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Anthropogenic and climate impacts on subarctic forests in the Nain region, Nunatsiavut: Dendroecological and historical approaches

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ABSTRACT
Several recent dendrochronological, macrofossil and palynological studies have surveyed modern spruce forests at multiple locations in the Nain region of coastal Nunatsiavut (north-central Labrador) in order to reconstruct past forest composition, growth rates, species diversity and harvesting patterns. The present paper synthesizes original and previously collected data to evaluate the extent to which the dynamics of the region's spruce forests over the past five centuries have been related to anthropogenic impacts. In three key case studies, *Picea* growth release events demonstrate multiple isolated forest disturbances prior to the late 19th century. In general, these events correspond to the local human settlement history rather than to regional climatic trends, suggesting that ongoing human impacts on the forest extend as far back as the 17th century. Disturbance regimes accelerated by *ca* 1875 and afterward in all of the study sites. This increase in forest disturbance corresponds to increased demands for wood triggered by socio-economic changes experienced by the region's Inuit and Settler communities. Ongoing surveys demonstrate the presence of markers of human exploitation of forests throughout the study region, and especially in coastal locations, suggesting that anthropogenic impacts are in fact generalised and not limited to specific areas of recent settlement.

RÉSUMÉ
Plusieurs études dendrochronologiques et paléoécologiques ont récemment porté sur la dynamique forestière dans la région de Nain au Nunatsiavut (centre-nord du Labrador). Ces études ont documenté la composition, le taux de croissance et la diversité des espèces de ces forêts ainsi que les patrons de récolte de bois par les résidents de la région au cours des cinq derniers siècles. La présente étude consiste en une synthèse des données publiées ainsi que de résultats originaux, afin d'évaluer dans quelle mesure la dynamique de la forêt d'épinettes est liée aux impacts anthropiques. Dans les trois études de cas choisies, des événements de détente de croissance radiale de *Picea* sp. montrent que plusieurs perturbations isolées de la forêt sont survenues avant la fin du XIX[e] siècle. En général, ces événements correspondaient à des activités anthropiques (remontant au XVII[e] siècle) plutôt qu'à des tendances climatiques régionales. Le régime des perturbations s'est accéléré vers 1875; cette augmentation est liée à une hausse de la demande en bois due aux changements socio-économiques vécus par les communautés inuit et les colons Européens. Les relevés de terrain en cours mettent en évidence des traces évidentes d'une exploitation forestière à travers la région de Nain et, plus particulièrement, en zone côtière, ce qui suggère que les impacts anthropiques ne se limiteraient pas aux zones spécifiques d'habitation humaine récente.

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Introduction

Multiple recent studies have demonstrated local human impacts on subarctic forests in Labrador (northeastern Canada) including through the direct harvesting of wood (Roy et al. 2012, 2017; Lemus-Lauzon et al. 2016, 2018) and through cultural land and fire management (Lemus-Lauzon et al. 2012; Oberndorfer et al. 2017; Cuerrier et al. 2019). As pointed out by these authors, studies of the ecological history of northern forests and of their management frequently underestimate or ignore the scale of anthropogenic forest impacts in regions with histories of minimal commercial or industrial forestry activity. This is particularly the case in the

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context of territories occupied by First Nations and Inuit communities, where subsistence activities have characterised land use and continue to do so to a significant extent. The vast territorial extent of northern forests and the small size and dispersion of human populations living within them in the past and present may suggest that human impacts on these forests might have been insignificant. However, work such as that cited above argue that defining northern forests as 'pristine' wilderness with little scope for non-industrial anthropogenic inputs underestimates the measurable impacts of human settlement and forest exploitation and ignores the diversity of activities involved in the practice of subsistence economies as defined by Wenzel (1991) and Williamson (1997).

Coastal north-central Labrador (the territory of Nunatsiavut) is, in topographic and ecological terms, a complex region composed of subarctic spruce forest (with closed and open gallery forest, erect trees and stunted individuals – krummholz), peat bogs on the continental plateau and in sheltered bays, and well drained and boggy forest tundra in outer bays and on islands. Despite its relatively southern latitude, the region's Low Arctic/Subarctic climate is controlled by the cold Labrador Current that flows southward from carrying icebergs from Greenland and drift ice from Baffin Bay and Davis Strait (Marko et al. 1994). Therefore, the region is characterized by a high inter-annual and intra-annual climate variability and extreme weather events. Using tree-ring data in combination with documentary and discursive sources, Ouellet-Bernier et al. (2020) documented several exceptional climatic years (extreme warm and extreme cold years) during the two last centuries in the study region. Climate variability and extreme weather events have direct and significant effects on the livelihoods of the region's inhabitants, motivating them for example to cut and collect more trees for fuel and to alter the conduct of their seasonal travel and foraging activities (Brice-Bennett 1977; Elton and Ashburner).

The Nain region has a complex settlement history extending back to approximately 7000 years before present (BP) and which comprises multiple archaeologically distinct cultural groups, the most recent of which are Inuit who moved into the area from the circumpolar north by approximately 500 BP and the Innu, descending from long cultural traditions originating from the continental south (Hood 2008). While these were all highly mobile foraging peoples, the Nain region appears to have seen a constant, maintained occupancy since its initial peopling. The size of the Inuit population in the Nain region has varied since the 18th century but historical sources demonstrate a general growth of population that lasted into the early 20th century. This demographic growth featured an approximately 300% increase in the population of Nain by the mid-19th century and the establishment of a dispersed network of permanent small settlements (1–3 households) which were maintained over generations in the study area (Jenness 1965; Taylor 1974; Brice-Bennett 1977; Kaplan 1983). European agents (fishermen, missionaries, trappers, traders, etc.) have maintained a permanent presence in the region since the mid- to late 18th century (Hiller 1977). This presence included the founding of a permanent missionary and administrative centre in Nain in 1771, which is now the largest and most northerly Inuit community in Labrador, as well as, in the mid-19th century, the establishment of a small number of dispersed homesteads of English Settler families involved in fishing, hunting and trapping (Brice-Bennett 1977; McGrath 1997). Various epidemics (e.g., tuberculosis, Spanish flu pandemic) lead to a net population decline in Nain between *ca* 1880 and 1920, which was followed by sustained growth through the rest of the 20th century (Jenness 1965; Taylor 1974; Brice-Bennett 1977; Elton and Ashburner; Kaplan 1983). Inuit has been, by far, the majority population in the Nain region since the 18th century (Jenness 1965; Taylor 1974).

Wood was an essential raw material for the fabrication of Inuit material culture, including substantial items such as kayaks, sleds and boats. While some European lumber was imported for building Moravian Mission structures, local wood was necessary for building both traditional sod houses and modernized plank houses in the 19th century and afterward, as well as infrastructures such as fences and docks (Kaplan 2009). Another significant use of wood was the construction of fish flakes used to dry fish for the commercial fishery (see Kaplan 2009). These structures could be voluminous and required a substantial quantity of wood. Moreover, while substantial fences and docks may have been limited to Nain, fish flakes may have been used in outlying communities with the effect of multiplying and dispersing the total demand for wood. Larch (*Larix laricina; pingik* in Inuktitut) was often used by Inuit in Labrador and Nunavik to build certain parts of sleds and boats (kayaks) because of its flexibility and resilience (Lemus-Lauzon et al. 2012; Steelandt et al. 2013). Spruce (*Picea* sp.; *kinnitannik* in Inuktitut) was preferred as fuel for cast iron stoves used for cooking and heating after *ca* 1860 and also as building material for building houses (Kaplan 2009; Lemus-Lauzon et al. 2012). Previous research has shown that wood was harvested continuously over the last four centuries, and suggests that wood consumption has increased over time (Lemus-Lauzon et al. 2012, 2018; Roy et al. 2017). The present-day forest of the Nain region and its archipelago contains a multitude of cut stumps while naturally dead trees are rare. Forests in the vicinity of Nain have an average of one cut stump per four live trees; small clear-cut areas are also observed (Lemus-Lauzon et al. 2018). This situation is a clear signal of the impact of wood harvesting.

