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Assessing the impact of human activity on cultural heritage in Svalbard: a remote sensing study of London

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In this study, we focus on the impact of tourism on Svalbard's cultural heritage within the context of natural and anthropogenic-induced formation processes. Established in northwest Svalbard, the cultural environment of London features the remnants of a marble mining settlement. This research covers the period from 1990 to 2014 and uses high-resolution remote sensing images in combination with ground-based surveys to: identify and map wear on vegetation caused by recent human activity, and analyse and assess changes in the state of the cultural environment. The number of visitors to London has risen from a few dozen in the mid-1990s to 1200–1300 annually. Our results show a gradual and ongoing deterioration of the vegetation cover. Worn and patchy vegetation is especially apparent along access trails to and in the vicinity of the most popular cultural heritage features. London as a cultural environment is changing, and our study has shown that visitors during the last 25 years have played a part in that transformation.

Keywords: cultural heritage; vegetation; remote sensing; monitoring; London; Svalbard

Introduction

Exploration and exploitation of natural resources have left a tangible human imprint on the Svalbard landscape since the Dutch explorer Willem Barentsz discovered the archipelago on 17 June 1596. The earliest traces of human activity in Svalbard are linked to whaling. Land-based stations and oil cookeries tell tales of an extensive whaling activity by the Dutch, Basque, English and Danish–Norwegians in the decades following discovery up until around 1750. Hunting and trapping was dominated by Russians (Pomor) from approximately 1700 to 1850, and by Norwegians from around 1800, onwards. Both Russian and Norwegian activities were commercially based, primarily focusing on profitable products such as the winter furs of polar bear and arctic fox. In the early 1800s, scientists and Polar explores from countries including Norway, Sweden, Russia, France, Germany, Austria and Great Britain took a keen interest in Svalbard and the High Arctic. A number of the expeditions to Svalbard focused on reaching the North Pole and remnants of the expedition bases are a visible testament to the exploration efforts of that era. Today,

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these cultural environments are among the most well-known and popular tourist destinations in Svalbard. Another important part of Svalbard's recent history is mineral exploitation. In the early 1900s, mineral prospecting, mining and industry came to the forefront with companies from several western countries operating in Svalbard. Claim markers, quarries, mines as well as a variety of buildings and machinery are nowadays a visible and important part of Svalbard's cultural landscape. The cultural heritage is significant not only as a physical representation of past human endeavour in a High Arctic environment, but also as a part of a common European history. The archipelago's history has a decidedly international character, and the associated cultural heritage is now regarded as international heritage.[1]

The Svalbard Archipelago was for a long time regarded as a terra nullius or no man's land, a status which underlies the internationality of resource exploitation in Svalbard.[2] The 1920 Treaty Concerning the Archipelago of Spitsbergen[3] granted sovereignty of Svalbard to Norway while maintaining rights, for instance to continued commercial exploitation, for all contracting parties. Nowadays, Norwegian sovereignty and exercise of authority on Svalbard is regulated through the Svalbard Act[4] while cultural heritage is covered by the Svalbard Environmental Protection Act.[5] According to this Act, "cultural heritage" and "cultural environment" encompass "all traces of human activity in the physical environment, including localities associated with historical events" and "any area where elements of the cultural heritage form part of a larger entity or context"[6] respectively. Furthermore, all fixed and movable cultural heritage older than 1946 is automatically protected, which means that "no person may damage, dig up, move, remove, alter, cover up, conceal or disfigure automatically protected structures, sites or movable historical objects, including any security zone, or initiate measures that may entail risk of this happening".[7] Cultural heritage in Svalbard is thereby afforded a very strong legal protection. However, cultural environments are not static and unchanging. Rather they are subject to transformation and decay through a multitude of environmental and anthropogenic-induced processes.

Natural hazards such as coastal erosion, wind wear and tear, flooding, thawing permafrost and bio-deterioration processes are among the known threats to cultural heritage in Svalbard.[8] Wildlife, such as polar bears can also pose a threat to cultural heritage. Climate change and the expected impacts of climate change are another major concern.[9] A changing climate can directly impact cultural heritage through physical changes that alter conservation conditions for traces of past human activity. Predicted increases in air temperatures are, for instance, expected to have an effect on ecosystems, and a higher mean temperature can impact cultural heritage through a longer growing season, changing vegetation zones, changing biodiversity and species diversity as well as a higher rate of bio-deterioration which can result in

[1]Dahle et al., *Kulturminneplan*; Sandodden et al., *Kulturminneplan*.
[2]Avango et al., "Between marks and geo-politics"; Kruse, *Frozen assets*.
[3]LOV-1920-02-09.
[4]LOV-1925-07-17-11.
[5]LOV-2001-06-15-79.
[6]§ 3f.
[7]§ 39 and 42.
[8]Barr, "Arctic and Antarctic"; Sandodden et al., *Kulturminneplan*.
[9]See e.g. Xu et al., "Temperature and Vegetation Seasonality Diminishment".

overgrown sites or rotting and decaying archaeological features.[10] Indirectly, climate change may also have an impact through our responses, that is to say, the measures put into effect to counteract the effects of climate change.

