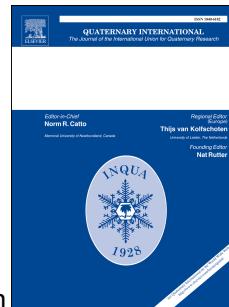


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Archaeological sites as Distributed Long-term Observing Networks of the Past
(DONOP)

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1 **Archaeological Sites as Distributed Long-term Observing Networks of the Past (DONOP)**

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36

37 Abstract

Archaeological records provide a unique source of direct data on long-term human-environment interactions and samples of ecosystems affected by differing degrees of human impact. Distributed long-term datasets from archaeological sites provide a significant contribution to establish local, regional, and continental-scale environmental baselines and can be used to understand the implications of human decision-making and its impacts on the environment and the resources it provides for human use. Deeper temporal environmental baselines are essential for resource and environmental managers to restore biodiversity and build resilience in depleted ecosystems. Human actions are likely to have impacts that reorganize ecosystem structures by reducing diversity through processes such as niche construction. This makes data from archaeological sites key assets for the management of contemporary and future climate change scenarios because they combine information about human behavior, environmental baselines, and biological systems. Sites of this kind collectively form Distributed Long-term Observing Networks of the Past (DONOP), allowing human behavior and environmental impacts to be assessed over space and time. Behavioral perspectives are gained from direct evidence of human actions in response to environmental opportunities and change. Baseline perspectives are gained from data on species, landforms, and ecology over timescales that long predate our typically recent datasets that only record systems already disturbed by people. And biological perspectives can provide essential data for modern managers wanting to understand and utilize past diversity (i.e., trophic and/or genetic) as a way of revealing, and potentially correcting, weaknesses in our contemporary wild and domestic animal populations.

58

59 1. Introduction

60 Archaeological data is a vital but underutilized resource for environmental managers and
61 policy makers. Archaeological sites are currently valued for preserving cultural heritage, tourism,
62 and place-based education for sustainability, but they can also generate very large, well-
63 documented collections of animal and human bone, shells, insects, and carbonized and
64 waterlogged botanical materials that span thousands of years. Advances in stable isotope, ancient
65 DNA (aDNA), and macrofossil analyses have improved the resolution of diverse organic
66 samples, improving key archives for understanding long-term biogeographical change (Hofman
67 et al., 2015), food web structure (Dunne et al., 2016), marine and terrestrial resource fluctuations
68 (McKethnie et al., 2014, Moss et al., 2016), and the long-term impacts of climate and human
69 settlement on both individual species and whole ecosystems (Erlandson et al., 2008). Improved
70 archaeological and palaeoecological datasets have significant relevance to contemporary
71 researchers and resource managers who face the challenge of *shifting baselines syndrome* in
72 which each successive generation of natural resource managers falsely identify their
73 contemporary (and already heavily depleted) ecosystems as a pristine natural baseline (e.g.,
74 Jackson et al., 2001; Bolster et al., 2012). Identification of accurate environmental baselines has
75 an essential relevance to major challenges of our time, including food security through
76 overexploitation of marine and terrestrial ecosystems (Yletyinen et al., 2016), restoring
77 biodiversity in heavily degraded environments, and the preservation of sustainable resource-use
78 practices (Klein et al., 2007; Barthel et al., 2013). The relevance of long-term (century- to
79 millennial-scale) perspectives offered by archaeologists and the natural sciences are recognized
80 increasingly as key data sources for future sustainable resource use (Engelhard et al., 2015;
81 Laparidou et al., 2015). The authors of this article are generally operating in a time scale that
82 encompasses the last millennium. Archaeology in the most general sense operates on two

83 temporal scales. The last ten thousand years, meaning the period beginning with the Neolithic
84 and the appearance of plant and animal domestication, and then the last two million years,
85 meaning the period beginning with the emergence of our genus and the appearance of material
86 culture. The authors belong to the first group. In each case the matching of millennial and
87 century-scale to the lived experience of humans at the generational-scale is a central priority of
88 archaeology.

89 While many archaeologists have been aware of the potential of the growing global
90 assemblage of well-dated, well-excavated sites with comprehensive archives of ecological
91 material since the birth of our discipline, it can be challenging to communicate this potential to
92 scientists from other disciplines engaged in global change research or to a wider public whose
93 perceptions of archaeology are conditioned by images of Indiana Jones and Laura Croft. A
94 challenge for archaeologists has been to shrug-off the perception of archaeology as an
95 antiquarian pursuit focused on collecting high-value artifacts, rather than a science-based
96 discipline that, among other pursuits, provides unique datasets for understanding long-term
97 human interactions with changing environments. As highlighted in Kintigh and colleagues'
98 (2014, pp. 6) *Grand Challenges for Archaeology*, "archaeological data and interpretations have
99 entered political and public, as well as scholarly, debates on such topics as human response to
100 climate change, the eradication of poverty, and the effects of urbanization and globalization on
101 humanity." Communicating the relevance of archaeological data to practitioners, such as
102 resource managers, using deep time perspectives illustrate not only the value of establishing
103 environmental baselines and understanding ecosystem structures, but also supply narratives
104 spanning multiple centuries to millennia of human resource-use and adaptation (Nelson et al.,
105 2016; Spielmann et al., 2016).

