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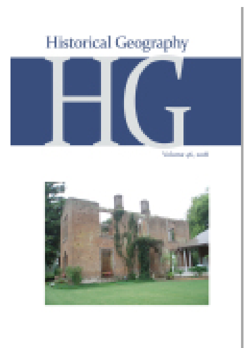

Matthew Bampton, A. R. Kelley, J. T. Kelley

Historical Geography, Volume 46, 2018, pp. 129-150 (Article)

Published by University of Nebraska Press
DOI: *https://doi.org/10.1353/hgo.2018.0028*

THE HYPERLOCAL GEOGRAPHY OF CLIMATE CHANGE IMPACTS

Long-Term Perspectives on Storm Survivability from the Shetland Islands

MATTHEW BAMPTON,
UNIVERSITY OF SOUTHERN MAINE

A. R. KELLEY,
UNIVERSITY OF MAINE

J. T. KELLEY,
UNIVERSITY OF MAINE

ABSTRACT: Climate histories are frequently modeled on hemispheric, ocean basin, or continental scales. Human impacts are local, varying significantly over small scales of space and time. Geographical differentiation of impacts between sites separated by a few tens of meters can have significant and enduring consequences. Archaeological, archival, cartographic, and sedimentological evidence, cross-scale analysis of regional climate trends, and simulation mapping of individual weather events offer novel perspectives on survival versus destruction at the hyperlocal scale, with relevance to current debates about climate change impacts. Shetland, north of Scotland, has had continuous human occupations for over six thousand years, where settlement has waxed and waned due to the complex interplay of cultural and environmental factors. Against general trends of both continuity and change, local exceptions stand out that illustrate extreme variability at the local scale. This paper focuses on the township of Broo destroyed by blowing sand in the late seventeenth century. In contrast, adjacent communities survived and flourished. Increased storminess, abundant sediment supply, and vegetation removal precipitated Broo's destruction. Local variations in landscape morphology influenced patterns of wind flow and sand deposition during storm events, creating localized effects that heavily impacted Broo. Reconstruction of Broo's historical borders, and analysis of place-names, farm locations, and archival records show that some inhabitants of the township adapted to the environmental challenges, relocated, and remained on the land. This pattern of resilience in the face of environmental change is visible in other locations in the region.

KEYWORDS: *little ice age, sand inundation, resilience, climate change, Shetland*

INTRODUCTION

Models of changes in the state of natural systems are necessarily made on regional and decadal scales of space and time, as the granularity of landscape markers obscures finer levels of detail. On the very broad scale the designation of the current geological epoch as the Anthropocene by the International Geological Congress is derived from global, hemispheric, ocean basin, and regional-scale environmental changes supported by evidence retrieved from geochemical, fossil, biological, and archaeological proxies.[1] Finer level markers can be seen from more localized events and processes: the eruption of Mount Tambora in 1815 resulted in an anomalous cold summer in 1816 that devastated farming communities worldwide.[2] However, human experience of environmental change frequently occurs on much finer scales of time and space. Technological developments and improving sensor networks continue to refine the spatial and temporal granularity at which important environmental changes can be analyzed. However, the few hours during which a storm passes over a region can have significant differential impacts measurable in minutes and meters. These hyperlocal short-term variations often fall below the resolution of broader models of change, and yet it is at this scale that important parts of the lived human experience occur, key human decisions are made, and lasting societal outcomes are determined. Human social processes at these scales can in turn feed back into natural systems. Untangling societal-environmental linkages by cross-tabulating data from archaeologists, historians, and earth scientists can "generate new research questions and insights, challenge facile interpretations, revise existing narratives, and identify tipping points in socio-environmental systems."[3]

Between the mid-sixteenth and mid-nineteenth centuries, during the little ice age (LIA), northern Europe experienced many closely coupled environmental and cultural changes. However, establishing causal links between the two sets of processes is challenging, particularly during the pre- and early-instrumental periods (prior to AD 1659 for the British Isles).[4] Climate reconstructions based on proxies, however accurate, are aggregated in time and space, and the complex drivers of social, cultural, and economic changes defy simple explanation. Yet systematic analysis indicates strong links between LIA climate changes and cultural impacts: individual weather events and seasonal patterns differentially impacted some communities and some people within those communities. When confronted with an environmental challenge, survival or failure was determined by varying levels of human competence and varying locational advantage. Small differences in individual circumstances had lasting impacts and complex knock-on effects. For example, in discussing central Europe, Pfister and Brázdil note,