Human impact on cultural heritage in Svalbard is primarily linked to use, but management efforts intended to counteract impacts of recent human activity can also, and are in fact intended, to have an impact. Cultural environments are loci for a range of contemporary human activities. Cultural heritage is listed among the main tourist attractions in the archipelago, and tourism is now one of, if not the principal human activity in many sites. Tourism has a long history in Svalbard. Ships have carried visitors to the archipelago since the later part of the 1800s and regular air traffic was established in the late 1950s.[11] The Norwegian Parliament designated tourism in Svalbard as a core area for development in the early 1990s, and the industry has increased significantly since then.[12] According to Statistics Norway, just over 43,000 overnight stays in Longyearbyen were recorded in 1999, while the number in 2013 was 107,000.[13] Generally, up to 30 cruise ships annually visit Svalbard, but the number of passengers carried by these ships have increased from around 20,000 in 2000 to just over 42,000 in 2012. Coastal tourism plays an important role in how people move around Svalbard, and the numbers of people going on expedition cruises have risen from around 5000 in 2001 to 10,000 in 2013.[14] The number of landing sites or disembarkation areas has also increased, from 139 in 2001 to 238 in 2012.[15]

Tourism is known to be a contributing factor to processes of transformation and decay in cultural heritage.[16] Visitor impact can be linked to people walking through cultural environments, physically disturbing structures, moving or removing loose objects, adding objects and so on. Over time, such activities can damage or even destroy cultural heritage features, and consequently may contribute to degrade or even destroy that which visitors wish to experience in Svalbard. Management authorities on both the local and national level have a strong focus on information, on educating tourists and other visitors regarding the vulnerable nature of cultural heritage in Svalbard and the restrictions inherent in current legal protection. The *Cruise Handbook for Svalbard* developed by the Norwegian Polar Institute contains information on wildlife, vegetation, geology, history, cultural heritage and landing sites, and also explains the heritage regulations and advocates that people show consideration toward cultural heritage assets.[17] For instance, the section on London specifically asks people to not remove objects from the site and to avoid walking or standing on structures.[18] In addition, the Governor of Svalbard has developed a series of pamphlets containing similar information. The handbook and pamphlets are readily available both in print and online to visitors and guides. Management authorities have, however, found it necessary to implement measures intended to

[10]Øseth, *Climate Change*; Barlindhaug et al., "Monitoring Archaeological Sites"; Kaslegard, *Climate Change and Cultural Heritage*.
[11]Conway, *No Man's Land*; Arlov, *Svalbards historie*.
[12]Governor of Svalbard, *Reiselivsstatistikk*.
[13]Statistics Norway, *Dette er Svalbard 2014*.
[14]Ibid.
[15]Sandodden et al., *Kulturminneplan*.
[16]Barr, "Arctic and Antarctic"; Sandodden et al., *Kulturminneplan*.
[17]Prestvold et al., *Cruise Handbook.*
[18]Ibid., 156.

lessen human impact on cultural heritage at several of the more popular tourist destinations. Restricting access through regulation has in several cases been the preferred option as signs or physical barriers may constitute a visually disturbing element in the Svalbard landscape. In 2010, access to nine significant cultural environments was regulated or closed.[19]

Natural hazards, biological degradation, wildlife and human activity constitute a threat to cultural heritage in Svalbard. Systematic monitoring is essential for getting a clear picture of what is happening and for understanding the interrelationship between various impact factors, both environmental and anthropogenic. Ground-based surveys have been conducted for decades, and a number of attempts have been made to develop and test monitoring methods. Systematic repeat photography of archaeological features has been tested.[20] Suitability assessments are often used in remote sensing, and recently a number of disembarkation areas for cruise ships have been the focus for assessing the suitability of digital orthophotography to detect and monitor damage to vegetation.[21] Regardless, there is a lack of systematic long-term monitoring data, and there is a lack of knowledge regarding impact from human activity. Improved monitoring methodologies are needed, something which has also been highlighted by Norwegian authorities. In a recent white paper on Svalbard, the Ministry of Justice and the Police underlined the need to develop new tools to manage Svalbard's increased traffic, and that mapping and monitoring is a necessary part of this process.[22]

Study area and research questions

London (Port Peirson), located in Kongsfjorden on the west coast of Spitsbergen (Figure 1), features the remnants of a marble mining settlement established in 1911 by the Northern Exploration Company Ltd. (1910–1934).[23] Marble, metamorphic crystallized limestone, occurs in places in West Spitsbergen[24] The quality of the marble deposits in the area around London was initially considered to be of very good quality and potentially profitable.[25] However, it soon became apparent that the marble was useless for commercial purposes as the extracted blocks crumbled due to frost action. After intermittent operation, the venture ended in 1920 and London was already in 1933 likened to a ghost town, described as a relic of yet another unsuccessful venture in Svalbard.[26] Materials and equipment brought in for the mines and the settlement were scavenged for reuse elsewhere, and in the 1950s, most buildings were moved to Ny-Ålesund on the south side of Kongsfjorden. Even so, London can today be described as a large and complex cultural environment. Housing was originally built for 70 people. Two wood-frame buildings are still standing, and the foundations of several more are visible. Today, London features

[19]Barr, "Arctic and Antarctic", 22.
[20]Bjerck, *Overvåking av kulturmiljø*; Roura, *The Footprint of Polar Tourism*.
[21]Tømmervik et al., *Metodikk*.
[22]Riksrevisjonen, *Riksrevisjonens undersøkelse*.
[23]Barr et al., *Gold – or I'm a Dutchman*.
[24]Hjelle, "Some Aspects of the Geology".
[25]Kruse, *Frozen assets*.
[26]Polunin, "Plant Life in Kongsfjord".