106 At a 2013 meeting in Paris between the interim Future Earth management team
107 (<http://www.futureearth.org>) and representatives of the Integrated History and Future of People
108 on Earth (IHOPE) group (<http://www.ihopenet.org>), the IHOPE presenters (Carole Crumley,
109 Tom McGovern, Jago Cooper, Steven Hartman, Andy Dugmore) coined the phrase 'distributed
110 observing network of the past' (DONOP) to communicate the value of archaeological sites for
111 global change research (GCR), and adopt a vernacular more familiar to the wider scientific
112 community and help argue the case for better inclusion of archaeologically-derived data sets into
113 the Future Earth agenda. The DONOP concept resonates with the description of existing
114 instrumental observation networks that monitor the current impacts of human activities on
115 environmental change (Hari et al., 2016; Proen  a et al., 2016; Theobald, 2016; Marzeion et al.,
116 2017). For examples, the Intergovernmental Panel on Climate Change (IPCC) occupies an
117 authoritative position monitoring the impacts of climate change on biophysical systems and
118 human societies. The International Oceanographic Commission (IOC) of UNESCO operates a
119 Global Ocean Observation System (GOOS) to monitor global changes to ocean temperature, its
120 ecosystems, and human communities reliant on the resources it provides. But long-term human
121 processes have been largely absent from many major monitoring efforts reports despite being in
122 a position to disseminate data relevant to GCR. This paper explores the relevance of DONOP
123 with a specific focus on work carried out in the North Atlantic region.

124 Archaeological sites are a core aspect of DONOP as they have the ability to both show
125 change through time as well as reveal local and regional dynamics. Ideally, the best DONOP
126 sites would be those that have deep temporal range and are parts of networks of sites that can
127 cover spatial scales from the local through the regional. Given the variety of sites and projects in
128 the Archaeological community such data can be relevant from the scale of the household (i.e.

129 how a particular individual settlement interacted with its local environment) to regional scales of
130 varying size. The examples offered by this article show some of the spatial and temporal range of
131 the application of DONOP.

132 2. Archaeological Sites as Distributed Long-term Observing Networks of the Past

133 Through the analysis of archaeological datasets, we have the potential to access long-
134 term records of human interactions with natural systems at a wide variety of temporal and spatial
135 scales and thus both reconstruct past environmental conditions and reveal the human dimensions
136 of these processes. There is a rich record of research into the shifting relationship between
137 culture, climate, and landscape change using archaeological data (Brown et al., 2012; Golding et
138 al., 2015a; McGovern et al., 2007; Simpson et al., 2001a; Streeter et al., 2012; Thomson and
139 Simpson, 2006). This effort has intensified as the key role of people within ecological systems
140 and the wide spectrum of natural and anthropogenic environmental change have been recognized
141 (Crumley, 2016). Alongside this, there have been major developments in the quantity and quality
142 of paleoclimate reconstructions at multiple temporal and spatial scales that make possible
143 effective connections to human systems. The increasing availability of sophisticated climate data
144 sets whose scales match those of human societies and the human experience has made a
145 profound difference to the ways in which we can understand interactions of people and
146 environment (Hoggarth et al., 2016). The growing recognition in the scientific, global policy, and
147 political arenas of anthropogenic climate change and the levels of extreme disruption that this
148 will bring to contemporary societies have served as a final, and possibly most potent, influence
149 on current research agendas and raising new questions that can only be answered with long-term
150 perspectives of our interactions with the natural world (Anderson et al., 2013).

151 The development of refined, high-precision chronologies has played a key role in the
152 translation of DONOP into a practical and very worthwhile reality. With tight chronological
153 controls, such as those provided by AMS radiocarbon dating using a Bayesian framework, data
154 from multiple sites can be combined with greater confidence. Thus, the extensive spatial
155 distribution of archaeological sites, each with variable temporal continuity, can be transformed
156 from a perceived weakness of DONOP to a real strength. Highly detailed but temporally-
157 inconsistent records can be combined to chart the waxing and waning interactions of people and
158 environment. An example of this is provided by the coastal middens that record long-term
159 human exploitation of marine ecosystems. This data illustrates the reality of 'shifting baselines'
160 and the chronic limitations of short observational timescales in fisheries management, as
161 discussed in Bolster's (2014) *The Mortal Sea* (see also Jackson et al., 2001). There is a clear
162 need for the effective integration of the *longue durée* with urgent issues of fisheries and marine
163 resource management (Moss et al., 1990; Holm, 1995; Ogilvie and Jónsdóttir, 2000; Jackson et
164 al., 2001; Perdikaris and McGovern, 2009). A major EU-funded initiative, the *Oceans Past*
165 program (<http://www.tcd.ie/history/opp>), has begun to correct the effects of shifting baselines
166 that can result in fundamentally flawed decision making with historical and archaeological data
167 sets (Pinnegar and Engelhard, 2008).

168 Archaeological DONOP are our best (and for many regions and periods of time our only
169 realistic) source of information on the resilience of past cultures to natural hazards. Past cultures
170 provide a vast range of human interactions with different climatic and ecological conditions
171 (Cooper and Sheets, 2012). Contrasting outcomes illustrate the consequences of different social
172 organizations, alternative adaptive strategies, and contrasting approaches to resource use,
173 sustainability, and building resilience. Though the past cannot be used as a direct analogue to

174 explain how present and future populations will deal with external environmental threats, it does
175 offer us significant opportunities to better understand processes of social interactions with
176 environmental change and to generate both data and new theory that can contribute to a wide
177 spectrum of managerial issues raised by contemporary anthropogenic climate change.

178 Distributed long-term observing networks have been (and can be) used to emphasize the
179 anthropogenic dimensions of data sourced from archaeological sites because the record is created
180 by people and extracted from the lived environment (Crumley, 2015). By aggregating *in situ*
181 evidence of human impacts on their local environments – through extirpation of local resources
182 and engineering of cultural landscapes (Smith, 2007) – to the regional and continental scale,
183 DONOP assimilate comparative interactions between humans and their environments with
184 chronological controls.

185 Firstly, the physical assemblages have been deposited as a direct result of human actions.
186 They will have specific biases created by diverse ways in which the environment has been
187 sampled and contrasts that reflect the beliefs, values, and knowledge of different social groups.
188 As such, DONOP provide comparative data reflecting different human behaviors. Secondly,
189 DONOP data is sourced from an environmental context that has been directly impacted and in
190 many cases directly formed through human actions. Whether the sample is from a wild species
191 that is subject to human predation or from an ecosystem that is shaped by the interaction of
192 human actions, ecosystem dynamics, Earth surface processes, and climate, this type of data holds
193 information about both natural *and* human processes.

