MONITORING CULTURAL HERITAGE ENVIRONMENTS IN SVALBARD: SMEERENBURG, A WHALING STATION ON AMSTERDAM ISLAND

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ABSTRACT

Cultural environments are not static and unchanging, they are subject to a number of site transformation processes. Environmental hazards and human activity are among the primary degradation parameters for cultural heritage in Svalbard. The objective of this contribution is to demonstrate the potential advantages of utilising remote sensing for mapping and monitoring cultural heritage in a high arctic environment such as Svalbard. Our data illustrate how various factors associated to an underlying site transformation impact a cultural environment in Svalbard. Furthermore, our findings are a basis for some clues regarding the use of vegetation as a potentially suitable indicator for cultural heritage monitoring.

We utilised digital aerial photographs (NIR-R-G) and scanner data including the Vexcel Ultracam sensor (RGB-NIR), WorldView-2satellite imagery, RGB data from an Unmanned Aerial System (UAS). Ground-based surveys included vegetation cover and species composition analysis. There were differences concerning the various sensor abilities to detect the full range of structures and objects within the cultural environment in Smeerenburg. This performance was highly dependent on image resolution, the character of the structures and objects, as well as the vegetation.

Our data provide strong indications that Smeerenburg as a cultural environment has been impacted by both environmental and anthropogenic processes linked to the site formation since 1990. Using vegetation indices *NDVI* and a greenness index, this study showed a decrease and damage on vegetation during the period 1990-2014. Indirectly a pressure on the cultural heritage could be detected, especially around and on the structures. The impact on the cultural environment in Smeerenburg was primarily attributed to coastal erosion, wind, sand drift, trampling and other damage by tourists. The impact from natural hazards such as erosion and sand drift is readily apparent throughout Smeerenburg, but human activity has contributed to the cumulative impact on structures and objects. The wear and tear by tourists to the vulnerable Arctic vegetation and cultural heritage features are exacerbating an ongoing degradation of Smeerenburg as a cultural environment.

We focused on vegetation as a potential useful indicator for cultural heritage monitoring in Svalbard, and we found that data describing the state of the vegetation and the factors that impact the vegetation can provide valuable information for threat and vulnerability assessments and for assessing the state of the cultural environment as a whole.

KEYWORDS

Svalbard, Smeerenburg, cultural heritage, vegetation, monitoring methodology, aerial and satellite imagery, UAS.

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INTRODUCTION

The Svalbard Archipelago was discovered in 1596 by the Dutch explorer Willem Barentsz. In subsequent years, extensive exploration and exploitation of natural resources have left a multitude of traces throughout the Archipelago. Traces that nowadays are considered cultural heritage. According to the Svalbard Environmental Protection Act all traces of human activity in the physical environment, including sites associated with historical events, are cultural heritage (1). Areas where elements of this cultural heritage form part of a larger entity or context are designated cultural environments. The Act provides cultural heritage a strong legal protection as all cultural heritage in Svalbard predating 1946 is automatically protected by law (2) which entails that no one may cause or risk destruction of, damage to or any alteration of protected sites, structures and objects (3).

The Norwegian national cultural heritage database, Askeladden, currently contains information on 2115 sites located throughout the Archipelago (4). These cultural environments are reminiscent of four centuries of human history; from European whaling in the 17th century, Russian and Norwegian winter hunting and trapping in the 18th and 19th and in the 19th and 20th century, respectively, and the scientific exploration efforts and industrial ventures in the late 19th and early 20th century. As the cultural heritage protection timeframe starts in 1946, thus objects and structures affiliated with the Second World War are also automatically protected.

Cultural environments are not static and unchanging; indeed, sites, structures and objects are subject to a number of site transformation processes. Environmental hazards such as coastal erosion, wind wear and tear, sand drift, flooding, thawing permafrost and bio-deterioration processes are well-known threats to Svalbard's cultural heritage (5,6). Also, damaged protected structures are known to be impacted by the transit of polar bears. Lastly, human activity may have a major impact of cultural heritage remains due to walking or trampling (5,6,7). Human impact is primarily linked to tourism activities driven by seasonal cruises.

The first cruise carrying tourists to Svalbard was organised as early as 1871 (8), and since 1990 the number of tourists has increased significantly due to development policies supported by the Norwegian Government (9).

Tourism is now one of the principal human activities on many sites if not the principal human activity (7). The harsh environmental conditions and increasing human activity mean that cultural heritage management in Svalbard is a challenging endeavour. This situation is further exacerbated by the lack of information regarding the current and long-term state of cultural heritage throughout the Archipelago. Likewise, Norwegian authorities have pointed out the need to improve methodologies for monitoring cultural heritage in Svalbard (10).

Cultural Heritage in Polar Regions. Natural and human impact on cultural heritage sites and environments (CULPOL) is a research project aimed at improving current methodologies for monitoring cultural heritage in Svalbard through a cross-scale and multidisciplinary approach based on data acquired through remote sensing and ground-based surveys. A central scientific question in this study is the current and long-term assessment of the state of cultural heritage. Another major motivation for our research is the development of indicators that can be applied in a long-term monitoring programme. Since Svalbard and the high Arctic are remote areas of difficult access, the use of remote sensing techniques is highly suitable for detecting and monitoring changes on cultural heritage at different spatial scales. However, this approach has never been attempted in these environments before.

Aerial photographs, very high-resolution satellite images (11) and Unmanned Aircraft Systems (UAS) (12), which have successfully been used in the past for mapping vegetation and wear/damage on vegetation in Svalbard, is also applicable to cultural heritage monitoring (13,14). Another, not unimportant factor is that the use of remote sensing provides an opportunity to carry out research and long-term systematic monitoring that minimizes the environmental footprint of such activities in sensitive Arctic ecosystems.

