**Site complementarity between biodiversity and ecosystem services in conservation planning of sparsely-populated regions**

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**SUPPLEMENTARY MATERIAL**

**DESCRIPTION AND DATA USED FOR EACH INDIVIDUAL ECOSYSTEM SERVICE MAPPING**

The mapping description was modified from Cimon-Morin *et al*. (2014).

**Provisioning services**

*Moose hunting*

The biophysical supply of moose (*Alces alces*) hunting was quantified using the extent of its aquatic and wetland habitat requirements (Timmermann & McNicol 1988; Tecsult 2006). All planning units containing moose aquatic and wetland habitats were considered as contributing to the biophysical supply. It was assumed that the density of this species was homogenous across the study area (Lamontagne & Lefort 2004). Potential-use supply was mapped using the accessibility proxies for local flow ES. Point locations of moose hunting in the study area over the past twenty years were obtained from the Ministry of Natural Resources of Quebec (MRNF [ministère des Ressources naturelles et de la Faune du Québec], unpublished data 2012). The sum of moose hunted per planning unit was used as demand data.

*Atlantic salmon angling*

The BS of Atlantic salmon (*Salmo salar*) angling was mapped for each planning unit using a map of salmon-inhabited rivers from the Natural Resources Ministry of Quebec (MRNF, unpublished data 2012), which takes into account the impassable physical barriers to upstream salmon migration, and the mean number of salmon migrating upstream each year per river (Caron *et al*. 2006). The sections of these rivers where salmon fishing is legally permitted (MRNF 2012b) were also used to refine the biophysical supply spatial range. The potential-use supply was modelled using proxies of accessibility. Demand was mapped using the mean number of catch per specific river for the last five years (MRNF 2012a). However, because the number of catches had been noted per river, the demand for salmon angling was further spatially estimated using demand proxies. These two variables were then standardized and summed.

*Brook trout angling*

Brook trout (*Salvelinus fontinalis*) is a species of fish present in almost every water body and waterway within the study area (Hydro-Québec 2007), with the exception of those located upstream a slope of 40% and at an altitude higher than 500 m above sea level (i.e. those that could not be naturally colonized following the last glaciation). The biophysical supply was modelled using the extent of the species’ habitat availability in each planning unit. A map of the inaccessible water bodies (Bellavance & Gagné 2012) was used to identify the planning units that were out of reach of this species. Potential-use supply was modelled using proxies of accessibility. Demand was also mapped using proxies because no catch data was available.

*American black duck hunting*

The biophysical supply of American black duck (*Anas rubripes*) hunting was modelled using its aquatic and wetland habitat selection ratio (Lemelin *et al*. 2010) and the area covered by these types of habitats in each planning unit. It was assumed that the duck’s density was uniform across the study area (Lemelin *et al.* 2004; Guérette Montminy *et al.* 2009). Potential-use supply and demand were mapped using proxies.

*Cloudberry picking*

Cloudberry (*Rubus chamaemorus*) is a plant species that grows in ombrotrophic peatlands (bogs). However, according to an expert, only non-forested bogs (i.e. open bogs) show a berry production high enough to enable picking (C. Naess, personal communication). The biophysical supply of this provisioning ES was mapped using mean yield value from field samples measured in the study area (C. Naess, unpublished data 2012) and the area occupied by open bogs. Potential-use supply and demand were mapped using proxies.

**Cultural services**

*Aesthetic features of wetlands*

Open peatlands, rivers, lakes and ponds are the wetlands and aquatic habitats that contribute most to the aesthetics of the landscape in the study area, according to a previous social assessment and expert knowledge (Pâquet 1997; Hydro-Québec 2007). We mapped the wetland aesthetic biophysical supply by scoring planning units according to four categories: (1) proportion of ponds and lakes, (2) proportion of rivers, (3) proportion of open peatlands (i.e. non-forested bogs and fens) and (4) wetland and aquatic habitat heterogeneity (i.e. the total proportion of ponds, lakes, rivers and open peatlands; Pâquet 1997). Each of these categories was divided into four proportion ranges, for which thresholds were specifically determined using the natural breaks in ArcGIS (ESRI 2012). A score was associated with each proportion range and the total biophysical supply value of the aesthetics for a planning unit was obtained by summing the scores obtained under all four categories (Pâquet 1997). For the potential-use supply, we combined the accessibility proxies with a distance buffer of 500 m around human infrastructures (Pâquet & Bélanger 1998; Pâquet 2003) in order to identify where the wetlands are part of the aesthetic features of the landscape. Demand for aesthetics was mapped by scoring each planning unit according to (1) appeal in regard to infrastructures (i.e. local, regional or national appeal), (2) users’ expectations and interests in landscape quality (i.e. low, moderate, high), (3) mean duration of users’ frequentation (i.e. occasional, seasonal, annual), (4) mean duration of users’ observations (i.e. from seconds to extended time periods), and (5) the number of potential viewers (i.e. low, moderate or high; Pâquet 2003).