194 Humans selectively sample the surrounding ecology and they collect specimens
195 (consciously and unconsciously) from across trophic webs, landscapes, and seascapes. Then,
196 given favorable post-depositional conditions, these samples are preserved in one place – the

197 archaeological site. Wherever (and whenever) humans and our ancestors have lived, and when
198 conditions allow for survival and preservation, it is possible to find these sites. Some DONOP
199 records are scattered and of limited duration but can be linked together to create a coherent
200 regional picture of change through the rigorous application of both relative and absolute dating.
201 If these sites accumulate long-term records they can produce very deep cultural layers and thus
202 large accumulations of material for analysis. Very high temporal resolutions can be achieved
203 within such contexts due to the wide range of dating methods that can be applied to both organic
204 (e.g., dendrochronology or radiocarbon dating within a Bayesian framework) and inorganic
205 artifacts (e.g., ceramic seriation). In turn, these datasets contain the signatures of environmental,
206 climatic, and cultural dynamics (Figure 1). Additionally, archaeological survey and

207 environmental analysis of landscapes dotted with small, ephemeral sites can reveal patterns in

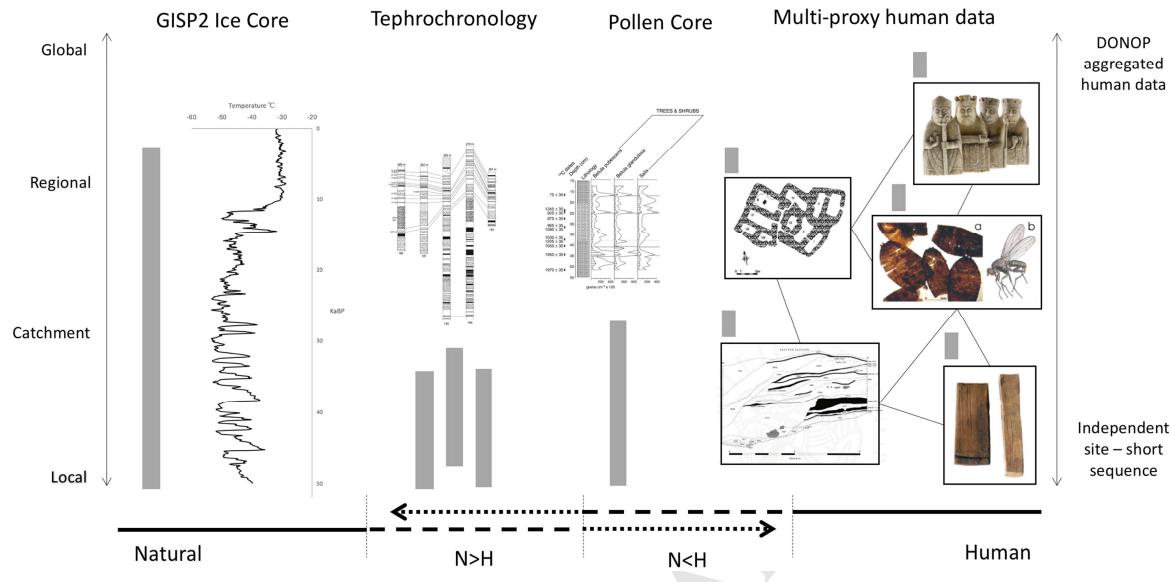


Figure 1- Observation records of natural and human processes in the past. DONOP is the aggregation of short sequences within the archaeological and environmental record to build a multidimensional record of human-environmental interaction and modification. Greenland Ice Sheet Project 2 (GISP2) data provides a local-to-regional scale proxy record of climate, storm and sea ice conditions, but provides no direct evidence of influence on human processes in the past (Dugmore et al., 2007). In regions with significant volcanic activity, such as Iceland, human impact on the environment and vegetation change can be measured using the tephra profile as a chronological control (Streeter and Dugmore, 2013). At the individual settlement scale, excavation data (for example: diet, artifacts, and architecture) can be aggregated to form regional and even continental-scale networks of subsistence, trade, and environmental modification.

208 the timing and nature of past landscape occupations, ecosystem impacts and resource usage that
 209 are important for understanding complex processes such as colonization, adaptation and
 210 abandonment (e.g., Altschul and Rankin 2008) and engaging with other *grand challenge* agendas
 211 for research that have relevance for contemporary debates (Kintigh et al., 2014; Jackson et al., in
 212 review). All of these optimal conditions are dependent on a wide set of variables that span from
 213 the effectiveness of the excavation strategy and methods, the local environmental conditions and
 214 the potential for organic remains to survive in situ until excavation, and the availability of
 215 continuous and deep chronological control. Yet such assemblages do exist and their number and
 216 spatial and temporal resolution are increasing.

217 There is a growing body of work focusing on archaeological data as a proxy for the
218 complex relationships between cause, response, and outcome in human ecodynamics (Hegmon et
219 al., 2008; Dugmore et al., 2013; Vésteinsson et al., 2014; Boivin et al., 2016; d'Alpoim Guedes et
220 al., 2016). DONOP provide detailed records of these completed long-term human ecodynamics
221 experiments of the past and the range of outcomes stemming from different pathways taken by
222 past cultures in the face of environmental change (Diamond and Robinson, 2010; Hegmon et al.,
223 2014). They can serve as examples of alternative choices and the pathways they create, and these
224 case studies can be used to assess contemporary ideas of how to build resilience and reduce
225 vulnerability in the face of both environmental and social stresses. They can provide both
226 inspiration and warnings.

