THE MIDDEN

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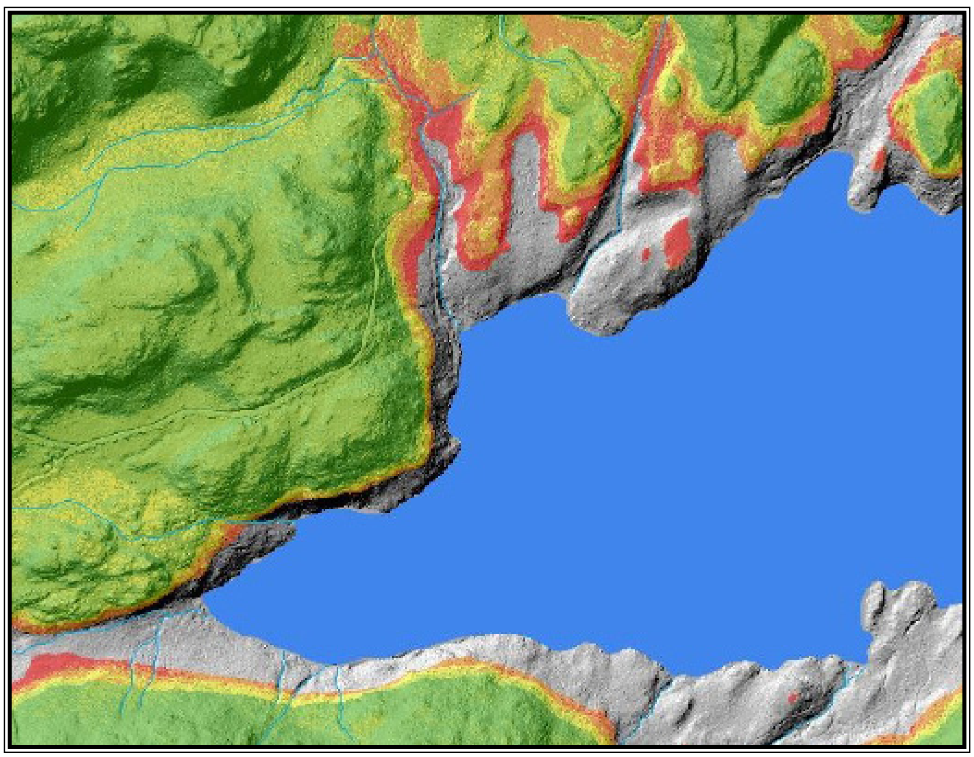
New Horizons: The Next Decade of Emerging Technology in Archaeology



THE MIDDEN

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SUBMISSIONS: The ASBC welcomes article contributions for The Midden on an ongoing basis. Periodically there will be themed issues with specific topics, but the ASBC always encourages the submission of articles related to a diverse array of topics that pertain to BC Archaeology for more wide-ranging issues. Please email submissions to asbc.midden.gmail.com

SUBSCRIPTIONS: Going forward the ASBC has decided to make The Midden digital and open access. The latest issue of The Midden will be emailed directly to ASBC members upon release, and will be open access to the public at:

https://journals.uvic.ca/index.php/midden

PARTNERSHIP: The ASBC publishes ***The Midden*** journal in partnership with the BC Association of Professional Archaeologists. Both organizations share funding of the open access journal, which is managed by ***The Midden*** Board of Directors.

Archaeological Society of British Columbia

Dedicated to the protection of archaeological resources and the spread of archaeological knowledge.

ASBC membership fees directly help to make the publication of ***The Midden*** possible.

ASBC Annual Membership Fees:
Individual: $25 Family: $35 Seniors/Students: $18
Corporate/Institutional Membership: $100
Lifetime membership $400

pay with email transfer
asbc.membership@gmail.com

or Paypal on our website
http://asbc.bc.ca

Visit our facebook page for updates on events
https://www.facebook.com/ASBCVictoria/

Archaeological Society of British Columbia meetings in Victoria featuring illustrated lectures are generally held on the third Tuesday of each month from September to May at 7:30 p.m. at the University of Victoria. Due to COVID-19, the lecture series will now be held online this fall. Please follow our Facebook page www.facebook.com/ASBCVictoria for details on upcoming lectures, or inquire with us about our email list.

THE MIDDEN

Volume 50, No. 2
Fall 2020

In this issue

ASBC Pages

Articles

Special Issue Articles

THE MIDDEN Subscriptions

A digital copy of each issue of **THE MIDDEN** are emailed directly to ASBC members upon release.

Subscription forms and membership application forms are available on our website (http://asbc.bc.ca/the-midden/).

Cover: This example of an archaeological predictive model shows a model with a graduated colour scheme overlaying a grey bare earth model derived from aerial LIDAR (base data acquired by the Hakai Insitute and UNBC; image generated by Alex Lausanne for 2018 M.Sc. geoarchaeology work).

The ASBC Pages

Archaeological Society of BC Initiatives 2020-2021

The Archaeological Society of British Columbia (ASBC) is working to fulfill our mandate to educate the public, support students and First Nations communities in their archaeological research and engage the CRM (Cultural Resource Management) community. In order to do this, the ASBC is now collaborating with community partners on a number of ongoing and new initiatives. Please see below for details.

We would also like to remind readers to renew their membership (www.asbc.bc.ca). The small income we receive from membership dues allows us to continue to our work and to produce The Midden.

ASBC Board of Directors

Continuing Initiatives…

ASBC Gerald Merner Field School Award

The ASBC contributes two annual awards of $300 to an undergraduate student and/or Indigenous community member participating in their first archaeological field school.

Details for application: Usually made on recommendation of field school instructor, practising archaeologist, or First Nations member. Due to field school cancellations during Covid, this award is on hiatus.

ASBC/University of Victoria Lecture Series

Our Tuesday night lecture series is on hiatus due to Covid and will restart following distribution of a vaccine. We are working on producing a number of online talks to share with members in the interim and may do fall field trips.

Kamloops ASBC Chapter

The Kamloops ASBC Chapter provides lectures and workshops in the Kamloops area, and several members are involved in the production of the “Dig It” series. Activity has slowed due to Covid but will continue next year. For more information contact kamloops.asbc@gmail.com.

New...

ASBC/ BCAPA Grade School Archaeology Speaker Funding

The ASBC and BC Association of Professional Archaeologists (BCAPA) have partnered to fund archaeologists and Indigenous cultural experts to guest speak at provincial grade schools throughout B.C. (or remote lectures during Covid).

The ASBC has also secured a City of Victoria Strategic Grant to fund additional archaeologists speaking at grade schools within the Greater Victoria Region.

CRM companies willing to provide archaeologist volunteers and or funding to this will be recognized in The Midden journal and elsewhere as partners in this initiative, and will receive charitable tax receipts for their contributions.

Archaeologists/cultural experts may apply with a school in mind, or request to be connected with a school in their region. The ASBC is regularly contacted by schools and teachers requesting archaeologist speakers, so we strongly encourage archaeologists to volunteer their contact information for future class visits. Contact us for details at asbc.president@gmail.com

Details for application:

- Archaeologist must submit a resume and/or reference to show that they have at least one of the following:
    - 7 years experience in CRM or academic position (or),
    - BCAPA membership (or),
    - completing or recently completed graduate or post-graduate studies at a B.C. university, with recommendation from supervisor (or),
    - are an approved speaker in the local school district.
- Indigenous cultural experts should have archaeological and/or cultural experience and recommendation from First Nations administration office, educational institution or CRM company.
- Applicant may submit an abstract of proposed talk/lesson/workshop. Note, presentations may also be general and geared towards informal Q and A presentations. Topic's must relate to B.C. archaeology.
- Following acceptance of proposal, applicant must show correspondence with applicable school.
- Limit of 4 school visits funded per individual. The decision to fund an individual beyond this number of classes will depend on annual allocation of funds and number of applicants available regionally.
- Between $100-$200 awarded to archaeologist for talk/lesson/workshop per school (depending on school funding contribution available). Larger grants may be given to those schools in greater need of financial assistance. Additional transportation costs, educational materials, etc. may be funded through "Scientists in Schools" Program (https://www.scienceworld.ca/sis/, contact us for details).

Tree Coring Workshop

The ASBC has proposed an informal dendrochronology workshop with Professor Bethany Coulthard from the University of Nevada (https://geoscience.unlv.edu/people/department-faculty/bethany-coulthard/) for CRM professionals and academics. If you have an interest in this workshop this November, please let us know. The workshop will take place over Zoom with a field component.

Offered:

Dendrochronology basics
Training in cross-dating, increment boring, sample processing

Cost will be $50 a person ($35 for ASBC members) and subsidized by the ASBC. Contact asbc.president@gmail.com if you would like more details (limit of 10 individuals).

ASBC Carbon-14 Award

The ASBC will accept applications from First Nation communities and post secondary students in B.C. looking to date archaeological or important cultural materials. Six dates will be offered annually, with a limit of one per applicant. A short application and results write-up will be requested for publication in The Midden.

This award is offered thanks to the help of three AMS laboratories throughout North America who have generously offered free C-14 dates for Indigenous communities and students through the ASBC.

- E. Lalonde AMS Laboratory at the University of Ottawa
- DirectAMS in Bothwell, Washington
- Keck-Carbon Cycle AMS facility at the University of California

The ASBC will pay for one of the six dates and will cover all sample delivery costs.

Details for application:

- One date sample per applicant.
- Application must either be from a B.C. First Nation or an enrolled B.C. post secondary student (with letter of support from academic supervisor/professor). Applications may be accepted from other institutions if there is a strong demonstration of support from associated First Nation and a lack of external funding.
- Material associated with otherwise well-funded development or CRM projects will not be accepted.
- Written application and results of dating will be submitted to the ASBC (asbc.midden@gmail.com) for publication in The Midden journal.
    - Application (400 word limit) must clearly explain the origins of the object or material and reasons for interest in it's dating.
    - Results, when known to the applicant, will be outlined and submitted to The Midden journal within two weeks of receiving dating results (500 word limit).
    - In particular circumstances, the ASBC will reserve its funding to cover a single C-14 sample date considered to be sensitive material not suitable for publication. The details of this date sample will not be made public.

The first two applications have been accepted and shown below as inaugural examples of this award. The first was offered to the Songhees and Esquimalt Nations for dating of a remnant midden site in the Greater Victoria area, and the second to the Gitga'at Nation and Kitasoo Xai'Xais Nation who have partnered with SFU for a study of outer Central Coast islands. The results will be released when ready. See details below.

First Two ASBC C-14 Sample Awards:

Royal BC Museum- Songhees First Nation
Funded thanks to the
E. Lalonde AMS Laboratory
at the University of Ottawa

A Radiocarbon date for Archaeological site DcRt-17

The Songhees and Esquimalt Nations are interested in the documentation of all the archaeological sites in the traditional Lekwungen territory around greater Victoria. I am assisting them in this objective. One general location that is lacking in information involves the six shell middens along the exposed eastern shore of their territory. All of these have been seriously impacted by modern development and none of them have been dated.

The most significant of these sites in size and depth was DcRt-17, at Telegraph Cove. There are 452 artifacts from this site and more information on examples from private collections. The shell midden sites along the most exposed southern shoreline of the Lekwungen territory all date within the last 500 to 1000 years. It is of interest to find out if this dating pattern persists on the exposed east side of the territory.

This site, however, has some distinct point types that are expected to be older than 1000 years. Sites older than 1000 years tend to be in more protected bays in the region.

The Songhees and Esquimalt are involved in developing outdoor posters for public education at various sites around Victoria and would like to be able to put a date on this site that is in a publicly accessible location. I have a good quality charcoal sample from a once intact part of this site.

Grant Keddie

Simon Fraser University, Gitga'at Nation, Kitasoo/Xai'Xais Nation
Funded thanks to
Keck-Carbon Cycle AMS
facility at the University of
California

A Radiocarbon date for outer Central Coast Islands

While it is now generally apparent and accepted that Northwest Coast Indigenous Peoples occupied, managed, used, and/or traveled through nearly every stretch of the B.C. coastline, the inhabitation of the furthest outer coast areas demonstrates their mastery of living in the maritime landscape (see essays in McMillan and McKechnie 2015). The outer shores offer access to unique and rich resources, though long open-water crossings and exposure to harsh weather present challenges to living in these places. Similar logistical challenges have also limited archaeological research on the outermost islands of the coast, which – now more than ever before in the past – are far removed from modern communities.