*Cultural sites for First Nations communities’ subsistence uptake*

The Montagnais First Nations communities (Innu) in the study area harvest several wetland and aquatic species for subsistence, including waterfowl, beaver, muskrat, moose, freshwater fishes and berries (Charest 1996; Walsh 2005). Thus, the biophysical supply for this ES was mapped according to the extent of habitat availability for subsistence uptake in each planning unit. The potential-use supply was refined from the biophysical supply using maps of the ‘community territories’ which are the zones across the study area that each of the four First Nations communities actually uses for their subsistence uptake activities (Charest 2005). Inside these zones, we were further able to delineate high and low uptake areas (Charest 2005). The average harvest intensities according to the total weight and total number of catches in these low and high uptake areas were used to map demand (Walsh 2005).

*Existence value of caribou*

Woodland caribou (*Rangifer tarandus* caribou) is an iconic and endangered subspecies of the Canadian boreal forest whose conservation is of global concern (Environment Canada 2008). The study area contains nearly a fifth of the total distribution range of woodland caribou in the province of Quebec. In addition to their terrestrial forested habitats, the caribou in the study are known to select water bodies and open and forested wetlands for their seasonal habitat requirements (Environment Canada 2008). Because this subspecies is sensitive to anthropogenic disturbances and seems to avoid disturbed habitats, the mean avoidance distance from each type of human disturbance in the study area was gathered from the literature (Dyer *et al.* 2001; Seip *et al.* 2007; Vistnes & Nellemann 2007; Vors *et al.* 2007; Vistnes & Nellemann 2008; Fortin *et al.* 2013). Caribou avoidance buffer zones were then mapped and planning units that fell inside them were excluded from the biophysical supply. In the remaining units, the mean occurrence probability of caribou (Environment Canada 2008), based on environmental niche models, was used to map the feature value for the protection of woodland caribou. All planning units containing a probability of occurrence higher than zero were considered as contributing to the biophysical supply. Due to the global spatial flow scale associated with this ES, the biophysical supply is equal to the potential-use supply and demand was set equal across each unit containing this feature.

**Regulating services**

*Flood control*

Flood control was mapped by modelling the capacity of each planning unit to reduce and stabilize the water that flows through it using the proportion of wetlands in each unit and its position in the watershed (Gouvernement du Québec 1993). Ombrotrophic peatlands (bogs) were excluded from the model since by definition there is great uncertainty regarding their role in controlling floods. Rivers and streams were also not considered. The position of the planning units in the watershed unit was estimated by calculating the mean Strahler order for each unit using ArcGIS 10.0 (ESRI 2012). After analysis, we considered planning units with a mean Strahler order of less than 2.5 as being headwaters. Because the spatial flow scale of this ES is regional, the potential-use supply was restricted to only those watersheds containing human populations and infrastructures. The demand was set equal across the spatial range of the potential-use supply.

*Carbon storage*

We chose to focus on storage rather than sequestration because of the considerable uncertainty regarding carbon sequestration in wetlands (M. Garneau, personal communication). Stored carbon for each type of wetland soil was modelled using a sample of primary data from the study area for bog peatlands (Magnan *et al*. 2011 and personal communication) and from the Soil Organic Carbon Digital Database of Canada for fen peatlands (Tarnocai & Lacelle 1996). Marsh and swamp carbon stock were estimated using a mean value for mineral wetlands (Horwath 2007). Lake and pond carbon stocks were calculated using an equation that established a relationship between their area and their carbon stock (Ferland *et al*. 2012). Because this ES has a global flow, each planning unit containing stored carbon could provide benefits to humans (i.e. the biophysical supply equals the potential-use supply) and therefore has equal demand.

Note: Maps of the biophysical supply and potential-use supply spatial range across the study area of each individual ES is available in Cimon-Morin *et al*., (2014).