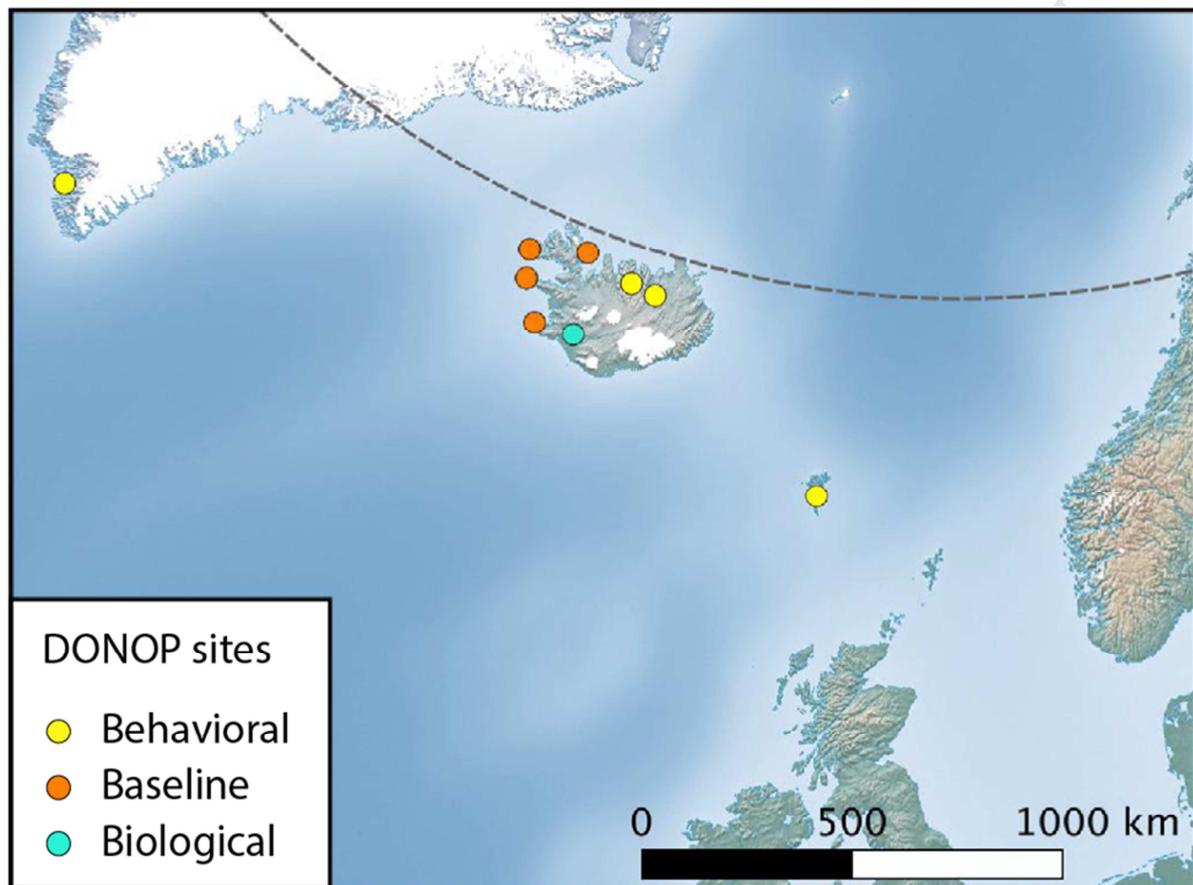
227 The ideal of deep temporal and broad spatial data that is at the core of DONOP aligns it,
228 and reveals a debt to, attempts to conceptually break down the borders between the ideas of
229 nature and culture (Chakrabarty, 2009). For example the concepts of coupled natural and human
230 systems (CNH) and socio-environmental systems (SES) both inspire much of the following
231 scholarship (Zeder et al., 2014). When examined over the longue durée, the myriad
232 interconnections between human and natural systems becomes clearer and the idea of static and
233 pristine ecosystems that host humans but that see no anthropogenic impact becomes much harder
234 to support. The history of the impact of humans, and other organisms, on landscapes continues to
235 be pushed deeper in time through archaeological work. The dynamics behind these impacts is
236 being revealed as more nuanced and increasingly complex. Niche Construction Theory is
237 perhaps the best expression of these relationships and is relevant to all the projects presented in
238 this article (Boivin et al., 2016; Sullivan et al., 2017; Zeder, 2016).

239 The utility of DONOP sites and the data they contain for contemporary global change
240 research can be explored from three perspectives: those that are 1) concerned with human
241 behaviors, 2) related to shifting baselines, and 3) addressing biology. The *behavioral perspective*
242 examines human action within intertwined social and natural systems. The *shifting baselines*
243 *perspective* emphasizes the contrasting implications of baseline data for species, landforms, and
244 ecology set before industrial expansion, commercial-scale resource exploitation, the ‘great
245 acceleration’ and other trends representing significant human impacts on their environments – all
246 in stark contrast to the typical temporally shallow modern data currently in use (Pinnegar and
247 Engelhard, 2008; Steffen et al., 2015a, 2015b). Finally, the *biology perspective* seeks to
248 understand and utilize past diversity (i.e., trophic and/or genetic) as recovered through
249 archaeological remains in order to develop tools and datasets that can be used to better manage
250 contemporary wild and domestic animal populations (Hofman et al., 2015; Boivin et al., 2016;
251 Zeder, 2015, 2016).

252 In the following section, we evaluate archaeological sites as DONOP within the
253 conceptual frameworks of human behavior, shifting baselines, and biological systems. We argue
254 that archaeological sites contain valuable, and at times unique, data that have the potential to
255 provide solutions to problems in the present and future. For this reason, there is a need to view
256 and value archaeological sites as ‘observable networks’ that capture the resourcefulness of the
257 past for understanding the impacts of human populations on their environments, establish
258 accurate environmental baselines, and learn from human adaptation to climate change over
259 century-to-millennial timescales. Furthermore, given the current and increasing threats to
260 archaeological sites from anthropogenic climate change, there is a pressing need to act quickly

261 and decisively to collect critical archives before they are lost forever (Dawson, 2015; Hambrecht
 262 and Rockman, 2017).

