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Human–environment interactions at a short-lived Arctic mine and the long-term response of the local tundra vegetation

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Abstract

Arctic mining has a bad reputation because the extractive industry is often responsible for a suite of environmental problems. Yet, few studies explore the gap between untouched tundra and messy megaproject from a historical perspective. Our paper focuses on Advent City as a case study of the emergence of coal mining in Svalbard (Norway) coupled with the onset of mining-related environmental change. After short but intensive human activity (1904–1908), the ecosystem had a century to respond, and we observe a lasting impact on the flora in particular. With interdisciplinary contributions from historical archaeology, archaeozoology, archaeobotany and botany, supplemented by stable isotope analysis, we examine 1) which human activities initially asserted pressure on the Arctic environment, 2) whether the miners at Advent City were "eco-conscious," for example whether they showed concern for the environment and 3) how the local ecosystem reacted after mine closure and site abandonment. Among the remains of typical mining infrastructure, we prioritised localities that revealed the subtleties of long-term anthropogenic impact. Significant pressure resulted from landscape modifications, the import of non-native animals and plants, hunting and fowling, and the indiscriminate disposal of waste material. Where it was possible to identify individual inhabitants, these shared an economic attitude of *waste not, want not*, but they did not hold the environment in high regard. Ground clearances, animal dung and waste dumps continue to have an effect after a hundred years. The anthropogenic interference with the fell field led to habitat creation, especially for vascular plants. The vegetation cover and biodiversity were high, but we recorded no exotic or threatened plant species. Impacted localities generally showed a reduction of the natural patchiness of plant communities, and highly eutrophic conditions were unsuitable for liverworts and lichens. Supplementary isotopic analysis of animal bones added data to the marine reservoir offset in Svalbard underlining the far-reaching potential of our multi-proxy approach. We conclude that although damaging human–environment interactions formerly took place at Advent City, these were limited and primarily left the visual impact of the ruins. The fell field is such a dynamic area that the subtle anthropogenic effects on the local tundra may soon be lost. The fauna and flora may not recover to what they were before the miners arrived, but they will continue to respond to new post-industrial circumstances.

Introduction

The discourse of Arctic mining is commonly characterised by a juxtaposition between a near-pristine, fragile landscape and the negative social, economic and environmental consequences of many megaprojects in the circumpolar north (Keeling & Sandlos, 2009). It is allegedly, "needless to say, such an intensive industry affects surrounding ecosystems and does not go without environmental issues" (Jóhannesson, Robaey, & de Roo, 2011). Mining historians, too, have emphasised the environmental changes that large mining projects brought to northern communities and the ongoing impact of mines after their abandonment (Keeling & Sandlos, n.d.). While championing abandoned mines for their great heritage value, their case studies are marred by heavy landscape modifications and significant environmental problems.

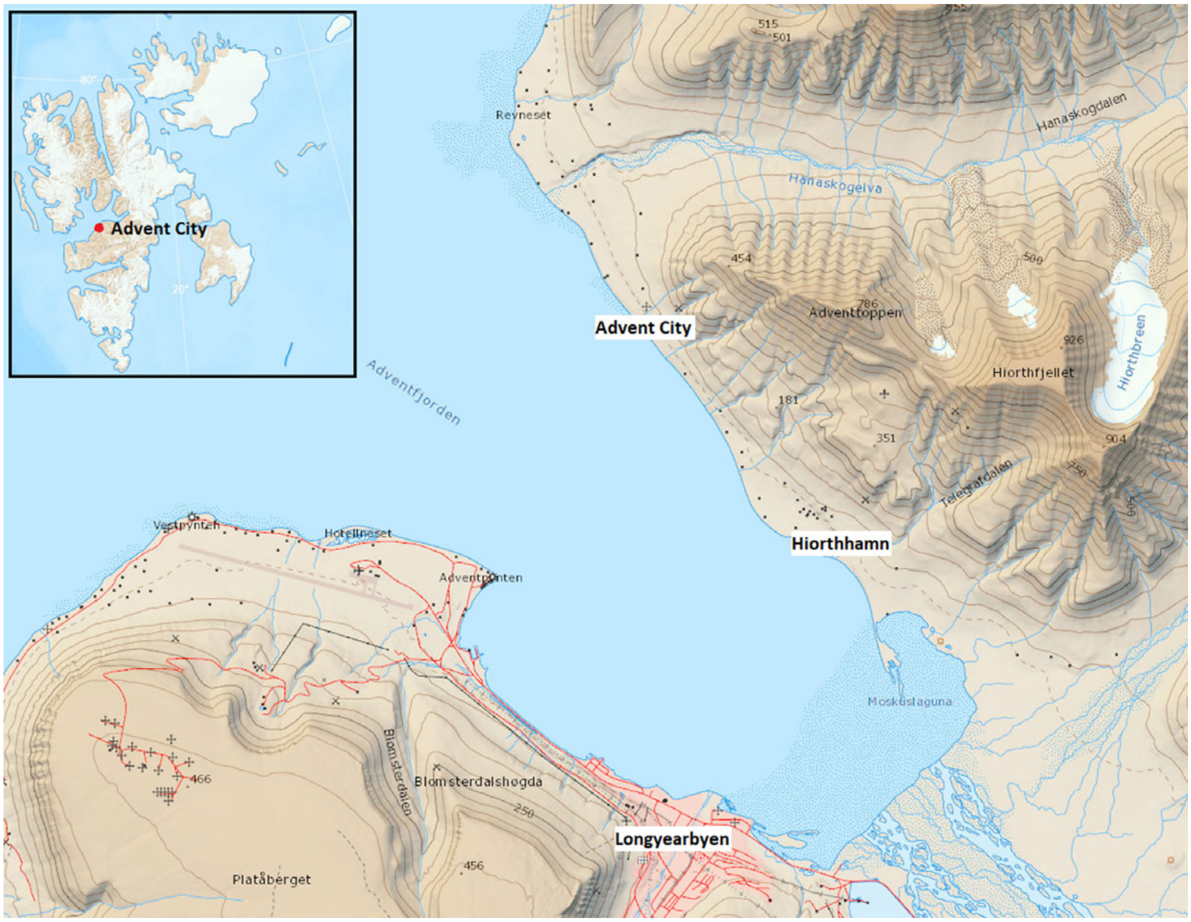

Fig. 1. Location map of Advent City in Adventfjorden in Svalbard. The distance between the site and the harbour of Longyearbyen is 4.4 km. Map: Norwegian Polar Institute & F. Kruse.

Increasing evidence suggests "when megaprojects go wrong they are the proverbial bull in the china shop" (Flyvbjerg, 2014).

Yet, Arctic mining was not always big and bad. The dawning European exploitation of Arctic mineral resources was characterised by opportunistic trial and error (Kruse, 2013, 2016a). The development from tentative exploration to full-scale production, which was by no means linear, is still evident in the coal mines of Svalbard. They present us with an opportunity to consider the gap between untouched tundra and messy megaproject.

Focusing on the onset of Arctic mining, we study the human actions and attitudes that lie at the very root of environmental impacts that persist today. Three central questions guide our study: 1) Which human activities initially asserted pressure on the Arctic environment? 2) Were early Arctic miners "eco-conscious"; that is to say, did they show concern for the environment? 3) How did the local ecosystem respond after mine closure and site abandonment? We chose Advent City in Adventfjorden (Fig. 1) as a case study. Advent City is the site of a former English coal mine and mining settlement. The site is fixed in space, time and magnitude, and it is an instructive example of the expansion of extractive industries from the European core region into the global periphery (Kruse, 2013).

We now widen the research scope to include the site's environmental history. Our study combines an assessment of historical sources with interdisciplinary fieldwork and subsequent laboratory analyses.

Historiography

Published references to Advent City are limited in number and scientific scope. During the mine's short lifespan, Advent City – then the world's northernmost town – had novelty value, more so in Norway than in Great Britain, and featured in newspapers and magazines (e.g. Fra Advent City, 1906; Fig. 2). Such popular articles now straddle the boundary between archival research and literature review.

In the years surrounding the First World War, many largely descriptive geographies emerged. The polar explorer and later professor of geography R. N. Rudmose Brown (1912, 1915, 1919a, b, 1922) and the geologist and geographer Henry M. Cadell (1920), whose father was a mining industrialist, focused on British developments on the archipelago, regularly citing Advent City as an early albeit unprofitable British accomplishment. Both promoted a Scottish exploration company, and their nationalistic tone served an economic as well as political purpose. Other nations, too, offered their opinions on the future governance of Spitsbergen (Svalbard), still a no man's land (e.g. Rabot, 1919), but naturally Advent City played no role in their rhetoric.

The Spitsbergen Treaty of 1920 put an end to geopolitical speculations and decided sovereignty in Norway's favour. In a case of "uninherited heritage" (Grydehøj, 2010), Advent City slipped into historical oblivion. The small, unprofitable and abandoned English coal mine inherited by the Norwegian authorities received only tangential scientific attention over time (e.g. Dreyer, 1928;

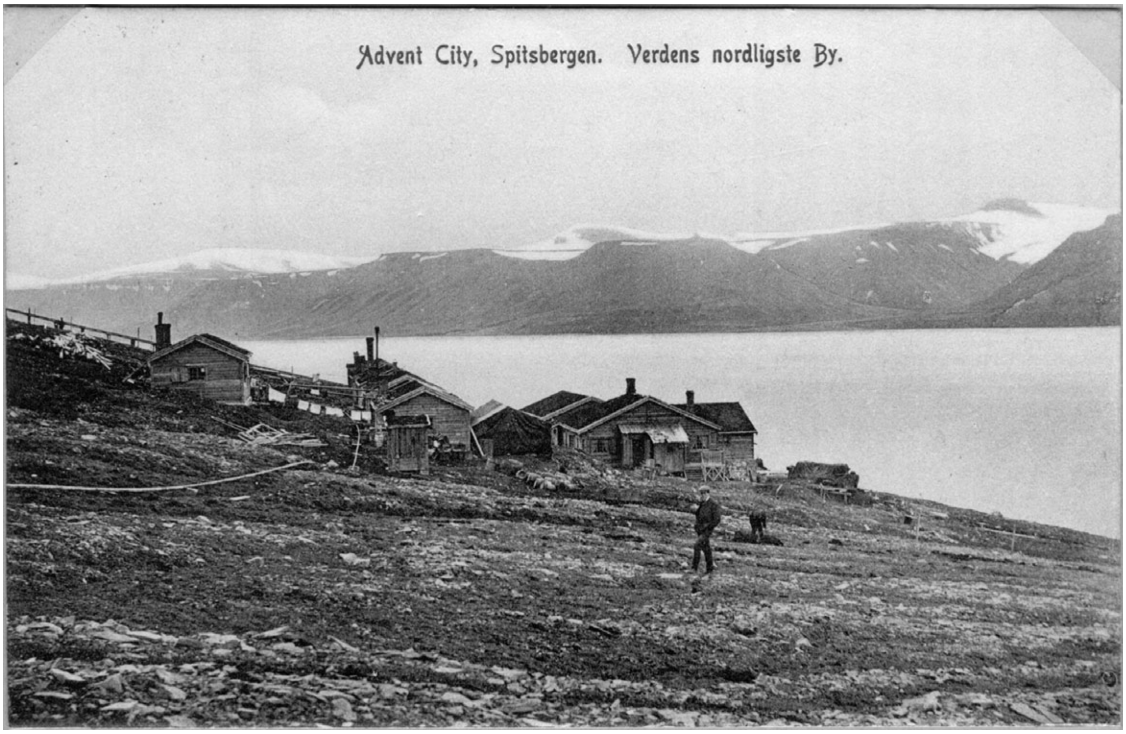

Fig. 2. Historical photograph of Advent City, "the world's northernmost town," taken by A. B. Wilse in summer 1906. Reproduced with the permission of the Norwegian Polar Institute.

Orvin, 1939). Hoel (1966) compiled a synthesis of Svalbard history, dominantly from memory and Norwegian sources, depicting British developments with considerable ideological and imperial bias. He points out failures at Advent City while ignoring any pioneering efforts and does not attempt analysis and interpretation.

Repetitive mentions by a handful of authors that the overwintering in 1905/6 was "the first" (Avango, 2017; Avango *et al.*, 2011; Avango, Hacquebord & Wråkberg, 2014; Avango & Roberts, 2017; Hacquebord & Avango, 2009, 2016) at any coal mine in Svalbard swelled the references to Advent City without providing new information. During the LASHIPA (Large Scale Historical Exploitation of Polar Areas) Project, archaeological fieldwork between 2004 and 2010 provided new data for a commendable publication effort (Hacquebord, 2012). A holistic comparison of the different industries, however, is still lacking. Moreover, an interdisciplinary approach enabling the evaluation of long-term environmental impact was not adopted.