This study is primarily focused on mapping and monitoring a cultural environment in Svalbard rather than single structures or objects within a cultural environment. Also, the intention of this study is to examine different impact factors affecting the cultural environment. The objectives of this particular study are to assess the performance of different UAS-based sensors to (a) detect structures within a cultural environment as well as their status, and (b) to assess the impact on cultural heritage based on vegetation indices.

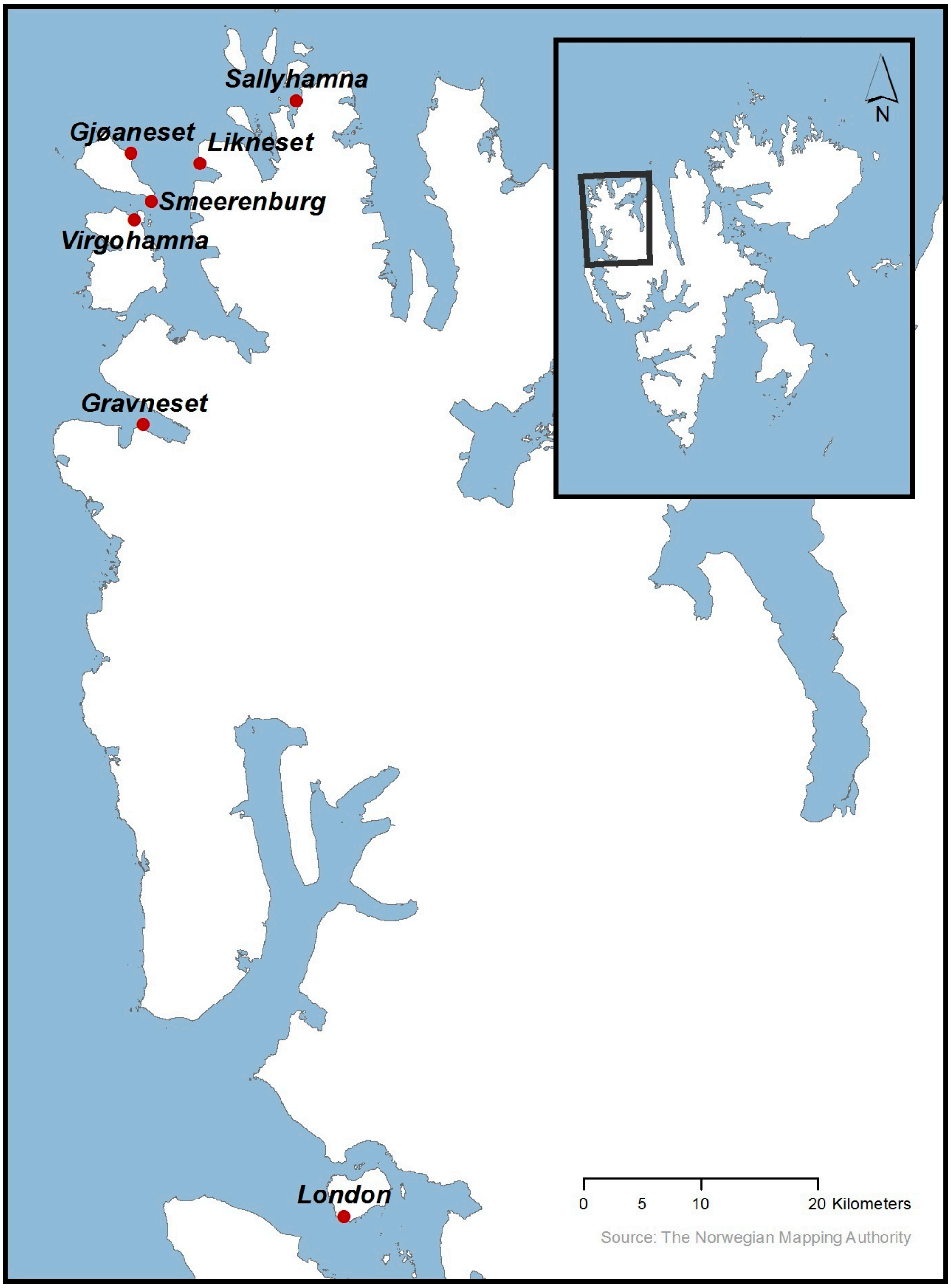

Figure 1: The research project CULPOL focuses on seven cultural environments encompassing cultural heritage covering the range of human history in Svalbard.

The study area Smeerenburg

Smeerenburg (79°40´N 11°00´E) is located on the south-eastern tip of Amsterdam Island in north-west Svalbard. The cultural environment is located in a beach landscape consisting of sandy shores with sparse vegetation dominated by mosses and crusts. The following vegetation types are represented: Creeping saltmarsh grass (*Puccinellia phryganodes*) communities and Moss-crust tundra communities characterized by *Saniona uncinata*, *Racomitrium canescens* and biological soil crust communities.

In the decades following the archipelago's discovery, Svalbard became a locus for European whalers (15). Initially, the whaling industry was land-based as whales were hunted in fjords and coastal areas, while oil was produced in cookeries close to shore. Smeerenburg (Figures 1 and 2), which literally can be translated as "blubber town", was the main base for Dutch whaling in the early 1600s. In 1614, a temporary whaling station was established by Noordsche Compagnie (Northern Company). Later in the 17th century Smeerenburg, a small settlement of around 200 inhabitants, was developed along with diverse structures including warehouses, workshops, residential buildings and a cemetery (15,16). Smeerenburg showed its largest civilization in the 1630ies followed by a decline when the whaling industry expanded into pelagic whaling. Despite the settlement abandoned around 1660, men who lost their lives to whaling were buried in Smeerenburg throughout the 17th and 18th centuries.