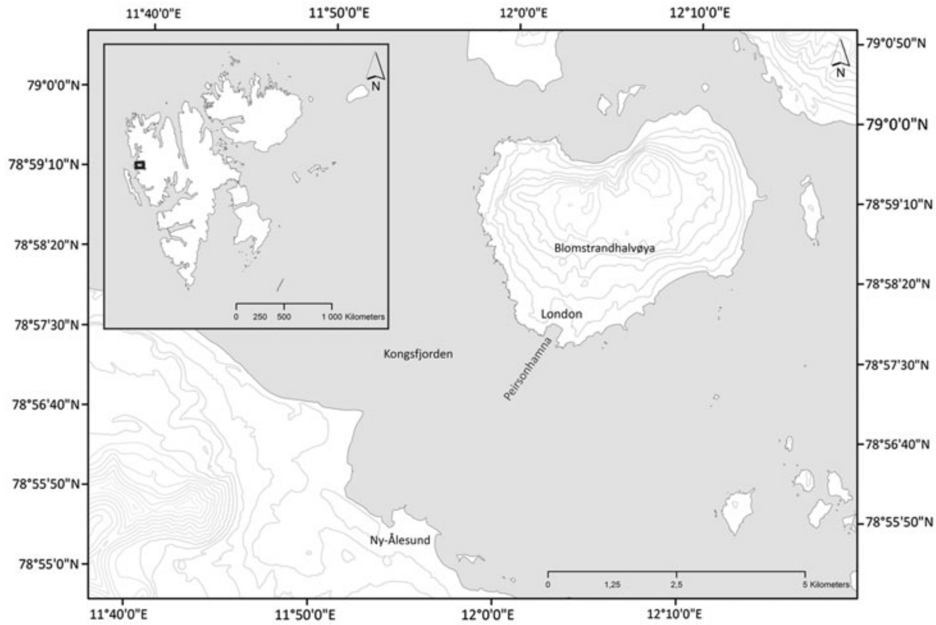

Figure 1. Map of the Svalbard Archipelago showing the location of London.
Source: The Norwegian Mapping Authority.

the largest collection of technical equipment predating First World War in Svalbard.[27] The remains of a machinery hall, workshops and storage facilities, quarries, spoil dumps, cranes, a railway, various pieces of heavy machinery as well as artefact scatters can still be seen around the site. The cultural environment is an important representation of Svalbard's industrial history. Not least, it is highly representative of the many commercial ventures in the archipelago where exploration of natural resources was a driving force, but where promising finds proved a disappointment and buildings, machinery and tools were left behind.

London is a popular destination and as with many other cultural environments in Svalbard, the number of visitors has risen noticeably since the 1990s. In 1996, a few dozen people visited, but currently around 1200–1300 visit annually.[28] The physical remnants of the mining operations are the main attraction for tourists. Regular visitors include researchers interested not only in the cultural heritage assets, but also other aspects of the cultural environment. London is also used for recreational purposes by the locals. The two remaining buildings are closed for tourists and researchers, but one is maintained and used by the community organization in Ny-Ålesund, which is the main centre for scientific research and environmental monitoring in Svalbard. Ny-Ålesund has around 30 permanent residents, but during the summer, the population multiplies significantly.[29]

[27]Prestvold et al., *Cruise Handbook*.
[28]Hagen et al., *Overvåking av ferdselsslitasje*.
[29]The Governor of Svalbard.

London is automatically protected under the Svalbard Environmental Protection Act and there is no restriction on use beyond the general regulations. London has undergone a number of changes since the establishment of the mining settlement in the early 1900s. In order to better understand London as a cultural environment in flux, we see it as important to assess its current state and unravel the different processes of site transformation at work. Our focus in this study is twofold. We focus on tourism as a site formation process within the context of other natural and anthropogenic-induced formation processes, and on the combination of remote sensing data and ground-based surveys as a means to map and analyse recent changes. One aim is to assess the overall condition of London as a cultural environment, and we have chosen to focus on the changing state of the vegetation cover as an indicator. We have acquired high-resolution aerial images of London that goes back beyond the onset of "mass" tourism, thereby providing an opportunity to document and analyse change over time. We use data from high-resolution images and ground-based surveys to (a) identify and map wear on vegetation caused by recent human activity, and (b) analyse and assess changes in the state of the cultural environment.