Advent City was a LASHIPA case study. Kruse (2011, 2013) combines historical and archaeological material to produce a socio-economic narrative of why the mine was started, how it operated and why it closed down. For our purposes, we learn that a coal claim was staked out in 1901 and the first structures appeared in 1903. Between 1904 and 1908, the Sheffield-based Spitzbergen Coal & Trading Co., Ltd built a settlement fit for 100 inhabitants. When the mine closed in 1908, unpaid guards initially confiscated portable possessions. Subsequently, a neighbouring mine salvaged some machinery and buildings (Hartnell, 2009). In 1917, all remaining houses were demolished and removed to nearby Hiorthhamn. A present-day plan of the site is shown in Fig. 3. We draw special attention to the former stables and piggery (7b & 7c), and one of the former workers' barracks (5c).

Based on a brief survey (Avango *et al.*, 2006), Kruse's LASHIPA subproject did not comprise any fieldwork at Advent City, let alone a campaign enabling the study of environmental history and lasting human-induced impact. The success of such a campaign would depend on the use of multiple proxies. Their importance is highlighted by the Joint Proxy Research Group in Tromsø and demonstrated at Smeerenburg in Svalbard. "A joint proxy is an archaeological site with good preservation conditions that contains proxy data of relevance for archaeological, geological, botanical, zoological and climate change research and interpretation" (Blankholm, 2016). The remains of a 17th-century whaling station at Smeerenburg constitute such a site. Following excavations in 1979 and 1980 (Hacquebord & de Bok, 1981), Hacquebord (1984) was able to draw on a wealth of data that allowed far-reaching conclusions about Dutch society. Such work is extremely topical today (e.g. Holmgaard *et al.*, 2019; Loonen *et al.* 2019; Sysselmannen på Svalbard, n.d.).

Away from the field of archaeology, there have been environmental impact assessments of various kinds in Svalbard (e.g. Hagen *et al.*, 2012; Lutnæs *et al.*, 2017; Retelle, 2019; Sander, Holst, & Shears, 2006; Ware *et al.*, 2012), "to elucidate the effects activities may have on continuous areas of wilderness, landscape elements, the flora, fauna and cultural heritage" (Ministry of Climate and Environment, 2002). Without detailed historical information and targeted archaeological proxies, however, such assessments lack time depth. They take the one-sided view of cultural heritage as a victim of modern environmental change – instead of an original cause.

One exciting study addressing "past Arctic aliens" (Alsos, Ware, & Elven, 2015) includes a review of the alien vascular plant record for Advent City coupled with a site walkover. The authors

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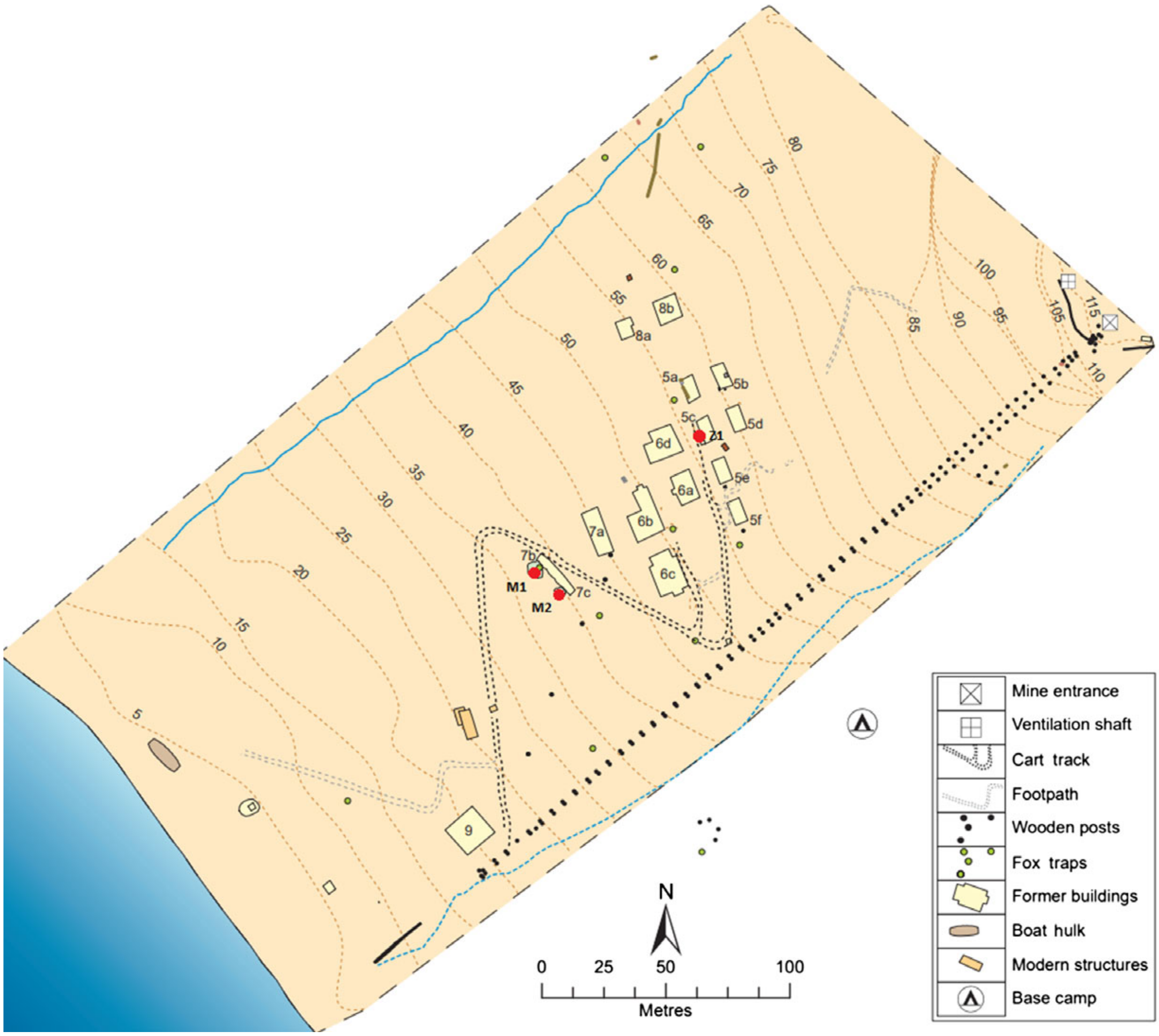

Fig. 3. Site plan of Advent City. The modern hut (in orange) lies at 78.269° N 15.626° E. The numbering of the former buildings is used throughout the text. Of particular interest are the former stable (7b), piggery (7c) and workers' barrack (5c) with the excavation trenches M1, M2 and Z1, respectively. Map: G. Nobles.

conclude that three exotic plant species identified in the 1930s had not established themselves. They do not go into detail about past human–vegetation interactions.

Materials and methods

Historical sources

Preparing for the field, we carried out a desk study of historical texts and images. A photo regression exercise proved particularly useful in determining site formation processes at Advent City (Kruse, 2016b) and distinguishing former human activities with potential environmental consequences (Kruse, 2016c). This aided the positioning of the excavation trenches and vegetation plots.

Interdisciplinary fieldwork

After an inspection of Advent City in 2014, Kruse designed a project suited to a small window of opportunity for research under Arctic constraints. Our team comprised four archaeologists and three botanists, one replacing another after a week on site. The work should have taken place between 5 and 16 August 2016, but two polar bears ended it on 12 August. On 16 August, we briefly returned to backfill the excavation trenches, collect the environmental samples and break camp.

Visual and topographic survey

A visual survey determined the character and extent of the site. We chose natural site boundaries: the shore, meltwater streams on both sides and the steep slope up the hill, where the former mine entrance marked the highest point at approx. 110 m above sea level. Beyond these boundaries, we searched a buffer zone for unknown archaeological features, but we recorded none. We confirmed the stable (7b), the piggery (7c) and one of the workers' barracks (5c) to be likely features holding historical environmental information. The stable and the piggery were each associated with grassy mounds preliminarily interpreted as dung heaps. Near the barrack, a number of wooden boxes were thought to be the remains of outhouses; they proved to be domestic ash dumps.

We carried out a topographic survey using a differential Global Positioning System (dGPS). The traverses lay parallel to the natural contours at a spacing of roughly 1 m. This spacing was adjusted to localised irregularities. Readings were recorded continuously

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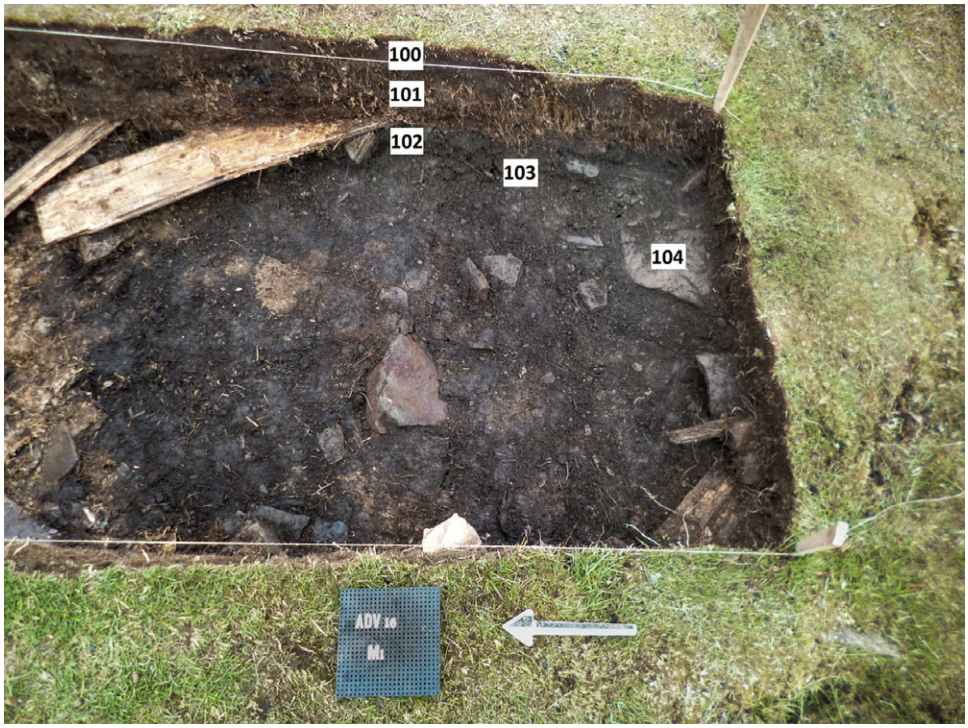

Fig. 4. Photograph of trench M1 in the stable midden, fully excavated, showing the five contexts: 100 – topsoil, 101 – anthropogenic deposit comprising horse dung, 102 – anthropogenic construction layer, 103 – buried topsoil, and104 – natural soil. Photo: F. Kruse, 2016.

roughly every 0.5 m. This number was increased to take sudden elevation changes into account, for example, the eroding coastline. In addition to the topography, we recorded archaeological details that were overlooked in previous surveys.

Archaeological excavation

The details of the excavation have been published elsewhere (Svalbard Science Forum, n.d.; van Bodegom & de Jong, 2017). The stable mound, the piggery mound and one domestic ash dump were partially excavated according to current standards (Chartered Institute for Archaeologists, n.d.; MOLA, 1994).

The largest diameter of the stable mound was about 3 m. Excavation trench M1 (Fig. 4) was 1.9 m long and 1.02 m wide with an irregular depth. Towards the centre of the mound, impenetrable permafrost was encountered at 0.4 m bgl before natural soil could be reached. Towards its edge, the deposits simply tapered out. We recorded five contexts: topsoil; an anthropogenic dung-rich layer, which included the majority of finds; an anthropogenic layer with timber cut-offs and nails; buried topsoil; and natural soil. The finds were hand-picked, and palynological samples and bulk samples were taken.

The largest diameter of the piggery mound was about 2.5 m. Trench M2 was a triangular sector measuring 2.28 m x 2.38 m x 3.15 m. The final depth was again irregular due to the tapering out from the centre towards the edge. The excavation was terminated at 0.4 m bgl in natural soil. The five contexts were similar to M1: topsoil; an anthropogenic layer characterised by animal bones capping an organic-rich amorphous substrate, which contained most of the finds; a layer with timber cut-offs and nails; buried topsoil; and natural soil. The artefacts and ecofacts were hand-picked, and palynological samples and bulk samples were taken.

The dimension of trench Z1 was determined by the wooden box. The final measurements of 0.7 m x 0.7 m x 0.4 m constituted 50% of the feature. The deposit was characterised by ash and charcoal and included artefacts and ecofacts that had partially been burnt. The finds were hand-picked, and a 20-l bulk sample was taken. The crate showed signs of smouldering. It was not sampled or lifted.

Generally, the stratigraphy of the investigated features was simple with anthropogenic deposits directly on top of the former tundra. We decided to treat the dumps as one depositional event.

Vegetation mapping

The investigation of the vegetation comprised eleven vegetation plots (Fig. 5) Nine of these were positioned within the likely sphere of influence of Advent City near or on anthropogenic features. These included the stable mound (plots R1, R2 and R11), the miners' footpath up to the mine (R3 and R4), the cart track (R5, R6 and R7) and an unexcavated domestic ash dump (R8). Outside the settlement, we selected two reference sites. Plot R9 was positioned on a damp slope. Plot R10 targeted a slope below a landslide.