Climate has also played a significant role in regional forest dynamics. For example, at *ca* 1000 calibrated years before present (cal. y BP), the establishment of *Larix laricina* on Dog Island located about 35 km from Nain, was linked to a return to relatively moist conditions before the Little Ice Age (Roy et al. 2012, 2015). An increase in larch recruitment in response to recent climate warming was documented elsewhere in northeastern Canada (Kharuk et al. 2006; Dufour-Tremblay et al. 2012), a process that appears to be occurring along coastlines around Nain, based on the authors' personal observations. Dendroecological analyses and historical and archaeological settlement data are combined in this study in order to document how wood harvesting corresponds to Inuit and European Settler land use and occupancy of the Nain region, and to gauge the scale of anthropogenic impacts on its forest.

Study region and sites

The study area, comprising the mainland around Nain and its surrounding archipelago, is illustrated in Figure 1. The central Labrador coast is characterized by broad bays and long inlets separated by prominent capes and headlands which are screened by clusters of islands. It lies on the Precambrian Shield, which is formed by metamorphic gneiss bedrock and igneous anorthosite outcrops.

The study region is located within a zone of transition between subarctic and arctic climates. The climate is strongly influenced by atmospheric and oceanic circulation patterns, in particular the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the El Niño-Southern Oscillation (Gustajtis 1979; Newell 1990; Way and Viau 2014). The annual mean temperature is −2.4°C and the annual mean precipitations are 893 mm, with more than 50% falling as snow (Environment Canada 2015). The region is part of the discontinuous permafrost zone (Brown et al. 2001).

Modern vegetation in the study area belongs to the coastal ecological zone as defined by Notzl and Riley (2013). Shrub vegetation dominates the landscape, it is represented by berry heaths (notably *Empetrum nigrum* and *Vaccinium* spp.), dwarf birch (*Betula glandulosa*), Labrador tea (*Rhododendron*

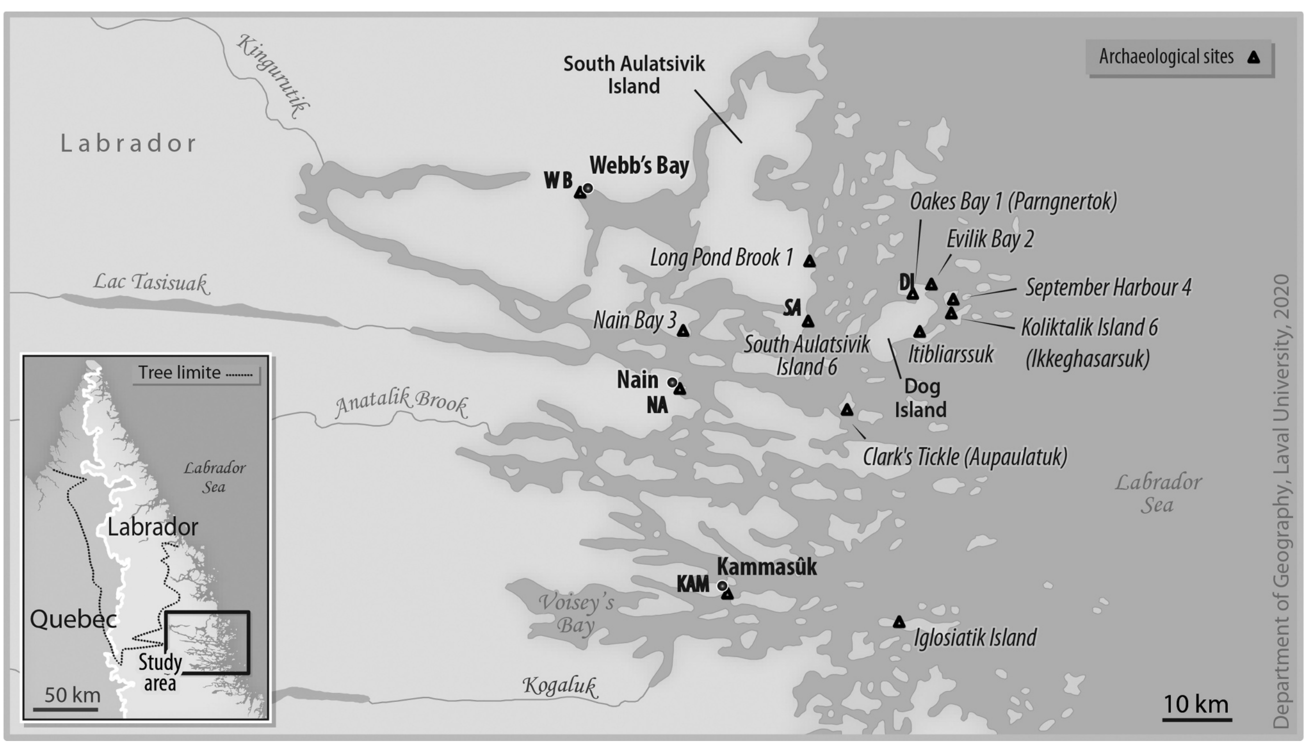

Figure 1. Location of Webb's Bay (WB), Nain (NA), Kammasûk (KAM), South Aulatsivik (SA) and Dog Island (DI) study sites and significant archaeological sites in the Nain archipelago.

groenlandicum, R. tomentosum), alders (*Alnus* spp.), and various willows (*Salix* spp.). Trees are restricted to sites sheltered from the wind. Lichen-spruce forests grow in well-drained sites, and moss-spruce forests grow in wetter ones. The dominant tree species are white spruce (*Picea glauca*) and black spruce (*Picea mariana*); larch (*Larix laricina*) is prevalent throughout the village of Nain and its surroundings. White spruce established itself on the mainland around Nain by *ca* 6000 BP and by *ca* 3000 BP in the Dog Island area (Short and Nichols 1977; Lamb 1980; Roy et al. 2012). In the present day, live trees 100 to 250 years old can be found at sites favorable for spruce, while trees 250 to 300 years old may be frequently found in protected and sheltered areas untouched by insect outbreaks and fire, such as islands (Zasada 1984). Labrador's tree line is located at Napaktok Bay, approximately 160 km north of the study area. Black spruce is also found at higher altitudes and in exposed coastal areas in the form of krummholz (stunted, horizontally growing) individuals (Payette 1983).

The three case study areas, located of the vicinity of Nain, South Aulatsivik Island and Dog Island, form a study transect extending from the continent to the seaward limit of the Nain/Dog Island archipelago. These study areas are described below.

Nain

Datasets for this study were drawn from sampling sites on the Labrador mainland near the Nain town site and in two adjacent large bays: Nain 1, Nain 2, KAM and WB (Figures 1 and 2).

Nain 1 and Nain 2 are located in two parallel valleys bordering the community (Figure 2(a)); in this study, these two adjacent sites are combined into a single dataset (referred to henceforward as Nain). In 1771, a permanent settlement was established at Nain by Moravian missionaries and the location has seen permanent, year-round settlement since that date (Taylor 1974; Hiller 1977). The town site is located on a travel route used by Inuit during seasonal migrations between the coastal and interior caribou hunting grounds, which lead to the establishment of a number of other seasonal settlements in the area (Taylor 1974). Other similar sites used by diverse prehistoric populations extending back to Maritime Archaic populations of *ca* 7000–5000 BP have also been documented (Hood 2008).