Data and method

The primary data are high-resolution images from 1990, 2009 and 2014 as well as data gathered during a ground-based survey conducted in July 2014. The main data sources for the vegetation analyses are the 1990 and 2009 images. The 1990 image is an IR image which has been digitally scanned producing a three-band image (NIR-R-G) with a spatial resolution of 25 cm. The 2009 image is a digital aerial orthophoto recorded with a Vexel Ultracam covering four bands (R-G-B-NIR), and which has a spatial resolution of 50 and 5 cm.[30] Another important data source was a Landsat TM/ETM-based vegetation map over Svalbard.[31] Geomorphological maps have also been utilized. In 2014, a Cryowing micro UAS (Unmanned Aerial System) was utilized to collect aerial images from London. The payload consisted of a commercial Canon EOS-M digital camera with a fixed 22 mm lens, which corresponds to a ground resolution of 3–5 cm at a flight altitude of 120 m above ground level. From a set of overlapping images from the UAS, an orthophoto and digital elevation model (DEM) was produced using a method known as structure from motion[32] provided in the commercial software Agisoft Photoscan.[33]

The 1990 and 2009 images have been used in a change detection procedure utilizing methods like unsupervised classification, change detection analysis based on vegetation indices, such as the Normalized Difference Vegetation index (NDVI) and Principal Component Analysis (PCA).[34] The NDVI index is a commonly used vegetation index that has regularly been used as a proxy for vegetation productivity,

[30]Tømmervik et al., *Metodikk*.
[31]Johansen et al., "Vegetation Mapping".
[32]Westoby et al., "Structure-from-Motion".
[33]www.agisoft.ru.
[34]Johansen et al., "Vegetation Mapping"; Tømmervik et al., *Metodikk*; Johansen and Tømmervik, "The Relationship".

vegetation health and change detection in vegetation monitoring during the last decades.[35] The PCA analysis can be described as a mathematical technique for reducing the dimensionality of a data-set,[36] and PCA can be used as a change detection technique in remote sensing.[37]

The 2009 and 2014 images have been visually analysed for traces of human activity using the software ENVI[38] and ArcGIS.[39] The analyses were based on RGB ("true colour") images, which, to aid interpretation, were put through enhancement processes. Image enhancement generally involves techniques for increasing visual distinctions between features in order to more effectively display or record data for a subsequent visual interpretation.[40] In the final analysis, the RGB images were subjected to linear 2% enhancement to increase contrast. The image data was also layered over the DEM produced in 2014 to aid interpretation. The visual analysis focused on detecting and mapping visible traces of recent human activity. All anomalies, that is detected impact from human activity were manually delineated.

The ground-based surveys serve to ground-truth and supplement the various analyses of the remote sensing images. The vegetation surveys focused on gathering more detailed information regarding the state of the vegetation cover. Leaf chlorophyll content is considered to be closely related to plant N content.[41] Chlorophyll metre measurements using fluorescence have been shown to be sensitive to differential N nutrition in various plants, hence it can be used as a plant health indicator. In this study, the leaf chlorophyll content and the leaf flavonols contents were analysed and the Nitrogen Balance Index (NBI) derived from these measurements. We also analysed plot-based NDVI images taken with a handheld proximal NDVI camera.[42] Vegetation cover analyses of vascular, lichen and moss plant species in continuous plots measuring 0.5 × 0.5 m was carried out along two transects of, respectively, 28 and 16 m, one of which crossed the main access route to the two remaining wood-frame buildings. As various species of lichen and moss have different tolerance limits, they are useful indicators of vulnerability.

The ground-based general survey was primarily focused on assessing the current state of the cultural environment on a general level, and on providing a knowledge basis for developing indicators useful for monitoring London and other cultural environments located in High Arctic environments. The entire site was walked, and photographic and written documentation was conducted throughout. Data gathering was focused on identifying and documenting evidence of recent human activity; on clarifying our understanding of the various natural and anthropogenic impacts factors at work; and, finally, on assessing the vulnerability of London's cultural heritage assets. Consequently, a detailed survey of the remaining standing structures, house foundations, quarries, machinery and loose artefacts scattered around the site was not conducted.

[35]Tucker, "Red and Photographic Infrared"; Barlindhaug et al., "Monitoring Archaeological Sites"; Johansen and Tømmervik, "The Relationship".
[36]Jackson, *Multivariate Data Analysis*.
[37]Muchoney and Haack, "Change detection".
[38]©2014 Exelis Visual Information Solutions.
[39]Esri©ArcMap™10.2.2.
[40]Lillesand et al., *Remote Sensing and Image Interpretation*.
[41]Schepers et al., "Transmittance and Reflectance Measurements".
[42]Bokhorst et al., "Vegetation Recovery"; Tømmervik et al., "Use of Unmanned Aircraft Systems (UAS)".

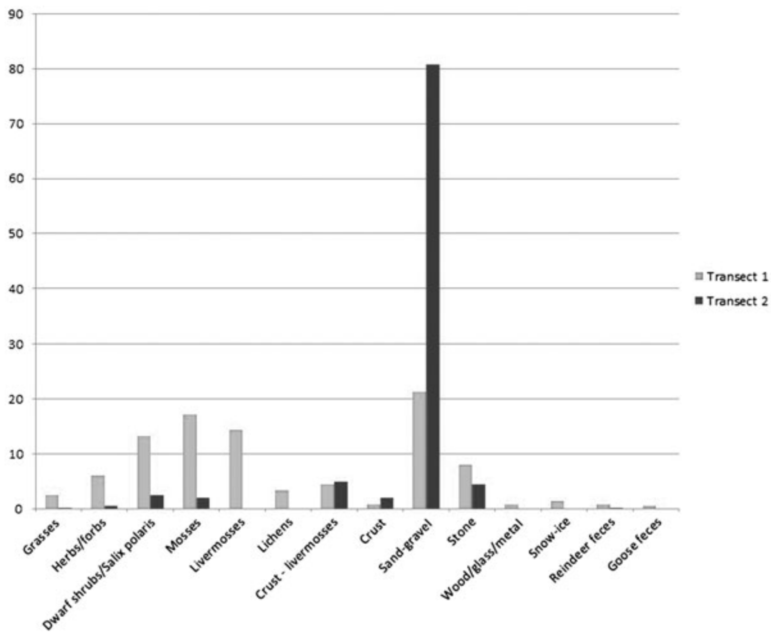

Figure 2. Plant cover analysis showing the percentage distribution of the vegetation along the two transects.