The vegetation plots were laid out to encompass a homogenous stand representative of the vegetation of the selected site. Plots of 1 m x 1 m are adequate for sampling the local tundra vegetation. Due to terrain conditions, however, our plots varied between 1 and 3 m in length and between 0.5 and 1.5 m in width. The minimum plot area was 1 m^2 and the largest 3 m^2. For each plot, all vascular plants, bryophytes, macrolichens and macroscopic *Nostoc* colonies were recorded. The total vegetation cover as well as the cover of each plant group were estimated as a percentage of plot size. For each species, the cover abundance was recorded using Braun-Blanquet's (1964) five-point cover scale. The plot locations were surveyed by dGPS, and photos were taken of each to show the context and capture its overall vegetation cover.

Vascular plants were identified in the field. Of each vascular plant species, a single specimen was collected as voucher material

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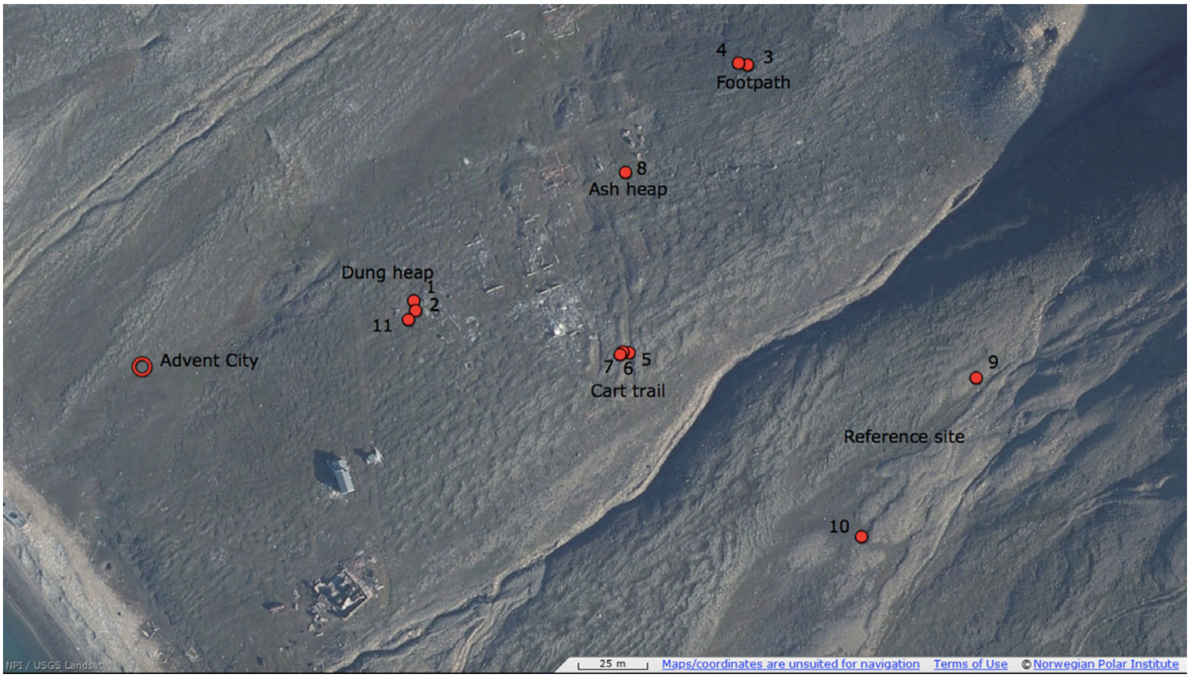

Fig. 5. Location map of vegetation plots R1–R11 on an aerial photograph of Advent City. In addition to the modern hut and the remains of the former buildings, the winding cart track is clearly visible. The fell field is subject to ongoing slope processes, in particular solifluction and meltwater flooding. Map: Norwegian Polar Institute & G. Nobles.

and dried in a flower press for later verification. In total, 28 collections of vascular plants were made. Bryophyte and lichen species were provisionally given a field name. From each plot, reference material of all bryophyte and lichen species, and *Nostoc* colonies, was sampled for later microscopical identification. The material was put into paper packets and subsequently air-dried, with open packets, in the tent for several days. In total, 107 collections of bryophytes, lichens and *Nostoc* colonies were made; a few collections blew away in heavy winds while drying in the tent and two of them were lost.

Laboratory analyses

Conservation and material studies

The conservation and documentation of the artefacts were done at the Laboratory of Conservation and Material Studies at GIA (Groningen Institute of Archaeology). We carried out a portable X-ray fluorescence (XRF) scan on the seams of the tin can fragments. Solder may contain lead. Since lead poisoning may have played a role in the demise of past Arctic expeditions (e.g. Battersby, 2008; Broadbent & Olofsson, 2002; Kjær, Aasebø, & Hultgreen, 2010), we tested the seams to investigate the health implications for Advent City. After analysis, all artefacts were returned to the Svalbard Museum.

Archaeozoology

Most animal bones collected from the three trenches were hand-picked. A few were retrieved from the bulk samples. The total faunal assemblage comprised 4,850 specimens (ca. 34.5 kg). All specimens were initially sorted to taxonomic class level (Mammalia, Aves and Pisces) and preliminarily quantified (estimates) at GIA. Within the constraints of the project, 2,544 specimens (ca. 22.0 kg) underwent further archaeozoological analysis (ESM: Table S1).

The mammalian remains were identified to the lowest taxonomic level using a reference collection and several standard works (Hillson, 1992; Nickel, Schummer, & Seiferle, 2004; Pales & Lambert, 1971; Reitz & Wing, 2008; Schmid, 1972; Zeder & Lapham, 2010). Where possible, taxon, skeletal element, portion, body side, fusion data, general age and sex were documented as well as pathologies, post-mortem modifications and weight. NISP (Number of Identified Specimens (NISP) and weight of identified Specimens (WIS) were recorded according to Lyman (2008) and Reitz and Wing (2008). Fitting or articulating parts of the same bone or animal were counted as one specimen. Minimum number of individuals (MNI) was estimated by considering the symmetrical properties (left/right sides) of animals (White, 1953). For Svalbard reindeer, it was possible to establish the age at death of several individuals, using the fusion stages for Cervidae (Reitz & Wing, 2008) and tooth wear patterns (van den Berg, 2018). With the exception of eight bones removed for stable isotope analysis, the faunal assemblage was transferred to the Svalbard Museum.

The preliminary quantification of the faunal assemblage from Advent City resulted in 335 bird bones. Due to limited loan and work time, their full analysis was not part of the research goals. Küchelmann examined 231 bird bones (ca. 86.1 g) from trenches M1 and Z1, however, during the selection process for isotope analysis. Two-hundred and twenty-one specimens could be identified to a taxonomic level of subfamily or lower. Similarly, Küchelmann checked 85 fish bones from trench M1 for the suitability of their isotopic signatures.

Archaeobotany

Hand-picked plant remains as well as macrobotanical and palynological samples were processed and identified at GIA. Approximately 3 l of the bulk samples from trenches M1 and M2 and 10 l of the ash deposit in Z1 were wet-sieved using mesh sizes ranging from 2 mm to 0.5 mm. Macro-remains were picked out of the residue and identified to the lowest possible taxonomic level.

Vegetation identification

The specimens collected from Advent City were identified at Naturalis Biodoversity Center in Leiden. Representative identified specimens are preserved in the herbarium of Naturalis (L).

The vascular plants were identified using Alsos, Arnesen, and Elven (1998) and Rønning (1996). Since the fieldwork took place after the flowering season, the identification of plants belonging to the genera *Draba* and *Saxifraga* was particularly difficult. Studying these plants in the laboratory solved most identification problems. The nomenclature of vascular plants follows Elven, Murray, Razzhivin, and Yurtsev (2018).

Bryophytes and lichens were identified using a stereomicroscope and a light microscope. For the bryophytes, the following floras were used: Damsholt (2002), Hallingbäck *et al.* (2006, 2008), Hedenäs and Hallingbäck (2014), Long (1985), Lönnell, Hallingbäck, and Hedenäs (2015), Patton (1999), and Smith (2004). The nomenclature of the bryophytes follows Damsholt (2002), Hallingbäck *et al.* (2006, 2008), and Hedenäs and Hallingbäck (2014). The lichen collections were identified using Oset (2014), Osyczka (2006), and Øvstedal, Tønsberg and Elvebakk (2009). Morphological identification of Arctic bryophytes and lichens is a labour-intensive and time-consuming process (own experiences; Hesse, Jalink, Stech, & Kruijer, 2012; Lewis *et al.* 2017) and not always possible.

Stable isotope analysis

Stable isotope analyses were carried out on a diverse range of animal and plant remains at the Centre for Isotope Research (CIO). Supplementing this paper, the aim was to reconstruct the ecological niche of various species present at the time of the mining operations, specifically at the time when the stables and the piggery were in use (1906–1908) and to produce an estimate of the contemporaneous marine reservoir offset. After pre-treatment, a sample of charred seeds from the ash dump failed to yield enough material for radiocarbon dating, but all other samples performed well. Both stable isotope data ($\delta^{13}C$ and $\delta^{15}N$) and radiocarbon (^{14}C) dates were obtained.

Results

Historical sources and visual survey

The outcome of the desk study is summarised in two reports (Kruse, 2016b, c; Svalbard Science Forum, n.d.) that form the basis of this section. We subsequently checked selected historical details against our observations during the site walkover.

One drawback of the photo regression exercise was that the mostly undated pictures were taken at different stages of construction or after structures were taken into use. Hence, we cannot offer a strict chronology; we merely pinpoint the first appearance of a feature in the sources. The walkover revealed the present-day situation at Advent City after abandonment, salvaging and demolition (Fig. 3). There are no upstanding historical buildings now, only a modern cabin and its shed. To enhance readability, we adopt the tripartite structure (coal mining, settlement construction and provisioning, and waste management) otherwise reserved for the Discussion.

Coal mining

In summer 1901, seven men investigated a coal seam and staked out a claim, thereby bringing industrial activities to this location. The first structure was a shed for tools and explosives, which only appears in a photo of 1907 (to prove our point about chronology). We surveyed its likely remains: a small, partly sunken log cabin at the shore that showed signs of charring. Explosives were probably used extensively, not just inside the mine, but also at the surface in order to penetrate the permafrost. Groundworks and landscape modification therefore initiated human-induced environmental impact, which we keep in mind during the following account.

A skipper and his crew of five assisted an expedition of 15 men in summer 1903. The opening of the mine continued, and the men constructed a smithy next to it and a simple ropeway down to the shore. The collapsed shell of the smithy remained, but there was no clear evidence of the early transport system. These activities required extensive levelling of the natural slope at pithead as well as stockpiling the coal near the shore. Stockpiling constituted dumping any amount of coal on the tundra vegetation. The men also collected sand and gravel on the beach as building material.

Twenty-six men upgraded the ropeway to a double-acting one in summer 1904. The ropeway tower bases, each of four wooden posts, still attested to this structure. Levelling, stockpiling, and using natural building materials, where possible, presumably continued.

In 1905, English finance enabled a large expedition of 94 people, yet mining activities during the summer were underrepresented in the sources. Twenty-four men stayed in the newly named Advent City in winter 1905/6. Year-round mining in economic terms is equal to year-round environmental impact in ecological terms.

By summer 1906, the ropeway had been replaced with a double-acting tram, strenuously sinking numerous postholes. When the tram was later removed, the posts were not dug up but sawn off. Photos indicated a roof over the mine entrance, which has since gone, and a small pier at the shore. A search for the pier came up with a few circumstantial wooden posts. During winter 1906/7, 70 people stayed at Advent City. One construction focus was the large engine house (Fig. 3: feature 9) for the gas producer plant.

The engine house was the last major addition to the mining infrastructure. Photos of summer 1907, taken from the fjord, only revealed a small roof to the auxiliary adit, electricity poles leading up to the mine and a substantial spoil heap near the shore. The spoil heap, too, constituted dumping any amount of waste rock on the tundra vegetation. In a picture of summer 1908, we clearly see the coal stockpile. We confirmed all of these features during our site visit.

In addition to the historical sources, our walkover discerned the former miners' footpath up to the mine. It was probably created by many feet trampling the plants, compacting the soil and kicking the gravel around until the coarsest material ended up to the side. The footpath's present-day vegetation has a more yellowish tinge than the vegetation next to it. There were strands of steel cable, different mining tubs and the casing of an electrical coal cutter. The oldest artefact on site may well be a tub featured in a picture from 1903. The mine entrance and auxiliary adit had collapsed, and the mountain was settling above them, but only very locally. Rocks had fallen on the remnants of the smithy. Looking down along the line of the former tram, a black colouration suggested the dusting of the tundra with coal, but we did not examine this. Overall, Advent City definitely gave the impression a coal mine, but we noticed few mining-related surface finds. Salvaging appears to have been very thorough.

Settlement construction and provisioning

The miners required a settlement that could function independently when supply ships could not penetrate the sea ice. The expeditions of 1901, 1903 and 1904, however, took place in summer. The men stayed on board and only built a simple mess in 1903, which they replaced the following year. Their documented environmental impact consisted of shooting seals, using their oil for lighting the mine, and hunting reindeer. Exact numbers are not available.