In the last year, a partnered project with researchers from Gitga'at Nation, Kitasoo/Xai'Xais Nation, and Simon Fraser University Department of Archaeology have undertaken work on small islands off the west coast of Aristazabal Island, on the north-central coast of BC. These islands are some of the furthest offshore from the mainland coast, and are a several-hours-long powerboat ride from the nearest modern villages of Klemtu and Hartley Bay. Today the islands are an important location for contemporary Indigenous harvesting of many resources not readily found closer to the mainland. Despite being the 'last stop' before what would be a daunting open water crossing to southern Haida Gwaii, this summer we identified abundant evidence for ancient human occupation on the islands. Archaeological remains from these sites provide a fascinating window into ancient lives at these under-studied reaches of the coast. At one site, we identified an exposure of eroding shell midden that included abundant animal bone remains of what appear to be shore birds and shells of California Mussel and abalone. Significantly, this exposure was associated with a larger archaeological site that suggested it was more than just a camp for forays from the inner protected waters.

Our team collected bulk samples of these ancient food remains to analyze for a better sense of the types of resources that may have attracted ancient occupants to these islands. We will radiocarbon date charcoal in association with the fauna, along with conducting a detailed zooarchaeological analysis of these remains to explore what was being harvested in this unique environment, compare ancient resource presence with what we know to be available today, and look for 'surprise' resources: is there anything in the assemblage that people must have brought with them from the mainland? In a future issue of The Midden we will report on the age of the deposit and the species identifications. This knowledge will contribute to a better understanding of the lifeways of these expert mariners of the past.

Bryn Letham, PhD

Reference:

McMillan, A.D. and I. McKechnie (editors). 2015. These Outer Shores: Archaeological Insights into Indigenous Lifeways Along the Exposed Coasts of British Columbia. Special Issue of *BC Studies*. Vancouver, BC: University of British Columbia.

ASBC/BCAPA Establishment of new Midden Board

The ASBC has created a new editorial board for the journal, The Midden, and has partnered with the BCAPA (BC Association of Professional Archaeologists) to support the journal as an open access publication into the future. This new board is a collaboration of Indigenous, academic and CRM archaeological professionals from around British Columbia. The ASBC and BCAPA are jointly funding the journal and will regularly contribute material for their respective memberships, but otherwise will hand off creative control and vision to this new team. The board's first issue is expected fall/winter of 2020.

The Midden journal will now be open-access and distributed online via www.uvic.ca/journals immediately upon publication, and will no longer be exclusively accessed by ASBC membership for 6 months prior to online distribution.

Please enjoy the articles in this latest issue, 50(2), of The Midden and we look forward to sharing more on this new chapter of the journal under the leadership of the newly established Midden Editorial Board. Stay posted for future issues later this fall!

BCAPA
BRITISH COLUMBIA ASSOCIATION OF PROFESSIONAL ARCHAEOLOGISTS

Editor's Note

New Horizons: The Next Decade of Archaeology

Time, space and change – these concepts are often taken for granted in everyday life, but are always close to the surface for archaeologists. When the theme for this journal issue was originally proposed earlier this year, the idea was to explore the new and emerging technologies of archaeology, with 2020 marking the onset of a new decade of archaeological practice and also the continuation of technological change in this constantly evolving field.

This decade certainly predicted change, but the global changes experienced in these first nine months of 2020 went vastly beyond what most people envisioned. The onset of the Covid-19 pandemic has rocked our views of time and space. From an everyday perspective, time and space are now ever-present, especially space. And time is a concept that is being re-evaluated and recreated, as we strive to make sense of the world and plan our lives, but not too far in advance. The age-old phrase "the passage of time" seems irrelevant at a moment when time can feel like more of an uncertain state of limbo.

This new decade has brought immense change, with certainly more to come. While we try and navigate these new challenges, let us work together towards solutions and continue to share knowledge and enthusiasm about the topics we are passionate about, such as archaeology in B.C.

Archaeological technologies develop at a rapid pace, and are being widely implemented by practitioners in B.C. who are breaking ground within their fields. With the emergence of novel technologies, new questions can be answered and at a faster rate and with new depth. In this issue 50(2), *The Midden* will explore what up-and-coming technological advances will present to the field of archaeology in British Columbia this decade. The issue aims to explore a broad range of topics and tools that assist in archaeological studies today, such as remote sensing techniques, ancient protein analysis, and emerging sampling technologies.

The seven articles in this journal issue speak to the changing times we live in, and notably, six of these articles are shared with us by women in B.C. archaeology. Although this is not the theme of this issue, it is important to acknowledge the tremendous contributions and strides women have brought to archaeology, and continue to bring to the field of archaeology, as historically this discipline has not always offered the level of inclusion that we are starting to see today. More effort is still needed to make archaeology more accessible. Let this decade lead to more positive growth on the fronts of archaeology.

It is with great pride that we share the following articles:

In her article on "the Digital Divide," Cecilia Porter addresses the important issue of accessibility in archaeology and the marginalization of Indigenous voices as a by-product of advancing technology.

Lindsey Paskulin's article highlights the development, advantages and applications of proteomics (the large-scale study of proteins) and the utility of analyzing ancient proteins to understand past subsistence patterns, health, food processing and more.

Camilla Speller expands on protein analysis by outlining the utility of the ZooMS (Zooarchaeology by Mass Spectrometry) approach that originated in Europe and for the high potential for researchers to further expand this technique into the toolbox of archaeology in North America.

Another powerful technique to gather zooarchaeological data (as well as other data) includes a geological sampling technology referred to as vibracoring. The article by Seonaid Duffield et al. uses this method to collect archaeological data within deep shell midden deposits in areas like the Broken Group Islands.

In the article by Raini Johnson et al., Machine Learning Algorithms (MLA) are introduced as a way to automate predictive models that are used to help locate archaeological sites.

Kelly Monteleone expands on the process involved in predictive modelling by using a case study of prospecting for potential archaeological sites on the submerged landscapes of the continental shelf of southeast Alaska.

Finally, as we enter this new decade of archaeology, it is important to pay homage to those who have paved the way for many decades prior. Bryn Letham shares insights on the substantial contributions of two "Flagship Archaeologists," George MacDonald and Ken Ames, who have greatly contributed to archaeology in the Prince Rupert Harbour, since the 1960s.

As the first fully open access issue of *The Midden*, it is in hope that we can continue advancing archaeology in B.C., while helping to make it more accessible to everyone. Please enjoy Midden issue 50(2) and thank you for your continued support.

~ Alex Lausanne, Guest Editor and Midden Manager

Archaeological Society of British Columbia

*Sul'sul'tun

By Angela Dyck

Sul'sul'tun means spindle whorl in Hul'q'umi'num' (from the online dictionary).

A spindle whorl, used for weaving, is a disc-shaped implement with a hole through the middle, through which a spindle (long stick) would be inserted. Spindle whorls were often made of bone, and they were used to add weight to help the spindle spin. Traditionally, wool from mountain goats and wool dogs would be spun into yarn using a spindle and spindle whorl.

Resources:

Hul'q'umi'num' to English Dictionary
A digital resource compiled through research projects in the 1970s to 1990s with various Elders in the Hul'q'umi'num' speaking community.

http://abed.sd79.bc.ca/hulqumimum-resourses/hulquminum-to-english-dictionary/

The First Peoples' Cultural Council assists B.C. First Nations communities in their efforts to preserve and revitalize their language, arts and culture. Some of the amazing programs they support include FirstVoices, an extensive online Indigenous language archive and teaching tool, and the Language Nest program, aimed at creating new language speakers through language and cultural immersion for young children. Find out more about these programs and resources:

http://www.fpcc.ca/language/Programs/

https://www.firstvoices.com/

Coast Salish Traditional Place Names projects
http://www.sfu.ca/brc/imeshMobileApp/place-names.html

https://salishseasentinel.ca/2019/02/work-begins-to-restore-coast-salish-place-names-on-mid-island/

Overcoming the Digital Divide: Some lessons from the Arctic for consideration in BC

by M. Cecilia Porter

It is becoming increasingly clear that there remains a pressing need for the de-marginalization of Indigenous voices in archaeological research. Digital technologies and web-based platforms delivering heritage content by way of visual media are gaining traction to answer this call, as they hold promise for genuine co-authorship with Indigenous communities as well as for engaging the public in constructive ways that could lead to greater involvement and dialogue between Indigenous communities and the broader public (Bonacchi and Moshenska 2015; Champion et al. 2012; Dawson 2016; Dawson et al. 2011; Lyons et al. 2012; Lyons et al. 2016b; Porter 2017; Robson et al. 2012; Rustad 2015; Walls 2014; Warwick 2012; Witcomb 2007). This is important, because knowledge is a prerequisite for respect. However, if there are barriers to Indigenous community members' ability to access these online-based materials, then the goal of genuine collaboration cannot be met, and the online-based materials become as unreachable as traditional text-based scholarship. As it currently stands, projects that use a technological means of delivering their message will only reach audiences who have the socioeconomic means by which to access them. This paper will use the Arvia'juaq National Historic Site Panoramic Virtual Tour (Porter 2017) as a case study to discuss the potential for immersive digital technologies in archaeology, the digital divide and its impact on archaeological projects, and some creative ways in which projects can overcome this barrier if they are going to be truly useful to the communities they wish to serve.

Archaeology and Digital Heritage

Archaeology as a discipline has inherited a deeply colonial legacy, and many Indigenous peoples have seen archaeology primarily as a tool of colonialism (Smith and Jackson 2006). Today, archaeologists largely recognize that they are working with the heritage of living people and the move towards an archaeological practice that collaborates with Indigenous communities is underway. However, observation of the manner in which Indigenous issues are discussed in the media and by the general public makes clear that the public is largely operating on decades-old (colonialist) stereotypes of Indigenous people. As archaeology has grown as a discipline, it has become clear that there is value to sharing cultural heritage information with the public and in involving Indigenous communities in projects (Green et al. 2003). This practice can lead to greater transparency, more collaboration, and increased reflexivity (Brock and Goldstein 2015). To properly work towards undoing the colonialist legacy, archaeology must work towards genuine collaboration with Indigenous communities, and it also must find ways to share the results of this collaboration with the broader public.

More and more, projects developing virtual tourism of heritage sites and the digital delivery of archaeological information are being created. These technologies are engaging, as they create an embodied sense of presence (i.e. you feel as though you are there) at locations that are often far removed from where a user is situated. Though digital technologies like Google Street View are new, using immersive imagery to virtually visit a place that would otherwise be prohibitively difficult to travel to is not novel, and was used in Victorian England (Dawson et al. 2018). Though there are pitfalls inherent in any project that wishes to put Indigenous Traditional Knowledge on the internet (Hennessy 2010), panoramic photospheres and map-based digital technologies are being successfully used in archaeology to create virtual tours of heritage sites of national and international significance. For example, Google's World Wonders Project uses its Street View platform to showcase such heritage sites as Pompeii (Google 2016), and Google's Arts and Culture platform delivers panoramic virtual tours of ancient sites such as Stonehenge (Google 2015). ArcGIS StoryMaps are being used for map-based tours of heritage sites in as broad a range as Cahokia Mounds State Historic Site (Prairie Research Institute 2019) and heritage buildings in Greater Victoria (Victoria Heritage Foundation 2019). Also in BC, the Sq'éwlets Website Project is using digital media to tell the story of the Sq'éwlets People (Lyons et al. 2016a), to allow Sq'éwlets youth to learn their own histories and identities and to allow the community to share "their own perspectives of Sq'éwlets history with the broader world of which they are a part but by which they are not well understood" (Lyons et al. 2016b).