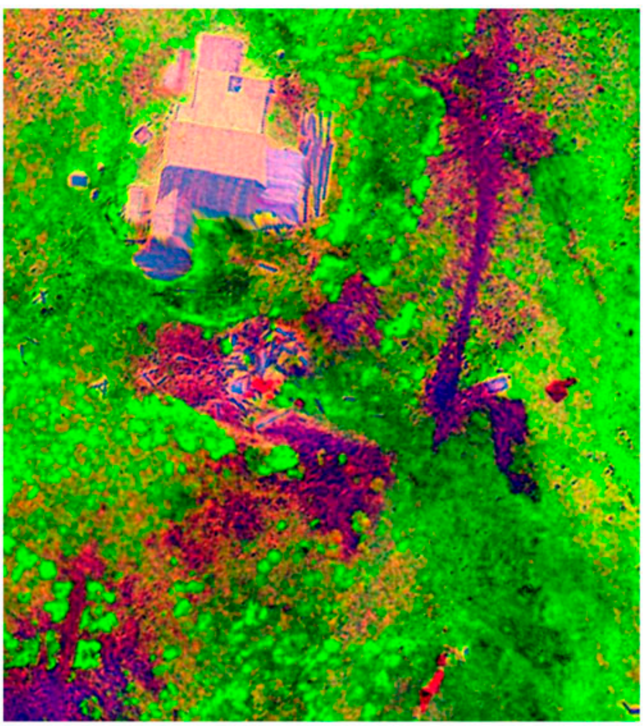

Figure 3. A PCA image based on the 5-cm resolution aerial image from 2009 showing total wear on vegetation and trails in black and significant wear on vegetation in dark grey.

Results

Results of the vegetation analyses and ground-based survey

In Figure 2, we present a plant cover analysis (%) of the vegetation along the two transects. Transect 1 covered an area with both vital vegetation and trampled vegetation, while Transect 2 was laid across the main trail leading towards the two standing buildings. As shown in Figure 2, the vegetation along Transect 2 was more or less removed, and the content of sand, gravel and crust (a mix of livermosses and cyanobacteria, etc.) is significantly larger in Transect 2, compared with Transect 1. In Transect 1, there is a cover of grasses, herbs, dwarf shrubs, mosses and lichens. The vegetated area in Transect 1 covers 57% of the total transect, while the vegetated area in Transect 2 was measured to cover only 5%.

The various analyses conducted on the 1990 and 2009 images proved the PCA procedure to be the most satisfactory for detecting wear on vegetation in London. As shown in Figure 3, detected wear is prominent along the trail up the slope towards the standing buildings. The NDVI index analysis applied to the same images also provided satisfactory results, which is of additional importance since we can use this index when upscaling to satellite images in future research on London.

In Figures 4(a) and 4(b), white and light grey areas indicate areas with dense vegetation, while grey and dark areas indicate sparsely vegetated areas or trampled vegetation. A change detection image showing wear on vegetation and increase of vegetation (denser vegetation) is presented in Figure 4(c). Using the unsupervised classification method on the two images, wear has been calculated within an area covering almost 63,000 m^2. As can be seen in Table 1, there is a marked increase in detectable wear from 1990 to 2009. In 1990, wear was detected in 1.3% of the total

Figure 4a. A NDVI image from London in 1990. White-grey areas indicate vegetation in good condition/health, while dark grey and black indicate areas undergoing wear or barrens without vegetation.

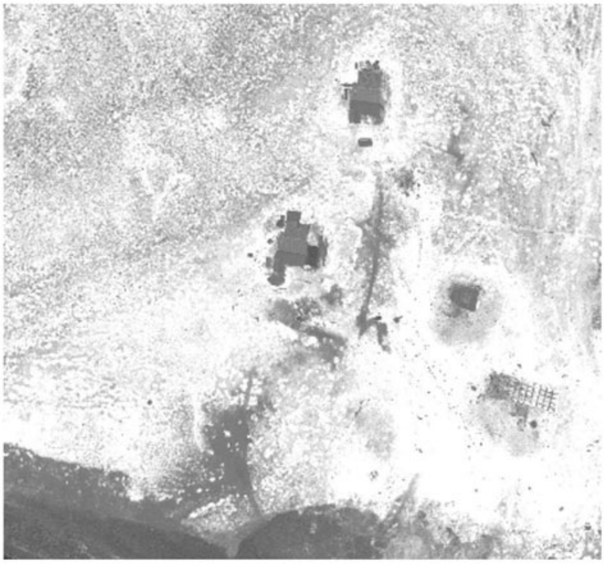

Figure 4b. A NDVI image from London in 2009. White-grey areas indicate vegetation in good condition/health, while dark grey and black indicate areas undergoing wear or barrens without vegetation. The trails are more apparent in 2009 than in 1990.