English plans for Advent City saw the construction of seven buildings in summer 1905: five barracks (5a, b, c, e and f) that could house a total of 90 workers, the manager's house (6d), and a store and shop (6a). We could easily reconstruct the layout indicated in the photos *in situ*. Levelling the slope for the housing platforms removed all vegetation at the time, which had since grown back. A picture of four live pigs pointed to the import of livestock.

In summer 1906, a large tent of unknown function stood between the buildings 5c, 5e, 6a and 6c (Fig. 2). The office (6b) and the official house (6c) were under construction, which affected the vegetation. The livestock now comprised four horses, two pigs, four dogs and one goat. There are photos of all but the goat. A shortage of food preceded the delivery of abundant provisions. Salted reindeer meat and dried fish were mentioned, but it is unclear if these were sourced locally, imported or both. Reindeer were hunted with varying success. A diary refers to only one being killed. Twenty-four then needed to be procured from a neighbouring mine. Nonetheless, a total of 123 reindeer skins was later exported together with 15 fox skins. Seals were not listed separately, but there was a picture of a probable sealskin fastened to the store (6a). We could verify an image of a water pipe leading into the settlement from the north in the field. Ice had split much of the metal.

The club house (8b) and the stable (7b) appeared in winter 1906/7. Two hunting huts were put up further afield, one of which appears in a photo of 1913. They probably also acted as claim markers, so likely locations were the limits of the claim at the mouths of Adventdalen and De Geerdalen. Again, provisions ran low, at least for the workforce, and their meat allowance was reduced. The lack of food was one of the causes of a strike breaking out. This was supposedly aggravated by heavy drinking. We counted several glass bottles among the surface finds. Away from the conflict, a blurry picture of hay may be our only indication of imported animal feed. We tested this during the excavation of the dung heaps (this paper).

In summer 1907, the effects of the strike needed to be mitigated before settlement construction could continue. By now, the surface works showed signs of slowing. A sixth barrack (5d) was erected, and the tent disappeared; we do not know if this was related. A family barrack (7a) was put up, and a concrete foundation of unknown purpose (8a) remained unfinished. Electricity poles led from the engine house into the settlement. The incoming workforce was pacified with a delivery of fresh beef. We investigate the question of whether this included live cattle or meat cuts only in this paper. The idea of netting beluga was seemingly not put into practice.

A last but important addition was the piggery (7c) shown in a photo of summer 1908. The dung seemed to be pushed out of a hatch in the wall, and we easily identified the resultant dung heap. The reported delivery of anthracite (high-quality coal) and carbide (for the miners' lamps) implies the import of other, potentially hazardous substances. Not distinguishing between local coal and anthracite, we noticed that the barracks had small supplies of coal. In one of the crates, we found worked fragments of bone, leather and metal, hinting at the workers' pastimes. Barrels of a white, solidified substance, presumably carbide, had been stored under the official building (6c), with the benign effect of occasionally sheltering rock ptarmigan.

After mine closure, the official building (6c) acquired the term "fangsthytta," probably because the winter watchmen of 1908/9 and 1909/10 used it as their trapping station. During our site visit, we found a number of unused fox traps here. We also recorded 11 fox traps *in situ*, but it was not possible to date these in order to establish any connection with Advent City. By 1917, all houses had been removed.

Our walkover provided extra information about the limited use of the local sandstone as building material. Crushed rock and beach gravel were mixed with imported cement, and unused barrels of cement now sheltered some plants from the wind. We recognised a track that led from the shore into the settlement. This had clearly been dug out in the past, and the vegetation on the track had recovered differently to that on the adjacent slope and the embankment of spoil (this paper).

Personal hygiene and waste management

Personal hygiene and in particular waste management have not attracted much attention from Svalbard mining historians or industrial archaeologists. It was, in fact, difficult to identify diagnostic features at Advent City. The workforce had access to freestanding outhouses. There was one to the east of the barracks and one to the west. The club house, too, had a freestanding privy. The manager's house, the office and the family barrack had toilets attached to their west walls that could be entered from within. The arrangements of the store and the official building had not been recorded. We intended to take environmental samples from the outhouses. However, each outhouse, a pair of cubicles, made use of metal buckets that were emptied elsewhere. As many as 11 discarded slop pails made them one of the most frequent finds classes, probably because no one wanted to recycle them.

We treat the former coal stockpile and spoil heap as sites of dumping and disposal with environmental consequences. The dung heaps of the stable and the piggery, and the domestic ash dumps of the workers' barracks constituted additional point sources of historical environmental information (this paper). Despite discarded timber and packaging throughout the settlement, surface finds were rare (e.g. broken glass, broken crock ware). Fewer still confirmed the former function of a building (e.g. cracked cooking pots, fragments of stoves and a feeding trough). There was no evidence for a general waste disposal site.

Archaeological excavation

The examination of the stable mound exposed two different anthropogenic deposits dumped directly onto the original ground surface (Fig. 4). The older deposit comprised dark soil, timber cutoffs and iron nails. We interpreted it as the construction layer of the stable (7b) dating to winter 1906/7. On top was a layer of dung and the majority of finds. The dung confirmed the former function as a horse stable. It fell out of use with the mine closure at the end of summer 1908.

Of the two anthropogenic deposits encountered in the piggery mound, the lower one was a construction layer. We dated the

Fig. 6. Photograph of the range of materials excavated from trench Z1, after conservation. They include cork, probable pumice, leather, window glass, wood, metal wire, tin cans and slag. Iron nails pertaining to the same assemblage are not depicted. Photo: G. van Oortmerssen, 2016.

construction to winter 1907/8 because the completed building (7c) first appears in a photo of summer 1908. Overlying this was a dark, organic-rich, amorphous to fibrous deposit. After visual and olfactory inspection, we could neither prove nor disprove the presence of pigs or other animals. This layer contained most of the finds, and it was capped by a layer dominated by mammal bones.

The domestic ash dump comprised a single deposit, the vegetated top of which was in the process of turning into topsoil. It contained mainly ash and charcoal and included partly burnt artefacts and ecofacts. This ash dump was closely associated with workers' barrack 5c. We therefore assigned it to the workers and assumed that it was in use during the barrack's lifetime from summer 1905 until autumn 1908.

Conservation and material studies

A bluish mineral encrusted some of the nails. This was probably vivianite, $Fe_3(PO_4)_2$ $8(H_2O)$, which has a notable tendency to change colour from white or greyish to blue on exposure to air (McGowan & Prangnell, 2006). The specific conditions for its formation appeared to exist in the Advent City dung heaps: sources of iron, phosphate and water, as well as low levels of oxygen and sulphide. The phosphate usually derives from degraded bone material. Microbial activity may play a part. Since vivianite usually indicates a very good level of conservation, we are confident that we had excellent and practically full recovery in trenches M1 and M2. This was supported by the recovery of several crumpled fragments of newspaper, which only required drying and mechanical cleaning with a soft brush. The destruction by fire before deposition, however, led to poor, impartial recovery in trench Z1.

In trench M1, probable horsehair confirmed the presence of horses, while some light-coloured bristles may have originated from either live pigs or a paintbrush. The recovered artefacts included fragments of leather, cloth, waxed textile and rope, but these could not be linked to any particular source or stable-related function. Some artefacts attested to the regular presence of at least one person. Fragments of an enamelled beaker, a glass bottle, tin cans of various sizes (one with a triangular hole in the top to drain fluids) and a probable tin can label represented eating and drinking at the stable, at least on a small scale. We recovered several pieces of a graduated cylinder that may have served a medical or veterinary purpose. Coal, ash and slag indicated that the stable was heated, while unburnt fragments of Norwegian newspapers suggested that a fire was not always on. The remainder of the finds (e.g. various nails and spikes, the handle of a paint can, fragments of window glass, short lengths of cable, metal strap and wire) belonged to a class suggesting construction and maintenance work. In general, the fragments were small and nondescript.

Artefacts were rare in trench M2 and did not specify a piggery or any other purpose. Most artefacts belonged to the class of construction and maintenance work; iron nails, a large iron nut, a small iron plate, short lengths of cable and wire, and some broken window glass. A well-preserved broom was used for cleaning. A short leather strap could have belonged to an item of animal harness or clothing. Besides some tin can fragments and a tiny piece of ceramic bowl or plate, evidence for people and their actions was scarce. Following the XRF scan on several tin can fragments from M1 and M2, the obtained values of lead showed no indication to assume any health implications. However, we do not know to what level the measured tin cans can be considered representative.

Fire affected many but not all of the artefacts from the domestic ash dump, so the stove was occasionally used for waste disposal. Either it was not always lit or it was sometimes easier to discard items directly out of the barrack and into the crate. The range of materials and objects included iron nails, fragments of coal and slag, likely pumice, broken window glass, some wire and some unburnt wood (Fig. 6). The inhabitants of barrack 5c, their needs and their actions were represented by a leather strap with button

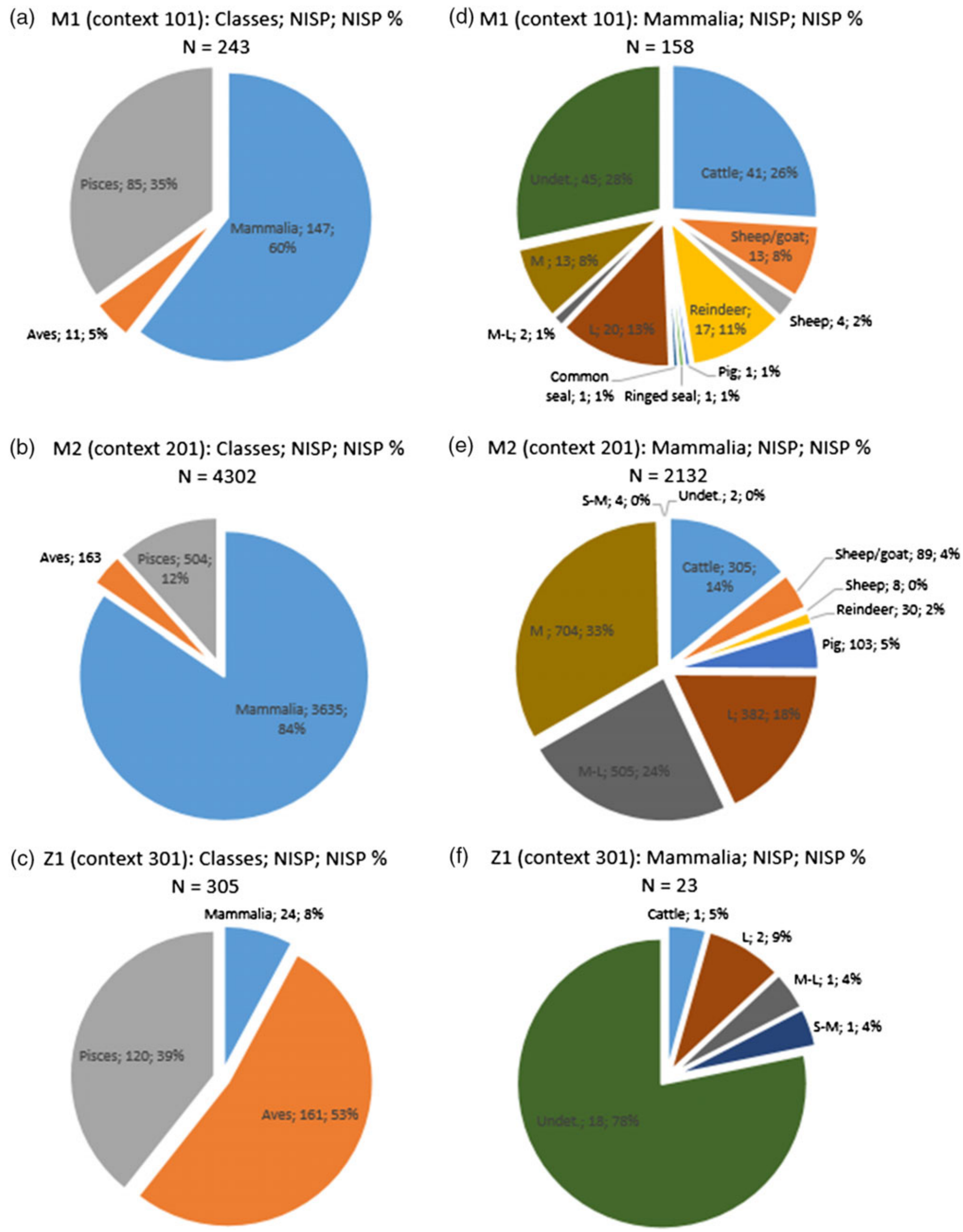

Fig. 7. Pie charts of the preliminary quantification of the faunal assemblage (a–c) and the taxonomic abundance per mammalian species (d–f) per trench. L – undetermined large mammal (e.g. the size of cattle, horse and red deer), M–L – undet. medium to large mammal (e.g. wild pig to donkey and reindeer), M – undet. medium mammal (e.g. sheep to pig), S–M – undet. small to medium mammal (e.g. hare to dog), undet. – undetermined size category.

holes (clothing), some fragmentary tin cans (eating), the fire (heating, maybe cooking), a wrought iron lamp holder (lighting) and unburnt pieces of Scandinavian newspapers (pastime). Of particular interest was a piece of wire that had been twisted around the leg bone of a ptarmigan (local game and hunting).