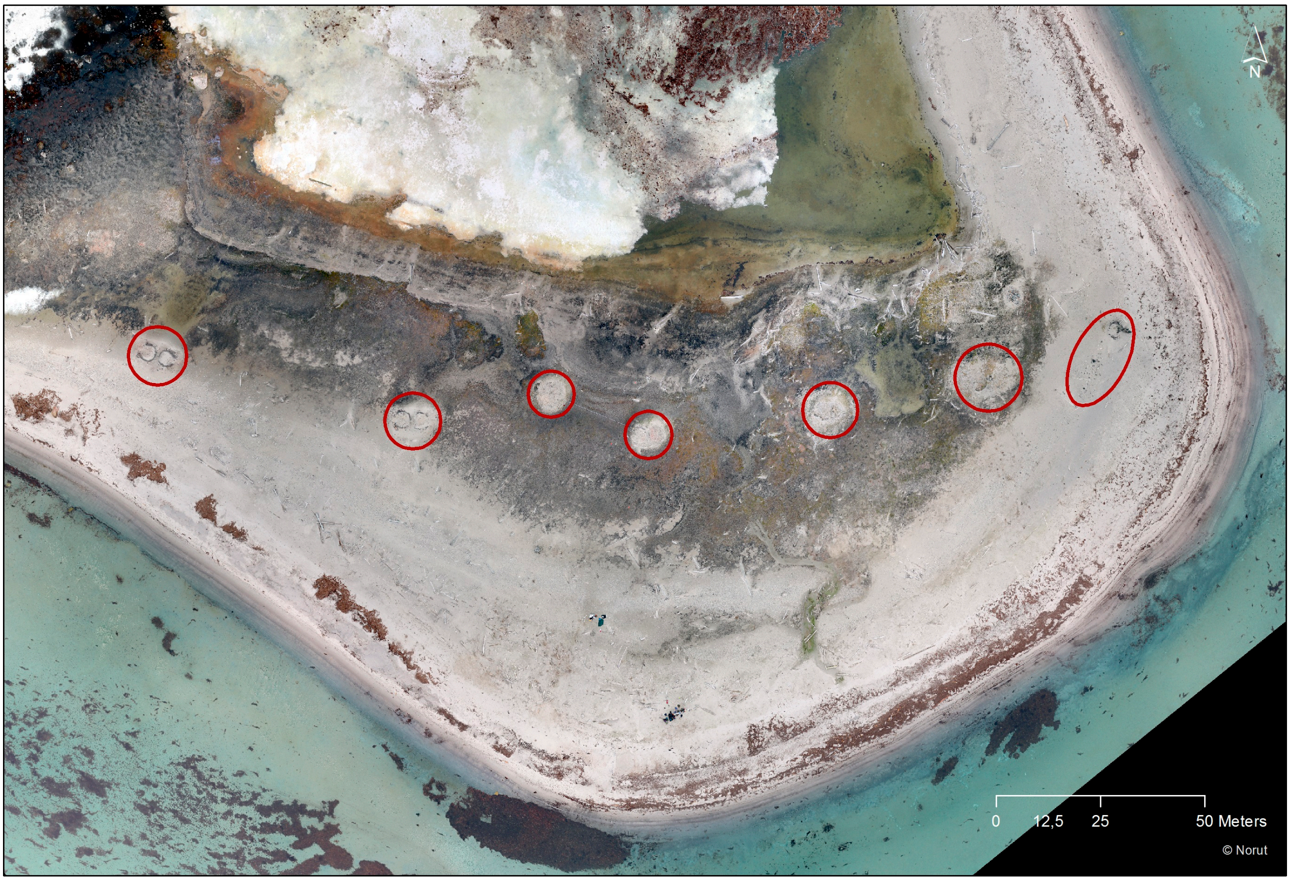

Figure 2: The remains of the tryworks for rendering oil, the so-called blubber ovens, are here outlined in red. The ellipse on the right marks an area where an eight oven has disappeared and another is well on the way to being destroyed by erosion. The image was acquired by UAS in July 2014.

Askeladden currently lists the remains of 19 houses and seven blubber ovens, six double ovens and one single oven, located in the beach landscape seen in Figure 2 (4). The listing also encompasses 101 graves located north of the whaling station. The blubber ovens and the graves are now the most visible remaining structures in Smeerenburg. The building remains, which are situated right behind and north of the remaining blubber ovens, are much less apparent due to the small size of the structures and the masking effect caused by the sand. The station location on a coastal shore means that the structures are exposed to coastal erosion. Also, our surveys showed that an eight oven present in 1928 was lost into the sea along with the buildings situated behind it due to coastal erosion (17).

The Svalbard Archipelago is a popular touristic destination for cruises touring the Arctic. With the exception of 2011, there has been a significant increase in both the number of people ashore and disembarkation sites since the mid-1990ies (18) (Table 1). Cultural heritage is one of the attractions in the settlements, which are the major stopping points, especially for the larger cruise ships. In that regard, the whaling station has become an increasingly popular destination since the mid-1990ies. Although there is variation from one year to the next, the statistics presented in Figure 3 (19) show that the overall trend has been an increase in the number of visitors since then.

Table 1: Cruise ship disembarkation sites in Svalbard and the total number of disembarkations.

