite the absence of a tree, the soil can continue to provide habitat and assist in controlling surface runoff. The relevance of the pollination service is questionable because most urban trees are wind-rather than insect-pollinated.

#### 4.2.2. Pruning

Tree pruning is predicted to have very little effect on ES in urban areas. Experts predicted that the provision of services would either be unchanged or only slightly reduced. Comments from experts were few and sometimes contradictory. Certain argued that productivity (regrowth of branches and leaves) would be increased, which would help to sequester more carbon, but others argued the opposite. Pruning can also have impacts on certain species of birds (Young, 2010). However, the greatest impact is at the onset of pruning. Some noted that pruning performed correctly could have a positive effect on the people's perception because pruning gives a sense of order which is well received by the public, but poorly executed pruning results in a negative perception, especially in winter.

#### 4.2.3. Study limitations

Several experts raised questions concerning certain parameters of the study. Indeed, it was suggested by some that the production of ES depends on a number of factors that are wider than the influence of the distribution line ROWs. While it may be fairly easy to estimate the provision of services with a relatively clear linear function, such as climate regulation through carbon sequestration, it is more difficult to estimate the more intangible services, such as cultural services. Several comments from experts were along these lines and highlighted the difficulty in relying on a subjective evaluation to estimate changes in ES.

Further work is needed to understand the relationship between humans and nature in the context of ES in order to make this a more reliable decision-making tool. Indeed, the specific nature of the interdependencies between the structure and diversity of biotic communities and ecosystem functioning are not always understood (Millennium Ecosystem Assessment, 2005; Mitchell et al., 2013; Alam et al., 2016). In this sense, understanding the quantitative relationship between biodiversity, ecosystem components and structures and processes for the production of ES must be established to validate expert knowledge.

The most challenging limitation of this study for the research community is maybe the method used here. The Delphi method can be successfully applied in social science research because there are many issues which are subjective in nature. In natural and experimental sciences, there is no, or limited, space for subjectivity. In that sense, this study is based simply on expert opinion and not on actual studies, where different treatments are applied and ES measured. However, if the majority of Delphi studies focused on social science topics, Taylor and Ryder (2003) showed through a study of water resources that this technique can effectively assess expert opinion on complex issues related to natural resources.

Given these limitations, these results should be treated as a first estimate of the impacts of various management scenarios in power line ROWs on the production of ES. The general scenario analysis seems consistent with the literature, but further work is needed to understand the long term dynamics of ecosystems in response to human intervention in this management context.

## 5. Conclusion

Overall, according to expert opinion, the pruning scenario is likely to have little impact on ES in rural or urban areas because an important part of the forest cover or tree in question is maintained. Pruning allows for the maintenance of environmental conditions similar to those of the untreated forests or trees. On the other hand, clear-cutting or tree removal scenarios are expected to greatly change the environmental conditions by creating large openings that alter the light, temperature, and humidity regimes. These changes are likely to have generally negative impacts on ES, which can be mitigated for some services by the presence of slash (for soil formation, nutrient cycling, and biological control) or shrubs (for flood control, habitats for biodiversity, water quality, air purification, and aesthetic and cultural values). In urban areas, removing a tree is expected to lead to the loss of almost all associated services.

It should be noted that these conclusions are not based in every case on a strong consensus of the experts surveyed. Several respondents also stressed that it was very difficult, if not impossible, to provide values for certain ES across the scales of the tree or the ROW. In particular, experts noted difficulty assessing provision of the services of water quality, biological control, flood control, and pollination at a small scale because they involve processes at larger scales. Although all experts suggested values, many indicated the need for caution in their interpretation.

Despite these limitations, this study provides a first estimate of the potential impact of management practices on the ES provided by the trees and vegetation under power line. This information may help managers make informed decisions in their planning. Furthermore, these results provide predictions and hypotheses that could form the basis for future field studies. In the end, our results suggest that pruning should be prioritised over other management practices because it is likely to maximize ES that benefit to local communities.

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