> Under the conditions of the Little Ice Age climate, two kinds of impacts were detrimental for agriculture in western and central Europe. Long wet spells during the harvest period had the most devastating impact. Continuous rains lowered the flour content of the grains and made them vulnerable to mold infections and attacks of grain weevil. . . . Besides long spells of rain in midsummer, cold springs did most harm to grain crops. From present-day agro-meteorological analyses it is known that grain yields depend on sufficient warmth and moisture in April. . . . [T]his implies that crops suffered from dry and cold springs, which were frequent during the Little Ice Age.[5]

Developing richly detailed studies of the interplay between the two can facilitate unpacking the complex interactions between human and environmental processes providing useful case studies of some of these interactions, serving as "completed experiments" that allow us to map the feedback loops between cultures and landscapes. Subarctic maritime communities are singularly vulnerable to environmental change as they frequently rely on seasonally abundant marine resources to supplement sparse terrestrial resources and challenging agricultural conditions. Objectively small environmental changes can propagate through ecosystem and economy. In Norse Greenland a marginal subsistence using European agriculture was only sustainable during the Medieval Climate Anomaly (MCA). The Greenland settlement, situated beyond the range of cereal agriculture, survived on a mixture of herding and hunting, and lasted from 1000 to c. 1450;[6] the MCA is typically dated from c. 950 to c. 1250.[7] For the Greenland Norse a small change in temperature precipitated other ecological changes that exceeded the adaptive capacity of the community. In other communities such as Iceland and the Faroes, people fared better as they enjoyed more forgiving environments and more resilient populations.[8] In such communities it is possible to explore the

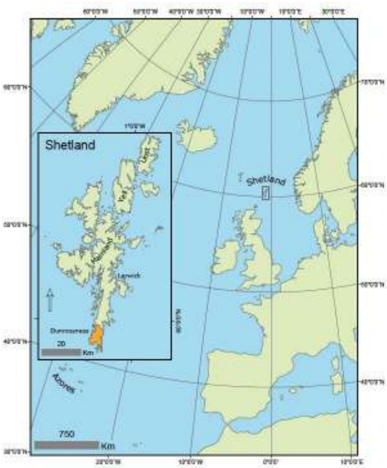

FIG. 1. Shetland, Dunrossness, and the North Atlantic. Map by M. Bampton.

relationship between environmental change and human response in some detail.

One such case can be found in the Shetland Islands, Scotland's northernmost archipelago (fig. 1). Here the balance between resilience and environmental challenge is illustrated in the sand inundation of the township of Broo, Dunrossness, where the core of the settlement was heavily impacted by blowing sand sometime between 1680 and 1720, at the end of the Maunder Minimum, in the LIA.[9] Neighboring communities within Quendale were less severely affected by the same events and remain viable farming communities into the present. Excavation of one of the Broo structures (Broo II) has yielded high-status artifacts, suggesting that this was an important building, possibly home to the township's proprietors. Archaeological data, historical records, sediment analysis, and optically stimulated luminescence (OSL) dates indicate that the site experienced several inundations over at least a millennium. Sand deposits dating from the eleventh, fourteenth, and sixteenth centuries are interlayered with anthropogenic soils. The presence of peat ash and vegetation debris indicates that these soils were at least in part "made": purposefully reestablished on the aeolian material.[10] By the early eighteenth century Broo II was overwhelmed; the site and its surroundings remain uninhabited to this day. Analysis of historical records and cartographic data shows that although the core of the township was destroyed and its lands incorporated into neighboring townships, the Sinclair family and several of its tenant farmers remained on the cultivable portions of the estate. The history of Broo is one of both catastrophe and resilience in the face of climate-induced environmental change. This was a population that demonstrated what some ecologists have described as the plasticity and tolerances to "ride the edge of tolerable climatic conditions."[11]

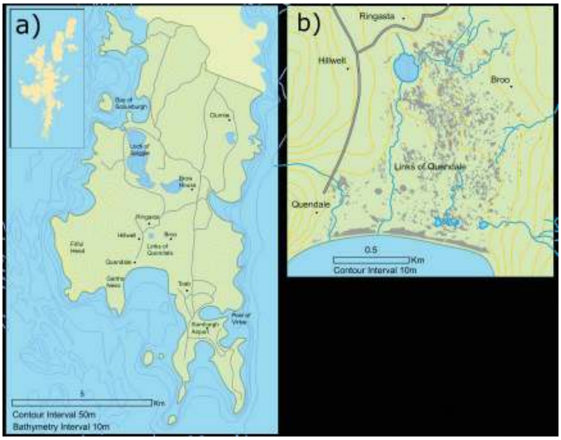

FIG. 2. Dunrossness County, Quendale and Broo. Map by M. Bampton.