	1997	1999	2001	2003	2004	2006	2008	2009	2010	2011	2012	2013	2014
People ashore	39109	36413	70067	71890	77866	99107	97704	101938	98232	86020	121189	136479	131286
Landing sites	76	111	139	163	164	164	160	163	166	177	209	221	195

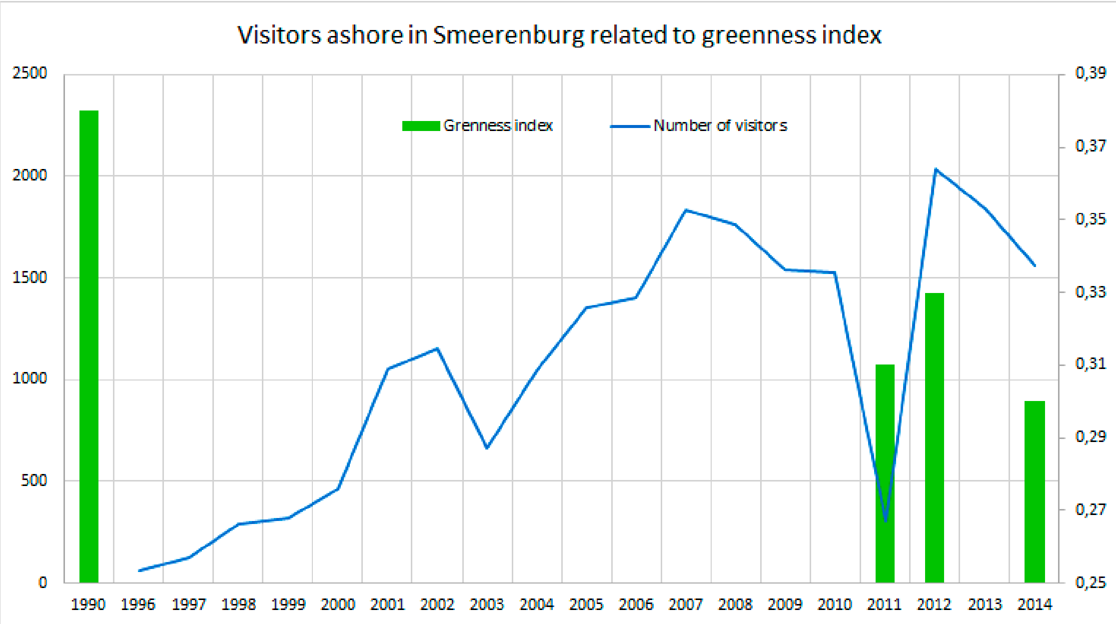

Figure 3: Visitors ashore in Smeerenburg in the time period 1996-2014 (19). The statistics are based on reported numbers from cruise operators and do not include people travelling privately or visiting for other reasons than tourism.

Generally speaking, environmental hazards, biological degradation, wildlife and human activity can be regarded as the primary degradation parameters for cultural heritage in Svalbard. Coastal erosion, sand drift, and wind wear and tear are the primary environmental impact factors in Smeerenburg. The consequences of coastal erosion are made quite clear when looking at Figure 2 where an area having one blubber oven has already been lost and another is on its way to be destroyed due to erosion. As the number of visitors to Smeerenburg has increased in recent decades (Figure 3), human activity has become an impact factor that must be taken into account.

METHODS

The cultural environments in Figure 1 were selected to ensure that our research encompasses a range of cultural heritage elements that are representative of various aspects of human history in Svalbard. In Smeerenburg, we find a high number of structures and objects reminiscent of whaling, especially the early phases of whaling during the first half of the 17th century. Another important criterion for selecting cultural environments was their exposure with respect to the impact factors known to threaten cultural heritage in Svalbard (5,6).

Mapping of cultural heritage objects was done based on aerial photographs (11), satellite images derived from high-spatial resolution sensors (WorldView-2 and UAS (Unmanned Aerial Systems) sensors, and ground-based surveys. Aerial and satellite measurements encompass three-band (NIR-RG) and four-band (RGB-NIR) imagery, respectively, with a spatial resolution of 50 cm (Table 2). The Vexcel Ultracam data is analogous to an aerial film image at a format of 23 cm × 15 cm, scanned at 13 µm. Aerial surveys were done with a Cryowing micro UAS (Figure 4) providing the basis for acquiring three-band images (RGB) from an altitude of 120 m above ground level resulting in a ground resolution of 2 cm. In sum, the remote sensing datasets used in this study cover a period of 24 years (Table 2), thus providing a basis for assessing site transformation and development trends since 1990.

Table 2: Specifications for the different remote sensors which provided data for our study of Smeerenburg. We also added the reflectance values for vegetation for the different sensors in order to adjust the different sensors and bands to each other.

Sensor	Date, year	Spatial resolution	Bands	$Channel\%_{green}$	NDVI	Average reflectance values (grey levels) for vegetation (original images)				Comments
						Red	Green	Blue	NIR	
Aerial photographs (digital)	17 August 1990	50 cm	NIR-R-G	0.33	0.17	116	108		164	Scanned film
Airborne Vexcel Ultracam sensor	22 July 2011	50 cm	R-G-B-NIR	0.34	0.24	81	82	76	133	
WorldView-2	15 August 2012	50 cm	R-G-B- NIR	0.34	0.15	98	85	86	132	Bands 2, 3, 5 and 7 + PAN The pan-sharpened version is applied in this study.
UAS RGB	8 July 2014	2 cm	RGB	0.37		107	102	63		Canon Powershot Resampled to 50 cm in reflectance analysis and RGB comparison analysis including $Channel\%_{green}$-index.

Since different sensors have different spectral and radiometric resolutions (20), images from different sensors were standardized for different land cover types (sand, ocean, vegetation) (Table 2) (20). For example, the red band of the aerial photograph from 1990 showed an increased red band value (grey level: 116) compared to the Ultracam (grey level: 81) and WV-2 (grey level: 98) imagery. This can mainly be attributed o the quality of the film and the scanning. The comparisons of spectral curves and responses showed that the differences between sensors are much less for sand and ocean which means that only the red band had to be adjusted for the different sensors. We used WV-2 as the master sensor since this image is better calibrated by the producer than the other sensors (20).