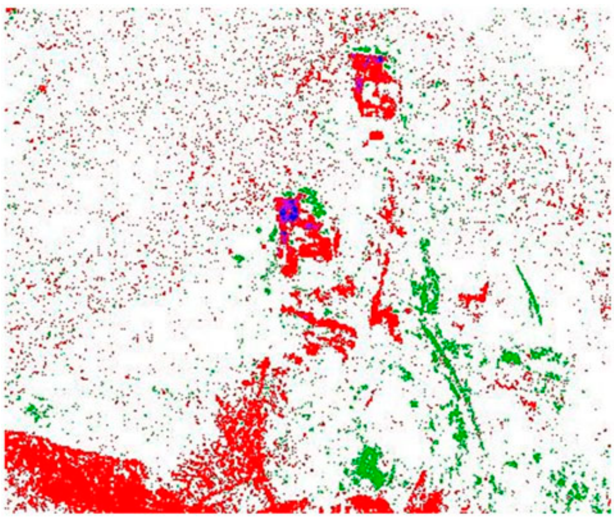

Figure 4c. A change detection image showing wear on vegetation in black and increase of vegetation (denser vegetation) in grey based on the NDVI images from 1990 to 2009, respectively. The white areas represent no significant change.

area analysed, while in 2009, 12.6% of the same area showed signs of wear on the vegetation. The most damaged area category increased from 0.4% in 1990 to 2.4% in 2009.

Table 1. Wear on vegetation in square metres.

	1990	2009
Total damaged vegetation (90–100% – sand gravel and clay)	272.0	1614.0
Partly damaged snow-bed vegetation	199.8	1060.3
Partly damaged – Dryas tundra[a]	355.8	5235.3
Total	827.5	7909.5
Total area analysed	62,887.5	62,887.5

[a]Dryas tundra = Mountain avens tundra (Dryas octopetala).

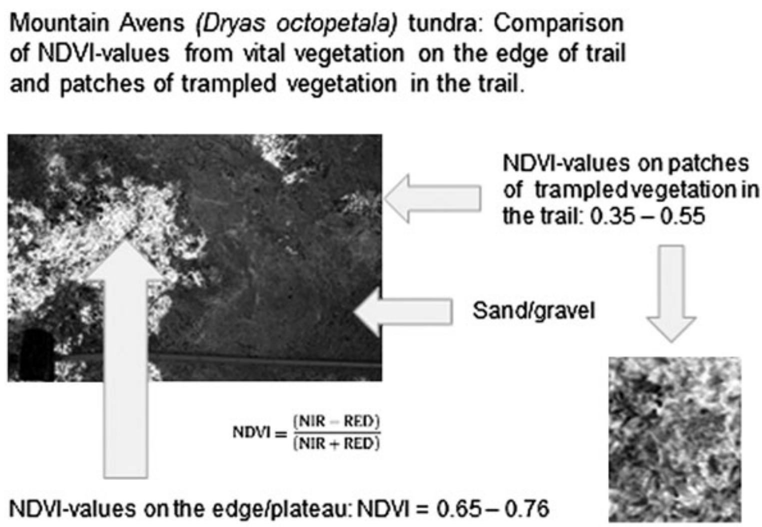

Figure 5. A comparison of NDVI values of vital vegetation dominated by Mountain Avens (*Dryas octopetala*) on the edge of the main trail in the study area and patches of trampled vegetation within the trail. White areas indicate high values of NDVI (good health condition), while grey and dark grey indicate low values (reduced health condition/wear on vegetation).

In order to measure in situ NDVI at the surface, NDVI images was acquired from 0.5 × 0.5 m plots along Transect 1 and 2. As we can observe in Figure 5, the NDVI values taken from plots along Transect 2 crossing the access route to the two standing buildings show that the NDVI values were significantly reduced in the plots where the vegetation was trampled compared to areas with more vital vegetation on the edge of the plot. White areas have high values of NDVI (0.65–0.76), which indicate good vegetation health, while grey and dark grey areas have lowered values (0.35–0.55), which in turn indicate reduced vegetation health condition and wear on vegetation.

Chlorophyll and nitrogen levels are useful for indicating stress in vegetation. Measurements from the plateau in front of the two standing buildings and from the main access route to these houses show that while the plateau area is definitely not undisturbed, the condition of the vegetation is much better than in the slope below. Chlorophyll analyses from a trampled patch of vegetation in the trail show near to half the average levels of the plateau (Figure 6). Nitrogen content expressed as the NBI was also shown to be reduced when comparing results from the vegetated patch

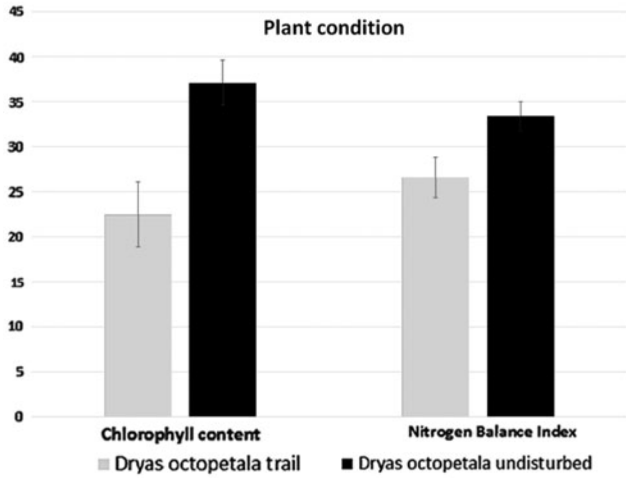

Figure 6. Measurements of chlorophyll level and nitrogen balance (NBI) of Mountain Avens (*Dryas octopetala*) taken from a vegetated but trampled patch within the access route (trail) up to the plateau and from an undisturbed patch on the plateau.