263



265 *Figure 2. A map of the eastern North Atlantic region showing the locations of sites in the Faroe Islands, Iceland,*
 266 *and Greenland that are discussed in this article.*

267

268 2.1 Human Behavior and DONOP

269 Over the last thirty years, research in the North Atlantic by the North Atlantic Biocultural
 270 Organization (NABO, <http://www.nabohome.org>) has, in part, been focused on comparing
 271 datasets from separate geographical areas towards understanding the contrasting fates of Norse
 272 medieval communities in the Faroe Islands, Iceland, and Norse Greenland (Figure 2; see Nelson

273 et al., 2016). These settlements were established by Scandinavians over several centuries,
274 starting with: the Faroes (ca. 860 CE), Iceland (ca. 870 CE), and Greenland (ca. 985 CE). These
275 three areas were settled by people of a shared cultural and biological heritage (Jesch, 2015). Yet
276 the paths chosen by these communities and their long-term fates contrast starkly. The Faroes
277 survived centuries of relative economic isolation, limited natural resources, and numerous socio-
278 political challenges, enduring to this day as a small but resilient nation (Brewington, 2015).
279 Despite environmental, economic, and epidemiological challenges, Iceland was able to transform
280 its economy, and has since become a highly-developed society with among the highest living
281 standards and health care in the world (Karlsson, 2000). The Norse settlement in Greenland, by
282 contrast, came to an end in the late fifteenth century. The contrasting fates of Iceland and
283 Greenland have come to be discussed in popular discourses around ideas of ‘collapse’ (Diamond,
284 2005) and remain active subjects for international interdisciplinary research (Dugmore et al.,
285 2012, 2013; Streeter et al., 2012; Nelson et al., 2016).

286 Viewing these cases through the lens of DONOP distills the research down to a series of
287 narratives that have important implications for current debates. First, the simple ‘collapse’
288 narrative of why societies choose to fail through maladaptation is too simplistic and actively
289 misleading for these cases (Dugmore et al., 2009, 2012). DONOP-based long-term perspectives
290 of the Scandinavian communities of the Atlantic islands in general, and Iceland and Greenland in
291 particular, provide specific examples of human behavior that was environmentally-nuanced,
292 adaptive, and sustainable over multi-century time scales. This creates a picture that is far more
293 disturbing than the simple collapse thesis because it shows that societies may undertake entirely
294 rational, adaptive strategies in the face of unprecedented challenges and yet still undergo painful
295 transformational changes (Butzer, 2012; Dugmore et al., 2012).

296 The example of Norse Greenland, which has often been used as a parable of human
297 inaction in the face of increasingly hazardous climates to the point of self-extinction, offers a
298 complex and bleak message (Diamond, 2005). A combination of new data acquisitions,
299 reinterpretation of established knowledge, and a somewhat different philosophical approach to
300 the question of collapse has revealed a society that was, in fact, flexible and adaptive in the face
301 of changing climates (Dugmore et al., 2012). Within the first generation of settlement in the late
302 tenth and early eleventh centuries CE, the Norse Greenlanders adjusted their diet to fit the
303 seasonal availability of local resources: fishing ceased and the large-scale exploitation of
304 migrating seals began (Ogilvie et al., 2009; Arneborg et al., 2012). The Norse went on to create
305 an effective economic network for communal provisioning and international trade (i.e., walrus
306 ivory). Provisioning networks consisted of imported domesticated species (sheep, goats, cattle,
307 horses, and pigs) supplemented with a broad set of wild resources (seals, caribou, seabirds, small
308 mammals, and some berries and herbs). Zooarchaeological and stable isotope data from DONOP
309 show that native caribou and non-migratory seal populations were managed sustainably over
310 multiple centuries (Arneborg et al., 2012; Dugmore et al., 2012; Ascough et al., 2014) .
311 Organization of economic networks emerged from the twelfth century, integrating domestic
312 subsistence systems with wild resource cycles, such as the spring harp seal migration, late-
313 summer bird collections, and walrus hunting (Ogilvie et al., 2009; Frei et al., 2015). In the mid-
314 to-late thirteenth century, further adjustment of lifeways and diet towards a deeper exploitation
315 of marine mammals in response to unprecedented climate change can be seen in the
316 zooarchaeological record as well as in stable isotope analysis of human burials (Arneborg et al.,
317 2012). The poignant and rather grim conclusion to this is that even with adaptive flexibility and,
318 in some cases, sustainable management systems, the Scandinavian settlement of Greenland still

319 failed. This was not a collapse due to simple maladaptation but change driven by a variety of
320 factors: spatial, climatic, demographic, social, political, and economic (Dugmore et al., 2012).
321 While a full explanation of the current understanding of the nature of the Greenland Norse
322 collapse is outside of the remit of this article, a recent assessment of the North Atlantic by
323 Nelson and colleagues (2016) offers a good summary of current research.

324 On a more successful note, DONOP records of archaeofauna from the Mývatn region in
325 the north of Iceland documents a millennial-scale case of successful, community-level
326 management of migratory waterfowl beginning at first settlement (*Landnám*) and continuing to
327 the present day (McGovern et al., 2006; Hicks et al., 2016). Today, there is an annual collection
328 of eggs from nesting migratory waterfowl that does not adversely impact these species
329 (Guðmundsson, 1979). Nesting waterfowl are monitored and protected; only a few eggs per nest
330 are taken and adults are rarely hunted (Beck, 2013). Looking further back in time, the restricted
331 collection of waterfowl eggs is documented in mid-nineteenth century written records, such as
332 diaries, journals, and visitors accounts. Using DONOP we can create even longer time
333 perspectives; some terrestrial (non-waterfowl) bird hunting has happened alongside waterfowl
334 conservation and egg utilization since the Viking age; archaeofaunal assemblages are rich in
335 waterfowl eggshells while bones were mostly from ptarmigan (grouse), a non-aquatic terrestrial
336 species (McGovern et al., 2006, 2007). This suggests that a community-level avian management
337 system produced a valuable crop of eggs while maintaining adult waterfowl populations. This
338 management strategy was not only useful in conserving waterfowl populations over the long
339 term: there is also historical and archaeological evidence that careful use of wild resources
340 helped Mývatn inhabitants buffer themselves against starvation during hard times caused by
341 climate change (McGovern et al., 2013).