The remote sensing data were visually examined and analysed based on two different vegetation indices, the Normalised Difference Vegetation Index *(NDVI)* and the greenness index $Channel\%_{green}$ in order to detect and map both environmental and human impact within the cultural environment. The latter one was used in order to link the RGB imagery with the *NDVI* imagery. The definition of *the* $Channel\%_{green}$-index (21) is as follows:

$$Channel\%_{green} = Channel_{green\text{-}DN}/(Total\ RGB_{DN}).$$

This greenness index is considered to be a good proxy and descriptor for *NDVI* ($R^2 = 0.62$, significance level $p<0.001$) and has been used in different environmental studies (21,22). Regarding the 1990-imagery; the red band is used as a proxy for the blue band due to lacking blue band for this image.

As impact from human traffic (predominantly tourists) was a concern, a transect was set between the blubber ovens and perpendicular to the recommended visitor track outlined in Figure 5a. *NDVI* values and the $Channel\%_{green}$ values from the different years/sensors were extracted along a transect outlined in Figure 5a, as a basis for assessing eventual environmental change along this transect.

Figure 4: Pre-flight inspection of the UAS-system in Smeerenburg. Photo: Elin Rose Myrvoll, 2014.

The ground-based surveys, which include vegetation cover and species composition analysis, supplement and validate the remote sensing data and provide additional information for assessing the current preservation status of the cultural heritage as well as its threats and vulnerability. The ground-based surveys were also vital for assessing the current state of the various structures and objects throughout the cultural environment.

RESULTS

Vegetation change indices

The sparsely vegetated moss-crust tundra found in Smeerenburg is very sensitive to walking and trampling. The creeping saltmarsh grass community is less sensitive but only covers a small portion of the study area and the transect where the ground measurements were taken. In Figure 5a, the green or greenish areas are partially composed of creeping saltmarsh grass (*Puccinellia phryganodes*), while the dark grey and dark green areas are crust and mosses. In order to analyse the vitality of the vegetation, *NDVI* and $Channel\%_{green}$ values were extracted along the transect outlined in Figure 5a. Images showed trends indicating reduced vegetation cover (moss-crust tundra) due to wear on the vegetation within the study area. Wear is apparent especially on and around the double oven on the left part of the transect (Figure 5a). In Figure 5b, we present the same transect superimposed on the RGB image obtained in 1990. In this case, the vegetation is intact and the greenness is higher with respect to the images obtained in 2014 (Table 3). Also, the fraction of vascular plants and mosses seems to be higher in 1990 (Figure 5b) with respect to 2014 observations (Figure 2 and Figure 5a). The high coverage of crust communities (27%) and sand (45%) indicates fairly large-scale wear or damage to the vegetation along this transect (Figure 6). The vegetation in Smeerenburg is very sparse, thus the *NDVI* values extracted from the different imagery acquired in the period 1990 to 2014 are very low (Table 3).

The *NDVI* values for the transect show a decrease from 0.15 in 1990 to 0.12 and 0.11 in 2011 and 2012, respectively. The same patterns were found for the $Channel\%_{green}$ regarding the 1990 (0.38), 2011 (0.31) and 2014 (0.30) images. Conversely, the greenness index for 2012 was slightly higher (0.33) with respect to 2011 (0.31) but smaller than that extracted from the images obtained in 2000.

Smeerenburg has become a more popular landing site for cruise ships travelling around Northwest Svalbard. The reduction of the greenness index ($Channel\%_{green}$) coincides with higher numbers of visitors since the mid-2000s (Figure 3).

Table 3: Brightness changes along the transect shown in Figure 5a. Averages of different band values (grey levels, R, G,B NIR), NDVI and $Channel\%_{green}$ *for the period 1990-2014.*

Year	Sensors	R	G	B	NIR	*NDVI + StDev*	$Channel\%_{green}$ + *StDev*
1990	NIR-imagery	104.58	128.12		140.66	0.15 +/- 0.02	0.38 +/- 0.003
2011	Vexcel Ultracam	106.87	93.67	109.72	135.33	0.12 +/- 0.03	0.31 +/- 0.003
2012	WV-2	91.64	93.22	98.12	114.74	0.11 +/- 0.03	0.33 +/- 0.001
2014	UAS RGB	93.70	80.62	88.66			0.30 +/- 0.002

We compared the *NDVI* values and the $Channel\%_{green}$ values along the transect in Figure 5a extracted from the Ultracam image from 2011 and the WV2 from 2012, and the relationships were reasonably good (R^2=0.56, p<0.001 and R^2=0.58, p<0.001, respectively). The relationship, however, between *NDVI* and the $Channel\%_{green}$ values for the aerial NIR-R-G-image obtained in 1990 was weaker but significant (R^2= 0.10, p<0.028).

Figure 5a: A RGB image from Smeerenburg acquired by UAS in July 2014. Vegetation acquired by UAS in July 2014. Vegetation is indicated by grey patches and areas of soil and sand are shown in light grey. The red arrows indicate wear on and around the blubber ovens, while the dotted red line encircles an area of worn vegetation. The white line marks the transect compared with other images in this study.