Archaeozoology

The state of preservation of the animal bones from the middens was exceptionally good. Rib cartilage and small, delicate fish bones, for instance, suggested that abiotic taphonomic processes did not cause much destruction on site. The preliminary quantification of the total faunal assemblage ($n = 4{,}850$) is shown in Fig. 7a–c.

Mammal remains

Mammal bones dominated the trenches M1 and M2 but played a minor role in trench Z1. A selection ($n = 2{,}313$) underwent further analysis (ESM: Table S2). Fig. 7d–f expresses the taxonomic abundance per mammalian species per trench. In each dung heap, we identified four domestic species. Although the cattle bones were the most abundant of the identified remains, we could only establish a combined minimum number of three individuals. The MNI for sheep/goat and pig were six and five, respectively. Wild reindeer, a terrestrial species, was common to both middens. Although the MNI of reindeer was also only three, we nevertheless noted three different age classes: one juvenile, one sub-adult and one adult. The two seal species from M1 added a marine aspect to that deposit. The specimens belonged to at least one common

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seal and at least one ringed seal. With the exception of a single cattle bone, the mammal specimens from trench Z1 were too fragmentary to be diagnostic.

We observed pathologies on only two bones, and post-mortem modifications were rare (ESM: Table S3). Only 13 specimens had actually had contact with fire, 7 of which from Z1. Three specimens from M1 had been slightly gnawed by rodents, while carnivores, more likely dogs than Arctic foxes or polar bears, had chewed on a total of 20 from M1 and M2.

Butchering marks, on the other hand, were common and confirmed the anthropogenic utilisation of these animals in all cases but one: there were no cuts on the flipper of the ringed seal. We recorded a variable butchery pattern. Carcasses had been split through the *Processus transversi* of the vertebrae as well as through their central body.

Following archaeozoological analysis of the mammal bones, we selected one pig bone, two reindeer bones, and one seal bone for isotopic analysis.

Bird remains

The analysed sample ($n = 231$) contained birds from the families Alcidae (auks), Anatidae (ducks and geese) and Phasianidae (chickens, pheasants, turkeys, grouse, etc.) According to the focus on finding ptarmigan and guillemot bones for isotopic analysis, specimens belonging to Anatidae were not identified further than subfamily or genus level.

All Phasianidae bones from Advent City ($n = 205$) were morphologically consistent with rock ptarmigan (*Lagopus muta*). This identification was substantiated by the zoogeographical detail that the Svalbard rock ptarmigan (*Lagopus muta hyperborea*) is a Phasianidae species endemic to Svalbard. Finding remains of any other wild Phasianidae species at Advent City is highly unlikely. All ptarmigan bones were found in trench Z1. They were from a minimum of 10 adult birds. The Svalbard rock ptarmigan is exclusively terrestrial and should therefore be a good candidate for a local terrestrial signal. Two right ulnae were selected to avoid the theoretical possibility of taking two bones from the same individual.

The second family under investigation were the Alcidae. Ten auk bones from trench M1 were analysed, substantiating its marine character. They belonged to adult birds and to at least two individuals. Four specimens were assigned to Brünnich's guillemot (*Uria lomvia*) with certainty. The others could not be morphologically distinguished and could stem from either Brünnich's or common guillemot. Both species are presently breeding birds in Svalbard from May to July, but common guillemot are much less common and restricted to the southern part of the islands, not reaching as far north as Adventfjorden. Brünnich's guillemot are more widely distributed, particularly along the west coast of Spitsbergen (Birdlife International, 2019; Prummel, 1998). Both guillemot species are suitable for a Svalbard marine signal, being restricted to Northern Europe with a foraging range of 7 to 100 km around their breeding colonies. They feed almost exclusively on small fish (Birdlife International, 2019). Hence, two guillemot bones from Advent City were selected.

Six bones belonged to the family Anatidae and could be separated by size into the subfamilies Anatinae (ducks, $n = 4$) and Anserinae (geese, $n = 2$). There are only three species of duck and three species of goose that migrate to Svalbard to breed there (Cramp and Perrins, 1996). Breeding mostly takes place in June, with only two species beginning in late May or extending into early July.

Fish remains

None of the fish remains from trench M1 ($n = 85$) showed the salmoniform pattern of Arctic char (*Salvelinus alpinus*), which was initially considered for an additional marine signal. Instead, several bones pointed to the Gadiforms that inhabit the sea around Svalbard (Froese & Pauly, 2019; Muus & Nielsen, 1999). The Gadiform pattern best fitted that of European hake (*Merluccius merluccius*), but blue ling (*Molva dypterigia*), tusk (*Brosme brosme*), polar cod (*Boreogadus saida*) and Arctic cod (*Arctogadus glacialis*) could not be excluded.

Candidates for a Svalbard marine signal were in any case difficult to pick from among the fish remains. Parts of the population of Arctic char, like many other Salmonidae, have an anadromous life cycle: they spend the initial stage in freshwater, continue in seawater and return to freshwater for spawning. Other individuals live their whole lives in freshwater (Froese & Pauly, 2019). Salmonidae are, therefore, unsuitable for a clean signal. Most Gadiformes are economically important. They have been traded dried in huge amounts, and it cannot be discounted that the excavated bones were entirely imported or mixed with those from local catches. Thus, there was too much uncertainty connected to the fish remains, and we made no selection for stable isotope analysis.

Archaeobotany

The results of the archaeobotanical analysis have been included in ESM: Table S4. In this section, we focus on relevant diagnostic findings.

The stable mound

The exceptionally well-preserved samples from trench M1 can doubtlessly be described as dung resulting from hay that must have been imported to Advent City. Most remarkable were the well-represented seeds of rattle (*Rhinanthus angustifolius/minor*). Rattle exists as a half-parasite on grasses, extracting nutrients from the hosts' roots. It does not occur in Svalbard (Alsos, Arnesen, & Elven, 1998). Combined with clover (*Trifolium* sp.) and other grass species, it pointed to moderately nitrogen-rich grassland (hayland) in a temperate climate. No edible plants were identified in the bulk samples.

Two palynological subsamples from the same context showed high percentages of grasses (*Poaceae*) and confirmed the major hay component. Traces of edible plants, namely cereals (*Cerealia*), were more prominent on one than on the other pollen slide. While hay fields do not usually contain trees, an abundance of trees in the vicinity may cause pollen rain. The absence of tree pollen in the samples, therefore, pointed to hayland in a practically treeless environment.

The pollen samples from the present and buried topsoils contained little distinguishable pollen. A few grasses were identified to family level (*Poaceae*) only.

The piggery mound

Dung was not explicitly recognised during the excavation of trench M2. Yet, the analysis of the amorphous bulk samples clearly indicated that dung resulting from hay made up much of the anthropogenic deposit, sharing many species with the samples from M1. A remarkable difference was the absence of rattle (*Rhinanthus angustifolius/minor*). The presence of several ruderal species, that is, species that first recolonise disturbed land, including henbane (*Chenopodium album*), spurge (*Spergula arvensis*) and bindweed (*Convolvulus arvensis*), which do not occur in Svalbard (Alsos,

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Arnesen, & Elven, 1998), pointed to an origin in a temperate climate with arable fields and/or a settlement nearby. The larger numbers of buttercups (*Ranunculus* sp.) suggest more nitrogen-rich grassland. A single fragment of heather (*Calluna vulgaris*) tentatively suggests the occurrence of heather near this grassland.

A pollen subsample only contained high percentages of grasses and cereal pollen. It did not contain heather or tree pollen. This again confirms that the hay was imported from a very open landscape.

The pollen samples from the present and buried topsoil were as non-diagnostic as those from related contexts in M1.

A large number of plum stones ($n = 161$) were already correctly identified in the field. There was no connection between the animal feed and the edible plums other than that the remnants of both had been discarded on the same midden. Plums are a terrestrial end-member, so stones were selected for isotopic analysis.

The domestic ash dump

As was to be expected, both the density and the preservation of plant remains from the ash deposit differed substantially from the dung-rich middens. More edible species were encountered, however, suggesting that food waste must have been deposited here as well. These species included blackberries (*Rubus fruticosus*), hazelnuts (*Corylus avellana*) and a non-identifiable charred cereal grain.

The cereal grain and some sedge seeds (*Carex* sp.) were collected for isotopic analysis for an additional terrestrial signal, but the charred material did not perform well.

Vegetation mapping

Advent City is situated on a fell field with a High Arctic tundra vegetation dominated by mountain avens (*Dryas octopetala*) and polar willow (*Salix polaris*). The fell field vegetation was grazed by Svalbard reindeer and, less frequently, by geese. Arctic bell heather (*Cassiope tetragona*) was more abundant and grew in larger patches in the area surrounding Advent City than in the former settlement itself. In the settlement, the species occurred only in small patches in-between the former buildings and seemed to be absent from the levelled building platforms themselves.

Based on the desk study and the walkover, we targeted localities with distinct human interference in the past to position the vegetation plots. Originally, the dung heap of the stable (plots R1 and R2) will not have been vegetated, while the area immediately below it (R11) may have been affected by its runoff. The plants on the footpath (R3) were trampled or worse as opposed to the presumably untouched vegetation beside the path (R4). The cart track (R5, Fig. 8) was dug out, removing all vegetation. The spoil was dumped alongside it, creating an initially barren embankment with a sloping flank (R6) and a flat top (R7). The domestic ash dump (R8) had initially no vegetation. Reference sites were difficult to select because of ongoing slope processes. R9 was placed on a moist slope, while R10 on a slope below a landslip of unknown age. Due to the evacuation, the vegetation survey could not be completed.

The results of the vegetation survey are presented in Table S5 (ESM). The 11 vegetation plots comprised a total of 121 plant species. With 50 species, the mosses show the highest species diversity, followed by the lichens (29 species) and the vascular plants (27 species); the liverworts were least speciose (14 species). The *Nostoc* colonies were small and did not exceed 3 mm in diameter. They counted as belonging to a single species, although they may belong to two.

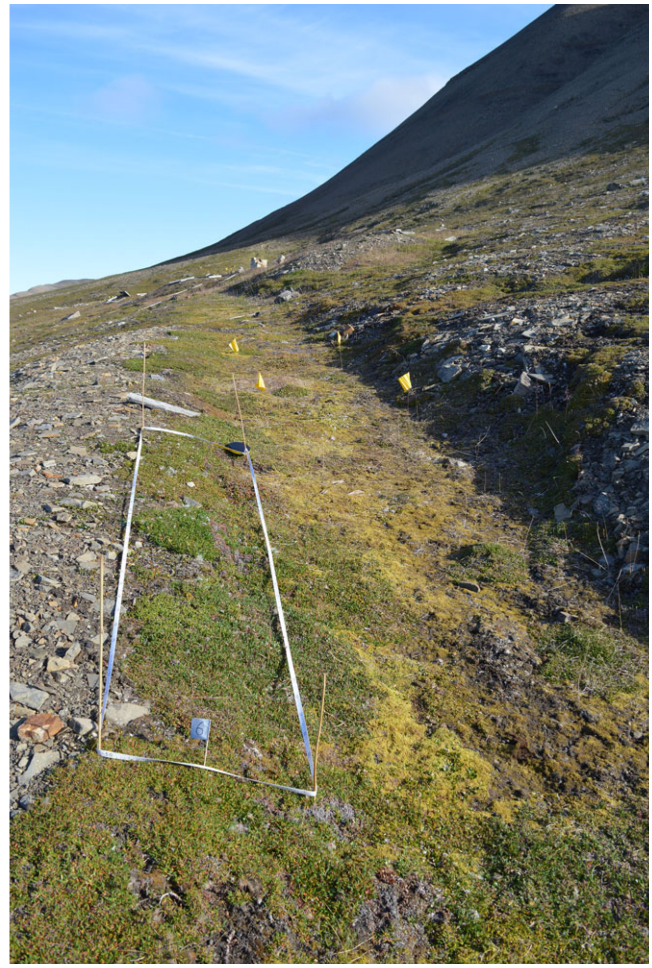

Fig. 8. Photograph of the former cart track that was once dug out, removing the original vegetation. Plot R6 was positioned on the flank of the embankment of spoil, which had been recolonised by plants including Dryas octopetala, Salix polaris and various bryophyte species. The yellow flags in the background mark plot R5 on the track itself. The yellow-green moss growing on the track is Sanionia uncinata. Photo: L. Messingfeld, 2016.

All vascular and non-vascular plant species found in the survey are native to Svalbard and none of them are threatened.

Present state of individual plots

We selected each vegetation plot with its archaeological formation process in mind. Because of the unfinished survey and an insufficient number of plots, in particular control plots, our data could not be used for statistical analysis. Refraining from detailed description, we therefore emphasise significant features in order to be able to compare and contrast the vegetation and the species composition in the studied localities. We give a few general remarks about the vegetation and the species diversity below.