SITE DESCRIPTION

Broo is located at 59°54′33.82″N, 1°18′45.32″W, in the center of Quendale Valley, a dune field some 3 km long by 2 km wide, situated at the southern end of Mainland Shetland, in the parish of Dunrossness (fig. 2). Quendale is the largest dune field in Shetland.[12] To the west Fitful Head rises 208m, and to the east Ward's Hill rises 90m. Shetland does not experience temperature extremes found in other high-latitude islands as it is in the path of the Gulf Stream. Yet the exposed ocean location results in famously high-velocity winds, protracted periods of storminess, and a reputation for harsh weather.

Some challenges exist in analyzing the history of Broo. There are no known extant boundary markers or township surveys. However, the estate's extent can be estimated using place-names and archival records. The name variously appears alone as Brow and Brew, and in compound forms such as "Browbreck."[13] We shall render it as Broo throughout unless quoting a primary source, or a referring to a contemporary named place. The name appears in a verifiable form in three other locations: 250m southwest of the excavation site is a rubble field identified on an 1878 Ordnance Survey map as "The Old House of Brow"; the Loch of

Brow and an extant farm called Brow House are approximately 1.5 km north of the excavation site (fig. 2).

The similarly named and geographically clustered sites of Broo show the location of the township's core, and offer some good indications of where the outer boundary lay. In the Shetland Ordnance Survey Name Book of 1877–78 the *Descriptive Remarks or General Observations which may be of Interest* for the place-name "Old House of Brow" are "The site of an old dwelling consisting of a pile of stones situated nearly ½ mile west of Loch of Hughsbrake and about ¾ mile south west of the Established Church." This entry is twice annotated: "This is not an antiquity but it may be the site of the old houses of the Sinclairs or St Clairs of Quendale," and then "Some (including Mr. Bruce of Sumburgh) think this is the site of the hamlet called Brow and not the mansion house."[14]

Exploratory GPR survey indicated that this debris field extended over a sufficient area to be interpreted as a viable structure.[15] Despite the ambiguity concerning the "House of Brow" versus Broo II, the core of the township can reasonably be postulated as the area covering the two locations, extending south from the excavation and deeper into the dune field. Archaeological evidence indicates that Broo Site II is one of the four farms that comprised Broo. Although it has been suggested that Broo II was originally a tenant farm repurposed as a home for the township's proprietors, the Sinclairs, following their flight from an original "Mansion House," others believe that it is probably the original manor.[16]

HISTORY OF BROO

The documented three-century historical arc of Broo begins with prosperity in the sixteenth century and ends with dissolution by the eighteenth century. Throughout this time the township was closely associated the Sinclair family. The oldest reference in the Shetland Archives to the Sinclairs of Broo is between 1574 and 1575, granting a land charter to William, son of Olav.[17] Numerous subsequent records refer to the township and its inhabitants. Rentals (the records of occupancy, production, and tenancy) from 1628 onward indicate a thriving and successful economy.[18] Yet difficulties become apparent by 1678 when Adam Sinclair sold land in the region.[19] By the early 1680s the Rev. James Kay describes the previously fertile landscape as covered with wind-blown sand.[20] Following this in both 1706 and 1716 the Sinclair family petitioned for tax relief following economic difficulties associated with the destruction of their land.[21] The difficulties of the Sinclair family notwithstanding, and despite the damage to the farmlands of Broo, tenants were still paying rent and engaging in cash transactions well into the 1760s,[22] and "Mrs. Sinclair of Broo" still maintained an active interest in the place in the 1820s.[23]

Our analysis of sand deposits, archaeological evidence, and archival records refines the history of Broo's transformation from a productive farming estate into a relic of a township.[24] Dated sand deposits show the long-term vulnerability of the region to aeolian processes. Sands from Quendale and from around the Broo excavation show episodes of deposition over four millennia (table 1). While almost certainly not a complete record, these indicate that the region experienced sand blows over 4,000 years BP, and as recently as 1780. Around Broo II there are two distinct "chapters" of sand movement shown by the OSL record: the first occurred from 1510 to 1550 and the second from 1720 to 1780. The mechanics of aeolian processes are complex, and the landscape record they leave is incomplete; typically some deposits are removed and others are redeposited. This noted, the two episodes of deposition in the sixteenth and eighteenth centuries, respectively, suggest two periods with an unusually high level of activity in the area.