The KAM site is located approximately 30 km south of Nain and approximately 1 km south of Kammasûk, a small abandoned settlement comprising three houses and a small Hudson's Bay Company trading post. Kammasûk is located on the sheltered side of a cape separating Voisey's Bay (Tasiujatsuak) and Anaktalak Bay,

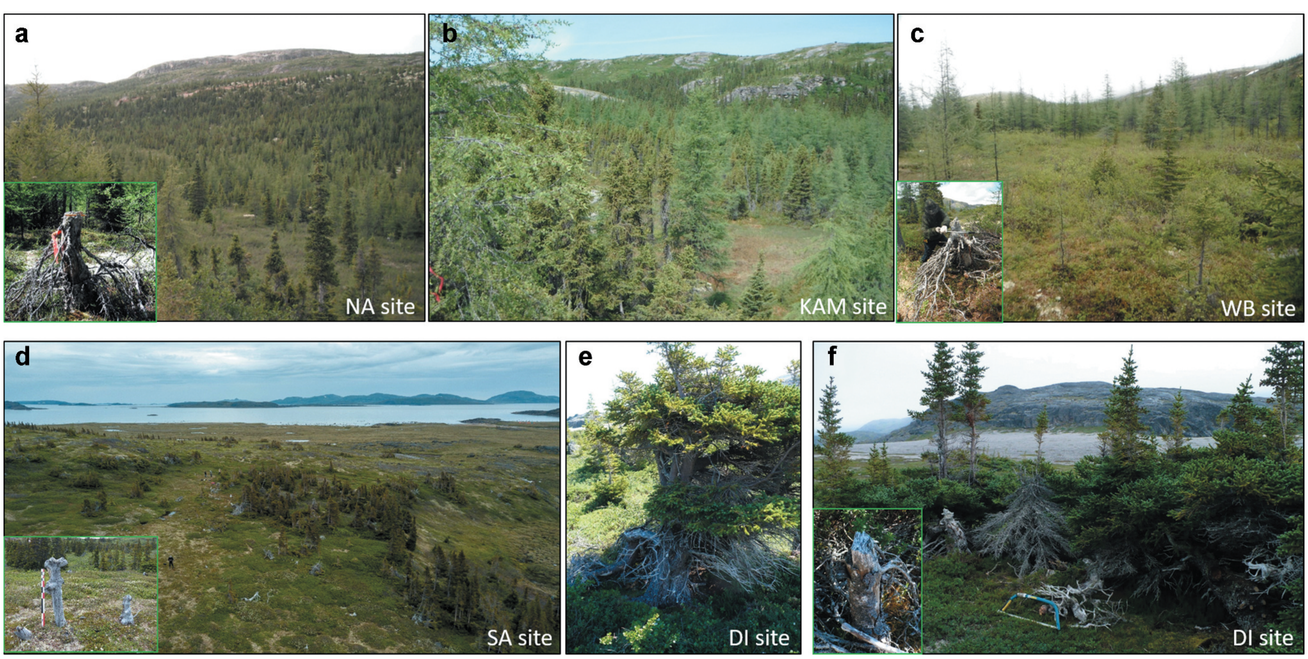

Figure 2. (a) Nain site near the town of Nain characterized by an open spruce and larch forest; a sawn tree stump is shown. (b) KAM site near the Kammasûk settlement showing an open spruce and larch forest. (c) WB site at Webb's Bay characterized by a very open spruce and larch forest; an axe-cut tree stump is shown. (d) SA site on South Aulatsivik Island showing a very open spruce forest on the southern bank of the river. (e) A spruce krummholz found at site DI, near the Oakes Bay 1 archeological site on Dog Island. (f) Site DI showing short spruce trees (2 m) and an axe-cut stump.

two ecologically rich fjord systems fed by substantial rivers draining long valleys extending deep into the Quebec-Labrador plateau (Figure 2(b)).

The Webb's Bay site, referred to here as WB, is a small settlement in the inner reaches of a large bay approximately 35 km north of Nain. It is located on the sandy banks and delta of a brook draining a valley extending into the highlands of the continental interior. This valley comprises a mix of spruce forest, lichen heath, lakes and peat bogs (Figure 2(c)).

South Aulatsivik Island

South Aulatsivik Island is located about 10 km from Nain; it is the largest island in the archipelago (456 km^2 in area) and on the Labrador Coast. The sampled site consisted of an open spruce forest colonising drained soils at about 25 m in altitude (Figure 2(d)). A short river about 3 km long originates in a small lake and flows east into the sea. The nearest archaeological site is located at about 2 km south of the sampling site on a low raised beach terrace (3 m asl). This site, named South Aulatsivik 6 (HdCi-20), includes the preserved ruins of at least eight house structures. These include semi-subterranean sod houses reflecting the architecture typical of winter iglosoak houses of the 18th to mid-19th centuries, with dug-out floors, sleeping platforms and entrance tunnels, as well as hybrid house structures combining turf and wood plank constructions that are more typical of the late 19th to early 20th century. A dendrochronological date of 1875 (Woollett et al. 2019) was obtained for a post associated with the excavation of one of the latter houses, a date confirmed by the artifact assemblage which includes late 19th century industrially produced items and a cast iron stove. Two other significant Inuit settlements sites, dated to the 18th and 18th to 20th centuries, respectively, are located in protected bays 6 and 12 km to the north of the South Aulatsivik sampling site.

Dog Island

Dog Island is located about 35 km northeast of Nain. It is a large island characterised by high summits and deep-protected bays. The area consisting of Dog Island and its surrounding islands is one of the most completely surveyed archaeological landscapes in Nunatsiavut, comprising over one hundred discrete archaeological sites representing every major phase of Labrador culture history extending back to *ca* 7000 BP (Hood 2008; Woollett 2010). Tree samples were taken from the slope of Mount Alagaiai (see Roy et al. 2017) that shelters the bay and delimits the northern shore of Oakes Bay and the Oakes Bay 1 archaeological site (HeCg-08) (Figure 2(e,f)). The slope from about 8 to 180 m asl is colonized by an open forest of white spruce and some mesic taxa such as *Betula glandulosa, Rhododendron groenlandicum*.

Methods

Collection of demographic data

A reconstruction of the structure and scale of Inuit and Settler settlement in the study region was based on published historical sources derived from Moravian Mission records, Royal Navy surveys and other historical sources (Jenness 1965; Brice-Bennett 1977; Kaplan 1983). The settlement history of the Kammasûk site was documented through interviews and oral histories published in a local history magazine (McGrath 1997) while the history of the Webb's Bay site was reconstructed through interviews (Lemus-Lauzon et al. 2012). The settlement histories of the South Aulatsivik 6 and Dog Island sites were documented through historical archives, ethnohistorical sources and archaeological evidence (Taylor 1974; Kaplan 1983; Woollett 2003; Woollett et al. 2019).

For the goals of this study, the scale of settlement at specific sites was extrapolated from various sources of historical and archaeological documentation, using numbers of households as a proxy. The settlement history of the Kammasûk site was documented through interviews (see Lemus-Lauzon et al. 2012) and oral histories published in a local history magazine (McGrath 1997) while the history of the Webb's Bay site was reconstructed through interviews (Lemus-Lauzon et al. 2012). Historical descriptions of these sites and of their inhabitants permit the attribution of dates and numbers of contemporaneously occupied houses which can be confirmed by archaeological inventories of standing houses and house ruins.

The Nain town site is a very complex palimpsest where modern occupations cut into and mask traces of previous settlement. Census data compiled by Moravian missionaries after 1774, Royal Navy surveys and various other colonial agents, for Nain and for some other sites described in Moravian records, were used in this study (Jenness 1965; Taylor 1974; Brice-Bennett 1977; Kaplan 1983). Absolute population sizes are recorded in these records but numbers of households are not consistently reported. For this reason, the number of households present at Nain was extrapolated, presuming an average of 20 persons per household. This estimation was based on data from 18th and early 19th century (see Taylor 1974). Plank houses of the 19th century were smaller than their 18th century predecessors and so this study probably underestimates the total number of occupied houses in Nain in the 19th and 20th centuries and hence the number of households. Finally, some archaeological sites (notably Oakes Bay 1 and South Aulatsivik 6) have little or no historical documentation. At these sites, the number of households is extrapolated by number of discrete inventoried house ruins whose occupation could be attributed to general (25 years) chronological intervals.