Panosphere-specific software can be used to create panoramic virtual tours of cultural sites that are otherwise difficult to access, such as the Arvia'juaq National Historic Site (Porter 2017). Arvia'juaq is located on a remote island in Nunavut and is physically difficult to visit for both the Arviamiut Inuit to whom this site is significant, as well

Figure 1: The hamlet of Arviat, Nunavut, is located on the northwest coast of Hudson Bay.

as to the Canadian public to whom the Arviamiut wish to tell their stories. Virtual tourism holds potential for cross-cultural engagement that could hopefully lead to greater respect for Indigenous communities, in addition to new and innovative ways for Elders to teach traditional knowledge to their youth. It is promising that this could lead to increased interest and understanding of archaeological sites and their importance, which is especially important for many smaller Indigenous communities where accessibility and remoteness are major barriers.

The Digital Divide

The Internet was initially lauded as a leveller, with the belief that marginalised groups would have the same ability to be heard as anyone else. Furthermore, by using the Internet, marginalised groups would have access to the same opportunities as anyone else; however, this has not been the case (Aporta and Higgs 2005; Cameron and Robinson 2007; Chapin and Threlkeld ; Lopatin 2006; Neuman 2008; Subramony 2007; vanDijk 2006; Warwick 2012;

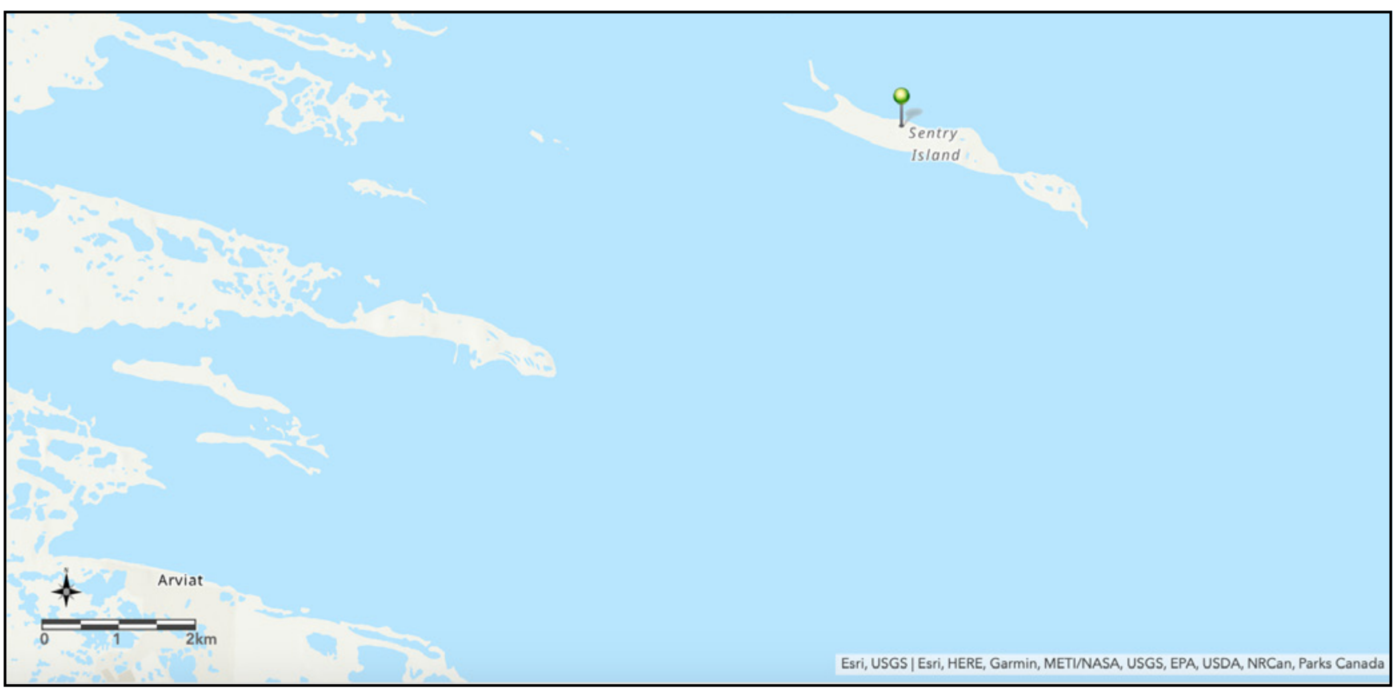

Figure 2: The island of Arvia'juaq is located a short boat ride to the northeast of Arviat.

Figure 3: Luke Suluk on Arvia'juaq during the recording of the videos for the Arvia'juaq panoramic virtual tour (Photo credit Darren Keith, 2015).

Waterton 2010). The reality is that though the World Wide Web creates the potential for marginalized communities to be given a voice, those who are minority groups in 'real life' continue to be minority groups on the Internet due to imbalances in access (Waterton 2010). Thus, online spaces tend to be dominated by those who are predominantly upper and middle class, and the dynamics, oppression and marginalisation of the 'real world' are simply recreated on the Internet (Waterton 2010). Accessibility then, is a concern of any online archaeology project, particularly any project that wishes to educate across distance as well as cultural and generational divides.

It may seem that the world is shrinking with the advent of the Internet, but some are being left behind. This gap between those with easy access to digital platforms, including Internet and computers, and those without is called the digital divide (Clark 2003; Dwivedi et al. 2016; Subramony 2007; vanDijk 2006). The term includes discrepancies in access between developed and developing countries, between those of lower and higher socioeconomic status within a single country, and those who are and are not able to use technology for empowerment (Moore 2007). Not only does the digital divide exist, but it is widening as more necessary information is put online, including government-implemented electronic systems to modernize delivery of public services (Dwivedi et al. 2016:512). Those without access are missing out on more and more. Access to the Internet is not the only issue, but available computing power and available Internet speeds can impede technology-based efforts at knowledge distribution and education, furthering the digital divide (Belton 2010; Dawson 2016; Moore 2007). Even if the Internet is present in a community, citizens require up-to-date computers and a fast connection in order to effectively participate in Internet-based interactions or endeavours, especially image heavy panoramic tours, story maps, or other immersive experiences. This is a particular issue when these citizens are intended to be collaborative partners and co-authors in these projects.

Canadian Challenges: The Arctic and BC

Despite its status as a wealthy nation the digital divide is an ongoing issue in Canada, particularly in northern or rural Indigenous communities where the Internet speeds are often so slow as to render much of the Internet unusable in practical terms. Unlike much of urban North America, high-speed Internet connections in every home are not the norm in the Arctic. In Iqaluit, the Territorial capital of Nunavut, Internet speeds are generally too slow to buffer large items like video, while in small hamlets, connectivity is often further limited to slow and expensive satellite Internet and is often accessible only at the local school, library, or community centre. This situation is also true of rural Indigenous communities across BC. For a virtual tour and/or other Internet or technology-based outreach to succeed with education or communication goals, and to be useful to these communities, it needs to contend with the limitations of available connectivity, bandwidth, and computer power. The incredibly slow Internet speeds in the myriad of villages in northern and rural Canada make streaming video, loading photo heavy web pages – or accessing a panoramic virtual tour with their own traditional knowledge – impossible. Therefore, when working in northern or rural communities, researchers must be aware of the realities of access and computing power available,

Figure 4: Qillaluguajarvik Qajaq Game, Arvia'juaq (Photo M. Cecilia Porter, 2016).

and refrain from making assumptions based on Internet access and computer speeds commonly expected in the more affluent parts of Canada.

Case Study: The Arvia'juaq Virtual Tour

For my Master's research (Porter 2017) I worked in the hamlet of Arviat, located on the northwest coast of Hudson Bay in Nunavut (Figure 1 and Figure 2). The Arviamiut Elders (Arviamiut meaning 'people of Arviat') have successfully lobbied the federal government to have their heritage site on the nearby island of Arvia'juaq recognized as a National Historic Site (Figure 3). Arvia'juaq has been identified as a site of national significance as it is a cultural landscape that commemorates the relationship between the Inuit and the land, and it is central to the Paatlirmiut ontology (Karetak-Lindell 2000). The island was a summer gathering place for the Paatlirmiut, and is dense with stone features including tent rings, shaman's healing stones, and games like the caribou crossing game and the qajaq game (Figure 4).

Due to its remoteness the site is inaccessible to most people. When Arvia'juaq was designated a National Historic Site, it was recognised that a well-conceived outreach programme would be necessary in order to impart the importance of Arvia'juaq to all Canadians (Keith 1997). Furthermore, the Elders wished to develop an engaging way to teach their heritage to their youth. With these goals in mind, and in collaboration with the Arviamiut Elders, I built a panoramic virtual tour (www.arviajuaq.ca, Figure 5 and Figure 6). This format allowed for the community members to give direction and provide edits and feedback in ways that are not possible with traditional text-based scholarship (Figure 7, Figure 8).

For the Arvia'juaq panoramic virtual tour to fulfill the goals set out by the Arviamiut Elders and be a useful and engaging tool with which to teach traditional knowledge to their youth, the digital divide needed to be overcome. A few creative solutions were developed, which will be described with the goal of assisting other researchers in efforts to make their own materials accessible to the very communities they're working with. The primary strategy used to work around the complex issues of the digital divide in Arviat was to develop an offline method of viewing the virtual tour. From the host website a user may launch the tour and view it in the browser, or they may download the tour for viewing offline. The ability to download the tour enables a user with an older computer or a slower Internet connection to download the tour over the span of several hours or days for later viewing offline. This function also enables a user who does not have Internet in their home, but who has access to Internet at the local library or school (which is a common scenario) to download the tour and then take the tour home for unlimited offline viewing. Another consideration in choosing the host software was the ability for the tour to be viewed on a variety of devices, including phones and tablets, for greatest flexibility.

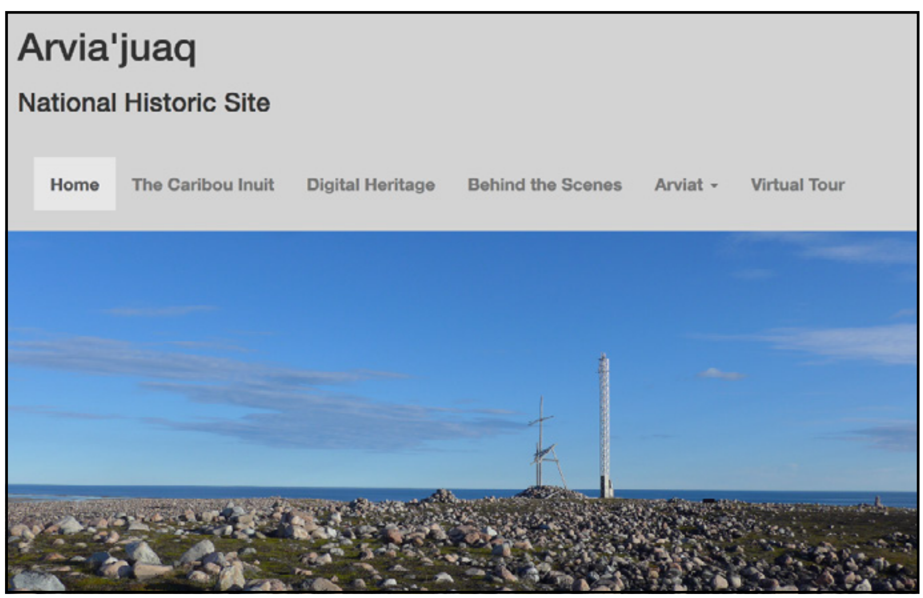

Figure 5: The home page for www.arviajuaq.ca, the website that hosts the Arvia'juaq panoramic virtual tour.

Figure 6: Arva'juaq panoramic virtual tour snapshot.

For the long term, the community expressed great interest in having a kiosk at the Margaret Aniksak Visitors Centre in Arviat. This kiosk would host the tour offline, and a localized hotspot could be created from the host computer which would allow users to view the tour on their own device as if they were logging on to the greater Internet. Most computers can create a local wi-fi network which has no connectivity to the larger Internet but allows viewing of the website and tour on a user's laptop or mobile device as if it were logging into a normal website.

Figure 7: Luke Suluk, Culture and Heritage Elder Advisor at the Department of Education, Government of Nunavut, gives feedback on the Arvia'juaq virtual tour (Photo Colleen Hughes, 2016).