The archaeological evidence supports our interpretation of the OSL dates, indicating several phases of the excavated structure's use (fig. 3).[25] The two rooms of Building 1, identified as the main residence, show a change in use through time. The Northeast Room is a sophisticated structure, with plaster covering clay-mortared walls, a large flued fireplace, windows, and wall niches. It is large and carefully built and was added to an earlier, simpler structure, the Southwest Room, more than doubling the structure's area. In combination with Building 2 the resulting complex resembles extant elite residences elsewhere in Shetland. Building 2 was variously filled with sand, cleared, subdivided, and repurposed from animal byre to dwelling over the course of its history. It was probably the last structure in use before the farm was totally abandoned. Bigelow describes "extensive window glass, fragments, tin-glazed Westerwald stoneware jug fragments, and multiple fragments of decorated wineglasses, all suggesting that the farm was a secondary, late established and short lived seat of the Sinclair proprietors of Broo. . . .

TABLE 1. Dune field OSL dated sand samples.

SULT #	*Dose rate / mGy a^{-1}*	*Stored dose / Gy*	*Years BP*	*Calendar years*	*Location (effort)*	*Significance*
2526	2.61 ± 0.11	11.48 ± 0.34	4390 ± 230	2380 BC ± 230	Off-site dune (Sorrell)	Age constraint initial aeolian activity
2529	2.65 ± 0.20	9.33 ± 0.17	3520 ± 270	1510 BC ± 270	Off-site dune (Sorrell)	Age constraint initial aeolian activity
2530	2.04 ± 0.15	2.00 ± 0.07	980 ± 80	1030 AD ± 80	Off-site dune (Sorrell)	Age constraint later aeolian activity
2527	2.67 ± 0.13	0.83 ± 0.14	320 ± 50	1690 AD ± 50	Off-site dune (Sorrell)	Age constraint later aeolian activity
2528	2.64 ± 0.19	0.76 ± 0.02	290 ± 20	1720 AD ± 20	Off-site dune (Sorrell)	Age constraint later aeolian activity

Source: M. Bampton, A. R. Kelley, J. Kelley, M. Jones, and G. F. Bigelow, "Little Ice Age Catastrophic Storms and the Destruction of a Shetland Island Community," *Journal of Archaeological Science* 87 (2017): 17–29.

[T]hese finds, plus clay pie stems and a series of Optically Stimulated Luminescence dates on the cover sands, all point towards the period 1680–1710 as the time when the Broo Sites were ultimately abandoned."[26]

Sediment analysis supports this interpretation: profiles adjacent to the excavation site show an alternating sequence of sand and organic materials (table 2). The soils contain midden materials, peat ash, and animal bones, suggesting that the soils may have been actively manured or enhanced with organics during some periods in an attempt to stabilize them and keep them cultivable.[27] Repeated occurrences of these anthropogenic horizons indicate that the people of Broo gained some significant periods of respite from dune migration, before the core of the township was finally abandoned.

The period of Broo's initial prosperity and eventual decline recorded in the surviving historical records spans the very last part of the MCA and the beginning of the LIA. OSL dates, artifacts, and historical records show that the worst of the destruction occurred during the Maunder Minimum (c. 1645–c. 1715), during which the British Isles experienced

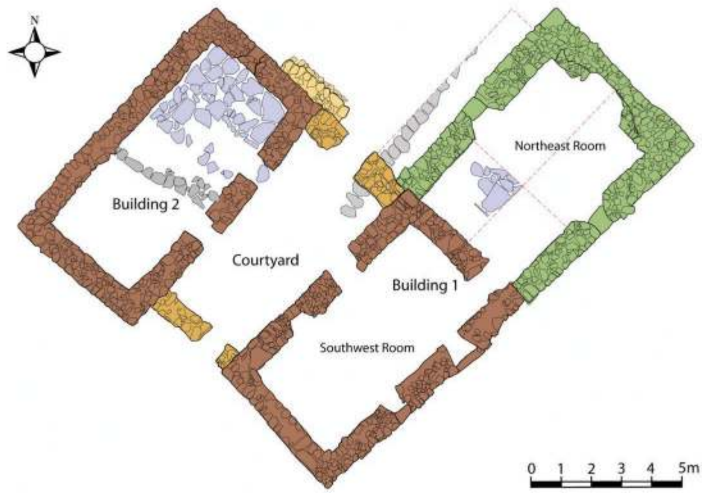

FIG. 3. Broo site complex. Courtesy of Robert Friel and Zoe Outram, School of Archaeological and Forensic Sciences, University of Bradford. Reprinted from M. Bampton, A. R. Kelley, J. Kelley, M. Jones, and G. F. Bigelow, Little Ice Age catastrophic storms and the destruction of a Shetland Island community, *Journal of Archaeological Science*, *87* (2017), 17–29, with permission from Elsevier.