Collection of field data for dendroecological analysis

Fieldwork at the study sites on the mainland around Nain involved mapping, stump sampling and tree coring conducted in the summers of 2010 and 2011. From each living tree selected for sampling at each site, two cores were extracted perpendicular to the trunk using a Pressler increment border. Cores were inserted at about 25 cm from the root collar of living trees while cross-sections from dead trees were taken at the root collar, using a saw. Sample transects established at each site were oriented perpendicular to their valleys (except for the WB site), starting at the altitudinal tree line on one side of the valley and crossing the valley to the tree line on the opposite slope. Each transect had a width of 5 m. The Nain1 and Nain2 transects were oriented east–west, whereas the KAM transect was oriented northeast–southwest. Because of its geomorphological setting on a wide and flat sandy terrace, the sampling strategy of the WB site included three small transects, two of which were oriented east–west and the other north–south. At these three sites, transect sampling followed a systematic scheme in which every fifth living tree having a diameter ≥ 5 cm was sampled. All trees within a transect that had a diameter ≥ 20 cm were also sampled. As well, each cut stump observed along these transects was noted and described (i.e., position, height, maximum diameter, and presence or absence of bark) and sampled. A total of 308 tree samples were recovered including 242 core samples of living trees and 66 dead-wood sections.

At South Aulatsivik Island, no formal transects were used because trees were distributed in clusters of clones, each one of which comprised an isolated tree stand. The density of trees in each cluster varied between 0.23 and 1.5 per hectare. The sampling area was a pair of linear terraces located on either side of a stream draining a wide valley on the island's southeast side. The samples were collected in an initial study undertaken in the summers of 2018 and 2019 and include both cores extracted from the trunks of live trees and cross-sections sawn from cut stumps. In total 19 samples were recovered including 13 core samples of living trees and six cut stumps.

At Dog Island, sampling was carried out in the summer of 2010 near Oakes Bay, using twenty 10 m-wide transects spaced every 100 m along a linear distance of 2 km (Figure 1). Each individual tree and krummholz stand observed along each 10 m-wide transect was measured and recorded, but only those having a diameter greater than 15 cm were sampled. Each dead tree with a stump that was not buried or decomposed was sampled. A total of 133 samples were recovered, including 41 core samples of living trees and 92 dead-wood sections. In addition, four pieces of spruce wood exposed during the excavation of House 2 at the Oakes Bay 1 archaeological site were collected for analysis.

Laboratory analyses

Tree growth patterns of the five study sites were analysed in order to detect growth release events. Lemus-Lauzon et al. (2018) published an initial analysis of data from the Nain, KAM and WB sites, these data are re-examined in the present study. Similarly, data used in the course of a similar study regarding Dog Island, published by Roy et al. (2017) have been re-examined and re-analysed here. The South Aulatsivik data represent a summary of the preliminary results of an ongoing research project.

Tree-ring widths were measured with a Velmex micrometer (precision of 0.002 mm) under a binocular microscope at 40x magnification. Diagnostic light rings, that is, growth rings with exceptionally few latewood cells, were used to date and cross-date living- and dead-wood sections following protocols of Filion et al. (1986). Archived light-ring chronologies derived from the L2 tree-ring sequence from Okak Bay (1680–1922, Payette 2007) and from Oakes Bay on Dog Island (1620–1978, compiled by Natasha Roy), which are available at the Dendrochronology Laboratory at the Centre d'études nordiques and Faculté de foresterie, de géographie et géomatique, Université Laval, were also used as validation tools. Cross-dating was also verified using the program COFECHA (Holmes 1983; Grissino-Mayer 2001).

Wood harvesting in forest stands improves growth conditions for neighboring trees. Forest openings reduce competition for resources such as light and water and can substantially modify local growth conditions. Improved growing conditions are reflected by a sudden increase in radial growth of surviving trees, which is maintained for several years. In closed forests, the increase in radial growth is normally recorded by the majority of trees surrounding an opening created by fallen or cut trees (Payette 2010). In open forests, it is also possible to use sharp growth increases of surviving trees to date tree harvesting (Roy et al. 2017; Lemus-Lauzon et al. 2018). However, only trees located in the immediate environment of the harvested tree will record significant growth release.

To distinguish growth changes due to factors other than disturbance events, we used the boundary line approach (see Black and Abrams 2003, 2004; Black et al. 2009), a criterion that responds to the suddenness and the duration of the growth changes unique to canopy releases (Lorimer and Frelich 1989; Nowacki and Abrams 1997). This method scales each release by its species maximum physiological potential, as defined by a normalized growth rate. The radial growth increase over a given year was calculated as follows: (M2-M1)/M1, where M1 is the average growth over the 10-year period prior to the given year and M2 is the average growth over the subsequent 10-year period (Nowacki and Abrams 1997). The relationship between prior growth and release potential is specific to species. For this reason, we calculated boundary lines using data from documented 64,851 white spruce growth rings from the Labrador area (ring width data from Payette 2007). The white spruce boundary line corresponds to an exponential curve ($968.22^{-2.393x}$) calculated from maximum increase recorded for each growth class (M1). Growth releases that exceed 20% of the boundary line and lasted a minimum of 10 years are reported. We used this method to identify and date growth releases on living trees and on dead trees.

Although growth releases persist over many years, only the first year of a release event was considered in this analysis. Also, when there was at least a two-year gap between two growth releases, those were considered as distinct events. Afterwards, the total growth releases of each tree were arranged in 10-year classes. Because the frequency of growth releases decreases backward in time due to the decreasing number of trees included in the analysis, we fitted a log-linear regression to remove the exponential trend in the number of detected growth releases (Morneau and Payette 2000).

The Labrador coast is strongly influenced by natural climate forcing such as the North Atlantic Oscillation (NAO) and the El Niño–Southern Oscillation (ENSO) cycle. In order to distinguish disturbance events (e.g., fires, insect outbreaks) from climate forcing, the 10-years mean window used here to calculate growth release is long enough to smooth the periodicity of the ENSO cycle, which is 3.5 years, and short enough to avoid the NAO signal, which is 40 to 60 years (D'Arrigo et al. 2003; Berg et al. 2006).

Results

Demographic data and household evolution

In Figure 3, population levels are represented in terms of number of households and, at archaeological sites, are extrapolated from number of house ruins dated to approximate time intervals. Oral histories give unambiguous estimates of number of households at certain sites. Censuses realized at intervals in the Nain region recorded numbers of resident individuals in the town and in certain outlying settlements (Curtis 1774, cited in Jenness 1965; Taylor 1974; Kaplan 1983). These population numbers were converted into number of hypothetical households assuming an average of 20 persons per household (average household size between 1783 and 1900) (Figure 3).

Nain

Inuit families settled in Nain in only modest numbers prior to about 1820, after which date a wave of religious conversions and more active participation in the trading post economy run by the Moravian missionaries encouraged an increase in Inuit settlement there (Taylor 1974; Brice-Bennett 1977, 1990). A set of episodic Missionary and military surveys and censuses provide demographic information for Nain. In the late 18th century, the village's population numbered 63 people, 168 by about 1820, 298 in 1840, 314 in 1850, 277 in 1850, 282 in 1876, and 263 in 1890 (Jenness 1965; Kaplan 1983). This corresponds to an increase in extrapolated household numbers from 5 to 15 from the late 18th century to the late 19th century. Then, population raised sharply during the last century; Nain is now a community of 1200 residents, of whom 90% identify as Inuit (Statistics Canada 2017).

Kammasûk

The site Kammasûk was settled by Amos Voisey, an English fisherman and trapper, in the mid-19th century (approximately 1845; McGrath 1997). By the early 20th century, Kammasûk comprised three houses belonging to three distinct households (Figure 3). A simple saw mill was set up in nearby Anaktalak Bay in the late 19th century and a modest wood-cutting operation including saw pits was also installed at Kammasûk in the early 20th century (McGrath 1997). These families had largely relocated to Nain by the 1960s. Presently, one house remains standing at the site.

Webb's Bay

The location was settled in 1859 by James Webb, an English settler, fisherman and trapper. His descendants maintained a permanent, year-round habitation there, incorporating a single household, into the mid-20th century (Henry Webb, Personal communication 2020) (Figure 3). Subsequent generations of the family have built seasonal houses at Webb's Bay since the mid-20th century, although the site has not seen permanent, year-round habitation since the 1960s. A small historic period Inuit winter settlement site and a series of prehistoric sites are located on islands and points at the entrance to Webb's Bay, approximately 10 km east of the sampling site.