In plots R1 and R2 on the stable midden, the total cover abundances were high (98% each). The cover abundances of the vascular plants were even the highest among the plots (R1: 90%; R2: 95%), while the total number of species was the lowest (R1: 16; R2: 12). The vegetation mainly consisted of a dense turf formed by the erect-growing grass *Poa arctica* ssp. *arctica* (Arctic bluegrass), which almost certainly benefitted from the eutrophic conditions at this locality. Notably, *D. octopetala* was absent from both plots, and R2 was the only locality on site from which *S. polaris* was

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missing. Two moss species had a remarkably high cover abundance, namely *Plagiomnium curvatulum* in R1 (35%) and *Bryum* sp. in R2 (30%). We found no liverworts and lichens.

The total cover abundances of the associated plot R11 (99%) matched those of the previous plots, but its vegetation was dominated by bryophytes instead. In fact, it had the highest bryophyte cover abundance among all plots (97%). The dominant species was the moss *Sanionia uncinata*, which formed a dense carpet, in density resembling the turfs of *P. arctica* ssp. *arctica* in R1 and R2. *S. uncinata* probably benefitted from the influx of nutrients from the dung heap (based on own observations in Ny-Ålesund, Svalbard). The cover abundance of the vascular plants was only 10%, which was mainly due to *S. polaris*; neither *P. arctica* ssp. *arctica* nor *D. octopetala* occurred in R11. *Peltigera refenscens* was the only lichen species in R11. With its foliose thalli growing among the shoots of *S. uncinata*, it reached a substantial cover abundance of 2%. Liverworts were not found. R11's total number of 20 species was higher than the numbers of R1 and R2, but lower than those of the other plots.

Plots R3 and R4 on and next to the former footpath, respectively, were neither markedly different from the reference sites nor from each other. Their total cover abundances were high (R3: 97%; R4: 98%). The cover abundances of vascular plants and bryophytes roughly matched and were between 40% and 50%. Lichens had a cover abundance of 25%. Despite the eye-catching presence of *S. uncinata* in R3, the dominant species were *D. octopetala* and the moss *Homalothecium lutescens*. In both plots, five liverworts species were found, the highest number of all plots. R3 is the only plot in which *Nostoc* colonies contributed significantly to the total cover abundance. The colonies grew mainly intermingled with the lichens *Polychidium muscicola* and *Leptogium gelatinosum*, forming a black crust with a cover abundance of 19%. The total number of species was intermediate (R4: 27) or high (R3: 31).

Plot R5 on the cart track (Fig. 8) shared the highest total cover abundance of 99% with R11. The bryophyte cover abundance was 90%, the second highest after R11. In both plots, *S. uncinata* was the dominant species and formed a dense carpet. The cover abundance of the vascular plant species was rather low (25%), with *D. octopetala* and *S. polaris* being most abundant. R5's total of 11 vascular species was markedly higher than that of the references sites, suggesting that the vascular plants may have benefitted from the former ground clearance. Similarly to R11, *P. rufescens* accounted almost solely for a lichen cover abundance (10%). Liverworts were not found. The total number of species (25) was intermediate.

After the plots on the stable midden (R1 and R2), plot R6 on the embankment flank (Fig. 8) had the highest cover abundance of vascular plants (80%), mainly accounted for by *D. octopetala.* The tiny liverwort *Cephaloziella* sp. reached a noteworthy cover abundance of 7%. R6 had the highest total number of species of all plots (37 species).

Plot R7 on the embankment top (Fig. 8) had a total cover abundance of only 7%, by far the lowest among the plots. The vascular plants dominated the open vegetation, with *D. octopetala* and *S. polaris* being co-dominant species. The total number of species (25) was intermediate, while the number of vascular plant species was 12, the highest among all plots. As suggested for R5 above, the vascular plants may have benefitted from the extreme soil displacement in the past. R7 is the only plot without *S. uncinata.*

Plot R8 on the unexcavated ash dump had a total cover abundance of 90%. The vascular plants, which may have been affected most by the remains of wood and coal fires, had a low cover abundance of 30%. The number of vascular plant species was five, together with reference site R10 the lowest number of the plots. In R8, the bryophytes and lichens had cover abundances of 40% and 25%, respectively. They also contributed significantly to the plot's total of 28 species.

The reference sites R9 and R10 had a total cover abundance of 98%, comparable with most of the impacted localities. The vegetation of both plots was quite different. In R9, the bryophytes had a cover abundance of 85%, with *Aulacomnium palustre* being the dominant species. However, the species was absent from R10. In R10, the bryophyte cover abundance was only 40%, with *S. uncinata* being the most abundant moss species. R10 was the only plot in which the lichens were dominant with a cover abundance of 50%, with an unidentified black crustose lichen being the dominant species. The vascular plants had a cover abundance of 25% in R9 and 40% in R10. The vascular plant cover was dominated by *D. octopetala, S. polaris*, and to a lesser degree *Equisetum scirpoides* (dwarf horsetail). Although the number of vascular plant species was low (R9: 6; R10: 5), the total species number was intermediate in R10 (27) and high in R9 (35). R9 had the highest number of moss species among all plots (22).

A remarkable difference between the reference sites (R9 and R10) and the impacted localities in Advent City (R3-7) was the structure of the bryophyte vegetation. In R9 and R10, the bryophyte species grew more often intermingled as well as tighter together than in the impacted localities.

General observations and holistic view

Against the background of past human disturbance and localised destruction of the vegetation at Advent City, the total cover abundances in the former settlement were generally very high (90 to 99%), except for the embankment top (R7). With the aforementioned exception of *C. tetragonia* and the dense turf of *P. arctica* ssp. *arctica* on the dung heap (R1 and R2), there were no general differences in vegetation composition and species richness in the former settlement and the reference sites on the fell field. However, we observed distinct differences between individual plots. Except for the dense vegetation on the dung heap and the sparse vegetation on top of the embankment, the vegetation structure was open and patchy in the former settlement as well as on the reference sites.

The vascular plants and mosses contributed most to the total cover abundances. Except for the *Nostoc* colonies on the footpath to the mine (R3) and the liverwort *Cephaloziella* sp. on the flank of the embankment (R6), liverworts and *Nostoc* colonies did not significantly contribute to the total cover abundances. The sites in Advent City, where human activities had displaced topsoil and rock fragments, that is, those at and next to the cart track (R5, R7), had the highest numbers of vascular plant species. Vascular plants may have benefitted from the creation of new, unoccupied habitat by the earthworks. However, a better availability of soil nutrients may have played a role as well, because the numbers of vascular plants species in one plot on the eutrophic dung heap (R1) and the plot downhill of the dung heap (R11) were also markedly higher than those at the reference sites (R9 and R10). The low species diversity of non-vascular plants on the dung heap was due to the dense turf of *P. arctica* ssp. *arctica.*

The three localities with the highest species diversity (R4, R6 and R9) have in common that they are sloping, albeit in different directions. This species richness could be coincidental, but it may also be based on shared abiotic factors, for example, drainage, snow cover and slope movement.

In seven plots in the study area (R3-7, R9, and R10), *D. octopetala* was the (co-)dominant species. In most plots (except R2), *S. polaris* occurred with significant cover abundance. The co-occurrence of these two species resembles the *D. octopetala–S. polaris* community described by Virtanen *et al.* (1997) from sites with low snow cover in winter at low to middle altitudes on a slope of Louisfjellet, not far from Advent City. However, in our study area, the mosses *Tomentypnum nitens*, *Aulacomnium turgidum*, and, in particular, *Hylocomium splendens* were either absent or less abundant than described for the *D. octopetala–S. polaris* community. While this community is generally indicative for little snow, the occurrence of patches of vegetation with *S. polaris* and *S. uncinata* in significant and roughly similar cover abundances, or even higher cover abundance for the latter, suggests a patchy accumulation of snow on the slope, for example, in shallow natural or anthropogenic depressions (e.g. on the cart track, R5).

Stable isotopes

The bones were generally well preserved and high in collagen (14-23%); moreover, the extracted protein was of excellent purity, as indicated by the closeness of the C:N results to the expected value of 3.2 (ESM, Table S6). The guillemot bones yielded slightly less collagen (5–8%), although this may simply have been a result of their permeability and fragility. All three plant specimens returned yields commensurate with samples of their size. Under the applied pre-treatment conditions, plants do not usually generate useful δ^{15}N results, as the extracted product (cellulose or reduced carbon) is essentially devoid of nitrogen.

Carbon and nitrogen stable isotope analysis

The stable isotopes (^{13}C and ^{15}N) become more enriched as the ecological niche occupied by each species becomes more marine. This is entirely expected, but there are other peculiarities in the stable isotope data that warrant closer examination. The δ^{15}N values for Svalbard reindeer are particularly low. While for other reindeer ecotypes, the low δ^{15}N values are attributed to the high proportion of lichen in their diet during winter (Bocherens *et al.*, 2005; Finstad & Kielland, 2011; Immel *et al.*, 2015), this seems not to be the case for Svalbard reindeer as the proportion of lichen in their diet ranges between an average of 0.2% and 2.4% from late summer to late winter (Bjørkvoll *et al.*, 2009). However, Svalbard reindeer forage on other low-nitrogen value plants year-round. Van der Wal *et al.* (2000) found that while forage availability is high during the 3-month growing season, Svalbard reindeer rather select for plant biomass than quality in terms of nitrogen content. During Svalbard's early and late winter, the plant nitrogen contents are considerably low as well (Bjørkvoll *et al.*, 2009), and thus there is a year-round intake of low-nitrogen forage, which can explain the particularly low δ^{15}N values of our samples.

The Svalbard rock ptarmigan, a terrestrial bird of the grouse subfamily, also returned depleted stable isotope values, which corroborate and bolster the sparse data available for this species. Both the reindeer and ptarmigan are slightly more depleted in δ^{13}C than the averaged data from terrestrial ruminants shown in Fig. 9, but such results have also been observed by other studies on these particular species (Immel *et al.,* 2015; Tarroux *et al.*, 2010).

The elevated δ^{15}N result obtained on the pig bone indicates an omnivorous diet, a result that matches the expectations that it would have been fed on a mixture of scraps. In fact, relative to the pure herbivores, the value of 9.3% implies there was a considerable amount of marine protein in its diet.

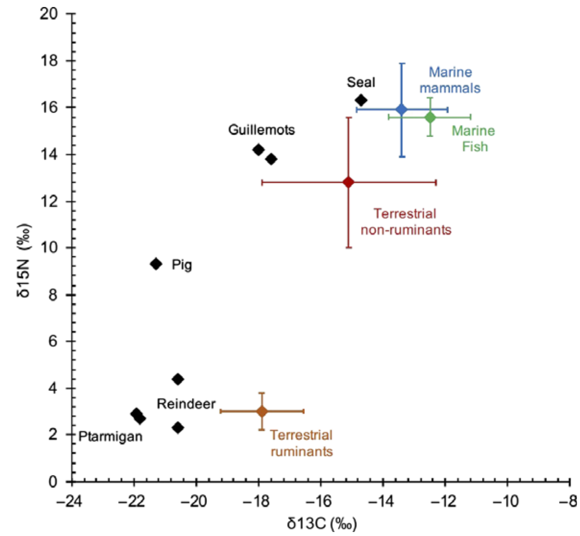

Fig. 9. Biplot of the isotopic results obtained on the Advent City samples compared to the average data of terrestrial ruminants and non-ruminants, marine fish and marine mammals.

The guillemots and seal bones exhibit considerably enriched carbon and nitrogen stable isotope values, in keeping with their wholly marine diet. The most parsimonious explanation of the 2% difference (in δ^{15}N) between the two is that guillemots consumed smaller fish (lower trophic level) than the seal.

Radiocarbon dating

Radiocarbon dates on marine organisms are usually offset from their terrestrial counterparts by about 405 yr BP (Reimer & Reimer, 2017). For this reason, marine samples must be calibrated against their own global reference curve (Marine13; Reimer *et al.*, 2013). The difference in ^{14}C values between the species with marine diets (guillemot and seal) and those with terrestrial diets is evident in our data set. Furthermore, a ΔR value for Adventfjorden, which represents the local ^{14}C offset from the global Marine13 reference, can also be estimated using our data. By comparing the Marine13 values for the expedition year (1907 ± 1 AD) with our results using the *^{14}C Chrono* applet (http://calib.org.deltar), a weighted average of 77 ± 36 (yr BP, 1 σ) was obtained. This value is close to the outputs of two previous studies in Svalbard (Mangerud & Gulliksen, 1975; Olsson, 1980). From the international database of marine reservoir offsets (http://calib.org/marine/), Olsson's (1980) value is given as 82 ± 70 (1 σ) for 1900 AD. However, only one measurement was obtained by this study, on a shell from Kapp Wijk, and the date of collection was not very precise (1900 ± 50 AD). Mangerud & Gulliksen (1975) made two measurements each for the years 1878 and 1925 AD. The weighted averages are given on the marine reservoir database as 145 ± 9 (yr BP, 1 σ) for 1878 and AD 77 ± 16 (yr BP, 1 σ) for 1925/26 AD.

More importantly, these three studies conducted in Svalbard indicate that the marine reservoir offset can be estimated at this crucial geographical position – the very northernmost extent of the so-called "Atlantic conveyor." If further samples become available from other precisely dated sites, preferably prior to the Industrial Age, a more extensive and diachronic analysis could be conducted on the anthropogenic impact on the North Atlantic ocean current (Ascough, Cook, & Dugmore, 2009; Paterne, Michel, & Héros, 2019).