an unusual period of cooling. The Hadley Center Central England Temperature record (HadCET) has annual average temperatures by year from 1659 to the present.[28] The average for the record as a whole, prior to the warming trend commencing in 1985 associated with current global climate change, is 9.18° C. In the 56 years between 1659 and 1715, there are only 14 years when temperatures rose above the series mean. Between 1669 and 1685 there were 17 consecutive years of below-average temperatures; between 1687 and 1701 there were 15 consecutive years of below-average temperatures. The HadCET records temperatures from stations located 51°05′ N–53°59′N and 2°58′ W–0°08′ E. The stations are thus approximately 10° south of Shetland, though roughly on the same longitude. Therefore, the record does not describe conditions in Shetland for this time period, but it gives support to an impression of regional cooling and an associated marked trend of climate stress.

Another indicator of regional climate stress is an increase in North Atlantic storminess visible in the GISP2 Na+ record.[29] Plotting the five-

TABLE 2. Broo complex OSL dated sand samples, climate history.

SULT #	*Dose rate / mGy a^{-1}*	*Stored dose / Gy*	*Years BP*	*Calendar years*	*Location (effort)*	*Significance*
2608	2.15 ± 0.08	1.37 ± 0.09	640 ± 40	1370 AD ± 40	Broo II (Sanderson)	Onset of sand deposition here
2607	2.15 ± 0.07	1.08 ± 0.13	500 ± 60	1510 AD ± 60	Broo II (Sanderson)	TPQ for flagstones
2441	2.39 ± 0.11	1.12 ± 0.08	470 ± 40	1540 AD ± 40	Adjacent to & NE of Broo II	Possible constraint for onset
2606	2.11 ± 0.06	0.95 ± 0.12	460 ± 60	1550 AD ± 60	Broo II (Sanderson)	TAQ for flagstones
2576	2.53 ± 0.11	0.73 ± 0.02	290 ± 15	1720 AD ± 15	Broo II (Outram)	Onset of sand deposition here
2442	2.64 ± 0.18	0.74 ± 0.04	300 ± 30	1730 AD ± 25	Adjacent to & NE of Broo II	TAQ for abandonment
2517	2.43 ± 0.13	0.62 ± 0.05	250 ± 30	1760 AD ± 30	Enclosure E of Broo II	TAQ for abandonment
2518	2.49 ± 0.16	0.49 ± 0.06	250 ± 20	1760 AD ± 25	Enclosure E of Broo II	TAQ for abandonment
2577	2.39 ± 0.11	0.55 ± 0.08	230 ± 35	1780 AD ± 35	Broo II (Outram)	Constrains deposition

Source: M. Bampton, A. R. Kelley, J. Kelley, M. Jones, and G. F. Bigelow, "Little Ice Age Catastrophic Storms and the Destruction of a Shetland Island Community," *Journal of Archaeological Science* 87 (2017): 17–29.

year rolling overage of Na+ and calculating the cumulative deviation from the mean of this record shows that there is a steady decline in storminess in the period from 600 AD until 1425, at which point there is an increase in storminess. Significant increases in the steepness of the CuDe curve occur in the 1500s, and again during the second half of the 1600s.[30]

Abundant supporting evidence is available in the historical record indicating that the period between the late 1600s and early 1700s experienced widespread cooling and significantly increased storminess.[31] One of the most compelling data points is Daniel Defoe's book *The Storm: Or, a Collection of the Most Remarkable Casualties and Disasters Which*

Happen'd in the Late Dreadful Tempest, Both by Sea and Land, describing the Great Storm of 1703.[32] The earlier Great Storm of 1697 was less dramatically documented but is also well recorded in contemporaneous records.[33] Climate proxies as diverse as ships' log books,[34] tree rings, and sediment analysis further substantiate this conclusion.[35]

As with the HadCET data, these accounts describe locations at varying distances from Shetland, but a general trend is evident throughout the British Isles during this period. Alistair Dawson summarizes the situation in Scotland in the late 1600s citing contemporary reports of cold weather, failed harvests, and destructive storms throughout the mainland, in the western Isle of Skye, in Orkney, and in Shetland.[36] He suggests that there may have been some respite between 1704 and 1708, but in Shetland conditions remained very harsh well into the 1730s. In sum, there is an overwhelming body of evidence from multiple sources to indicate that in the period of Broo's destruction, region-wide conditions were colder than average for protracted periods of time, and further that this cold period was associated with an increased number of severe storms.