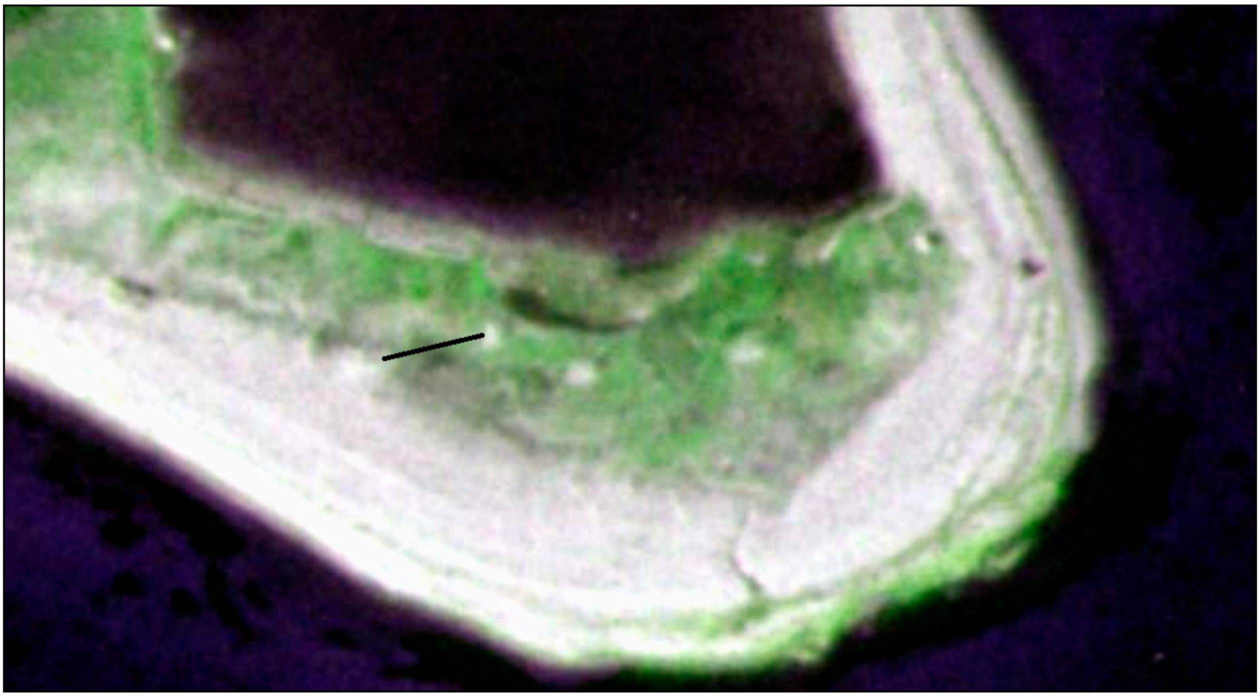

Figure 5b: The black line indicates the same transect as in Figure 5a. A RGB-image from 1990 is placed in the background.

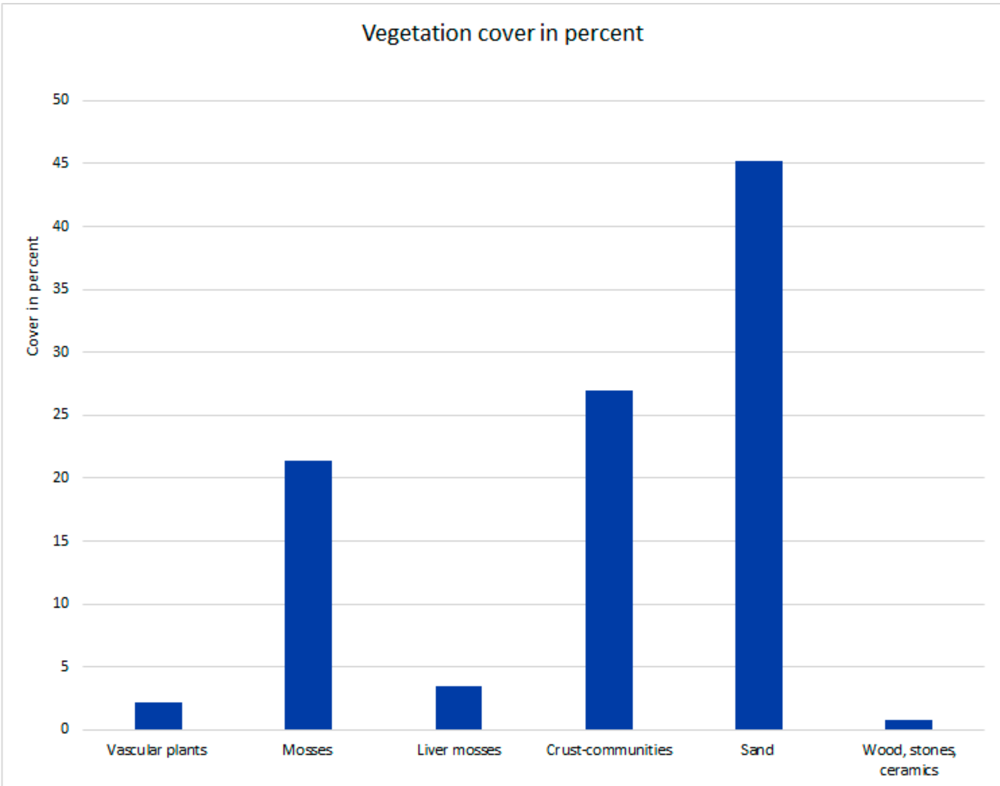

Figure 6: The vegetation and soil characteristics cover along the transect outlined in Figure 5a.

The feasibility of optical remote sensing to detect individual structures and objects within a cultural environment is important for mapping and monitoring purposes. In Smeerenburg, features such as the remains of blubber ovens, were easily detected by all sensors (Table 4 and Figures 7 and 8). However, the blubber ovens and graves appeared somewhat more blurred in the NIR imagery from 1990 (Figures 5b and 8). The graves were also difficult to pinpoint in the panchromatic WV-2 image but they appeared more clearly in a pansharpened multispectral WV-2 image. The widest range of cultural heritage was identified in the 2011 and 2014 imagery. Although the building remains are generally difficult to detect, several house structures were identified in these images. An overview of structures detected by the remote sensing sensors in Smeerenburg is shown in Table 4.