South Aulatsivik Island

This large island, located at the interface of continental and marine environmental zones north of Nain is characterised by varied topography. It currently hosts dense and tall spruce forests and large lakes on its western portions, with thin and forested tundra including open spruce woodlands and some krummholz individuals, peat bogs and lichen barrens on its eastern side. The island has seen ongoing human occupation since its initial settlement by Maritime Archaic people about 7000 BP (Fitzhugh 1978; Hood 2008). Sites of each major culture-history phase are identified on the island, clustering locations at ecological interfaces such as fluvial valleys connecting the interior to the sea, and capes extending into marine hunting areas.

The ruins found around the sampled site are consistent with late 18th–19th century Inuit winter house architecture and are not noted in Moravian censuses between 1773 and 1820; for this study the site is assumed to date to the mid-19th century and to represent the maintained occupation of a single household. Three isolated settlement sites consisting of single house structures or ruins are documented in coves between Long Pond Brook and South Aulatsivik 6 (Figure 1). All of these date between the late 19th and late 20th centuries. Three other isolated settlement sites are documented on the southwest shoreline of South Aulatsivik Island, all consist of single structures constructed in the early to mid-20th century.

Structure of forest stands in the Nain Archipelago

Tree-ring width analysis shows contrasting growth patterns of inland and island forest stands. Mean ring-widths for 50-year intervals of mainland forests show a higher growth rate during the 20th century than the island forests (Table 1). For the period of 1850–1900, all sites show a mean ring-width distribution lower than that of the 20th century, with the exception of Kammasûk, which is located further to the south and in an area well protected from strong northeastern winds.

The overall forest composition of the island sites contrasts with the continental sites in terms of age and composition of forest stands. The Nain, Kammasûk and Webb's Bay sites all have young age profiles with very few trees older than 100 years old of age. They are also

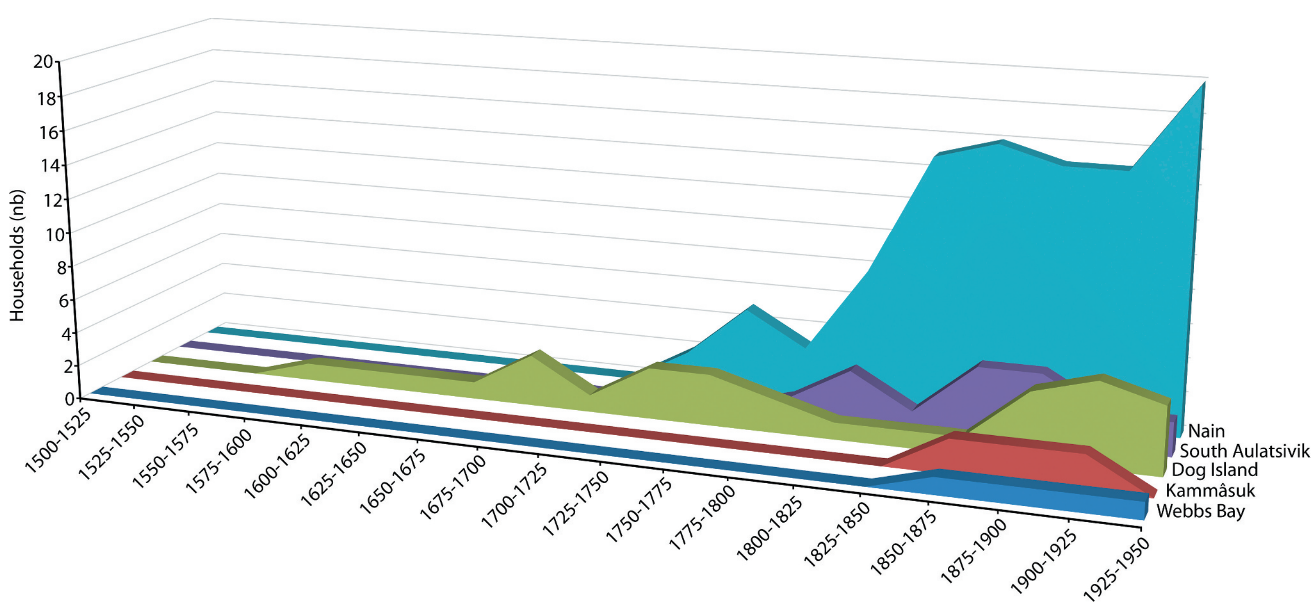

Figure 3. Estimation of Inuit settlement size at the five study sites based on archaeological, oral history and textual historical sources. Population levels are represented in terms of number of households and are extrapolated from historical records and number of archaeological house ruins dated to approximate time intervals.

Table 1. Mean ring width (mm) of *Picea* sp. for 50-year time periods at Nain, Webb's Bay, Kammasûk, South Aulatsivik and Dog Island.

Site	1518–1550	1551–1600	1601–1650	1651–1700	1701–1750	1751–1800	1801–1850	1851–1900	1901–1950	1951–2009
Nain	-	-	-	-	-	-	-	0.292 ± 0.07	0.538 ± 0.19	0.781 ± 0.13
Webb's Bay	-	-	-	-	-	0.959 ± 0.57	0.653 ± 0.15	0.451 ± 0.11	0.533 ± 0.16	0.806 ± 0.16
Kammasûk	-	-	-	-	-	-	0.676 ± 0.26	0.913 ± 0.18	0.779 ± 0.11	0.811 ± 0.14
South Aulatsivik	-	-	0.400 ± 0.15	0.412 ± 0.12	0.547 ± 0.10	0.434 ± 0.06	0.315 ± 0.08	0.338 ± 0.08	0.519 ± 0.20	0.692 ± 0.13
Dog Island	0.320 ± 0.17	0.230 ± 0.10	0.324 ± 0.17	0.265 ± 0.12	0.230 ± 0.11	0.292 ± 0.14	0.308 ± 0.16	0.332 ± 0.17	0.399 ± 0.22	0.548 ± 0.33

composed of a mix of white and black spruce and larch. This contrasts with the island forests of South Aulatsivik and Dog Island, where old growth trees (older than 100 years) represent 63% and 81% of samples, respectively (Table 2). The South Aulatsivik and the Dog Island forest stands are almost entirely composed of white spruce trees. During fieldwork, no larch trees have been observed at South Aulatsivik while only three young larch were noted at Dog Island. Finally, an important observation, cut stumps were plentiful at each study site and no dead wood was observed lying on the ground.

Growth release analysis

Nain site

A total of 80 dated samples were collected across two transects in the Nain area. These are composed of white spruce (31%), black spruce (41%) and larch (28%). The oldest sample is a larch dated from AD 1824 to 1902. At the Nain site, the *Picea* sp. chronology extended from AD 1852 to 2009 and the average age of spruce trees was 88 ± 27.5 years (Table 2). All of the 49 spruce trees sampled showed at least one growth release. The first observed growth release occurred in the 1850s and these events became more frequent between 1910 and 1970 (Figure 4).

Kammasûk site

The 31 samples from Kammasûk are composed of white spruce (58%), black spruce (6%) and larch (36%). The oldest sample is a larch dated at AD 1789. The larch chronology spans the period from AD 1789 to 2004, while the *Picea* sp. chronology extended from AD 1821 to 2009. The average age of spruce trees at this site was 92 ± 34 years (Table 2). All of the 20 spruce trees sampled showed at least one growth release. The first documented growth release occurred in the 1830s and they occurred more frequently in 1910 and between 1950 and 1960.

Webb's Bay site

A total of 34 samples were recovered from a well-drained terrace adjacent to the present-day settlement site. The assemblage of samples from Webb's Bay is composed of *Picea* sp. (5%), white spruce (24%), black spruce (18%) and larch (53%). Webb's Bay is the site where larch trees were the most abundant in this study. The oldest sample is a larch dated to AD 1721. The larch chronology extended from AD 1721 to 2009. The *Picea* sp. chronology extended from AD 1821 to 2009, the average age of spruce trees in the sampling area was 88 ± 37.6 years (Table 2). All of the 15 spruce trees samples showed at least one growth release. The first growth release occurred in the 1810s, and they became more frequent in the 20th century. Even if they were infrequent, growth releases remained statistically significant as demonstrated by the residual curve presented in Figure 4.