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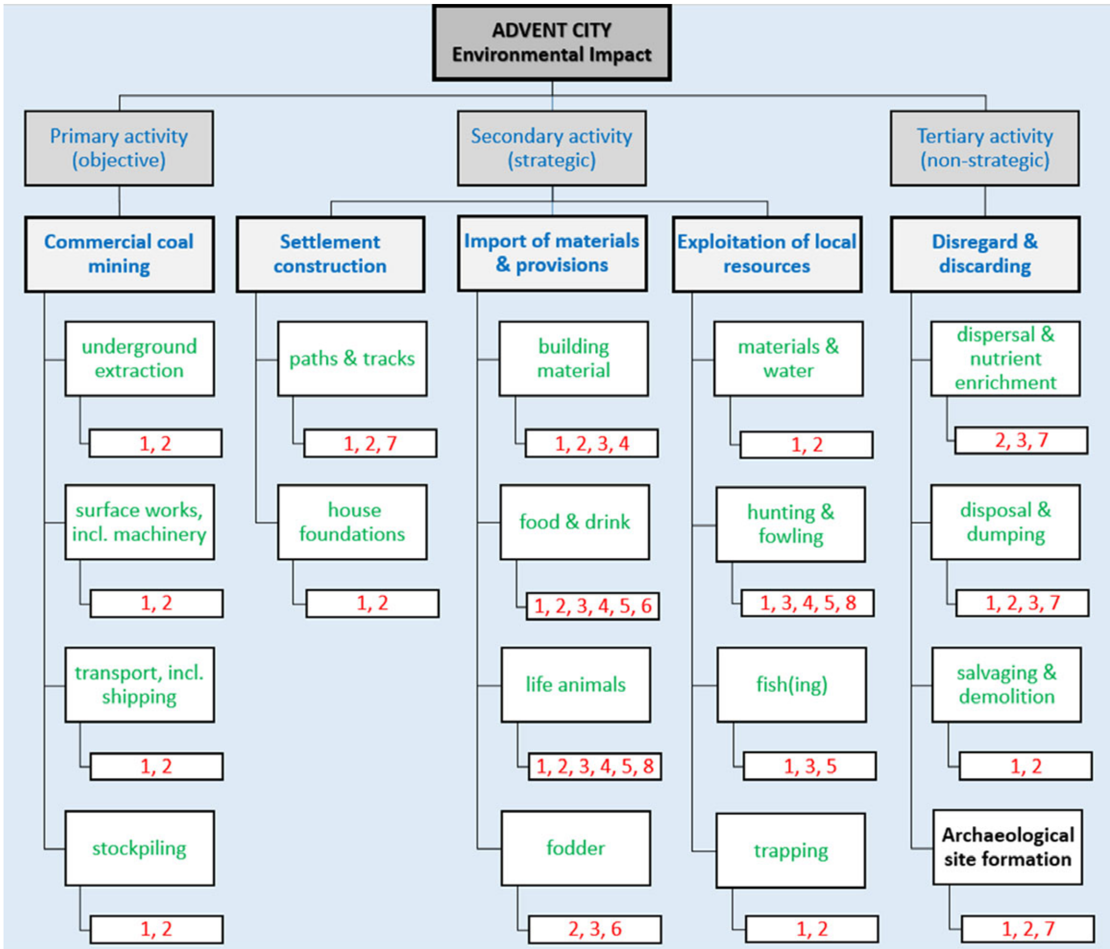

Fig. 10. Flowchart indicating the interdisciplinary methods used to investigate different aspects of past human–environment interactions at Advent City. 1 – historical sources, 2 – survey (visual, dGPS and photogrammetry), 3 – archaeological excavation, 4 – material studies, 5 – archaeozoology, 6 – archaeobotany, 7 – vegetation survey and 8 – stable isotope analysis.

Finally, although the terrestrial ^{14}C dates all correspond to the Early Modern plateau in IntCal13 (Reimer *et al.*, 2013), some do not include the true date (1907 ± 1 AD) in their 95 % range. The average terrestrial (IntCal13) calibration curve value for 1907 AD is 90 ± 7 BP, which is noticeably different from even the plum seeds (145 ± 17 BP). The cause of this disparity is unclear. It may relate to some small localised offset, or it may simply be a statistical anomaly, which would be overcome with more data.

Discussion

The flowchart (Fig. 10) indicates the structure of this section. It combines our methods with the aspects investigated in order to enhance our knowledge of past human–environment interactions at Advent City and improve our understanding of lasting anthropogenic impacts. We distinguish between primary, secondary and tertiary human activities of consequence. The company pursued an overall goal of financial profit through the primary objective of coal mining. Secondary activities were strategic, that is, they were intended to facilitate successful Arctic mining. They included settlement construction, the import of materials and provisions, and the exploitation of local resources. Tertiary activities were non-strategic. They were an unintentional by-product of the kind nowadays closely monitored by environmental impact assessments. We specifically consider the disregard for materials and objects, and the practices of discarding them. The flowchart offers a loose chronology from left to right. The activities accidentally culminated in the formation of an archaeological site, preserving the environmental data without which our study would not have been possible.

Commercial coal mining

Research on the effects of coal mining on the environment – usually detrimental – has reached an extremely high resolution in Svalbard (e.g. Khan *et al.*, 2017). In the archives and on site, we also identified underground extraction, surface works and transport arrangements as agents of direct environmental consequence. We include the stockpiling of coal here, because gathering coal was a primary objective. In environmental terms, it also constitutes a form of material dumping similar to the spoil heap. The question why plants had not recolonised the coal stockpile to the same extent as the rocky spoil remains unanswered. We suspect soil chemistry to be the limiting factor.

Settlement construction

Paths and tracks created by people, horses and carts featured both in the sources and in the field. The footpath to the mine was

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highlighted in yellow-green by *Sanionia uncinata*, although this moss was actually more abundant next to it. Human interference had probably created a linearity that stood out better than the more randomly orientated patches of *S. uncinata* beside the path. The higher number of species in R4, due to a higher number of moss and lichen species, tentatively supports this idea.

Plots R5, R6 and R7 on and next to the former cart track differed in exposition, coarseness and compaction of the topsoil, and the availability of water. The track had been dug out and the clear depression was again highlighted by *S. uncinata* (R5; Fig. 8). In addition to the accumulation of snow and poor drainage, the moss may benefit from horse dung and other animal faeces enriching the soil. The spoil forms the parallel embankment, the inward slope of which appears more sheltered and perhaps warmer, and visibly supports a higher cover of vascular plants with a vegetation characterised by mountain avens (*Dryas octopetala*) and polar willow (*Salix polaris*) as dominant subspecies (R6). In contrast, the gravelly top of the embankment is very exposed and remained practically barren (R7).

The possibilities for determining human impact due to track construction is limited because we could only investigate two reference sites. However, we did observe barren patches as well as patches with high cover abundance of *D. octopetala* and *S. polaris* or *S. uncinata* outside Advent City (e.g. R10). Since the fell field is patchy in soil surface roughness, vegetation cover and vegetation composition, we may tentatively assume that natural patches with soil surface features and vegetation similar to those on and next to the former cart track also occur outside the settlement. This also applies to the footpath to the mine (R3).

Import of materials and provisions

The company imported the vast majority of its building materials. The walkover showed that the wood, concrete and brick remains of Advent City were of no environmental consequence. Beyond barrels of cement and carbide, we noticed no hazardous substances, which would in our opinion require environmental mitigation. The aforementioned coal stockpile may, however, be seen as a substance or chemical product generated by mining.

The import of food and drink was evident in frequent tins and bottles. We excavated some edible plant species – brambles, cereals, hazelnuts and plums – none of which had propagated over time. The arduous pitting of the plums seemingly took place at the piggery before the fruits were brought into the settlement. The measurements of the stone dimensions can be used to classify different subspecies (cultivars) and their possible origin (Woldring, 2012; ESM: Fig. S1). We cannot discount British or other origins of the plums, especially if they arrived in tins, but a Norwegian origin is more likely. Growing plums has a long tradition in Norway, where the main plum growing areas are situated along the west coast up to ca. 62° N (Sekse, 2007).

The domestic animals came from outside Svalbard. Historical sources indicated that dogs, horses, pigs and at least one goat were shipped alive. We found foot bones from cattle and a mandible from sheep/goat in the stable midden. Since the primary butchering process of killing and dressing an animal usually removes non-meaty parts like the head and the feet (Rixson, 1988), these finds supported the presence of live cows and sheep or goat at Advent City. The faunal assemblage of the piggery midden consisted primarily of meat-bearing bones like vertebrae, ribs and elements of the hind legs and front legs. Notable exceptions were foetal pig remains, possibly stemming from the removal of the intestines of an adult sow, as well as deciduous teeth belonging to juvenile pigs, and an occipital fragment of a cow. These may have resulted from the secondary butchering process of dividing a carcass further (Rixson, 1988).

In addition to deliberate imports, pests and perhaps pathogens may have been introduced accidentally. In the past, rats were highly problematic in Longyearbyen (e.g. Balstad, 1955), and at present, the house mouse (*Mus musculus*) and the sibling vole (*Microtus levis*) are listed in the Governor's action plan against harmful alien species (Sysselmannen, 2013). Neither the historical sources nor the walkover relate if rats and mice were an issue at Advent City. We merely found three bones gnawed by rodents. Since we retrieved a tiny spider from the palaeobotanical samples, we are confident that we did not overlook any other stowaways.

Imported livestock raised the question of feeding it. Where pigs were previously released on islands, they overturned the ground and destroyed the native fauna and flora (Gade, 2000a). Similarly, ungulates reputedly overgraze when their numbers surpass the capacity of the land to support them. "The process begins when first cattle, and then sheep, deteriorate the range, after which the invading brush is suitable only for the goats." (Gade, 2000b, p. 535). However, the Arctic tundra and the shore (e.g. washed-up seaweed) offered very little grazing to begin with, so that the company needed to import animal fodder. Ignoring a blurry photograph of possible hay bales, a wooden feeding trough was the only surface find to this effect.

An archaeobotanical study at the aforementioned whaling station at Smeerenburg (van Wijngaarden-Bakker, 1984) reports that the two grasses *Poa arctica* and *Phippsia algida* occurred in such low abundance that domestic herbivores would not have survived on them. Hence, their bones probably stemmed exclusively from preserved meat. We excavated hay, however, and our archaeobotanical results clearly indicate hay in the animal dung, underlining its deliberate import as fodder. This import greatly increased the risk of introducing non-native species to Advent City. Although we cannot completely rule out that a few non-native species encountered in the excavation (e.g. *Chenopodium album*, *Trifolium* sp. and *Ranunculus* sp.) and other common human-following plants (e.g. *Poa annua*) may have survived for a short time, we found no exotic species in the extant vegetation. Checking against Elvebakk and Prestrud (1996), Hagen and Prestø (2007) and *Artsdatabanken* (2019), we found neither red-listed nor threatened plant species.

Exploitation of local resources

Coal, sandstone, sand and gravel, driftwood and meltwater were locally available raw materials. The desk study and the walkover attested to their limited utilisation. We did not investigate this further, focussing instead on the exploitation of living resources.

Texts, photographs, artefacts and ecofacts provided evidence for hunting and fowling. The local decimation of reindeer, seals and birds will have had significant impact on the species abundance, and Svalbard reindeer in particular were already thought to be overhunted (Kruse, 2013). To test this, we considered the age categories represented by the excavated reindeer remains. Selection for age may point to a careful hunting strategy, in turn influencing the composition of the population and its reproductive success. Our age distribution suggests that there was no strict selection for age of the reindeer. This disagrees with Hambleton and Rowley-Conwy (1997), who state that hunting is likely to produce a cull of mainly mature animals. However, they focus on the

Norwegian mainland and on another subspecies of reindeer. Our sample size is very small and the age data should not be overinterpreted.

Indiscriminate hunting may have serious, even irreversible consequences. While caribou and reindeer elsewhere migrate over large distances to avoid pressure on the herd, the Svalbard reindeer is site-bound (Punsvik, 2009), commonly residing in the same valley year-round (R. W. J. Visser, personal communication, 30 April 2018). Therefore, once a local population has been exhausted, an area is less likely to be repopulated. Furthermore, the Svalbard reindeer fluctuate greatly due to weather-related food limitations like icing over of the feeding range (Solberg *et al.*, 2011). When local reindeer already suffer from increased natural stress, additional hunting pressure could push the herd to extinction. Between 1925 and 1983, the Svalbard reindeer were protected.

The bird assemblage comprised the remains of ducks, geese, Svalbard rock ptarmigan and guillemots. There was no historical or archaeological evidence for imported ducks and geese. Instead, we have small but definite proof that the occupants of Advent City engaged in seasonal hunting of ducks and geese. At present, ptarmigan are hunted from September to December, and the practice may have existed in the past. One of the 205 ptarmigan bones from the ash dump, a *tarsometatarsus*, was excavated with an iron wire looped around it. The wire was not used to catch the bird: suitable nooses have to be made of flexible yet tear-resistant material like horsehair (Fenton, 1978). It is more likely that the birds were shot, guns being allowed throughout the settlement (Kruse, 2013), then hung up by the leg until needed for human consumption or as bait for trapping Arctic foxes (Adams, 1961).