Figure 7: The remains of tools used for rendering oil in Smeerenburg. The oven depicted here corresponds to the oven on the right in Figure 6a.

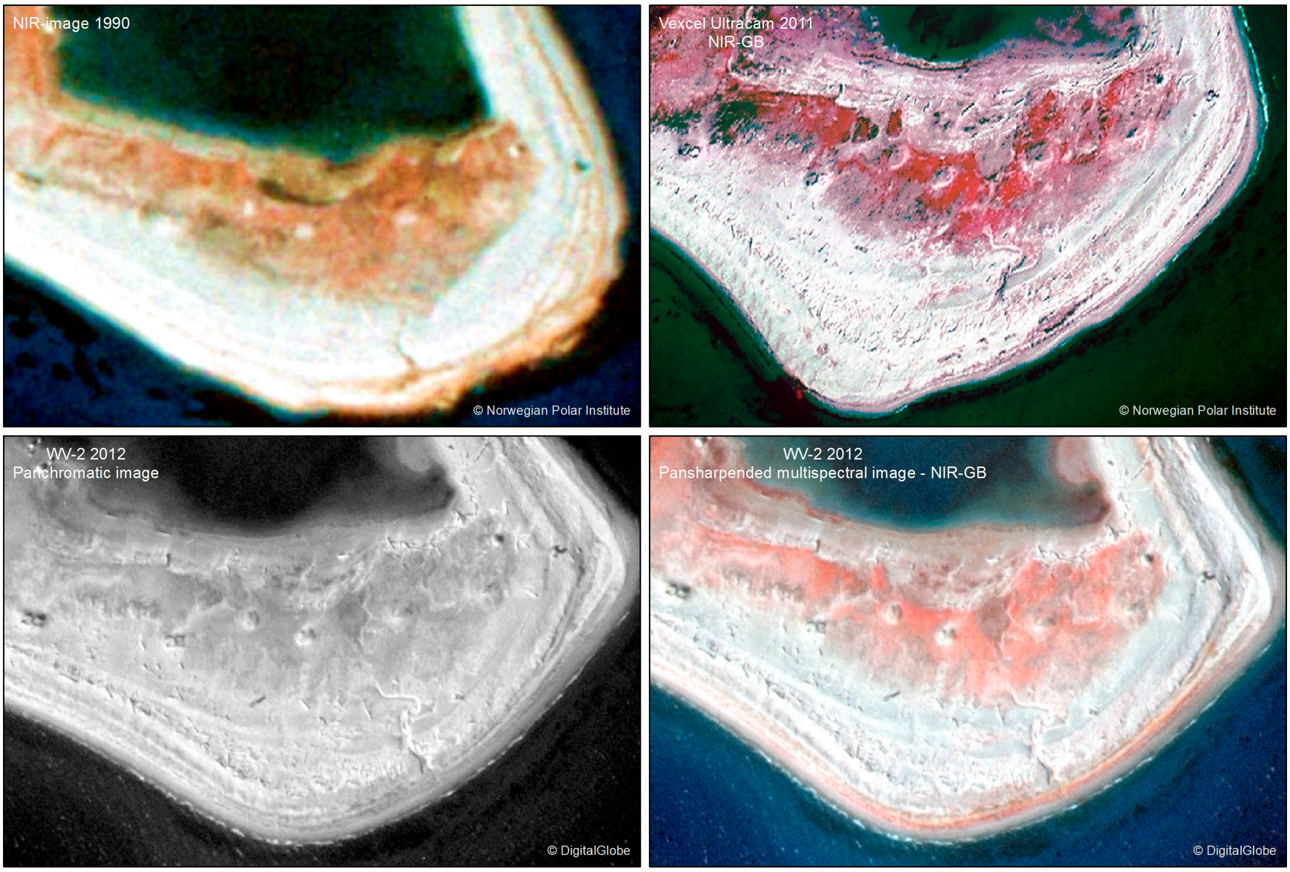

Figure 8: Selected images for 1990, 2011 and 2012 showing the adjacent area around the whaling station. Structures and objects which are not detected or difficult to detect in the 1990 image appear clearly in the 2011, 2012 and 2014 imagery (see Figure 2).

Table 4: The potential of the imagery to visually detect different cultural heritage in Smeerenburg. +: An obvious feature was visible in the image; −: No obvious feature could be observed in the image.0 = locations not covered by the UAS imagery.

Year	Sensors	Spatial resolution	Blubber ovens	Building remains	Graveyard	Graves
1990	NIR-imagery	50 cm	+	-	+/-	+/-
2011	Vexcel Ultracam	50 cm	+	+/-	+	+
2012	WV-2	50 cm (PAN)	+	-	+/-	+/-
		50 cm MUL - pansharpened	+	+/-	+/-	+/-
2014	UAS RGB	3-5 cm	+	+	0	0

DISCUSSION AND CONCLUSIONS

Our data and results provide strong indications that Smeerenburg has been impacted as a cultural environment by site formation processes during the time period covered by our data. Studying both the RGB and *NDVI* imagery for different years, it was found that sand drift and coastal erosion are the primary impact factors of cultural heritage in Smeerenburg. In this area, it might thus be difficult to discriminate human from environmental impact based on remote sensing images.