South Aulatsivik

Nineteen samples were taken in the vicinity of the South Aulatsivik 6 archaeological site. Those samples were composed exclusively of white spruce, no larch trees were identified in the sampling area. The preliminary results show that the white spruce chronology extended from AD 1640 to 2018 and the average age of the trees was 142 ± 85.5 years (Table 2). All of the 19 spruce trees sampled showed at least one growth release. The first growth release occurred in the 1670s, and they became more frequent in the 20th century.

Dog Island

A total of 133 samples were collected from Dog Island. These samples consisted almost exclusively of white spruce; only three larch trees were identified during the 2010 field season and these were not sampled. The white spruce chronology extended from AD 1518 to 2009 and the average age of the trees was 180 ± 55.1 years (Table 2). At Dog Island, 86% of the trees sampled showed at least one growth release. The earliest growth release was dated to the 1540s and two subsequent episodes of abundant growth release events occurred between 1790 and 1820 and between 1910 and 1950 (Figure 4).

At each site, a high frequency of growth release is recorded at the beginning of the 20th century. Prior to 1900, growth releases were infrequent, except at South Aulatsivik and Dog Island, where these events extend far back in time to the 17th and 16th centuries (Figure 4).

Discussion

We examined tree growth patterns in forest ecosystems around several human settlements in the Nain region of Labrador. The abundance of cut stumps and the scarcity of naturally dead trees throughout the area implies significant local wood harvesting by the Nain region's occupants. Although wood harvesting seems to have been a primary factor affecting these forest ecosystems, some other disturbances have been observed, especially at the Dog Island site, where bark beetle outbreaks were documented during 1790, 1910, 1920 and 1970–2000 (Roy et al. 2017). At the Nain site, no evidence of insect damage or fire was found (Lemus-Lauzon et al. 2018) and no evidence of fire was noted at Kammasûk and Webb's Bay although a forest fire of moderate size did occur in the latter region in 2004 (Brehaut and Brown 2020).

Growth releases associated with wood harvesting were observed on many spruce trees at these study sites. They occurred more or less sporadically except for the end of the 19th and beginning of the 20th century, when all sites showed consistent and significant occurrences of growth releases. In a previous study, Roy et al. (2017) concluded that the pattern of radial growth observed at the Dog Island site (significant initial growth followed by a gradual slowing of growth) was typical of trees growing in proximity to clearings, in this case gradually infilling cut clearings. In contrast, climate change tends to produce more constant, sustained growth effects.

The chronology of growth release events coincides with extrapolated human population levels of the study area over the last approximately 300 years. A particularly clear correspondence between forest disturbances and population is noted everywhere for the beginning of the 20th century, suggesting that increased forest disturbance was caused by increased total harvesting by a larger population inhabiting the area on a more permanent basis (Figure 5). Prior to 1900, however, there were several periods during which there was no clear correspondence between population and forest disturbances. The interaction of forest disturbance and occupancy for these two periods is discussed in detail below.

Forest-disturbance events and human occupation before 1900

Isolated growth release events were identified prior to the late 19th century in all study areas. The residuals of many of these release events are not significant, nevertheless they point to the possibility of ongoing human impacts on patches of spruce forest extending back as far as the 17th century, well prior to the use of cast iron stoves or construction of buildings and infrastructures that demanded great quantities of wood. The appearance of release events coincides with human occupation in nearly all of the sample areas except Nain, where local wood harvesting is the most extensive.

At the Nain site, the scarcity of growth release events before 1900 could be related to the young age of the forest, which contains few if any trees old enough to document forest dynamics prior to the mid-19th century. Since the establishment of a permanent Moravian mission at Nain in 1771, the town has maintained a nucleus of Inuit and Euro-Canadian inhabitants (Taylor 1974). In addition, some English settlers established themselves in the peripheries of the Nain region during the 19th century, and they adopted elements of traditional Inuit land use. All these inhabitants harvested wood from the forest around Nain for their domestic needs (fuel for heating) as well as for their episodic raw material needs (e.g., building houses). In interviews, elders from Nain related that standing dead wood was specifically sought out as firewood because of its ease of combustion, leading Lemus-Lauzon et al. (2012) to conclude that the lack of dead wood was the result of intensive harvesting.

A second factor that could explain the absence of old trees and dead wood is the high decomposition rate of wood caused by significant soil humidity. A much different pattern was observed at Dog Island, where living old trees were common and dead trees were frequently preserved (Table 2). This study area is much more exposed to cold currents and generally receives less snow cover, which tends to favor better preservation of wood. In addition, its isolation as an island environment

Table 2. Characteristics of *Picea* sp. samples from each site.

	Nain	Kammasûk	Webb's Bay	South Aulatsivik	Dog Island
Nb samples	49	20	15	19	133
Nb growth release	74	26	22	20	115
Growth release (%)	151	130	146	105	86
Time series	1852–2009	1821–2009	1767–2009	1640–2018	1528–2009
Average age	88 ± 27.5	92 ± 34	88 ± 37.6	142 ± 85.5	180 ± 55.1
Oldest tree	151	188	152	283	384
Trees older than 100 years (%)	30	40	40	63	81

well separated from the mainland protects its forests from fires and insects, a condition demonstrated elsewhere by Payette (1988) and Zasada (1984).

Occasional disturbance events were identified at the South Aulatsivik site between 1650 and 1710, a period where there is, as yet, no archaeological evidence of local habitation (Figure 5). The cause(s) of these disturbances are hard to explain, however the sampling area offers easy access to wood for people living in and traveling amongst the surrounding islands, especially when travelling on winter fast ice with dog teams. Williamson (1997) noted that contemporary winter travel routes pass north-south along the eastern side of South Aulatsivik Island, directly in front of this sampling site and in direct sight of it. A dozen significant winter settlements dated to the 18th and 19th centuries are documented in the islands surrounding the South Aulatsivik