Another solution used to distribute copies of the tour to individuals was to pre-load USB drives with a Linux operating system with the website and tour hosted locally, and have it programmed to launch the site and tour upon booting. While this takes some up-front set-up by someone with computer skills, the drive can then be cloned indefinitely, allowing for sharing of the tour without use of the Internet at all. This solution is inspired by the Nunavut Department of Education's policy of distributing all digital materials to schools via flash drives, which are affordable, durable, can easily be sent through the mail, and have none of the bandwidth constriction issues of attempting to access content on the Internet.

Figure 8: Qitiqliq Middle School: Doreen Hannak, Principal (left), and Billy Ukutak, Guidance councillor (centre), explore the landscape of Arvia'juaq using Google Cardboard viewers, while Cecilia Porter (right) looks on.

Solutions employed by other northern focused projects include partnering with Inuit web developers based in these communities, such as Pinnguaq (based in Pangnirtung) or IsumaTV (based in Igloolik). These developers can assist southern-based researchers as they are better aware of the limitations of available cyberinfrastructure. It has been suggested that to truly overcome the disadvantages of the digital divide, it is not enough for cultural groups to have access to the technology to become Internet consumers, but that it is necessary to make the transition to become a technology producer (Subramony 2007). Pinnguaq and IsumaTV are groups that have made the transition to technology producer.

Conclusion

For too long Indigenous communities have experienced outsiders arriving for short-term assignments to conduct research and then take away their findings (Atalay 2012), either by removing physical artifacts or by extracting their cultural anthropological information and publishing it in academic journals, which also do not return to or benefit the community in any way. Web-based platforms for archeological and cultural outreach are becoming more common as a way to collaborate with and give voice to Indigenous communities. Similarly, it is repeatedly stated that community-based archaeology will 'empower' Indigenous peoples. Because differential access to power is at the root of colonialism, decolonization of archaeology must rethink power relations between Indigenous peoples and archaeologists. However, community-based practices do not 'empower' Indigenous peoples so much as they desist from disempowering them (Smith and Jackson 2006). Therefore, if a web-based collaborative outreach project does not work to overcome the digital divide, it will be inaccessible to the community that collaborated on its creation and will act to reinforce rather than subvert the existing imbalances of power and access.

The Arvia'juaq panoramic virtual tour was an immediate success in meeting the goal of engaging the youth of Arviat. In my presentation at the Qitiqliq Middle School in Arviat, given to gauge youth interest, when the school day ended the children had all their attention on the tour and had no interest in leaving the classroom. Throughout the rest of my time in Arviat I was stopped in the street by young people asking me how to download the tour to their iPod Touch. There have since been inquiries from the community about creating a slide show with images and videos from the tour and showing it on the television in the single-room airport. As a slide show in the airport waiting room the Elders' voices would pass traditional knowledge to community members waiting for loved ones to fly in, as well as reaching visitors who are often waiting for much delayed flights.

The use of the Arvia'juaq panoramic virtual tour as a case study is relevant to BC archaeology because Indigenous and rural communities in BC and in Nunavut face similar challenges with regards to Internet access and connectivity. The digital divide issue severely restricts the use of digital platforms – platforms which are ever more pervasive – and this issue must be addressed in order for truly collaborative projects to succeed.

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Proteomics: Advantages, Applications, and Relevance to Archaeology

by Lindsey Paskulin

Introduction

Ancient proteins have regularly been analysed in archaeology since the mid-1900s. Collagen, the main protein in bone, forms the basis for both the radiocarbon dating and stable isotope analysis of archaeological bone. However, it was not until the advancement of mass spectrometry in the 1990s that ancient protein studies were able to be developed further. This progress has been marked by the extraction and sequencing of ancient proteins from a range of different materials for the interpretation of past heath, diet, subsistence, food production, crafting, tool production and use, archiving, and conservation, among others. Proteomics identifies and characterises all ancient proteins within an analysed substrate, and thus has important implications for the analysis of archaeological material. This article will explore proteomic methods and approaches as they apply to archaeological contexts, and demonstrate their significant potential to address research questions specific to Canadian archaeology.

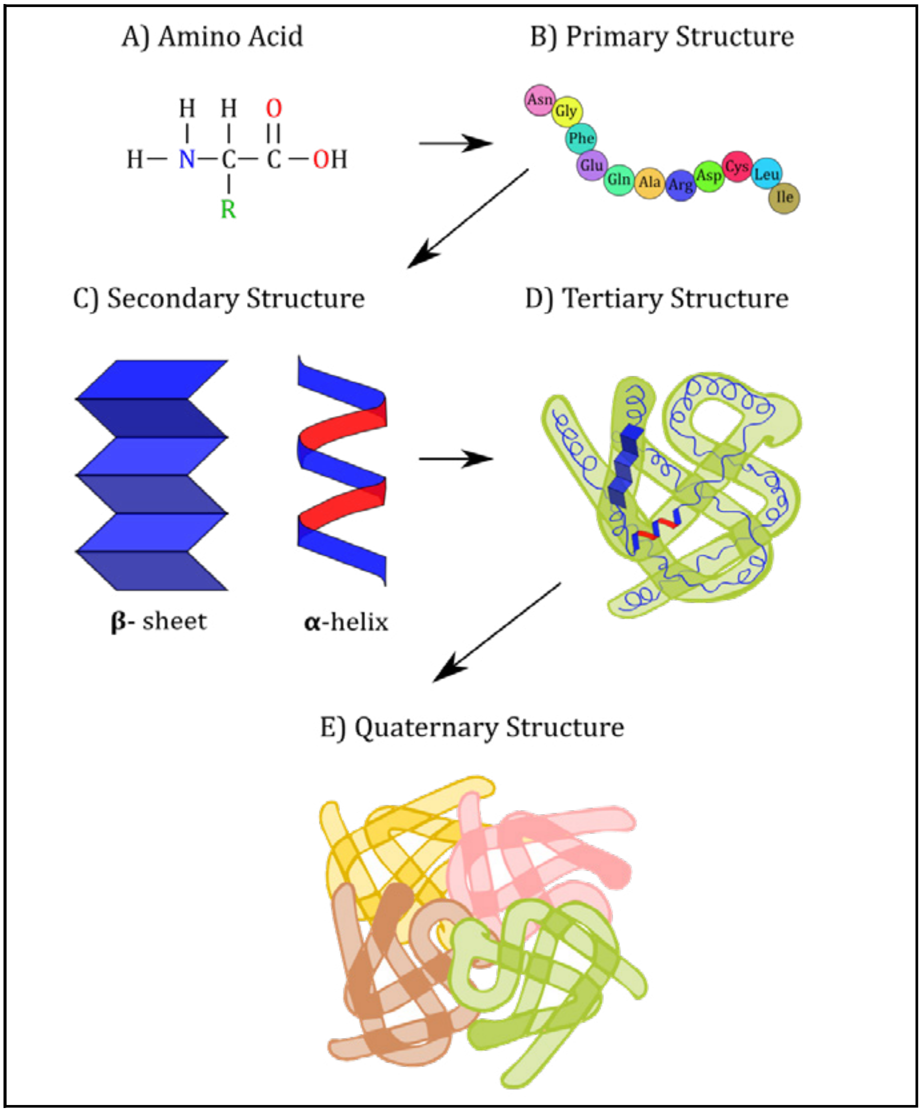

Figure 1: The structure of a protein.
(A) The primary units of a protein are amino acids composed of a central carbon atom (C), a hydrogen atom (-H), an amino group (-NH2), an acidic carboxyl group (−COOH), and a variable side chain (R group), which determines the protein's function. (B) These amino acids are organized into chains, called peptides, and bonded together by peptide bonds to form polypeptide chains. (C) In the secondary structural phase of protein, polypeptides coil and fold into different structures, i.e., α-helices and β-sheets. (D) The resulting 3-D structure of the polypeptides is referred to as the tertiary structure, with (E) the quaternary structure being characterized by the protein macromolecule containing structured, bonded polypeptide chains.

Methods of protein analysis in archaeology

Proteins are complex molecules characterized by their unique structure and their functional diversity (Figure 1). Prior to the development of high-resolution mass spectrometry, ancient proteins were commonly detected using immunoassays, which analyse interactions between antibodies and potential antigens preserved in ancient material (Lowenstein 1981) (Figure 2). Within a protein, antigens are small regions of a peptide sequence which span approximately six amino acids. The point at which antibodies bond to an antigen is known as an epitope. Antibody-antigen binding is specific enough that the binding of an antibody can be indicative of a particular protein present within a sample. Though the immunological approach has been successfully applied in modern medical and forensic contexts, there is controversy concerning the extent to which immunological techniques are able to confidently detect proteins that have been degraded through diagenesis (e.g., protein denaturing), such as those found in archaeological contexts (Downs and Lowenstein 1995; Eisele et al. 1995; Fiedel 1996; Hendy et al. 2020). Immunological techniques require the survival of the antigen and specifically the epitope of a protein, which is not always likely when ancient proteins are affected by diagenetic degradation (Downs and Lowenstein 1995).

This controversy is exemplified in attempts to extract blood proteins from stone tools using immunological techniques (e.g. Loy and Hardy 1992; Gerlach et al. 1996; Tuross et al. 1996), which have been critiqued based on the likelihood for contamination, cross-reactivity from the burial environment, and an inability to replicate results (Downs and Lowenstein 1995; Eisele et al. 1995; Fiedel 1996).

In addition to requiring fairly intact protein molecules, immunological methods are also an example of "top-down" proteomic analysis, which targets a limited number of predefined proteins of interest (Figure 2). As such, "top-down" proteomics requires archaeologists to confine their investigations to particular protein targets, limiting the amount of information that may be obtained from a sample. In contrast, "bottom-up" proteomics, (also known as shotgun proteomics) characterizes all of the proteins within a particular sample, and is designed to work with fragmented proteins. As such, it is a more appropriate method for ancient protein research.

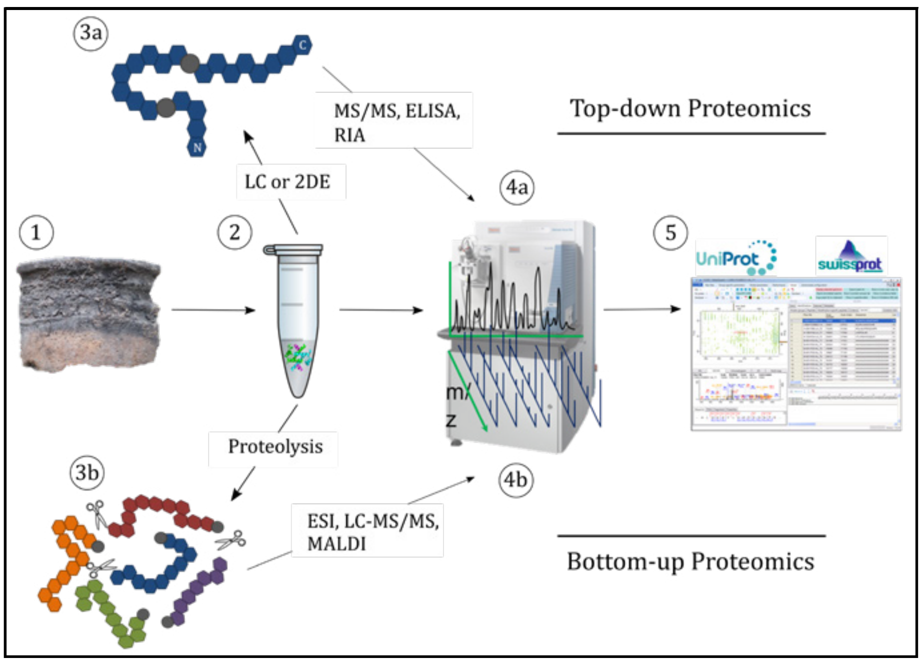

Figure 2: "Top-down" proteomics versus "Bottom-up" (Shotgun) Proteomics; (1) Archaeological material is targeted for proteomic analysis; (2) Proteins are extracted from archaeological material; (3a) In "Top-down" proteomics, fully intact proteins are separated from the protein mixture using liquid chromatography or 2D-electrophoresis, targeting particular proteins of interest; (4a) Antibody/antigen reactions are analysed using radioimmunoassay (RIA) or enzyme-linked immunosorbent assay (ELISA); while development of tandem mass spectrometry (MS/MS) allowed for a more precise execution of "top-down" proteomic techniques; (3b) In "Bottom-up" proteomics, the diverse array of unknown proteins within the mixture are enzymatically cleaved into peptides; (4b) Fragmented peptides are separated through liquid chromatography, ionised through electrospray ionisation, and identified through tandem mass spectrometry (MS/MS); (5) For both top-down and bottom-up methods, MS results are compared with databases of known peptide sequences for identification and characterisation such as the UniProt Knowledgebase (The UniProt Consortium 2019).