342 Successful long-term resource management is also evident from DONOP records in the
 343 Faroe Islands, where zooarchaeological (Brewington and McGovern, 2008; Brewington, 2011,
 344 2014) and documentary (Baldwin 1994, 2005) evidence suggests that local seabird colonies have
 345 been sustainably exploited for over a millennium. As in Mývatn, fowling in the Faroes has long
 346 been carefully controlled by local communities (Nørrevang, 1986; Baldwin, 2005). This
 347 community-level management regime employs a sophisticated body of local ecological
 348 knowledge to gauge the relative vulnerability of individual bird species and nesting areas on a
 349 year-by-year basis. Faroese resource managers (traditionally, landowners) are thus able to
 350 determine sustainable harvest limits for birds and eggs each season (Williamson, 1970, pp. 153–
 351 156; Nørrevang, 1986). Also of critical importance for the success of the system has been the
 352 ability to effectively monitor and manage nesting sites, protecting this sensitive resource both
 353 from overexploitation by people and from destructive domesticates such as pigs (Brewington et
 354 al., 2015).

355 In terms of behavior, DONOP from the North Atlantic can be used to draw two key
 356 lessons relevant to the present and future: sustainable millennial-scale management of natural
 357 resources is an attainable goal and adaptability in the short- or even medium-term is no guarantee
 358 of long-term survival.

359

360 2.2 Shifting Baselines and DONOP

361 Shifting baseline syndrome is a concept that describes situations in which communities
 362 formulate natural resource management decisions on ideas about primal or pristine natural
 363 resource populations that are inaccurate (Pauly, 1995; Pinnegar and Engelhard, 2008). Given that
 364 decisions about the management of natural resources can often be based on a ‘baseline’ standard

365 that is constructed around an idea of a minimally exploited population, then the assumptions
366 behind this baseline are very important. This can be a problem in conservation and resource
367 management if the baselines used to define sustainable exploitation of populations are based on
368 inaccurate, misleading data such as that from flawed human memory or temporally shallow data
369 sets (Papworth et al., 2009). Recent discussions of fishery management in the North Atlantic
370 have a distinct relevance to DONOP. The problem centers on what datasets people are using to
371 define a sustainable fish population. Pauly (1995) and others have described a phenomenon
372 where fishermen and fisheries managers use a combination of their own memory of the early
373 days of their fishing careers and catch data with a shallow time depth as baselines for what a
374 sustainable fish population should be. This concern runs deeper into environmental movements,
375 the media, and scientific works about rewilding (Monbiot, 2013). A specific example of this is
376 described by Bolster and colleagues (2012) in which they argue that the North Atlantic fisheries,
377 especially cod fisheries, have seen significant human impacts on fish populations from at least
378 the early nineteenth century. Yet consistent catch data on North Atlantic Cod (*Gadus morhua*) in
379 the North Atlantic has only been consistently collected since the beginning of the twentieth
380 century (Bolster et al., 2012). Thus, many of the assumptions about what baseline cod
381 populations and catch levels should be are based on populations that were already significantly
382 impacted by human exploitation. This situation can lead to a misperception of the level of human
383 impacts on a natural resource that can lead to much higher levels of stress on these populations
384 than anticipated. Zooarchaeology (the analysis of animal remains sourced from archaeological
385 sites) can help clarify if this is in fact a problem, especially when it utilizes recent advances in
386 the analysis of aDNA and stable isotopes of animal remains. Though there has been significant
387 and innovative research on shifting baselines in the North Atlantic that focuses on past ecological

388 conditions and past landforms, this article, in the interest of brevity, will discuss examples that
 389 are addressing the species level of analysis (i.e., Dugmore et al., 2000; Simpson et al., 2001;
 390 Dugmore and Newton, 2012; Streeter and Dugmore, 2013, 2014; Golding et al., 2015).

391 In 2012, Atlantic cod (*Gadus morhua*) was ranked by the Food and Agriculture
 392 Organization of the Union Nations (2014) as the 11th-most fished species in the world. In
 393 addition to being an important contemporary marine resource, this species was also crucial in
 394 both the medieval and early modern European colonial expansions. It was, and continues to be, a
 395 key species for both subsistence and the economic well-being of communities across the Atlantic
 396 from Maine to Norway.

397 The DONOP data represented by fish bones found in middens (refuse deposits from
 398 which archaeologists often excavate organic remains) across the North Atlantic region have long
 399 been of interest to zooarchaeologists focusing on the origins of the trade in dried cod and the
 400 onset of intensified non-subsistence fishing in North West Europe (Barrett et al., 2004).
 401 Zooarchaeological analysis charting the changing patterns of fish utilization has produced data
 402 crucial to understanding Atlantic cod's transformation from a subsistence good to an
 403 internationally traded commodity (Perdikaris, 1999; Perdikaris et al., 2007). Stable isotope
 404 analysis of fish bones is now revealing what regional populations of Atlantic cod are represented
 405 in the archaeological record (Orton et al., 2014).