in the trail to the more undisturbed area on the plateau. These results clearly indicate that the vegetation is more stressed in the most trampled areas. The measurements of the chlorophyll level and the nitrogen balance measurements seem to fit well with the NDVI measurements taken with proximal cameras along the trails and the remotely sensed NDVI measurements.

Results of the visual analyses and ground-based survey

The visual analyses of the 2009 and 2014 images covered area of almost 62,000 m^2 that encompassed most of the main features in London. The analyses were aimed at delimiting areas where recent human activity was interpreted to have contributed to (a) visible wear on vegetation, (b) loss of vegetation and/or (c) erosion or other damage to the vegetation cover. Both the 2009 and 2014 images revealed multiple areas where the vegetation was visibly worn, patches of bare ground and larger areas devoid of vegetation and/or affected by erosion. These areas, which were primarily observed in relation to the main cultural heritage features, are particularly apparent around the two standing buildings, some of the house foundations like the remains of the engine house, the cranes and some of the other larger pieces of remaining machinery. Wear or areas devoid of vegetation was also apparent in the images as trails to and from features. People visiting London generally travel by smaller ships

Table 2. Visible impact in square metres.

	2009	2014
(1) Visible wear on vegetation	728	904
(2) Visible loss of vegetation, erosion	348	459
(3) Visible traces of recent incidents	0	13
Total	1076	1376
Total area analysed	61,910	61,910

or private yachts. The remaining buildings are located on a plateau where the primary access from the shore is up a slight slope. These access routes or trails are now largely devoid of vegetation and there are clear signs of erosion. Table 2 provides an overview over the extent of areas that, based on the visual analysis of the images, have been interpreted to be significantly impacted by recent human activity. As the numbers show, there is an increase in detectable wear from 2009 to 2014. In 2009, wear and erosion was detected in 1.7% of the total area analysed, which is comparable with the most damaged category of 2.4% from the classification (Table 1). In 2014, 2.2% of the analysed area showed signs of wear on or loss of vegetation (Table 2). The visual analyses show that human activity after 2009 has left marks. A new trail seems to have been established up the slope towards one of the two standing buildings, and patches of vegetation have been removed in the vicinity of the standing buildings and the house foundations.

The results from the ground-based survey concurred with the results from the image analyses in showing that the most severe wear on vegetation generally occurred in the proximity of prominent cultural heritage features or along the access routes to these features. Visitors to London clearly, and not unexpectedly, congregate around the more striking and visible structures and objects. Walking, trampling and even kicking the ground has left a mark in the form of visibly worn vegetation, patches without vegetation and areas where the top layer of soil has been disturbed. The recent disturbances noted in the 2014 image did encompass a new trail up the slope towards one of the remaining houses. In addition, there were traces of something heavy being dragged through wet areas just above the shoreline, the vegetation and top layer of soil removed or kicked loose in several places nearby a house foundation and partially buried objects had been removed from the ground near the two standing buildings. A multitude of trails have formed along the main access routes from the shore to the features, between features and up to elevated vantage points around London.

Generally speaking, signs of walking, trampling and other traces of recent human activity were observed over large parts of the cultural environment. The ground-based surveys made it clear that human activity has had an impact throughout London. In this respect, the results from the visual analyses of the images do not totally reflect the actual situation in London. Both the image analyses and the surveys made it clear that substantial areas surrounding various features in London have been impacted by recent human activity, but signs of widespread wear were not apparent in the images. For instance, the vegetation on the plateau on which the two remaining houses are situated show signs of wear, but fixing the limits or evaluating the degree of wear based on a visual analysis of the images proved somewhat difficult. What the image analyses have highlighted are areas within the cultural environment where visitors have had a significant impact on the vegetation cover. In addition to documenting traces of recent human activity throughout London, the ground-based surveys made it clear that the degree of impact is not only connected to human activity and the rising number of visitors; the type of vegetation, the type of soil, topography, the presence of water and melt water are important factors. For instance, the impact of walking and trampling is more severe in some parts of the cultural environment because of melt water or generally wet conditions. Other vulnerable areas are the access route to the plateau as that crosses an area of fine-grained soil/sand with thin Dryas tundra and moss-dominated tundra vegetation which has low resistance to trampling.

London – a changing cultural environment

The results from the classification and analyses of image data and the ground-based surveys have provided evidence for stating that London as a cultural environment has undergone significant changes since 1990. London is known to be popular tourist destination and the number of visitors has risen in the last decades.[43] Our study clearly indicates that increased human activity in the last decades has had an impact on the cultural environment. The vegetation analyses, that is the analyses of the remote sensing images, have shown a marked increase in worn and damaged vegetation from 1990 to 2009 (Figures 3, 4(a)–4(c) and Table 1). The vegetation data gathered during the ground-based survey also points in the same direction. The plant cover analysis (Figure 2) shows that access routes up the slope, which are areas with a high amount of human traffic, are largely devoid of vegetated areas. Further tests (Figures 5 and 6) have shown significantly reduced plant vitality along these paths.