Shotgun proteomics is a widely encompassing technique for the characterization and quantification of multiple peptides within a single sample (Figure 2). This permits the analysis of complex mixtures of proteins produced by individual organisms (proteomes) or groups of organisms (metaproteomes). In contrast, peptide mass fingerprinting, the basis for Zooarchaeology by Mass Spectrometry (ZooMS) (see Buckley et al. 2009; Buckley et al. 2010; and Buckley et al. 2014), targets one or two dominant proteins in a sample, (such as collagen from bone), primarily for the purpose of protein identification. Shotgun proteomics is made possible by the development of high-resolution mass spectrometry, an advancement that has transformed ancient protein research. The use of liquid chromatography tandem mass spectrometry (LC-MS/MS) allows for the detection and analysis of hundreds or thousands of individual peptides present in complex proteomes (see Cho 2007; Yates 2013; Zhang et al. 2013). LC-MS/MS can also detect denatured and fragmented proteins, enhancing the analytical potential for degraded protein material (Cappellini et al. 2014). Shotgun proteomics moreover enables investigations of post-translational protein modifications, which have been related to diagenesis, pre-deposition activity, and time (van Doorn et al. 2012; Wilson et al. 2012; Solazzo et al. 2014; Schroeter and Cleland 2016; Ramsøe et al. 2020).

Advantages and limitations of proteomics in archaeology

Shotgun proteomics supports the characterisation of peptide sequences from multiple protein sources within a single sample, allowing for the analysis of protein modifications, protein abundance, taxonomy, protein function, and more. In archaeology, the advantages of proteomics are particularly demonstrated in cases where other biomolecular techniques, such as lipid residue analysis and DNA, are unsuitable.

First, proteins have been found to be more resistant to degradation than aDNA (ancient DNA), resulting in survival farther into the past and in a wider range of climates (Cappellini et al. 2012; Cappellini et al. 2014; Hendy et al. 2018a). For example, ancient proteins have been recovered from 3 mya ostrich eggshells from Laetoli, Ethiopia, far beyond the predicted range of DNA survival (Demarchi et al. 2016), as well as from other climates with a poor record of aDNA survivability, including South America (Welker et al. 2015) and Thailand (Wasinger et al. 2019). Relatively intact proteomes have been characterized for extinct and extant taxa (e.g., Welker et al. 2015; Welker et al. 2017), including Neanderthals, Denisovans, and extinct apes (e.g., Welker et al. 2016; Welker 2018; Welker et al. 2019; Chen et al. 2019), providing new insight into hominid evolution and taxonomy beyond the limits of DNA.

As a basic component of living cells, proteins constitute most tissues within plants, humans, animals, and microorganisms. Thus, proteins may survive in a wide range of substrates, including bindings and glues (e.g., Dallongeville et al. 2011), parchment (e.g., Fiddyment et al. 2019), eggshell (e.g., Demarchi et al. 2016), soil (Oonk et al. 2012), food residue and ceramic vessels (e.g., Solazzo et al. 2008; Hendy et al. 2018b; Shevchenko et al. 2018), and textiles (e.g., Solazzo et al. 2011), as well as dental calculus (Hendy et al. 2018c), bone collagen, dentine and enamel, soft tissue, antler, and ivory (Hendy et al. 2018a). Proteomic evidence from this range of materials can thus be used to address diverse research questions encompassing not only archaeology and anthropology, but phylogenetics and systematics, pathology and immunology, and cultural heritage. Proteins are also frequently specific to individual tissue and environment, meaning proteomics can distinguish, for example, between meat and milk, or plant seeds and leaves. This is a particular strength of proteomics over DNA, for which all cells contain the same genetic information.

A third advantage is that unlike lipid residue analysis, proteomic approaches can distinguish substances that have been mixed, or those found in multi-purpose vessels. For example, at the site of Çatalhöyük, Hendy et al. (2018b) identified proteins from milk and cereals cooking within the same ceramic pot. As palaeoproteomics also identifies a wider range of products, it is more likely to identify material that may be obscured in lipid residue analysis by more fat-based animal sources, such as plants (Hendy et al. 2018b).

Nevertheless, due to similarities in protein sequences across closely related taxa, proteomic approaches may not always be able to identify particular proteins to the species level. For example, proteomics cannot always differentiate between closely related protein isoforms of wheat and barley (Colgrave et al. 2013), or between the muscle proteins (e.g., actin, myosin) of mammalian species.

Like ancient DNA, ancient proteins are susceptible to modern contamination. Specialized protocols for sampling, processing, and analysing ancient proteins have been proposed in order to limit potential contamination (see Hendy et al. 2018a). There are also a number of criteria which should be followed to authenticate data as being derived from truly ancient proteins rather than modern lab contamination. For example, new techniques for differentiating between ancient proteins and contaminants are currently in development and focus mainly on the protein degradation markers, (e.g., amino acid deamidation rates), for relative age determination (Ramsøe et al. 2020).

Currently, the cost of shotgun proteomics is still relatively high, limiting its routine use within archaeology (Welker 2018). However, as methods and analytical instruments continue to be optimized, many of the current limitations of proteomics will be addressed and overcome.

Applied proteomics and the potential for the technique in Canada

As proteomics has only been recently applied to ancient material, there are few examples of this method being used to address research questions specific to Canadian archaeology. Despite its novelty, the potential for proteomics mirrors the significance of other biomolecular techniques commonly utilised within Canada, including stable isotope (Burchell and Harris 2018) and DNA (Speller 2018) analysis. Globally, proteomics has been applied to a range of research questions which each demonstrate the scope and value of this technique. When considered within Canadian archaeology, proteomics can create unique views into ancient lifeways, particularly in respect to diet, health, and food processing, as well as in the study of cultural heritage objects.

In typical archaeological contexts, proteins preserve best when they are bound to a surviving mineral structure. Collagen, for example, is protected largely by its close structural association with bioapatite, the main mineral component of bone. This structural component is particularly relevant for the survival of proteins in older samples and allowed, for example, proteome sequences to be extracted from 1.9 mya (million years old) dental enamel from *Gigantopithecus blacki* (Welker et al. 2019). When considering samples for proteomic analysis, it is therefore recommended that there exists a bonded mineral component to ensure that existing proteins are less susceptible to contamination from the burial environment. Previous studies have used, for example, dental calculus (Warinner et al. 2014; Warinner et al. 2015; Hendy et al. 2018c), dental enamel (Wasinger et al. 2019; Welker et al. 2019), limescale residues (Hendy et al. 2018b), and ceramics (Solazzo et al. 2008; Hendy et al. 2018b) as mineral structures that support the preservation of ancient proteins.

The identification and characterisation of ancient proteins preserved within dental calculus (also known as teeth tartar) has addressed questions of diet and health within past populations. The mineral matrix of dental calculus presents a host of different biomolecules relating to the composition of the oral microbiome, to the health of the individual, to inhaled/ingested microdebris, food particles, and occupational and/or environmental debris (Hendy et al. 2018c). The proteins preserved in dental calculus therefore represent a source of data relating to the contemporary environment, activities, health, and diet of past individuals, many of which would otherwise leave ephemeral traces within the archaeological record (Warinner et al. 2014; Warinner et al. 2015; Hendy et al. 2018c). An example is the recovery of proteins specific to periodontal disease, and to the consumption of milk and oats within dental calculus from Tjærby cemetery individuals in Denmark (Jersie-Christensen et al. 2018).

Like stable isotope analysis, proteomics can be applied to animal remains for insights into dietary ecology. The investigation of animal behaviour relating to the reconstruction of past environments could be supported through the characterisation of dietary proteins within dental calculus or coprolites of herbivores, omnivores and carnivores. This technique also has potential to investigate changes in animal health and microbiomes over time. As previously exemplified through stable isotope analysis, animals can be invaluable as proxies for human diet (Guiry 2012; e.g., McManus-Fry et al. 2018). Dental calculus from animals that serve as proxies for human diet, such as dogs, can thus similarly be used to address questions of human-animal relationships and human diet. This is particularly relevant when considering plant consumption shared between humans and dogs, as plants can be underrepresented by stable isotope analysis.

Proteomic methods have also been successfully applied to ceramics (e.g. Solazzo et al. 2008; Hendy et al. 2018b) and various ceramic residues (e.g. Hong et al. 2012; Hendy et al. 2018b). For example, in point Barrow, Alaska, proteins specific to myoglobin, a muscle tissue protein, were identified in an Iñupiat potsherd fragment from the Punuk period (~1200-1400 AD), and taxonomically traced to marine mammals (Solazzo et al. 2008). This data supports the known importance of marine mammals in Iñupiat lifeways, but can be taken even farther in order to better understand food production and processing, vessel use, and the social context of specific foods. As proteomics allows for the composition of a sample proteome, archaeologists have been able to reconstruct ancient foods and their preparation methods from their protein composition, e.g., kefir dairy (Yang et al. 2014) and sourdough bread (Shevchenko et al. 2014). Thus, proteomics is a powerful tool for investigating dietary preference, agricultural practice, ritual consumption and deposition, ceramic use, communal consumption, food processing, and food production in archaeological contexts.

Proteomics has also been used to better understand the composition of cultural heritage objects, and thus how to best preserve them. An example is the proteomic study of Coast Salish blankets to determine their composition (Solazzo et al. 2011). The use of dog fur in a number of the blanket samples provided insights into human-animal relations among the Salish and the social role of dog hair blankets compared to blankets made from other material. Proteomics has also been applied to cultural heritage objects for the investigation of proteinaceous material, such as binders, coatings, and adhesives in artwork and polychromies (Barberis et al. 2018; Vinciguerra et al. 2019). Biological proteins bound to ancient parchment and manuscripts have also been explored through proteomics, providing insights into the production, handling, and use of these important objects (Fiddyment et al. 2019). This is further supported by the development of non-invasive sampling strategies for extracting proteins (Barberis et al. 2018; Fiddyment et al. 2019), which may be extended to recover proteins from other items of cultural importance, including bone and antler artefacts/belongings.

Conclusion

Despite its novelty to the field, shotgun proteomics has already made great strides in the identification and characterisation of ancient proteins. Information from ancient proteins has been harnessed for the reconstruction of past health and diet, food production and processing, crafting, and tool use and production, as well as investigations of archival and artistic material, and cultural heritage objects. Mineral structures which encase proteins are particularly ideal for protein preservation and include dental calculus, dental enamel, ceramic matrices, and mineral residues from pottery. Further investigations into the preservation of ancient proteins within different substances will only broaden the utility of this technique. There is thus significant potential for proteomics to be increasingly applied to archaeological material prevalent in British Columbia and the wider region.

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ZooMS - a Rapid, Cost-Effective Method for Identifying Archaeological Faunal Remains

by Camilla Speller

Introduction

Reconstructing the diet, subsistence practices, and physical environments of past peoples is in large part dependent on the accurate identification of animal bones from archaeological sites. The analysis of ancient faunal remains — zooarchaeology— has traditionally been conducted through anatomical comparison of archaeological vertebrate remains with modern reference collections. However, taxonomic identification based on morphology is challenging when bones are fragmentary, from juvenile animals, or from anatomically similar species. For example, whale bone, frequently encountered in coastal sites, is composed primarily of oil-filled, spongy bone, which easily breaks up into non-diagnostic fragments. Likewise, the post-cranial bones of many fish cannot be easily identified to species. Moreover, animal bone is frequently used as a raw material for artifacts, and in almost all cases, morphological characteristics necessary for identification are removed during manufacture. Accurate identifications of these remains to the species level, however, are essential for addressing a wide range of anthropological and archaeological questions, including hunting and fishing technologies, seasonality of site occupation, sedentism and storage, distribution of resources within and between communities, as well as for interpreting functional (form, properties) and symbolic (ideational, cultural) factors in the selection of raw materials for worked objects/belongings.