IMPACTS ON THE LANDSCAPE

We have previously demonstrated that Broo's location is singularly vulnerable to deposition of wind-blown sands.[37] Using wind simulations based on measured wind speeds and vectors from contemporary severe storms that are comparable to past events, we show that the Broo site is situated in a low-velocity wind zone in almost all storm conditions. Figure 4 shows a selection of results from wind simulations using the software WindNinja[38] using hourly records for the Braer storm from Sumburgh airport, 5.5 km from Broo.[39] The Braer storm was selected as it was judged a good analog for past severe storms in Shetland, based on reconstructed synoptic charts of the Great Storm of 1697.[40] The local velocity anomaly and the site's proximity to abundant foreshore dune sands immediately to the south makes the settlement vulnerable to catastrophic sand deposition during periods of increased storminess.

This vulnerability to aeolian processes was not unprecedented: the destruction of Broo at the turn of the seventeenth century was not the first sand inundations in the Quendale Valley. At least two prior landward mobilizations of foreshore dunes have been identified from 4000

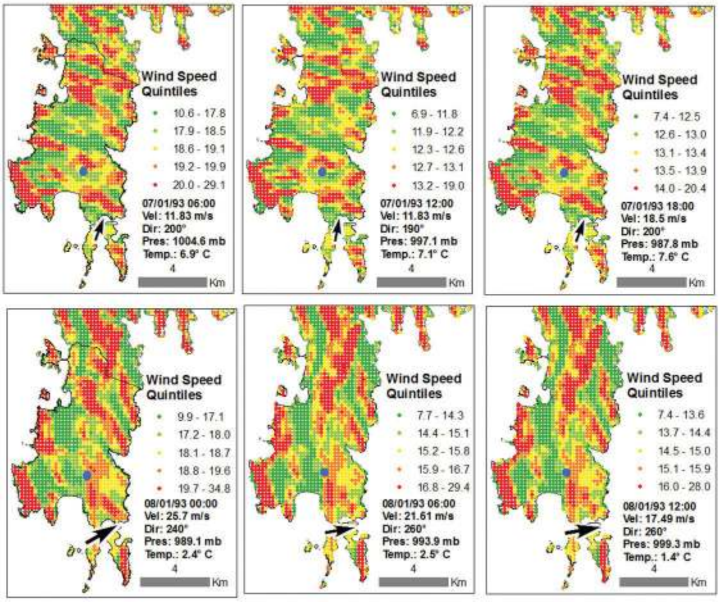

FIG. 4. Wind simulation results from Braer storm, showing low-velocity region in all wind vectors associated with Quendale dune field. Reprinted from M. Bampton, A. R. Kelley, J. Kelley, M. Jones, and G. F. Bigelow, Little Ice Age catastrophic storms and the destruction of a Shetland Island community, *Journal of Archaeological Science*, *87* (2017), 17–29, with permission from Elsevier.

BP and 2000 BP.[41] These are evidenced in truncated relict dunes seaward of the current shoreline (fig. 5). The OSL dated sands from Quendale in table 1 show at least fifteen deposition dates, some prehistoric and some more recent, indicating that several episodes of sand mobilization occurred in the region.

Increased storminess and abundant sands are necessary but not sufficient conditions for the mobilization of the large volume of sand seen in Quendale. For sands to be entrained by wind, vegetation must be removed. This can happen as a result of either environmental change or human land use. We know from reports such as those cited in Dawson's work that Shetland experienced a rolling series of economic, demographic, and agricultural crises between 1680 and 1730, but there are no specific references to land-use pressure from overcultivation, overgrazing, or invasive species in Quendale.[42] However, in the mid-nineteenth century Evans notes:

> On the north-east of Quendale Bay lies the estate of Brow. As happened to the Culbin estate in Moray, only on a smaller scale, the property, which in the middle of the last century was worth some 3000 merks a year, equivalent to £200, was destroyed by an overwhelming accumulation of sand. This state of affairs, it is said was caused by inhabitants pulling up bents [coarse grass], and then allowing the pigs to grub about in the sand, thereby destroying the root stocks, nor did the rabbits improve matters by making their burrows there.[43]

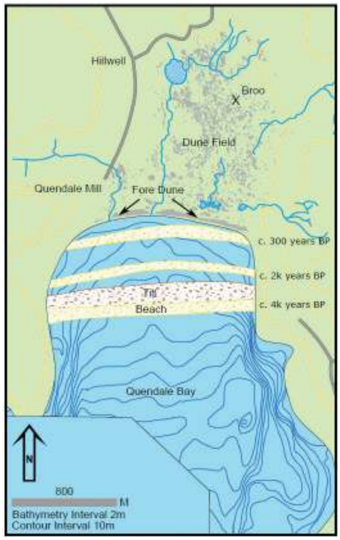

FIG. 5. Relict foreshore dunes showing past sand inundations. Map by M. Bampton.