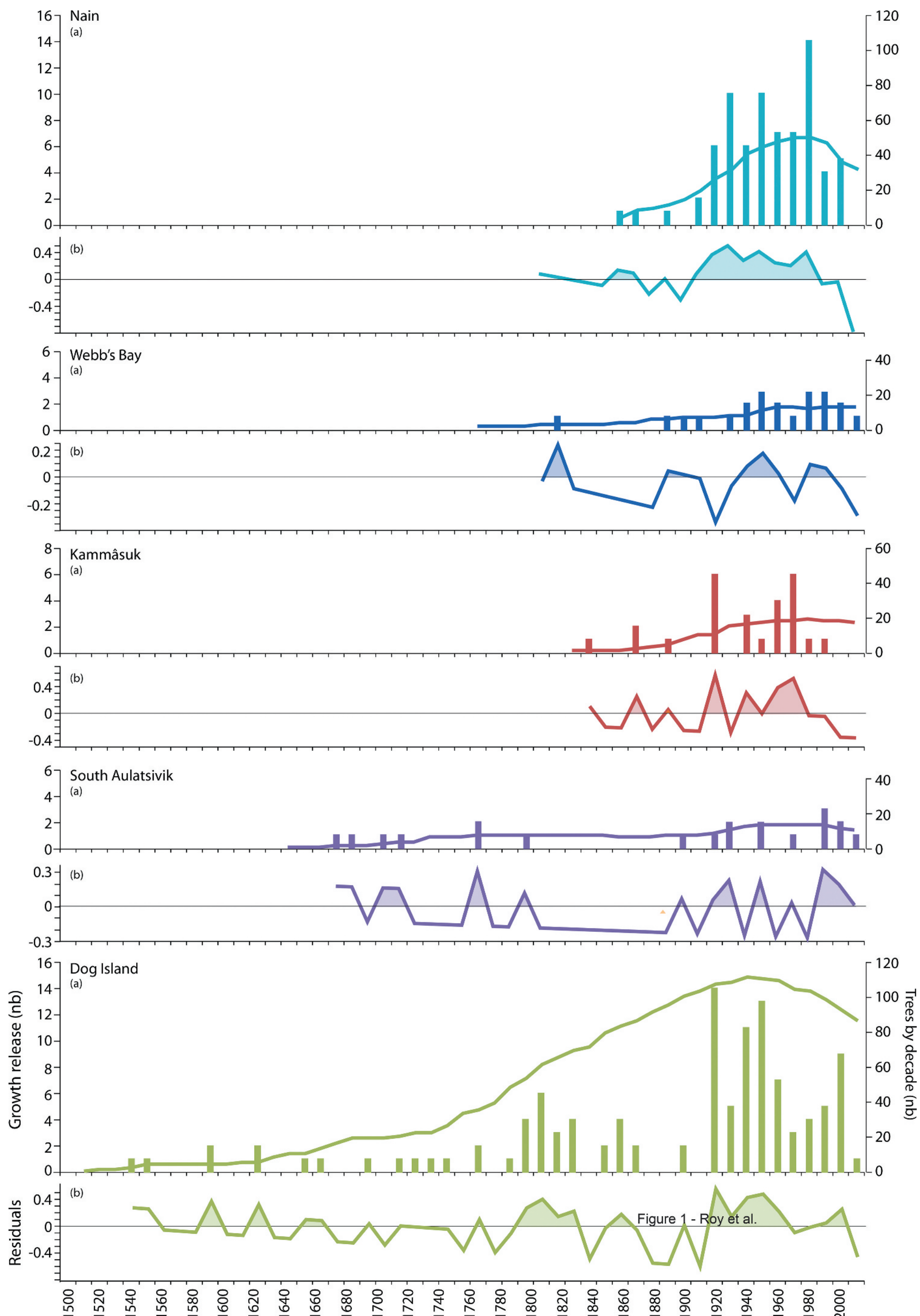

Figure 4. For each of the five study sites: (a) number of disturbance events (left, bars) and number of trees (right, line) per decade; (b) residuals of the log-linear regression of the age frequency distributions of release events.

site (Kaplan 1983) many of which currently have no local available wood; this small forest therefore represents a potentially significant source of wood for the region.

No growth disturbances were observed at South Aulatsivik between 1790 and 1880, despite the presence of dwellings dated to the mid to late 19th century (Figure 5). The lack of concordance between growth release and occupation records may be due to the very small sample size of this preliminary data collection (19 samples). Nevertheless, the beginning of observed disturbance at South Aulatsivik corresponds to a period of more constant occupation of the adjacent settlement site between 1870 and 1900, as inferred by archaeological research to date (Woollett et al. 2019). Ongoing fieldwork in this region will assure access to a more reliable data set.

The Dog Island site shows a continuous series of moderate disturbance events since about 1550 (Figure 5). The sampling site is adjacent to the Oakes Bay 1 archaeological site which had episodes of occupation from the 16th to late 18th century (Woollett 2010; Roy et al. 2012; Foury 2016). Additional similar archaeological sites are located on nearby islands, such as September Harbour 2 (17th century), Koliktalik 6 (1780s) and Evilik Bay 2 (mid 19th to 20th centuries). Many other cabins were inhabited throughout these islands during the late 19th and 20th centuries (Brice-Bennett 1977; Kaplan 1983; Williamson 1997).

The period of most intense occupation of the Oakes Bay 1 (17th century to 1772) does not coincide with statistically significant occurrences of growth releases in the local forest as demonstrated by residuals. Several growth occurrences were observed scattered throughout this time period, suggesting a minor level of ongoing harvesting, but their impact is not statistically demonstrated. Given the scale of the archaeologically documented occupation of the site, this minor level of forest impacts suggests that wood harvesting prior to the 19th century was limited. Quantities of wood, including spruce trunks of >20 cm diameter were used in the construction of the site's dwellings, as was well demonstrated in the archaeological excavations (Woollett 2010).

Wood appears to have been of relatively minor importance as a fuel during this time period, however. Seal oil, burned in steatite lamps, was the principal fuel for lighting and heating poorly-ventilated winter houses and for cooking into the 19th century (Taylor 1974). Wood was used principally as fuel for well-ventilated fires outside houses. Archaeological excavations at Oakes Bay 1 provided evidence consistent with these habits. Floor deposits from house interiors at the site included numerous fragments of steatite vessels and lamps with burnt fat residues as well as discarded masses of charred fat resulting from the cleaning of lamps (Woollett 2010; Couture et al. 2016; Foury 2016). Thus, a possible hypothesis explaining the relative lack of forest impacts prior to the 19th century is that 'traditional' Inuit modes of land use did not require intensive wood harvesting except during periods of house construction. A second important possibility is that the relatively poor preservation of trees of this age hinders the evaluation of forest disturbances prior to about 1800.

A period of multiple significant growth release events was noted at Dog Island between 1790 and 1870. Historical and archaeological data suggests that Oakes Bay 1 was no longer occupied as a winter settlement during this time period. However, other winter settlements with traditional sod house dwellings came in use in the region, Koliktalik 6 by 1780 and Evilik Bay 2 in the mid-19th century. It is probably that these disturbances are related to harvesting of wood for the construction of dwellings at these sites, they lack local sources of wood and are only 3 to 5 km from the sampling area (Figure 1), close enough to transport wood from the Dog Island forest via dog sled.

Forest-disturbance events and human occupation after 1900

A period of widespread, constant and significant growth release events was recorded at all sampling sites between 1890 and the present day. These show a clear correspondence with an increased population until *ca* 1950, as extrapolated by the number of households in the Nain archipelago. During this period, wood was used universally in the construction of plank houses and hybrid sod and wood houses (Figure 6). These structures require significant amounts of wood for construction and consumption of much more fuel (wood) as they were heated with cast iron wood stoves (Kleivan 1966; Brice-Bennett 1977; Kaplan 1983). Both Nain and the outlying settlements around it were permanent sites used in multiple seasons if not year-round and over multiple years. This pattern of settlement would inevitably have produced a constant demand for wood and a significant and maintained level of local wood harvesting.

Permanent settlements were established in localities around of all of the study's sampling sites during this time period and they all saw their maximum historical populations in the 20th century (Figure 5). The smaller study sites (DI, SA, KAM, WB) all had populations resident within 0 to 2 km from the study sites with additional small isolated settlements in a radius of 10 km. As a general trend, people living in outlying settlements relocated to Nain between 1950 and 1970, a process which added significantly to the population of Nain and which increased local