For many archaeologists, ancient DNA represents the 'go-to' approach for identifying ancient remains. Indeed, reductions in the cost of sequencing over the last 15 years have opened up the potential for obtaining ancient genomes dating back to the Middle Pleistocene (Orlando et al. 2013). Ancient genomic information can provide exceptional taxonomic specificity, identifying remains to species, subspecies and even population-level. In spite of decreasing sequencing costs, genomic techniques remain expensive. Over the last decade a new molecular technique has emerged for identification of ancient remains, one is which is faster, and more cost effective than DNA analysis: peptide mass fingerprinting of bone collagen (Collins et al. 2010; Buckley 2018; Buckley et al. 2009).

Collagen and the ZooMS Method

Collagen peptide mass-fingerprinting, also known as ZooMS ('Zooarchaeology by Mass Spectrometry') provides a taxonomic identification based on differences within the amino acid sequence of an organism's collagen protein sequences. Collagen is a slowly evolving protein consisting of three chains wound together as a triple helix, and ZooMS specifically analyses collagen type I, the dominant protein within the organic component of living bone (Fratzl 2008; van der Rest and Garrone 1991). In mammals, collagen (I) is composed of two α1 chains (derived from the same COL1A gene), with a third, more rapidly evolving α2 chain (COL1A2) (Vuorio and de Crombrugghe 1990), while in many fish species, it is composed of three different chains (Piez 1965; Burgeson and Nimni 1992). The collagen amino acid sequence is highly conserved, with one amino acid substitution occurring ca. 1-8 million years (Buckley and Collins 2011), depending on the vertebrate class, with fish having the most variable collagen sequences, and birds among the most conserved (see Buckley 2018 for expanded discussion).

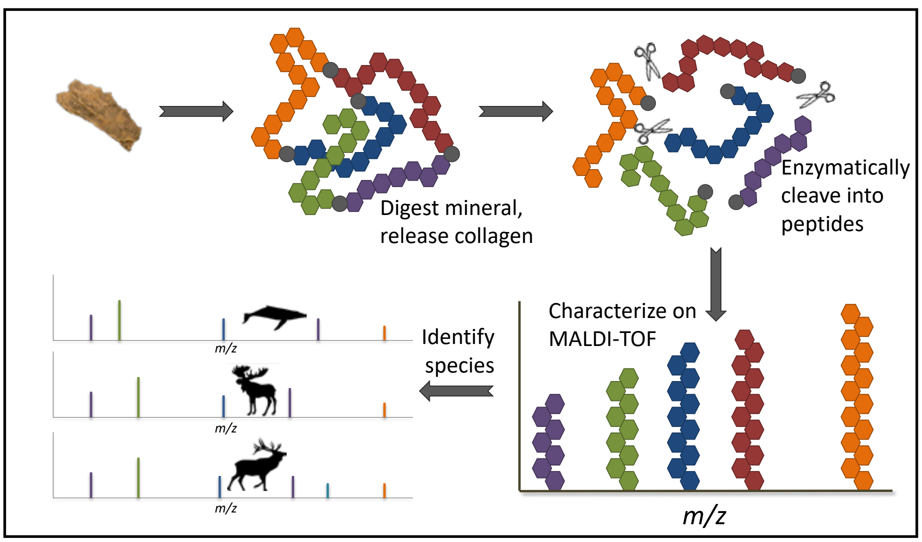

Figure 1: The ZooMS method: Bones are demineralized in a weak acid solution; collagen is gelatinized and enzymatically cleaved into peptides, before being spotted with matrix onto a target plate. Peptide masses are measured by mass spectrometry (MALDI-TOF). The presence of specific peptides is used for taxonomic identification.

This relatively slow rate of evolution means that collagen type I is similar enough to map differences across widely-dispersed taxonomic groups, but still variable enough to discriminate among most mammalian genera.

ZooMS is a form of peptide mass-fingerprinting —a widely used approach for protein identification based upon patterns of mass-to-charge (m/z) ratios observed through mass-spectrometry (Cottrell 1994; Henzel et al. 2003). In the ZooMS method (Figure 1), collagen is extracted from archaeological bone and subjected to enzymatic digestion, which produces a characteristic mixture of peptides (i.e., short molecules consisting of two or more amino acids). The peptides are analysed through mass spectrometry (specifically matrix-assisted laser desorption/ionization time-of-flight mass spectrometry 'MALDI-TOF-MS), and species can be distinguished by their distinct 'peptide mass fingerprint' through comparison with a reference database of collagen sequences from multiple animals.

Minimally Invasive and Non-Destructive Modifications

Collagen is relatively abundant in archaeological bones, and unlike ancient DNA, collagen extractions do not need to be undertaken in a specialized clean-lab to reduce contamination risks. ZooMS requires only very small sample sizes for analysis —sufficient collagen can frequently be obtained from bone samples of 10-20 mg (around the size of a sunflower seed). Previous studies have shown that sufficient collagen may even be recovered by soaking, rubbing, or through the triboelectric effect (Fiddyment et al. 2015) which can enable artifacts of high cultural value (such as worked bone tools and artifacts/belongings) to be sampled non-invasively. For example, van Doorn et al. (2011) developed a minimally-destructive protocol to release collagen from bone samples by immersion in a gentle ammonium bicarbonate solution, avoiding bone demineralization. Last year, Krista McGrath and colleagues (2019) demonstrated that sufficient collagen can even be removed by gently rubbing bones within a ziplock bag or with a PVC eraser. In their analysis of ca. 500-700 year old St. Lawrence Iroquoian bone points from Quebec, they were able to identify the use of bear, human and deer bone simply by analyzing the collagen adhering to the plastic bags the samples were stored in. Martisius et al. (2020) pushed back the limits of these non-destructive techniques to the Middle Paleolithic, identifying the raw material of Neanderthal bone *lissoirs* (smoothers) by analyzing collagen adhering to the plastic storage boxes. While these non-destructive methods may not always be effective or appropriate for all samples or archaeological contexts, they open up potential avenues for the analysis of culturally sensitive material.

Archaeological Applications

Over the last 10 years, ZooMS has been developed to discriminate among most large mammals (Buckley and Collins 2011), ruminants (von Holstein et al. 2014; Taylor et al. 2018), rodents (Buckley et al. 2016; Prendergast et al. 2017), bats (Buckley and Herman 2019), marine mammals (Buckley et al. 2014; Biard et al. 2017; Hofman et al. 2018), marine turtles (Harvey et al. 2019) and fish (Korsow-Richter et al. 2011; Harvey et al. 2018; Korzow Richter et al. 2020; Rick et al. 2019; Guiry, Buckley, et al. 2020) from archaeological contexts. This high-throughput approach enables the rapid taxonomic screening of thousands of fragmentary bones, at a fraction of the time and cost of traditional DNA barcoding approaches (Speller et al. 2016). For example at Pin Hole cave, UK, Buckley et al. (2017) screened over 12,000 bone fragments using ZooMS to reconstruct the Late Pleistocene faunal diversity in the UK —a sample size an order of magnitude larger than that of any ancient DNA study to date. The ZooMS approach is particularly powerful for identifying fragmentary hominin remains within large faunal assemblages. For example, the ZooMS has been used to screen thousands of remains to identify minute fragments of human, Neanderthal or Denisovan bone in Middle and Upper Paleolithic archaeological sites (Welker et al. 2016; Brown et al. 2016; Hublin et al. 2020), and has even revealed the presence of misidentified human remains within faunal assemblages (Evans et al. 2016).

While ZooMS has many advantages as a taxonomic identification technique, it largely lacks the taxonomic precision of DNA analyses. Due to the similarity of collagen sequences, identifications are usually to the genus, rather than the species level. Thus, taxa that have diverged relatively recently —such as domestic animals— or experienced recent post-glacial expansion or speciation events share a common collagen fingerprint (Buckley and Collins 2011). For example, domestic animals and their wild counterparts cannot be differentiated from one another using ZooMS, neither can anatomically modern humans, Neanderthals and Denisovans (Welker 2018; Brown et al. 2016). Among the Elephantidae, mammoth, African and Asian elephants seem to share a common collagen peptide fingerprint — although this group can be distinguished from mastodon (Buckley et al. 2011). Likewise within Ursidae, black and brown bear cannot be distinguished (McGrath et al. 2019). Although most cervid genera can be identified, red deer (*Cervus elaphus*), fallow deer (*Dama dama*) and moose (*Alces alces*) cannot be separated using ZooMS (von Holstein et al. 2014). Within cetaceans, most baleen whale genera have unique collagen fingerprints, while species and/or populations from different ocean basins (e.g., North Atlantic and North Pacific right whale; Atlantic and Pacific grey whale) cannot be distinguished from each other; odontocetes can frequently only be assigned to the family level (Buckley et al. 2014). ZooMS has yet to be extensively developed for fish, birds and reptiles. Due to the relatively rapid amino acid substitution rate in fish, there is a high potential for developing species-specific diagnostic peptide markers, especially for species that diverged more than 1MYA (Harvey et al. 2018; Korsow-Richter et al. 2011). The slow evolution of collagen (I) in the class Aves, however, suggests that this technique may have more limited use for taxonomic identification of fragmentary bird bone (Buckley 2018; Buckley et al. 2009). In these cases, genetic identification methods may be required for greater taxonomic resolution.

Although DNA analysis may provide precise identifications, ZooMS is particularly effective for contexts where ancient DNA may not preserve. Like most proteins, collagens are extremely robust, and preserve into deep time (at least the Middle Pleistocene (Chen et al. 2019)) as well as in humid, tropical contexts where DNA may more readily decay (Welker et al. 2015). Like DNA, however, collagen is damaged by extreme heat, and thus bone samples that have undergone cremation or burning above 155°C are unlikely to provide sufficient collagen for identification (Fellows Yates 2013).

Archaeological bone is not the only material that can be analyzed using ZooMS. Any type of collagen(I)-rich material can be readily identified, including antler, ivory, leather/skin. For example, ZooMS has been used to identify the animal species material used to manufacture antler combs (von Holstein et al. 2014; Luik et al. 2020), ivory gaming pieces (Brandt et al. 2018), and leather footwear (Ebsen et al. 2019). ZooMS has also been effective at identifying ruminant species used in the manufacture of parchments and book bindings (Fiddyment et al. 2015; Teasdale et al. 2017). ZooMS can also be used to identify keratinous materials like hair, nail, and whale baleen (Solazzo et al. 2017, 2013), and distinguish avian eggshells (Stewart et al. 2014, 2013) and mollusc shells (Sakalauskaite et al. 2020) based on their intracrystalline protein fingerprints —although in these latter applications, peptide fingerprint databases need to be curated and developed specifically for the proteins of interest.

ZooMS in North America

Originally developed and applied in Europe, the ZooMS approach has yet to be implemented extensively in North America. Nevertheless, the limited number of studies to date have already demonstrated the particular potential of this technique in coastal contexts, where marine mammal bones may be highly fragmented. For example, Hofman et al. (2018) applied ZooMS to fragmentary faunal remains recovered from California's Channel Islands to investigate some of North America's earliest marine mammal hunting strategies (ca. ~12,500-8500 cal BP). Likewise, Szpak et al. (2018) combined ZooMS and isotopic analysis to investigate changes in marine mammal ecology in the Arctic. Recently, Kurzow-Richter et al. (2020) expanded the capability of ZooMS to differentiate between species of anadromous Pacific salmon, applying this technique to investigate Yupiit pre-contact subsistence and fishing patterns in Nunalleq, Alaska. Although ZooMS is successful at identifying anadromous species, stable isotope analysis is necessary for differentiating the more recently diverged freshwater and anadromous ecotypes (e.g., kokanee and sockeye; steelhead and rainbow trout) (Guiry, Royle, et al. 2020). Similarly, in their analysis of Salmonidae from the Great Lakes, Guiry et al. (2020) noted that although ZooMS could broadly differentiate Atlantic salmon (*Salmo*), char (*Salvelinus*) and whitefish (*Coregonus*), DNA analysis were required to separate the post-glacially diverged whitefish species *C. clupeaformis* and *C. artedi* (Royle et al. 2020). In addition to Salmonidae, Rick et al. (2019) developed ZooMS to differentiate among 'billfish' (suborder Xiphioidei, including swordfish, marlin, swordfishes, marlins, sailfishes, spearfishes), applying this technique to elucidate swordfish exploitation in Chumash archaeological sites within the Santa Barbara Channel region of California. Meanwhile, on the Atlantic coast, Harvey et al. (2019) developed ZooMS to differentiate between species of marine turtles in Florida and the Caribbean.