406 *CodStory* is a current project that examines demographic and ecological data of Atlantic
 407 cod derived from archaeological excavations of DONOP fishing sites (Ólafsdóttir et al., 2014).
 408 In 2011, a pilot project began to investigate the feasibility of using Atlantic cod vertebrae to
 409 examine the historical genetic structure of Atlantic cod populations, and showed that this work is
 410 both feasible and rewarding. DNA was successfully extracted from fish bones and the

411 cytochrome B gene sequenced from a time series of zooarchaeological samples in western
412 Iceland dated from 1500-1910 CE. Further analysis of the genetic variation indicates a sharp
413 decline in effective population size of Atlantic cod in the fifteenth century, and further
414 population size fluctuations coinciding with recorded temperature changes (Ólafsdóttir et al.,
415 2014). Although the concomitant loss of genetic variation in the sixteenth century does suggest a
416 severe bottleneck, estimates of the genetic structure of Atlantic cod may be complicated by shifts
417 in population structure distribution and changes in feeding migrations that occur as the cod seek
418 favorable temperatures and feeding grounds because the Icelandic cod stock comprises both
419 migratory and coastal elements (Hovgård and Buch, 1990; Rose, 1993; Vilhjálmsson, 1997;
420 Pampoulie et al., 2006). To test these ideas, the *CodStory* project has continued by producing
421 higher resolution genetic data, stable isotopes assays, and shape analysis and growth
422 reconstruction based on otolith increments. The otolith analysis indicates a shift in the abundance
423 of migratory and coastal Atlantic cod populations in the historical catch and suggests that growth
424 conditions for the two Atlantic cod ecotypes changed in the early modern period (Ólafsdóttir et
425 al. 2017). Together, these results signal a disruption in the North Atlantic marine ecosystem
426 coinciding with a temperature minimum in the North Atlantic. Using archaeological samples, the
427 *CodStory* project is generating paleodemographic data on one of the most important maritime
428 resources of the North Atlantic while also investigating the effects of changing climate on these
429 fish populations at a high temporal resolution.

430 It is also possible to use DONOP archaeological data coupled with aDNA analysis to
431 understand the distribution of marine mammal populations before the commercial and industrial
432 exploitation of the Arctic oceans with potentially major implications for historical biogeography,
433 modern conservation biology, and marine management. A pilot project, completed in 2014,

434 included 35 presumed marine mammal specimens from archaeological sites in Iceland,
435 Greenland, and the Faroes; six samples gave positive results for aDNA. Four specimens were
436 identified to the species level, including one blue whale (*Balaenoptera musculus*, AK-CESP-
437 001), two fin whales (*Balaenoptera physalis*, UJF-CESP-003 and HRH-CESP-002) and one
438 harbour porpoise (*Phocoena phocoena*, SGN.103-CESP-507). Two additional specimens (UJF-
439 CESP-001 and UJF-CESP-008) were identified as being species of right whales, but were not
440 isolated to unique species beyond *Eubalena* spp. In order to further test how universal the
441 primers were, DNA extracted from a 13,000 year old bowhead whale bone was included, and
442 two samples from the Swedish Museum of Natural History, one bone sample previously
443 identified as being a humpback whale and a sample from a sperm whale tooth. The primers
444 managed to amplify DNA confirming the species (Anderung et al., 2014). The successful results
445 of this pilot project mean that marine mammal bone from DONOP sites, which can be difficult
446 for zooarchaeologists to identify morphologically, can now be identified, providing a window
447 into species distributions in past seascapes. Future work will also use methods such as protein
448 analysis, ZooMS, which is proving to be cheaper and often more useful under a variety of
449 different taphonomic circumstances than aDNA analysis (Buckley, 2018).

450 Due in part to the success of this pilot project, a three year NSF-funded project (*Assessing*
451 *the Distribution and Variability of Marine Mammals through Archaeology, Ancient DNA, and*
452 *History in the North Atlantic* – NSF award #1503714 – PI Dr. Vicki Szabo) commenced in 2016.
453 This has expanded analysis to approximately 300 archaeological samples of whale, seal, and
454 walrus bones across the Norse North Atlantic. Species-level identification of DONOP
455 archaeological material will allow deeper historical access into the premodern Arctic, Subarctic,
456 and North Atlantic societies' impacts on marine mammals, adding to recent groundbreaking

457 studies of pre-modern North Atlantic walrus exploitation and biogeographies (McLeod et al.,
458 2014; Frei et al., 2015). Norse economies, hunting or scavenging strategies, commercial uses of
459 marine mammals, and subsistence will be reassessed. aDNA analysis will allow insights into
460 genetic diversity and drift, possibly paleodemographic data, identification of now-lost or
461 endangered species in certain regions, and provide historical depth to the management of species
462 under threat today.

463 These projects are pushing baseline data of key natural species back into the last
464 millennium. In both cases they are focusing on species that have seen predation by humans, at
465 varying levels of intensity since the Neolithic period. Each one is focusing on the medieval to
466 early modern transition and attempting to build demographic data that could radically alter
467 current ideas of what a ‘normal’ or sustainable population is and of the historical spatial ranges
468 of these species.

469

470 2.3 Biological Records and DONOP

471 Analysis of aDNA has revolutionized our understanding of the history of our species as
472 well as that of our commensals and domesticates (Magee et al., 2014; Orlando, 2015; Scheu et
473 al., 2015; Zeder, 2015). aDNA analysis from DONOP sites can also directly contribute to
474 understanding the results of modern day breeding programs; revealing vulnerabilities and
475 suggesting improvements (Fahrenkrug et al., 2010). Finally, aDNA, with the advent of gene
476 editing technology, has the potential to become a source for past genetic variation that could be
477 reintroduced into modern domestic animal populations, allowing us to restore some of the
478 variability lost to modern industrial breeding programs.