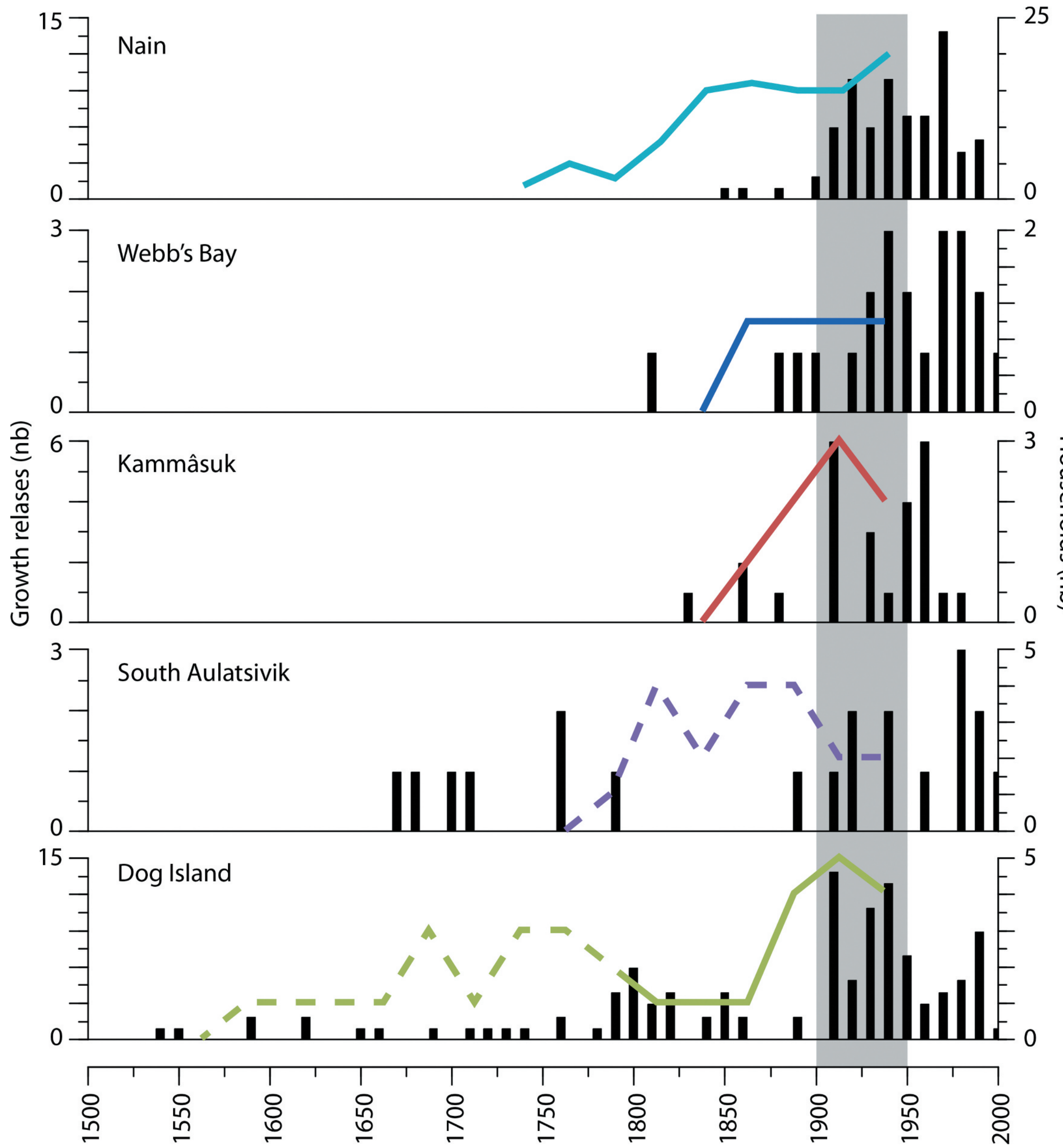

Figure 5. Correspondence between growth release events (left, bars) and the scale of local human settlement in the five study sites in terms of extrapolated number of households (right, line) for the last 500 years. The shaded area shows regional forest disturbance between 1900 and 1950. Note that the scale for number of households (right) is not the same for all studied sites. Dotted lines indicate periods when the extrapolated number of households is based exclusively on the number of documented house ruins at archaeological sites, in absence of detailed historical data.

wood harvesting. According to interviews performed with the residents of Nain (Lemus-Lauzon et al. 2012), wood harvesting conducted throughout the locality, on the mainland and on the adjacent islands, is still a major ongoing activity during the winter and spring months.

Conclusion

The results of this preliminary study based on dendroecological data and demographic information suggest that human settlement in the Nain region has had a widespread and measurable impact on forest composition and growth patterns. This impact is clearly observable in the recent and historical past (after about 1890), as the bulk of statistically significant growth release events (as measured by residuals) occurred since 1500 but accelerated at *ca* 1875–1890 at all five of the study locations. This increase in forest disturbance was triggered by changes in socio-economic conditions of the local Inuit and Settler communities. The dispersal of the

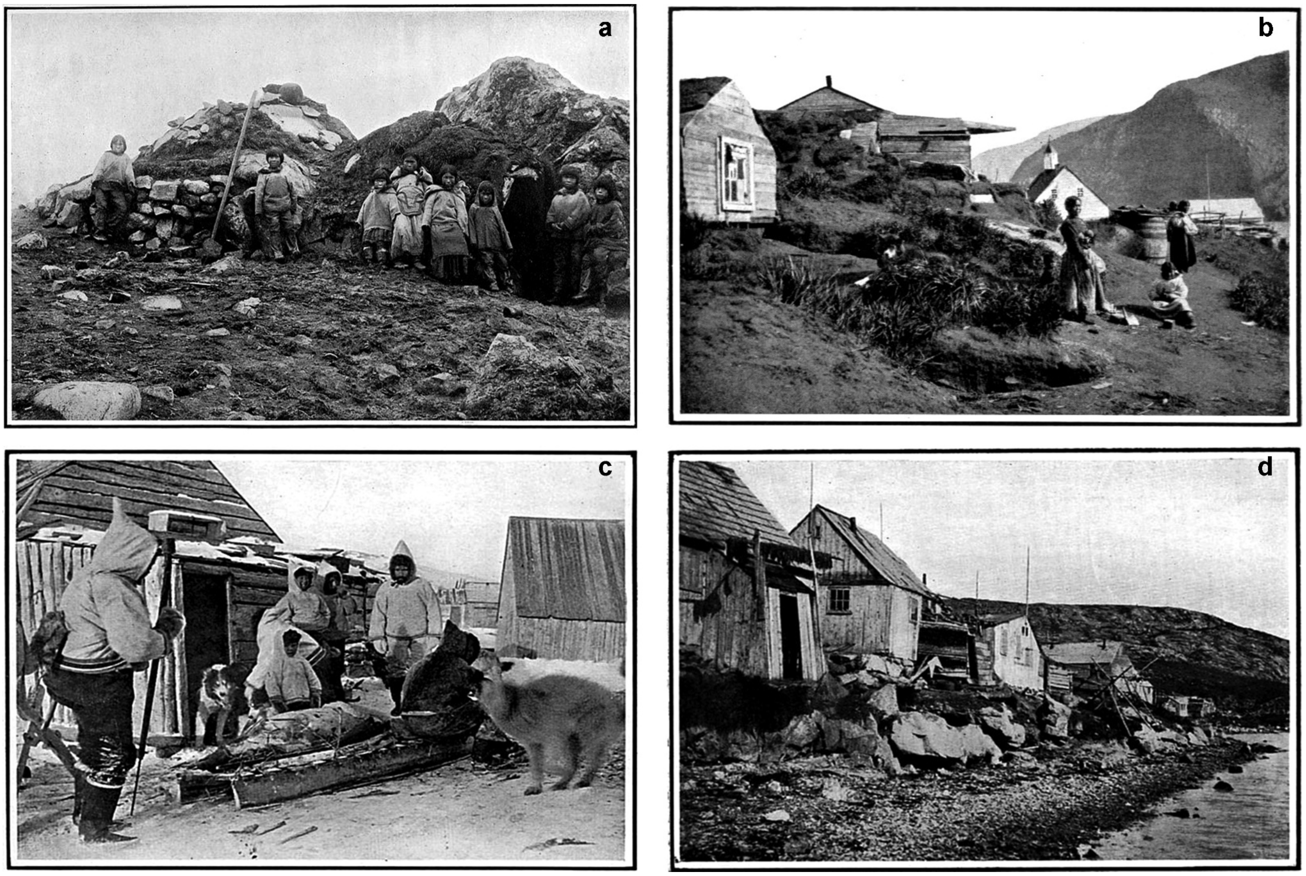

Figure 6. Architectural uses of wood during the evolution of the Inuit winter houses from the 19th to the 20th century. (a) Two examples of winter semi-subterranean sod houses (iglosoak) constructed in the 19th century and typical of the 18th to mid-19th centuries: wood is used in walls, entrance, roof support posts and the roof itself. (b) In Ramah, hybrid house structures combining turf, timber posts and wood planks in the late 19th – early 20th century. (c) In Okak, plank houses and wooden sled dated to *ca* 1912. (d) In Okak, plank houses with visible stovepipes indicating the use of cast iron stoves, dated to *ca* 1912. Pictures from Hutton (1912).

population in small permanent settlements such as Kammasûk may have created demand for wood that required harvesting over the whole region. Furthermore, the adoption of above-ground wooden houses, and especially cast iron stoves greatly increased demand for building materials and fuel which were met by harvesting wood. Forests throughout the Nain region have been extensively harvested and have been impacted by this activity through the creation of clearings and by the removal of old trees and standing dead wood. This study confirms the need to take anthropogenic factors such as wood harvesting into account when conducting ecological studies of subarctic forest dynamics.

This study could be strengthened by analyzing a larger number of trees and cut stumps taken from several sites across the Nain region and its archipelago. Based on this study, ideally, a minimum of 50 samples in a single study area ought to be collected in order to obtain a sufficiently detailed record of growth releases. The main limitation of this research is the scarcity of old trees because they have either been harvested or are decomposed.

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