Marine resources are not the only area to be elucidated using ZooMS. In terrestrial contexts, Guiry and Buckley (2018) paired ZooMS with isotopic analyses in their analysis of rodent diets in historic urban and rural contexts in Ontario, while Sanchez et al. (2018) applied ZooMS to confirm cervid identifications ahead of radiocarbon dating the Par-Tee site in Oregon. ZooMS has also been applied to investigate raw material used in the manufacture of bone artifacts/belongings, including a Paleoindian bone rod from Grenfell, Saskatchewan (Ives et al. 2014) and bone points from three St. Lawrence Iroquoian village sites in Quebec (McGrath et al. 2019).

Currently, the greatest limiting factor to expanding ZooMS in North Americas is a lack of reference collagen sequences, especially for fish and bird species. Collagen sequences can be obtained either through the analysis of reliably identified museum specimens and/or through the translation of COL1A1 and COL1A2 gene sequences to amino acid sequences. As collagen databases continue to expand to include a greater number of North American terrestrial and marine taxa (including a greater diversity of economically and culturally significant birds, mustelids, molluscs and fish species), ZooMS will become an increasingly useful tool for North American archaeologists and Indigenous communities in their investigations into past ecosystems, subsistence patterns and traditional resources and environmental management practices.

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Vibracore Sampling in the Broken Group Islands

by Seonaid Duffield, Iain McKechnie, Denis St. Claire, and Duncan McLaren

Introduction

Vibracoring is a geological sampling technology designed to obtain large-volume cores from a variety of sediments. The technology has utility in coastal archaeology particularly for recovering stratigraphically intact sediments and zooarchaeological data from deep coastal archaeological sites. The efficacy of vibracore technology was initially tested in a large shell midden site on the Central Coast of BC with the support of the Hakai Institute and Dr. Duncan McLaren's Hakai Ancient Landscapes Archaeology Project (Duffield 2017). In the summer of 2017, the UVic archaeological field school in Barkley Sound supported a smaller vibracoring project in the Broken Group Islands in Tseshaht First Nation territory on western Vancouver Island (Duffield 2018). This article provides a short overview of how we applied this technology at two sites in the Broken Group Islands to evaluate the efficacy of this sampling method for generating zooarchaeological and chronological data from deep coastal shell middens.

The vibracore unit used in these projects is manufactured by Wink Vibracore Ltd (Richmond, BC). The unit consists of a Honda motor, drill head, flex cable, drill rod, drill bit and "gin pole" assembly (Figure 1).

To collect a core sample, sonic vibrations are transferred from the motor through the flex cable to the drill head. The drill head vibrates at a high frequency (7,000 to 12,000 acoustic vibrations per minute), which causes sediments in contact with the drill rod to mobilize. The weight of the assembled unit coupled with the sonic vibrations, allow it to sink into the ground and recover a sediment sample in a clear plastic core sample tube fitted inside the threaded drill rods (Figure 2 and https://youtu.be/Oe4fNHEXGzw). Drill rods can be threaded together to achieve total depth of 7.6 m.

The drill rod size used for this project accommodates a 7.5 cm diameter sample tube. The length of the rods and sample tubes are 152.4 cm (5 feet) in length and required five extensions for this project. Deploying the unit in

Figure 1. Right: Vibracoring at Kakmakimilh (Photo: Iain McKechnie). Left: Keith Island 1 profile drawing, GSC core photograph, radiocarbon sample locations and date ranges (cal BP) and description of core stratigraphy.

Figure 2. Tseshaht Beach Keeper, Cody Gus transporting a successfully recovered vibracore sample tube from Kakmakimilh (Photo: Iain McKechnie).

the field requires some considerations for transport as the unit is bulky and weighs approximately 135 kg (~300 lbs.).

Once the desired depth is achieved, cores are extracted using a winch system (the "gin pole" assembly) that hoists the corestring from the ground. This is achieved by replacing the drill head with a "hoisting cap" (threaded cap with an eyelet). The gin pole is set up over the embedded sample; the gin pole wire is attached to the hoisting cap and winched out of the ground one-rod section at a time. The "ball controller" stops the sample from slipping back into the ground while removing or "breaking" the core rod sections from the corestring (Wink Vibracore Ltd n.d.). The recovered samples are stratigraphically intact as the sediments are not churned up during collection (Duffield 2017).

A small working area is cleared of vegetation to facilitate safety while a three-person team operates the machine. It is additionally important to have a level working area close to the core location to enable the threading and un-threading of heavy rod sections. The vibracore is an ideal method for efficient and minimally invasive recovery of deep archaeological samples and an excellent alternative to conventional excavation as it only leaves a 7.5 cm diameter hole in the ground.

Vibracoring in the Broken Group Islands

Following discussion with Tseshaht First Nation council members and staff, we opted to collect vibracore samples from two ancient Tseshaht settlements and reserve locations (Figure 3) in the Broken Group Islands (Tl'ihuuw'a, Nettle Island, DfSh-5, 305T and Kakmakimilh, Keith Island, DfSh-17, 306T). The sampling fieldwork was part of the Keith Island Archaeological Project and the University of Victoria field school in Barkley Sound, co-directed by Iain McKechnie and Denis St. Claire. The Broken Group Islands are monitored by the Tseshaht Beach Keepers as part of a partnership agreement between Tseshaht First Nation and Pacific Rim National Park Reserve.

Over two and a half days, the vibracore team recovered a total of five core samples from deep shell midden ridges and house terraces. The deepest core was recovered from the height of the prominent shell midden ridge at Tl'ihuuw'a (Nettle Island), 527.5 cm below surface. A total of 14.62 meters of coring recovered a total of 8.04 meters of sediment, indicating an overall compaction rate of 55% with variation between cores ranging from 49-78% (Duffield 2018:16). Post-field analysis included assistance from Dr. Randy Enkin from the Geological Survey of Canada's core-logging facility at the Institute of Ocean Sciences (Sidney). This lab provided measures of magnetic susceptibility (SI E-5), density (g/cm3), and a high-resolution image of the entire length of the core in one continuous photo. Scanned cores were split lengthwise, preserving the stratigraphy and integrity of the core section (Figure 1 shows an example of the stratigraphy, profile and radiocarbon date for a Kakmakimilh sample).

Samples were transported to the University of Victoria where sediments

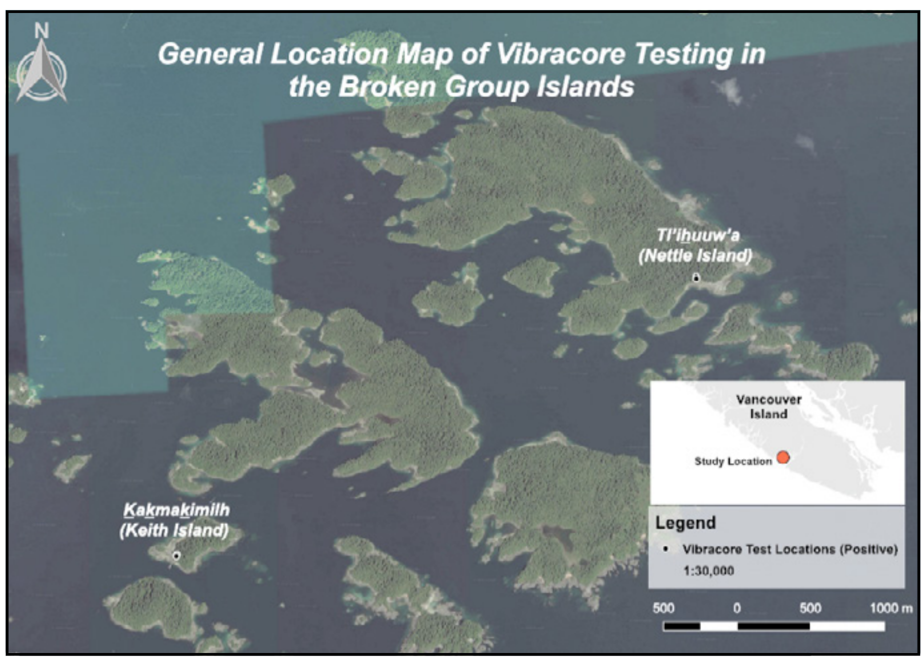

Figure 3. Overview map showing the locations of vibracore tests on Tl'ihuuw'a (305T, Nettle Island) and Kakmakimilh (306T Keith Island) within the Broken Group Islands (Base map: Google satellite imagery).

from the split cores were sorted in 5 cm increments, wet-screened through ¼-inch and 2 mm nested screens, dried, and picked for all vertebrate remains. Zooarchaeological identification was achieved by the first author with the guidance of specialist Rebecca Wigen at the UVic zooarchaeological laboratory. A total of 1,308 vertebrate specimens were identified from within a total volume of approximately 21 litres of core sediments from vibracores at Tl'ihuuw'a and 898 from Kakmakimilh with the vast majority of identified specimens being fish (95.6%), followed by mammals (3.0%) and birds (1.2%). While these assemblages demonstrate Indigenous use of a wide range of marine resources, Pacific herring (Clupea pallasii) and northern anchovy (Engraulis mordax) were the two most proportionally abundant fish species recovered from both sites, which is consistent with other fine screened assemblages in Barkley Sound as well as other assemblages from these same sites (McKechnie 2005, 2014, McKechnie et al. 2019).

Five small artifacts were recovered from two different cores at Tl'ihuuw'a including 4 fragments of bone tools and one green chert debitage flake (Figure 4). Given the total volume of examined core sediments, the estimated number of artifacts per cubic meter (~250 artifacts per cubic metre) is considerably higher than conventional excavations conducted in the region (McMillan and St. Claire 2005:45, 2012:35). However, no artifacts were recovered from vibracores samples from Kakmakimilh despite a similar examined volume indicating variability in artifact recovery in small volumes.

Figure 4. Photo of green chert debitage recovered from Tl'ihuuw'a using Dino-lite digital microscope (Photo: Angela Dyck).

We obtained eight radiocarbon dates from the A.E. Lalonde AMS Laboratory at the University of Ottawa on charcoal recovered from the cores. Results showed vibracore-sampled deposits at Tl'ihuuw'a dated as early as 2,700 cal BP and ranged from 1,182 -505 cal BP from two areas of a shell midden ridge at Kakmakimilh. The majority of dates show stratigraphic integrity and have accumulation rates between 20-45 cm per century (Duffield 2018:16).

Conclusions

Vibracore technology was successful at quickly recovering stratigraphically intact sequences of zooarchaeological data, charcoal, and artifacts from multiple locations within deep shell midden deposits in Tseshaht territory dating to the late Holocene. This coring methodology combines and improves on the use of bucket auger sampling and percussion coring (Cannon 2000; Martindale et al. 2009) which disturbs and compacts sediments to a greater degree. The expense and logistical support required to acquire and complete this project is considerable but this coring methodology holds promise for more adequately sampling deep and complex shell midden deposits across the coast more broadly.