The visual analyses of the images show the same tendencies, although not to the same degree (Table 2). The difference between classification and visual detection of the most damaged vegetation in 2009 (2.4% versus 1.7%) is not large since the first is pixel based on an automatic unsupervised classification on the RGB-NIR, while the other one is drawn by vector-based visual analysis of the RGB image, which can explain the difference. In addition, the NIR band contribute to detection of reduced vitality and wear on vegetation (health status) not or hardly visible to the human eye and in RGB only.[44] It should also be noted that the visual analyses of images only cover the 5-year period from 2009 to 2014, while classification and analyses of vegetation covers a period of almost 20 years prior to 2009. The ground-based survey made it clear that traces of recent human activity in the form of worn or patched vegetation can be found throughout the cultural environment, although visitors obviously centre their attention on the two standing buildings as well as other highly visible remains of the marble mining operation in London.

Viewed together, the results from the image analyses and the ground-based survey clearly indicate a gradual and ongoing deterioration of the vegetation cover in London, especially in areas surrounding the popular cultural heritage features. For instance, erosion on the slope up towards the eastern side of plateau where the two standing buildings are located has become more pronounced during the period from 1990 to 2014. The edge of the plateau is also eroding to the south (facing the ocean), but human traffic is a clearly a contributing factor to the extensive erosion on the eastern side of the plateau. Our general impression of London as a cultural environment is that the site is vulnerable to impact from a combination of natural and anthropogenic-induced processes. Natural processes known to be a general threat to cultural heritage in Svalbard[45] are also at work in London. Site formation processes include wind, frost action, snow accumulation, melt water, fluvial action and, as mentioned, landslide erosion is apparent along the southern part of the plateau. Rust, rot, mould and fungal growth are also contributing to a continuous degradation of the remaining structures and objects. In addition, animal activity (reindeer, polar bears, geese) is a potential threat. The impact of recent human activity on the cultural environment as a whole is, however, significant and very visible.

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[43]Roura, *The Footprint of Polar Tourism*; Hagen et al., "Managing Visitor Sites".
[44]Tucker, "Red and Photographic Infrared"; Lillesand et al., *Remote Sensing and Image Interpretation*.
[45]Barr, "Arctic and Antarctic"; Sandodden et al., *Kulturminneplan*.

Previous studies have shown that there are numerous small changes taking place that affect cultural heritage in London. Repeat photography has showed that a multitude of changes occur on the structure level.[46] Common *in situ* changes are rearranged positions of objects, but also fragmented or otherwise damaged objects caused by human activity, although weather and frost activity can have the same effect. Even so, none of the major features in London appeared to have changed substantially over the decade covered by the survey, although that assessment could not be assumed to hold for the entire cultural environment.[47] Results from our study indicate that overall, ongoing changes in London are rather encompassing. Natural erosion processes combined with wear caused by human activity are gradually damaging the vegetation cover, particularly in the vicinity of cultural heritage features and along access trails to these features. We have shown that recent human activity has had significant negative impact on the cultural environment, and that human activity is a significant contributor to change in London. Thus, it is likely that our results reflect the increasing number of tourists visiting London since the earliest image was taken in 1990 prior to the onset of "mass" tourism. Natural site formation processes are continuously at work, but our results indicate that the many visitors have contributed to a higher rate of deterioration than would otherwise have occurred from natural processes alone. Visiting London today, the worn vegetation and bare patches around the major features is apparent, as is the erosion along the main access routes and the edge of the plateau. Over time, the cumulative effect of these changes may result in significant site transformation that in the long term may adversely affect the cultural heritage values in London.

Conclusion

London as we see it today has been shaped by natural processes and human activity. The Svalbard Environmental Protection Act provides cultural heritage in Svalbard with a strong legal protection. According to cultural heritage management authorities, it is, however, neither possible nor desirable to protect all cultural heritage from the effects of natural processes.[48] Measures should rather be implemented to counter or slow down the impact of such processes in order to protect selected and uncommonly valuable cultural environments. The user aspect and the opportunity to experience cultural heritage is by management authorities regarded as an important part of the value of cultural heritage.[49] With this in mind, as long as tourism is an acceptable and even desired use of cultural heritage in Svalbard, it follows that it is acceptable that tourism may be a contributing factor to site transformation and degradation. In our opinion, it is therefore important to document what is happening and to understand why it is happening. London as a cultural environment is changing, and visitors during the last 25 years have played a part in that transformation. The extent of the changes in London in recent years underscores the importance of monitoring. It is necessary to establish long-term systematic monitoring programmes of selected cultural environments in order to be able to track and explain the quantitative and qualitative changes that are occurring in Svalbard. Our study is

[46]Roura, *The Footprint of Polar Tourism*.
[47]Ibid.
[48]Sandodden et al., *Kulturminneplan*.
[49]Riksantikvaren, "Kulturminne og kulturmiljø".

based on a multi-scale and multidisciplinary approach where high-resolution remote sensing images have been used in combination with ground-based surveys to form a comprehensive assessment of London as a cultural environment.

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