479 A collaboration between the University of Maryland Zooarchaeology Laboratory,
480 Recombinetics LLC, and the aDNA Laboratory of the Catholic University of the Sacred Heart in
481 Piacenza, Italy is aligning the interests of the historical sciences with those of present-day animal
482 sciences. This project is beginning with an initial investigation focusing on aDNA analysis of
483 cattle bones from archaeological sites in Iceland. This will produce DNA sequence-based data
484 that sheds light on the interactions between humans, domestic animals, and a variety of
485 exogenous forces such as climate change, epidemics, trade, and ideology. In addition, the
486 sequence data provides an orthogonal element to the genetic record of livestock that shed insight
487 into decoding the genomes of contemporary domestic animals. The discovery of unique genetic
488 variation from the past could, for example, represent lost genetic variants effecting a wide
489 spectrum of phenotypes. Bioinformatic analyses will attempt to isolate unique genetic variants
490 underlying specific traits in pre-modern domestic animals that could be introduced back into
491 current domestic animal populations using genome editing technology. This project will attempt
492 to mine the genetic heritage of domestic animals that can be found within the faunal component
493 of archaeological sites to create resources that increase the resilience or reproductive capacity of
494 current populations of domestic animals. Given the stresses and hazards that anthropogenic
495 climate change will generate, this project is also attempting to utilize historical data as a tangible
496 resource for mitigation and adaptation to climate change threats and the improvement of animal
497 well-being. The sequence data and results from subsequent analyses that includes information
498 from the archaeological long-term observational networks will form the basis for direct and
499 tangible resources for mitigating against climate change threats to food animal production while
500 also producing key data for understanding the dynamics between social and ecological systems.

501 This is, of course, a ‘brave new world’ for the potential uses of historical genetic
502 material. The most dramatic and potentially visible impacts that aDNA could have in the near
503 future are best demonstrated in the projects that are investigating the possibility of reviving
504 extinct species (Charo and Greely, 2015; Diehm, 2015; Edwards, 2015; Shapiro, 2015; Weaver,
505 2015). Such projects could not be possible without access to genetic material from either
506 museum or archaeological specimens. A vigorous debate is developing around the ethical and
507 practical ramifications of such approaches (Kristensen et al., 2015; Martinelli et al., 2014;
508 Oksanen, 2008; Oksanen and Siipi, 2014; Siipi, 2016). Yet what can be said without debate at
509 this point is that developing biotechnologies focusing on editing genomes will have a profound
510 impact on the way historical genetic material is perceived and utilized.

511

512 3. Discussion

513 The article presents just a few of the projects that illustrate how data from archaeological
514 sites can be mobilized for application to contemporary problems. This idea is at the core of the
515 concept of DONOP. Indeed, an important difference in perspective between traditional
516 archaeological research focused on the interpretation of specific sites and the DONOP concept is
517 the selective use of records from archaeological contexts to tackle specific ‘grand challenge’
518 research agendas of demonstrable importance beyond narrow disciplinary confines (Kintigh et
519 al., 2014; Armstrong et al., 2017; Jackson et al., in review). They represent research projects that
520 could form key contributors from the historical sciences towards navigating the future challenges
521 of global change. Cooperative scholarly organizations such as IHOPE are driving efforts to
522 increase engagement with GCR, while governmental and non-governmental organizations have

523 recognized the potential of archaeological data, and threats to cultural heritage arising from
524 anthropogenic climate change.

525 The archive of DONOP sites and the behavioral, baseline, and biological data they
526 contain is unique. Yet this archive is threatened with destruction by the very global changes it
527 records; this is a modern equivalent to the burning Library of Alexandria. The rate of damage to
528 archaeological remains is continuing to accelerate as ground temperatures, moisture regimes, and
529 erosion patterns change (Rockman, 2015; Hollesen et al., 2016; Hambrecht and Rockman, 2017;
530 Hollesen et al., 2017). Without the mobilization of substantial international resources to
531 recognize, manage, and when needed, rescue these endangered archaeological archives,
532 irreplaceable records will be lost. DONOP sites are important not just because of the inherent
533 value of our shared human historical inheritance but also as a direct cultural archive of social-
534 ecological interaction over the *longue durée*.

535 Recognition of the importance and utility of DONOP has grown beyond direct
536 practitioners. The US National Park Service has taken the lead within the US government, setting
537 out federal policy and strategic guidance on the importance of addressing impacts of climate
538 change on cultural heritage (including archaeology) and using cultural heritage to inform both
539 research and the management of climate science, adaptation, mitigation, and communication
540 policies (National Park Service, 2014; Rockman, 2015; Rockman et al., 2017). In this approach,
541 it is recognized that cultural heritage is both affected by climate change and is a source of data on
542 how to address climate change (Harvey and Perry, 2015).

543 There are many other international, national, and local efforts addressing the interaction
544 of climate change with cultural heritage but there is a danger that a piecemeal approach will not
545 be the most effective. A global response to threatened archaeological sites focused on their utility

546 as DONOP is likely to produce the most effective global outcomes. International funding
547 organizations such as the US National Science Foundation, the Belmont Forum, the EU Science
548 Commission, and Future Earth have the potential to create funding streams that are focused on
549 utilizing the past to better understand the present and navigate the future (Costanza et al., 2007,
550 2012). Many archaeological sites, especially in coastal, montane, and polar regions, are now at
551 critical risk of loss to climate change. Saving all threatened sites will not be possible. Many will
552 be irrevocably lost over the next century due to the impacts of climate change. Guided by a series
553 of focused research questions, it is essential that archaeologists identify, excavate, or at least
554 sample 'at risk' sites and, where possible, protect key archives under threat (Van de Noort,
555 2013). The issue is no longer one of just preserving archaeological sites so that they survive for
556 future generations, though that is important on its own terms. It is now an issue of protecting
557 and/or rescuing key data sources that will help us better face the future. On a local and regional
558 scale, past societies have experienced global changes that have dramatically altered the structure
559 of their spatially-limited worlds; the scale of future change is such that it is likely to have
560 unknown impacts on contemporary societies and their cultural, social, environmental, and
561 economic capital. Archaeological sites and heritage in general should be redefined to include
562 their utility towards addressing and recording anthropogenic global change. Funding
563 organizations and governments are recognizing the importance of archaeological data, but more
564 needs to be done to encourage engagement between archaeologists, GCR, and practitioners.

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