**Generalization from ES mapping**

Mapping ES potential-use supply (PUS), which is the accessible subset of biophysical supply (BS), showed that wetland ecosystems provide different bundles of ES according to the access human beneficiaries have to the sites that contain them (see Fig. S1 below). On the one hand, accessible wetlands provided a maximum supply of provisioning (i.e. hunting, angling and berry-picking activities) and cultural services (i.e. aesthetics and cultural sites), especially in the case of peatlands. On the other hand, inaccessible wetlands provided no tangible direct-use benefits in regard to the provisioning services we analysed, even if they had the biophysical capacity to supply them, simply because no beneficiaries could gain access to these benefits. These wetlands also provided less of the cultural ES we examined than accessible sites, since some cultural ES provide benefits on a local spatial flow scale, such as aesthetics. For most wetland types, accessibility was accompanied by a much wider spectrum of ES than inaccessible wetlands could provide. Inaccessible rivers and streams supplied none of the ten services assessed. Moreover, some ES were supplied by a single wetland type, such as salmon angling in rivers and streams, and cloudberry picking in peatlands, while others were provided by several wetland types, such as carbon storage and cultural sites. Wetland types also differed in their capacity to supply particular services. For example, peatlands stored more carbon than lakes, ponds, marshes and swamps, and on average they also provided a greater bundle of the assessed ES than other wetland types.

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**Figure S1** Basic framework describing the relationship between the capacity of major wetland types to supply direct-use ES benefits and beneficiaries’ access to wetland ecosystems. The summed ‘inaccessible’ and ‘accessible’ capacities of each wetland type represent their biophysical capacity to supply ES. When the accessibility of the wetland ecosystem is taken into account, different bundles of ES potential-use supply are provided by the same wetland type. A value of 0 signifies that the service is not produced, a value of 1 signifies that this wetland type is a producer of the service, while a value of 2 signifies that the wetland type is a major producer of the service. Accessible wetlands are not necessarily altered by anthropogenic disturbances. The terms ‘accessible’ and ‘inaccessible’ refer to the capacity of the beneficiaries of each particular ES to have physical access to the wetland and ultimately, to obtain the benefits it provides. For example, cultural site beneficiaries are solely indigenous communities; accordingly, their access to the territory, and to the wetlands, is much greater than that of the beneficiaries of other local flow provisioning ES (i.e. the non-indigenous population). Provisioning services group together salmon and trout angling, moose and duck hunting and cloudberry picking. Regulating services are carbon storage and flood control, while cultural services are aesthetic value and iconic species.

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**Figure S2** The spatial range of demand for ecosystem services. Demand for service was measured as the probability that a specific location would be used or needed for the accessible provision of a particular service to a given set of beneficiaries. Demand was assessed quantitatively and summarized by three levels of demand: nil, low and high.

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**Figure S3** Networks assembled under the five conservation scenarios. Except for the AUS-BD unconstrained scenario (13.6%), all networks cover the same total area, which is 10% of the study area.

**References**

Bellavance, M. F. & Gagné, J. (2012) Cartographie des lacs sans poisson de la Minganie. Commission régionale sur les ressources naturelles et le territoire. Conférence régionale des élus de la Côte-Nord, Baie-Comeau, Québec, Canada.

Caron, F., Fontaine, P.-M. & Cauchon, V. (2006) État des stocks de saumon au Québec en 2005. Ministère des Ressources naturelles et de la Faune du Québec, Direction de la recherche sur la faune. 18 p.

Charest, P. (1996) Les stratégies de chasse des Mamit Inuat. *Anthropologie et Sociétés* 20: 107-128.

Charest, P. (2005) Chapitre 4 - L'organisation socio-territoriale de la chasse. In: *Les Montagnais et la faune*, eds. P. Charest, J. Huot & G. McNulty, pp. 235-353. Université Laval. Québec.

Cimon-Morin, J., Darveau, M. & Poulin, M. (2014) Towards systematic conservation planning adapted to the local flow of ecosystem services. *Global Ecology and Conservation* 2: 11-23.

Dyer, S. J., O'Neill, J. P., Wasel, S. M. & Boutin, S. (2001) Avoidance of industrial development by Woodland Caribou. *The Journal of Wildlife Management* 65(3): 531-542.

Environment Canada. (2008) Scientific review for the identification of critical habitat for woodland caribou (*Rangifer tarandus caribou*), B. P., in Canada. Environment Canada. Ottawa, Canada. 72 pp. plus 180 pp Appendices.

ESRI (2012) *ArcGIS* 10.0. Redlands, USA: Environmental Systems Research Institute Inc.

Ferland, M. E., del Giorgio, P. A., Teodoru, C. R. & Prairie, Y. T. (2012) Long-term C accumulation and total C stocks in boreal lakes in northern Quebec. *Global Biogeochemical Cycles* 26.

Fortin, D., Buono, P. L., Fortin, A., Courbin, N., Gingras, C. T., Moorcroft, P. R., Courtois, R. & Dussault, C. (2013) Movement Responses of Caribou to Human-Induced Habitat Edges Lead to Their Aggregation near Anthropogenic Features. *American Naturalist* 181(6): 827-836.

Gouvernement du Québec. (1993) Hydrologie. In: *Manuel de conception de ponceaux*: Gouvernement du Québec, Ministère des Transports, direction des structures, service de l'hydraulique.