However, the reduced *NDVI* and greenness indices covering the period 1990-2014 indicate that remote sensing data are valuable for monitoring cultural environments such as Smeerenburg. Also, the *NDVI* imagery agreed with the experiments made in Adventdalen in Svalbard (12) where wear on vegetation caused by snowmobiles (snow-scooters) was associated with low *NDVI* values and a general reduction of the cultural heritage.

The weak relationship (R^2= 0.10) between the *NDVI* and the $Channel\%_{green}$ index for the 1990 image was probably related to the variable quality of the NIR-film as well to problems associated with the digital scanning of the film, hence care should be taken when utilising this kind of scanned imagery. However, the $Channel\%_{green}$ index is still a good proxy for the *NDVI* if suitable imagery are not available and the imagery are acquired using proper digital sensors or cameras (22).

In this case, $Channel\%_{green}$ values were relatively high (0.33) with respect to values derived from the Ultracam sensor (0.31) and taken the year before. This is possibly due to the WV-2's enhanced radiometric resolution and dynamic range of 11 bits per pixel and/or its capability of recording other spectral bands (bandwidths/spectral ranges) than the other sensors. - Thus, care should be taken to compare different sensors (21,22). Discrepancies between WV-2 and Ultracam images may also be attributed to different acquisition dates; Indeed, the Vexcel Ultracam image and the UAS RGB image were acquired earlier in the summer (July) than NIR and WV-2 images (August) (Table 2). However, this is unlikely as "evergreen" mosses are the dominant vegetation communities in the study area (Figure 5). Also, this community emerges from the snow in early spring and is apparently associated with peak greenness (23). Thus, the phenological stage is considered to be a minor factor explaining image differences in this area.

Conversely, the *NDVI* values which showed a slight decrease from 2011 to 2012 indicate that *NDVI* is a better indicator with respect to the $Channel\%_{green}$ index which agrees with the results reported by Westergaard-Nilsen et al. (22).

The influence of natural site formation processes such as erosion and sand drift was clear in our data. Also, the impact of human activity was visible at to varying degrees and impacted not only the environment in which the remains of the whaling station were located but also the surrounding structures and objects. Wear is apparent especially on and around the double oven on the left (Figure 5a). As shown previously, the high coverage of crust-communities (27%) and sand (45%) in areas along the transect between two blubber ovens indicate worn or damaged vegetation. This indicates that significant parts of the cultural environment in Smeerenberg is impacted. Lack of vegetation or worn vegetation in the area surrounding the different structures may represent a change in the overall state of the cultural environment indicated by the reduction in *NDVI* and $Channel\%_{green}$ values since 1990 (Table 3). Also, the loss of vegetation may contribute to the observed increase in erosion and sand drift, and a further degradation of archaeological structures and objects.

There were some significant differences regarding the ability of various sensors to detect the full range of structures and objects within the cultural environment. The spatial resolution was a key factor, as UAS-borne sensors had a superior performance for identifying a wide size range of cultural heritage objects in Smeerenburg. The 50 cm resolution of the 2011 and 2012 imagery provided satisfactory results for major structures within the cultural environment. Conversely, the NIR imagery corresponding to 1990 and having a spatial resolution of 50 cm were not satisfactory to map structures partly due to the fact that measurements were based on scanned imagery.

Our ability to map the various structures and objects in Smeerenburg was also influenced by size, shape, building materials, vegetation cover or lack of vegetation cover and depended on whether structures or parts of structures were covered by sand or partly eroded. The blubber ovens were easy-to-detect features regardless of the sensor used. This is not surprising as these structures are quite large and regular (i.e. the ovens form an easily recognisable pattern). Another important factor underlying the high visibility of the blubber ovens was the presence or lack of vegetation (Figure 7).

Equally important are methodological advances regarding remote sensing methods for archaeological purposes. Effective automatic procedures for detecting cultural heritage have yet to be developed, but semi-automatic approaches and/or enhancement techniques have provided quite satisfactory results, keeping in mind that their performance has repeatedly proved to be “site- specific” or “feature-specific” (14).

Our results provide strong indications that the cultural environment has been impacted by both environmental and anthropogenic site formation processes since 1990. The impact from natural hazards such as erosion and sand drift is apparent, but human activity has also contributed to the cumulative impact on structures and objects as well as on the surrounding vegetation. Impact due to wear and tear was substantial along the recommended visitor track (Figure 5a). This is reasonable as visitors of cultural environments in Svalbard tend to congregate around the more visible and striking features of interest within the cultural environments (9). In the open beach landscape of Smeerenburg, the blubber ovens are highly visible and natural attraction points for visitors. Although difficult to perceive, the blubber ovens are quite fragile structures. People walking through or standing on the ovens, or even removing fragments of the ovens, may easily contribute to further erosion.

In this study, vegetation was studied as a potential useful indicator for cultural heritage monitoring in Svalbard. It was found that vegetation condition and factors impacting vegetation can provide valuable information to assess threat and vulnerability of plant communities and determine the state of the cultural environment as a whole. Worn and patchy vegetation or denser vegetation on structures as well as in the areas surrounding cultural heritage features may represent a significant change for the overall state of a cultural environment. In Smeerenburg, the combined impact of coastal erosion, sand drift, and wear and tear caused by visitors to both vegetation and cultural heritage are processes contributing to the deterioration of the cultural environment.

Monitoring programmes incorporating remote sensing and using vegetation as an indicator have a potential to be a significant contribution to cultural heritage management in Svalbard. Our study underlines the value of site-specific data for assessing vulnerability and impact factors. Long-term monitoring is essential to better understand the ongoing site transformation and the relationships between various environmental and anthropogenic impact factors. Smeerenburg and other cultural environments studied by the CULPOL project will be the focus of further investigations using image classification and change detection techniques and visual methods in the future.

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