At present, little auk (*Alle alle*), which we did not excavate, inhabit the seabird colonies in Adventfjorden. Guillemot can only be found further afield (Kruse, own observations). If this was similar in the past, catching guillemot at Advent City was either a coincidence or the occupants went on hunting trips, for example to Diabasodden, ca. 20 km by boat but still within the company's claim. Similarly, shooting seal at Advent City would have been luck; seal remains in the stable midden strengthen our opinion that boat-based hunting took place elsewhere. The number of excavated bird bones is too low to assess human impact on the species represented.

Evidence for fishing and trapping was circumstantial. We know that the diet at Advent City included dried fish, and we could see a substantial number of fish bones in both the middens and the ash dump, but without complete analysis of the archaeozoological remains, we cannot be certain if the fish was locally caught, imported or a combination both. The fish remains were in any case too few for local fishing to have influenced the fish stock significantly.

Fox trapping around Advent City was evident in the sources and the archaeological remains of several deadfall traps, yet we found no fox bones. Deadfall traps were manufactured on site near the official building (6c). Eleven or more were put up around the site by propping up the deadfall (a wooden pallet), weighing it down with rocks, and placing bait. Ptarmigan was one of the options. Only three of these traps are currently registered in *Askeladden* (Riksantikvaren, 2019). We have no indication who maintained the traps and when, how many were put up at any one time or further afield, and how many foxes were ultimately caught with Advent City as a trapping base. As with fishing, local trapping probably had little impact on the fox population.

Disregard and discard

We make two assumptions regarding "waste." Firstly, resources were scarce and difficult to come by, so that anything already imported warranted repairing, re-using and recycling. Secondly, the company had given no particular thought to the production of waste and its disposal. We distinguish between the inadvertent dispersal of animal dung, the semi-informed disposal of disused objects and unwanted materials, and the final salvaging and demolition of all structures, not by the company itself but by third parties. Waste and its management tell us something about the organisation of Advent City during its short lifespan. Most importantly, they imply human attitudes towards resources and the environment.

The inadvertent dispersal of alien species is a popular research topic (e.g. Ware, Müller, & Alsos, 2012). Having touched on pests, pathogens and non-native plants, we now look at animal dung, human faeces and food waste, and their potential for enriching the Arctic soil. Localised evidence for animal dung derived from references to live animals as well as the middens, where it caused eutrophic conditions. It was apparently not used as manure. Instead, the draft horses and possible feeding pens may have led to a wider spread of nutrients, and we already mentioned the cart track as a likely area of enrichment. We do not know if the livestock, including the dogs, were free to forage in Advent City, potentially increasing the coverage.

We found six former outhouses but could not discern where the human faeces was disposed of. We identified butchery and food waste in the excavation trenches, where they contributed to the nutrients of the point source. We highly suspect that waste from the kitchen and the meals was dumped elsewhere. In addition to the point sources themselves, we examined the possibility of downhill transport by water of nutrients in one vegetation plot (R11). The difference between dense turfs of grass (*P. arctica* ssp. *arctica*) on the stable mound but a dense carpet of moss (*S. uncinata*) in R11 indicated that the dung heap was much more eutrophic than the area possibly affected by runoff. Following additional survey, we expect to see a very patchy anthropogenic pattern of soil enrichment in Advent City.

Regarding disused items, we expected to encounter the greatest abundance of artefacts among the former buildings. While the walkover showed much wooden debris, there were by no means many surface finds. Fewer still were diagnostic of the buildings' functions or the people who lived and worked in them. The settlement seemed archaeologically inert. Ignoring nails and similar fasteners, there were almost no intact objects in the stable midden. Placing people and their activities on the scene was difficult but not impossible. We saw no signs of repair, re-use or recycling. The piggery midden and the domestic dump gave a comparable impression. Alternatively and significantly, we may actually be witnessing the perfect expression of careful resource management: everything may in fact have been used to the point of only the most unusable scraps being discarded. Nothing was seemingly wasted.

Dumped materials covered up the topsoil, and their nature influenced what plants grew back and when. As with the coal stockpile, the spoil heap remained almost barren with only a slight re-colonisation of plants. Closer investigation may detect the underlying reasons. We prioritised the stable midden, an organic- and nutrient-rich substrate presently favoured by the grass *P. arctica* ssp. *arctica*. Overall, high eutrophication had led to a low species diversity. Although the domestic ash deposit was not directly dumped onto the tundra, the effect of putting a crate

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down was the same. The deposit would be toxic and carcinogenic to humans, yet after a century of inactivity, the vegetation was not sparse. Its height was lower than in the vicinity, but the average and maximum heights were intermediate among other plots. Most remarkable was the high degree of evenness.

Regarding salvaging and demolition of Advent City, historical sources relate that building material and equipment were highly coveted by third parties, who intended to mine at other locations in Adventfjorden. All mining-related items were valuable to others and practically recycled in their entirety. There is little we can say about the items that have now gone besides the fact that they no longer have an impact on the site. Interestingly, a third-party decision to leave items at Advent City is a reflection on the company's initial choice and its inherent wastefulness. We observed that three large and expensive gas producer engines were bought for Advent City, for example, but no one had removed them. Strategically, other companies may have preferred other options for power. Practically, the engines may have been too heavy to take down and transport by local means. Whatever the reason, it will have been an economical one, not an environmental one.

The walkover indicated that the site is in constant flux. We noticed, for example, concrete building foundations tilting, cracking and slipping downwards in the active layer of the permafrost that melts each summer. It was difficult to identify suitable reference sites in such a dynamic slope environment. Fig. 5 shows that R9 and R10 were situated in an area that was affected by meltwater flooding more recently than Advent City itself. The lower cover abundances of vascular plants and lichens tentatively suggest that R9 was more recently affected by flooding than R10, but the differences in vegetation cover and composition and the heterogeneity of the terrain indicate that more plots need to be surveyed in the area to draw firm conclusions.

Conclusion

Advent City in Svalbard is a case study at the very onset of Arctic mining to investigate the research gap between untouched tundra and messy megaproject. At the time of writing, it was 119 years ago that a coal claim was staked out and 103 years ago that the last structures were removed from site. The most intensive activity took place between 1904 and 1908. Using multiple proxies in an interdisciplinary approach, we identified a range of past human–environment interactions. In this Conclusion, we return to our questions regarding the lasting anthropogenic impact at Advent City.

Which human activities initially asserted pressure on the Arctic environment?

We differentiate between primary mining-related activities, the secondary need for shelter and food and tertiary acts of discarding unwanted items and materials. Significant environmental pressure primarily arose from landscape modifications, the import of non-native animals and plants, the hunt of local wildlife and waste disposal on the tundra. The demolition of Advent City lifted any human-induced pressure, giving the wildlife and the vegetation a chance for recovery.

Landscape modification ranged from trampling and soil compaction to extensive levelling. There were signs of ground clearance and surface works all over Advent City. Some work was done manually; on other occasions, explosives were used. Above the mine, the mountain was settling into the voids below. These modifications are clearly visible today. Although the turning over of soil and rocks destroyed much of the vegetation, it essentially constituted the creation of new habitat.

Imported livestock did not directly compete with the local wildlife, although foraging contributed to the loss of a food source. The domestic animals enhanced the trampling, added to the nutrient enrichment across the site and could have caused the spread of parasites and pathogens. The risk of introducing non-native species increased with the import of animal fodder and edible plants. Hay may have hidden and sustained rats, mice and other pests. However, likely the detrimental consequences, we have no evidence for either temporary or lasting harmful effects of exotic animals and plants.

The game animals at Advent City included reindeer, seal, sea birds and terrestrial birds. They were hunted locally and on hunting trips. Overall, our information is too limited to comment on the scale of the hunt and the consequences for the different populations. The Svalbard reindeer, however, was already overhunted and the indiscriminate practices at Advent City will only have made the situation worse.

Regarding waste disposal, we discerned no strategy other than practices of least effort expressed in point sources. The eutrophication in the middens was to a lesser degree noticeable on the cart track, suggesting that an overall enrichment on site was at least possible. We also witnessed changes to the vegetation brought about by dumping material directly on the tundra.

Were early Arctic miners "eco-conscious"; that is to say, did they show concern for the environment?

We do not see the Arctic miner *per se*. We see an expression of the English mining company in all that was deliberately brought to the site and taken from it. We also see an expression of the local management in how the structures were put up and used. If we want to get an impression of individual activities and attitudes, we need to home in on the finds of the excavation trenches.

Thus, we are able to place a Norwegian groom with considerable responsibility at the stable. He maintained the building, tended to the horses and probably the dogs. He drank, ate and read during his breaks and occasionally lit the fire. We do not think that he slept there. His additional tasks were hunting-related. We do not know if he joined the hunting trips, but he butchered the reindeer, seals and sea birds, probably with some help. Notably, marine animals were only found in this trench, which points to recreational as opposed to subsistence hunting. All discarded items were greatly reduced to scraps. The groom was therefore highly economical, but there is not proof that he held the environment in special regard.

We cannot place any particular person at the piggery and assume that the groom also tended to the pigs, sheep and goat. We observe an important step in the provision chain of the settlement, whereby any food in need of primary treatment was delivered to the piggery before moving up into the kitchen. Plums were pitted; the majority of domestic animals and reindeer were butchered; fish were probably gutted or at least boned. Birds may be entirely absent because they did not contribute to feeding the workforce. Nothing that was prepared for consumption further up in the settlement later made its way back down here. All food waste was discarded elsewhere. Again, care was taken of material resources. Again, there is no proof for environmental consciousness.

Finds from the ash dump show that the Scandinavian workers enjoyed some recreational freedom at their barrack. They drank, ate, read and occasionally lit a fire. Fruits, nuts and locally caught birds were probably only a snack with the main meals being eaten elsewhere. Geese and ducks were available to them in summer. Ptarmigan may have been hunted in autumn and used to bait foxes, with which the miners could improve their pay. The artefacts were unrecognisable scraps with the exception of a wrought-iron lamp holder.

We conclude that the individuals represented by the finds in the excavation shared the material attitude of "waste not, want not." The scarcity of resources in the Arctic may arguably have had the side effect of environmental protection. Although the workers had individual environmental fingerprints, they were not decidedly eco-conscious. The trenches are point sources; they give clues but not the full picture.

How did the local ecosystem respond after mine closure and site abandonment?

Historical-archaeological research exposed past human–environment interactions, which we compared with a site walkover and a survey of the present-day vegetation in our search for long-term impacts and related vegetation responses. Landscape modifications, the import of non-native animals and the attitude towards waste continue to play a significant role, while we judge the effects of foreign plants and local hunting to be negligible. The intense interference with the original fell field did not lead to total destruction. Instead, we witness anthropogenic habitat creation, characterised by physical and chemical changes to the topography and the substrate (e.g. depressions and expositions, coarseness and compaction, availability of water and poor drainage, nutrient enrichment). We did not study any abiotic factors in detail.

In general, the total vegetation cover was very high, and the most notable response of the effected tundra was the reduced patchiness of recovering communities. The vascular plants apparently benefitted from the former ground clearances and occupied the newly created habitat. An exception was the slow-growing *Cassiope tetragona*, whose plants probably suffered from the surface works. Individual dwarf shrubs can be more than 100 years old (e.g. Rayback & Henry, 2005), and after a century of inactivity, *C. tetragona* has not yet recovered within Advent City. However, slow recovery may be a natural process. In the settlement, the bryophytes less often grew intermingled and less tightly together than at the reference sites. Highly eutrophic conditions were unsuitable for liverworts and lichens. We observed a negative correlation between the density of the vegetation formed by vascular plants and mosses and the occurrence and abundance of liverworts and lichens, but we could not explain the underlying causes.

We did not record exotic, red-listed or threatened species. The biodiversity was high, but we cannot discount that rare and sensitive species disappeared because of human activity.

We do not know why differences exist between the vegetation in the fell field of our study area and the fell field described by Virtanen *et al.* (1997). It may well be that after a century of response, we are seeing a transitional state, which may never be concluded. Hence, we prefer the word *response* to *recovery*. Because of natural agents like cryoturbation, erosion, occasional floods and other geomorphological processes, the fell field is such a dynamic area that the impact of human activities on the vegetation and on the ecosystem as a whole is very limited. Gravity is a great equaliser.

Closing remarks

We value Advent City as a powerful reminder of a bygone Industrial Age. Although its damaging human–environment interactions are a thing of the past, the ruins will have a highly visual impact for a while yet. We are relieved that the unthinking introduction of Arctic aliens and haphazard hunting are outdated in Svalbard, and that animal populations have a chance of recovering from overexploitation (even if Arctic warming and the spread of global pollutants pose new threats). The team received momentous visits from Svalbard reindeer, belugas, minke whales and many different birds; an Arctic fox passed by us near the airport. Although there is no mention of them in our historical sources, polar bears, too, sent us packing and claimed back Advent City. And so they should.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0032247420000418

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Conflict of interest. None.

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