Contemporary studies show a long-term close link between vegetation and geomorphic processes in Papa Stour, further north in Shetland.[44] They suggest that arable activity and grazing both contributed to periodic sand blows. More subtle changes in land use such as the replacement of cattle with sheep, or even replacing one breed of sheep with another, can have significant and enduring detrimental effects on vegetation cover in Shetland pastures.[45] Finally, while domestic animals such as cows, sheep, and pigs arrived in Shetland during the Neolithic, many other mammals, including rabbits, arrived in Shetland during the seventeenth century.[46] Thus it is highly likely that several of these possible anthropogenic vegetation changes triggered dune mobilization.

RESILIENCE

Despite the devastation of the core of the Broo estate, there is evidence to indicate that the township's inhabitants did not abandon the region. Smith contrasts the township of Scatness with the devastation of Broo.[47] He identifies references in Catton 1838 to a surviving member

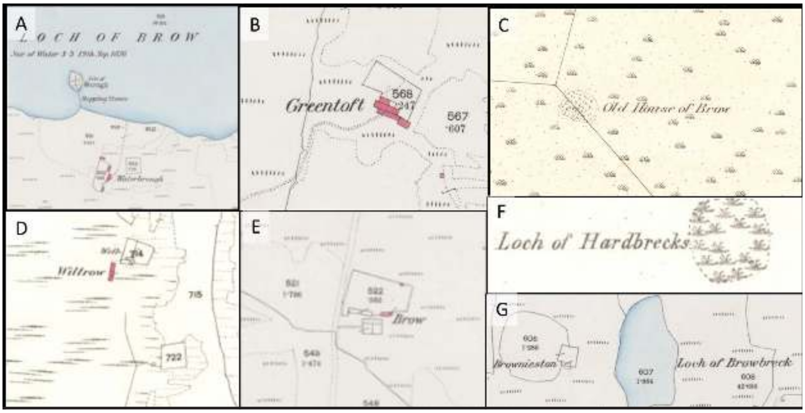

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FIG. 6. Approximate boundaries and named outset settlements of the Broo estate, based on historical descriptions and surviving landscape features. Boundary estimate courtesy of Brian Smith, Shetland Archives. Map by M. Bampton.

of the Sinclair family, a nonagenarian widow, still resident in a relocated "House of Broo."[48] This house still stands today and marks the probable northern extent of the old Broo estate. There is further record of surviving elements of the Broo estate in the Shetland Archive. The heritable bond of Alexander Sinclair of Brew to Robert Dick notes: "£41 18s 5d Sterling, to be paid forth out of all his lands of Brow, with its 'offsetters' of Waterbrough, Skippermires, Hardbreck, Greentoft, Wiltrow, Newlands, Troubletown, North Vosgerth, South Vosgerth and Burdeaux,

TABLE 3. Broo structures and named outset settlements visible on past maps, or listed in CANMORE register of historic and prehistoric sites (https://canmore.org.uk/).

Name	*Lat*	*Long*	*BNG_Northing*	*BNG_Easting*	*UTM_Easting*	*UTM_Northing*	*Canmore_Ref*	*OS_Maps*
Old House of Brow	59.90778	-1.31667	1113840	438331	594146.90	6642337.42	458[a]	
Waterbrough	59.92194	-1.30056	1115433	438360	595007.35	6643937.77	190591[b]	OS 1878 Survey
Greentoft	59.91944	-1.30972	1115149	438700	594502.07	6643646.30	190592[c]	OS 1878 Survey
Greentoft 2	59.92125	-1.30444	1115217	438975	594792.13	6643854.99	N/A	
Wiltrow	59.91111	-1.29111	1114210	439749	595566.40	6642745.17	568[d]	OS 1878 Survey
Hardbrecks	59.91516	-1.31401	1114620	438399	594274.64	6643163.15	190759[e]	
Hardbrecks 2	59.91516	-1.31401	1114642	438103	593909.03	6643136.03	N/A	OS 1878 Survey
Broo Excavation	59.91253	-1.32006	1114013	438553	593943.64	6642861.87	N/A	OS 1878 Survey
Brow House	59.92333	-1.30639	1115571	438877	594677.33	6644084.06	N/A	OS 1878 Survey
Loch of Browbeck	59.94086	-1.27775	1117539	440458	596245.42	6645988.39	N/A	OS 1878 Survey

engrossed on 29 September 1766" (SC12/53/4/ folio 4v). Some of these place-names, Skippermires, Newlands, Burdeaux, North and South Vosgerth, and (the extraordinarily named) Troubletown, are not present in contemporary or historical gazetteers. However, the remaining five names can be located on the 1878 OS sheet of the region (plate 1). Many are also in gazetteers, are visible in contemporary maps of the region, or are listed as historic sites in CANMORE, Historic Scotland's online database.