Guérette Montminy, A., Berthiaume, E., Darveau, M., Cumming, S., Bordage, D., Lapointe, S. & Lemelin, L. V. (2009) Répartition de la sauvagine en période de nidification entre les 510 et 580 de latitude nord dans la province de Québec. Canards Illimités Canada - Québec, Rapport technique no Q14. 43 p.

Horwath, W. R. (2007) Carbon cycling and formation of soil organic matter. In: Paul EA, Ed. Soil microbiology, ecology and biochemistry. New York: Academic Press. p 303–390.

Hydro-Québec. (2007) Complexe de la Romaine - Étude d'impact sur l'environnement. Hydro-Québec Équipement et Hydro-Québec Production, Quebec, Canada [www document]. URLhttp://www.hydroquebec.com/romaine/documents/etude.html.

Lamontagne, G. & Lefort, S. (2004) Plan de gestion de l'orignal 2004-2010. Ministère des Ressources naturelles, de la Faune et des Parcs du Québec, Québec. 265 p.

Lemelin, L. V., Bordage, D., Darveau, M. & Lepage, C. (2004) Répartition de la sauvagine et d'autres oiseaux utilisant les milieux aquatiques en période de nidification dans le Québec forestier.Environnement Canada, Service canadien de la faune, Série de rapports techniques no422. Québec. 70 p.

Lemelin, L. V., Darveau, M., Imbeau, L. & Bordage, D. (2010) Wetland use and selection by breeding waterbirds in the boreal forest of Quebec, Canada. *Wetlands* 30: 321-332.

Magnan, G., Garneau, M. & Payette, S. (2011) Paleohydrologyand long-term carbon dynamics in the ombrotrophic peatlandsof the North Shore of the Saint-Lawrence, Northeastern Québec. *International Symposium on Responsible Peatland Management and Growing Media Production*, Québec, Canada.

MRNF (2012a) Bilan de l’exploitation du saumon au Québec 2011. Ministère des Ressources naturelles et de la Faune, Secteur Faune Québec, Secteur des opérations régionales.

MRNF ( 2012b) La pêche sportive au Québec – Périodes, limites et exceptions - Zone 19 sud. Ministère des Ressources Naturelles et de la Faune, Québec: 14 pp.

Pâquet, J. (1997) Analyses du paysage visuel. In: *Application de la cartographie écologique à quelques éléments de la gestion forestière*, eds. J. Bissonnette, V. Gerardin & J. Pâquet, pp. 41-74. Ministère de l'Environnement et de la Faune du Québec, Direction de la conservation et du patrimoine écologique, Québec.

Pâquet, J. (2003) Outil d'aide à la décision pour classifier les secteurs d'intérêt majeurs et définir les stratégies d'aménagement pour l'intégration visuelle des coupes dans les paysages – Objectif de protection ou de mise en valeur des ressources du milieu forestier visant le maintien de la qualité visuelle des paysages forestiers. Ministère des Ressources Naturelles, de la Faune et des Parcs du Québec, Direction des programmes forestiers, Québec: 15 pp.

Pâquet, J. & Bélanger, L. (1998) Stratégie d’aménagement pour l’intégration visuelle des coupes dans les paysages. Réalisé par C.A.P. Naturels dans le cadre du « Programme de mise en valeur des ressources du milieu forestier » du ministère des Ressources naturelles, Québec: 40 pp.

Seip, D. R., Johnson, C. J. & Watts, G. S. (2007) Displacement of mountain caribou from winter habitat by snowmobiles. *Journal of Wildlife Management* **71**(5): 1539-1544.

Tarnocai, C. & Lacelle, B. (1996) Soil organic carbon digital database of canada. Eastern Cereal and Oilseed Research Center, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Canada.

Tecsult (2006) Raccordement du complexe de la Romaine – Étude des populations de caribous et d’orignaux. Rapport final présenté à Hydro-Québec Équipement. Pagination multiple + annexes.

Timmermann, H. R. & McNicol, J. G. (1988) Moose Habitat Needs. *Forestry Chronicle* 64(3): 238-245.

Vistnes, I. & Nellemann, C. (2007) Impacts of human activity on reindeer and caribou: The matter of spatial and temporal scales. *Rangifer Report* **12**: 47-56.

Vistnes, I. & Nellemann, C. (2008) The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. *Polar Biology* **31**(4): 399-407.

Vors, L. S., Schaefer, J. A., Pond, B. A., Rodgers, A. R. & Patterson, B. R. (2007) Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management* **71**(4): 1249-1256.

Walsh, G. (2005) Chapitre 5 - La récolte faunique. In: *Les Montagnais et la faune*, eds. P. Charest, J. Huot & G. McNulty, pp. 355-422. Université Laval. Québec.