Mapping these surviving place-names forces us to reevaluate our narrative of Broo's destruction. First, we can estimate both the core of the original township and its overall boundary based on place-names and landscape features such as Browbeck (fig. 6). Second, the surviving outset farms form an arc to the north of the sand sheet and dune field, and outside the wind anomaly. The structures marked on the 1878 Ordnance Survey sheet with filled red outlines were inhabited, indicating that several of the identifiable outsets were still viable settlements at the time of the survey. Some are still occupied today.

[a] https://canmore.org.uk/site/548/old-house-of-brow

[b] https://canmore.org.uk/site/190591/waterbrough

[c] https://canmore.org.uk/site/190592/greentoft

[d] https://canmore.org.uk/site/568/wiltrow

[e] https://canmore.org.uk/site/190759/hardbrecks

DISCUSSION AND CONCLUSIONS

The core of the old Broo Township, comprising the rubble mound identified on the 1878 OS sheet as the Old House of Brow and the excavation at the Broo II site are well within the sand sheet and on the northernmost edge of the dune field. They are also at the northern extremity of the wind anomaly. As previously noted, Bigelow's archaeological data suggest that Broo II was a smaller building, repurposed as a high-status elite house and occupied by the township's proprietors following the abandonment of an earlier structure—possibly the Old House of Brow (though this last is questioned by Bruce in his annotations to the 1877–78 OS gazetteer). Further, the archaeological data suggest the house was abandoned in stages. Sediment analysis indicates repeated attempts to stabilize the sands around the Broo II site by manuring unstable deposits. The presence of a surviving Sinclair living in 1838 in the still extant

House of Broo, adjacent to the Loch of Brow, indicates a third and final move. It also suggests the remarkable resilience of the inhabitants of Broo. All available evidence suggests catastrophic sand accumulation was well under way by 1680. Despite this, at least some of the township was still inhabited and productive 150 years later.

Some locations in Scotland and the Scottish islands that have suffered sand inundations appear to have been abandoned once they were overwhelmed. The most celebrated of these, Skara Brae, was occupied from c. 5130 BP and abandoned c. 4450 BP.[49] Archival and folkloric accounts of communities on the east coast in Aberdeenshire and Nairn lost to dune migration: Forvie in the fifteenth century (c. 1413), and Culbin and Rattray in the late seventeenth century (c. 1694 and c. 1696, respectively).[50] Other locations overwhelmed by blowing sand have more complex histories of abandonment and reoccupation. Coileagan an Udail in North Uist (Hebrides) was occupied and abandoned at least ten times between 4000 BP and the late 1600s.[51] West Voe to the south of Quendale had at least two phases of occupation between 5500 BP and 5200 BP.[52] The onset of destructive sand blows forced the inhabitants of Broo to abandon agriculture on the southern half of the township's land, but they successfully resisted the destruction in the balance of the area. The wind fields prevailing in the south made the land uncultivable, uninhabitable, and therefore unviable. However, a few tens of meters outside this area it was possible to survive. The difference between the lost township and the surrounding landscape is described by Samuel Hibbert in the early nineteenth century; looking south and west from Broo he notes, "These dreary sand-hills are agreeably contrasted on the opposite side of the bay, with the green verdure of Garthsness and Quendal."[53] The inhabitants of Broo did not disappear; they migrated to the margins of their township and kept on farming.

ACKNOWLEDGMENTS

This material is based in part on work supported by the National Science Foundation grant numbers PLR 0444078 and PLR 1026911. Data, equipment, and engineering services were provided by the UNAVCO Facility with support from the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) under NSF Cooperative Agreement No. EAR-0735156. Parts of this paper were written during a 2014–15 Fulbright Fellowship at the University of Edinburgh Institute for the Advanced Study of the Humanities (IASH). Dr. Gerald F. Bigelow of Bates College and director of the Shetland Islands Climate and Settlement Project provided data, technical reports, and images. Professor Michael Jones of Bates College provided key ideas and historical data points. Mr. Brian Smith of the Shetland Museum Archive provided data, archival records, unpublished manuscripts, and editorial comments. Professor Andy Dugmore of the University of Edinburgh provided editorial comments and insights that contributed significantly to the development of the ideas in this paper. Opinions, findings, and conclusions in this material are those of the authors and do not necessarily reflect the views of the NSF, UNAVCO, the Fulbright Commission, the University of Edinburgh, or the above acknowledged individuals.

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