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Reviewing Machine Learning Algorithms to Determine Best-Fit Models for Archaeological Predictive Modelling in British Columbia

by Raini Johnson, Andrew Mason, and Andrew Martindale

Introduction

Predictive modelling is a tool often used by archaeologists to quantify the potential of a given region to contain archaeological sites. Archaeological sites are geographical places containing physical evidence of past human activities and are therefore best studied using archaeological methods of investigation. Although an archaeological site is restricted to the area containing physical evidence, the location of a site also relates to other uses and experiences within the broader landscape. Thus, there are important causal relationships between the locations of archaeological sites and a wide range of variables (environmental, behavioural, social, and cultural). For example, site location often correlates with proximity to fresh water sources, flat terrain, and subsistence or resource areas. These recurring patterns in the physical environment, as well as documented material evidence from prior archaeological analyses, are the most common factors for identifying patterns in heritage locations and predicting where they might recur. Prediction is recognized as a valuable archaeological tool to assist in the location, recognition, investigation, and protection of heritage landscapes. However, archaeological site prediction is limited by the capacity of archaeologists to create models with a representative suite of variables due to the factors: 1) variables are collected from a variety of sometimes conflicting sources; 2) not all relevant variables are available to or sought after by archaeologists,; and 3) variable correlates of site locations likely vary considerably by context, creating a wide and heterogenous array of meaningful relationships. Given the common challenges of modelling heterogenous phenomena with large potential pools of relevant variables, we argue that machine learning algorithm-based predictive models are a useful tool for locating archaeological sites in British Columbia.

Machine Learning Algorithms (MLAs) are computer-based programs which are created either to facilitate the exploration of large and complex datasets (unsupervised learning) or to make automated predictions and decisions (supervised learning). For predicting the locations of archaeological sites, supervised MLAs would be chosen to recognize patterns and learning processes in data that are pre-labeled, classified, or organized. For example, based on locations of known archaeological sites (pre-labelled true presence data) and known non-sites (pre-labelled true absence data), a supervised MLA could determine which environmental and topographical variables correlate with site location. Such an algorithm could also determine the probability of sites in areas where presence of archaeological sites is currently unknown, thereby identifying areas with high archaeological site potential.

With increased computing power and technological advances, MLAs are likely to become increasingly important in archaeology, especially in Indigenous heritage management and its interface with cultural resource management (CRM) archaeology. Specifically, utilizing MLAs for predictive modelling will 1) lead to increased accuracy in predicting site locations; 2) identify and rank correlations between site location and environmental, topographical, and cultural variables; 3) model large regions and determine similarities and differences between site in that region; 4) model lesser known site types; 5) model different time periods; and 6) lead to increased knowledge about precontact site location choice.

Utilizing MLAs for archaeological predictive modelling is a relatively new endeavor with a limited number of case studies currently available (Ducke 2003; Banks et al. 2008; Fernandes et al. 2011; Galletti et al. 2013; Kirk et al. 2016; Oyarzun 2016; Guyot et al. 2018; Novielo et al. 2018; Wachtel et al. 2018; Zhu et al. 2018; Benner et al. 2019; Walker 2019; Yaworsky et al. 2019). In this review of MLAs for archaeological predictive modelling, thirteen case studies were identified and examined. From these, four types of MLAs and two types of Machine Learning Programs (MLPs) were identified and compared. MLPs are programs which utilize multiple MLAs to increase predictive accuracy. Based on necessary input data, sample size cutoffs, and overall fit, it is likely that MaxEnt, an MLP that employs maximum entropy modelling, is the best fit method that utilizes MLAs for archaeological potential modelling in British Columbia.

Archaeological Predictive Modelling in BC

In the field of archaeology, predictive models are used to assist with the evaluation of archaeological potential, i.e., a quantified assessment of the probability that an area contains archaeological sites (Verhagan and Whitley 2011). A predictive model showcases a simplified set of relationships or information about a more complex system from the real world (Nakoinz and Knitter 2016). The term “archaeological potential” is most commonly used to refer to those locations that have a significantly greater likelihood for archaeological deposits to be present and detectable using standard investigative techniques. Such determinations of potential are most commonly based on an analysis of known site locations, cultural practices, and environmental characteristics (e.g., water features, slope, forest cover) that typically correlate with archaeological site locations. It is important to remember that archaeologists routinely employ some form of predictive modelling in their work, even if it is simply framed through a concept of likelihood or low vs. high potential, and even if it is drawing only on professional experience. Formal models replicate such practices but do so with clearly stated assumptions and evidence.

In BC, predictive models are often created as part of Archaeological Overview Assessments (AOAs) and submitted to the Archaeology Branch for approval (Archaeology Branch 2009). AOAs compile existing knowledge about previously recorded archaeological sites, First Nations land use, and environmental variables that are thought to correlate with archaeological site locations. In addition to providing a summary of existing knowledge, AOAs identify areas with potential to contain unrecorded archaeological sites, assess conditions affecting site preservation, and evaluate the likelihood that archaeological sites, if present, are detectable using available methods.

The two main approaches to developing AOAs with predictive models, professional judgement and geographical information system (GIS) analysis, are compared in Table 1. Professional judgement (deductive qualitative) models are commonly used for smaller areas (<10,000 ha) where regional information (maps, field observations, literature reviews, etc.) are used to manually identify areas where archaeological site potential is high. These informal approaches often rely on positive correlations between site location and environmental context or negative correlations between environmental content and the absence of sites. For example, slope is a common trait that plays both roles in which low slope (i.e., flat) and high slope (i.e., steep) areas are respectively associated with higher and lower site location potential. In comparison, a GIS statistical analysis (inductive quantitative) method is often utilized for large areas (>10,000 ha) for which digital information is mined to determine and quantify a wide range of environmental attributes that correlate with known archaeological site locations. In both cases, maps are produced which show the areas on a landscape which have potential for containing archaeological sites. Both judgemental and quantitative models are based on prior knowledge of archaeological data and landscapes. Both have value and can increase site location predictions above a random assessment. However, quantitative GIS methods tend to be 1) more reproducible; 2) do not require long periods of professional experience to achieve; 3) permit the evaluation of unanticipated correlations; and 4) allow for complex multi-variable correlations to be modelled. Unfortunately, both methods are limited by professional knowledge, project timeline, and the environmental and cultural attributes chosen by the archaeologist. MLAs combine elements of both judgmental (qualitative) and statistical (quantitative) approaches to create more accurate and expansive predictive models.

Machine Learning

Machine learning is part of the discipline of data science in which algorithms are used to facilitate data exploration or to automate data processes. The ‘machine’ in machine

Table 1. Professional Judgement versus GIS Supported AOA predictive models (from Provincial AOA Standards and Guidelines 2009:3)

Professional Judgement Model	GIS-Supported Model
• Appropriate for smaller study areas • Less expensive per hectare • More difficult to revise manually derived maps to incorporate new information • Subjective, based on qualitative criteria • Judgmental models do not find data in representative proportion to their presence in the population	• Cost-effective for large study areas • Modelling requires digital environmental and cultural information at appropriate scale • Accuracy depends on statistically valid site samples (i.e., large enough to achieve representation against taxonomic heterogeneity) • Based on objective, quantitative criteria often combined with subjective modification • Requires detailed review to eliminate redundant and incorrect site location data

learning refers to computers, which can automate and evaluate vast quantities of data quickly and accurately. Common definitions of terminology can be found in Table 2. Within archaeological predictive modelling, MLAs allow for the inclusion of a greatly increased number of parameters, including those that are not known definitively to produce positive correlations. For example, based on professional knowledge and GIS modeling, there is a known strong correlation between locations of archaeological sites and nearness to a fresh water source, however, an MLA may be able to determine that there is also a strong correlation between site locations and nearness to a lookout position etc. MLAs automate complex inferential statistical tests and can therefore evaluate many possible parameters and combinations as well as rank their influence. For example, nearness to fresh water is a better correlator for site presence than flatness of ground surface. As with any model, MLA outcomes are determined by the quality of input data as well as the appropriateness of the algorithm(s) used.

Table 2. Common Machine Learning and Predictive Modelling Terminology.

- **Predictive model** – A construct developed to make inferences about unobserved phenomena based on the observed characteristics of similar phenomena. In archaeology, models are often used to predict site distributions in areas that have not been examined in the field.
    - **Inductive Model** – correlations in data are not assumed prior to the compilation of data. From gathered data, a theory is developed. For example, based on known site locations and their observed nearness to fresh water it is theorized that site location and fresh water source locations are correlated.
    - **Deductive Model** – correlations in data are inputted along with the raw data. From gathered data, a theory is tested. For example, based on previous studies it is suggested that site location and fresh water source locations correlate; however, the project specific inputted raw data may or may not suggest this.

- **Data science** – an interdisciplinary field that uses scientific methods, processes, algorithms, and systems to extract knowledge and insights from data in various forms, both structured and unstructured, similar to data mining. The objective of the data science process is to improve decision and prediction making.
    - **Structured data** – data that has been organized into a formatted repository (e.g., database) so that its elements can be made addressable for more effective processing and analysis.
    - **Unstructured data** – data that either does not have a pre-defined data model or is not organized in a pre-defined manner.

- **Machine Learning** – involves the construction of a set of computer algorithms to facilitate exploration of large or complex datasets (unsupervised learning) and to facilitate making automated predictions and decisions (supervised learning).
    - **Algorithm** – a process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer.
    - **Supervised learning** – the computing task of recognizing patterns and learning processes in data that are pre-labeled, classified or organized typically using ML algorithms.
    - **Unsupervised learning** – the computing task of recognizing patterns and learning process in data that are not pre-labeled, classified, or organized using MLAs and other statistical methods.

- **Data** – facts and statistics collected together for reference or analysis.
    - **Input Data** – data that a computer receives. For example, locations of archaeological sites.
    - **Output Data** – data that a computer sends.
    - **Training Data** –labeled data used to teach MLAs to make proper decisions.
    - **Test Data** –known data used to test the accuracy of MLAs.
    - **True Presence Data** – through sampling (positive tests), the locations of archaeological sites are determined, creating a list of true presence data.
    - **True Absence Data** – through sampling (negative tests), a location is determined to be not an archaeological site, creating a list of true absence data.
    - **Pseudo Absence Data** – locations which have not been sampled but are labeled as absence data either by hand or through an MLA algorithm when only True Presence Data has been gathered.

There are numerous algorithms which fall under the MLA definition; however, different algorithms speak to different datasets (inputs) and produce different results (outputs) (Brownlee 2019). There are two main types of MLAs: SLAs (Supervised Learning Algorithms) and ULAs (Unsupervised Learning Algorithms) (Figure 1). SLAs use labeled training data (structured data) to learn the mapping function that turns input variables (X) into the output variable (Y) while ULAs are used when only the input variables (X) are known, with no corresponding output variables (i.e., unstructured data). For example, taxonomy is a common kind of SLA in which we use a predetermined typological structure of site types (habitation, rock art, CMT, etc.) and ask how each type is predicted from known environmental and archaeological data. In contrast, cluster analysis is a form ULA that generates the typology from the data without prior expectations. Since the goal of archaeological predictive modelling is to predict the locations of archaeological sites as the output (a known output) from certain variables (known input) SLAs are usually the best fit for AOAs.

Figure 1 depicts how many MLAs are set up to make predictions. First, the data sample is split into two subsets, training data and testing data. For example, out of a sample of 300 known archaeological sites (true presence data) and 300 known non-sites (true absence data), 200 each could be chosen for training data and 100 each left behind for future testing.

Secondly, an MLA is chosen to run the data in order to train the model. The 400 training data samples would be inputted into the chosen MLA along with common environmental, topographical, cultural, and ecological variables to create a model which predicts the probability of archaeological sites on the landscape.

Once a model is created, the third step in the process would be to use the testing data to evaluate the predictive model. The 200 test data locations would then be inputted into the newly created MLA model without being labeled as true presence or true absence data.

The fourth step is evaluation, in which the accuracy of the MLA predictive model in determined based on the inputted test data. Using difference methods of testing accuracy (visual, area under the curve, statistics, etc.), the 200 test data sample locations are compared to the created model. If the known site and known non-site locations correspond to areas with high and low archaeological site potential then the model can be considered to be well-fit, accurate, and useful for predicting areas with unknown archaeological potential. However, if the test data does not correspond to the model (under-fitting), it needs retraining. This could be caused by poor sample size, lack of environmental variable data, or a poorly chosen MLA based on the data available. If the testing data fits perfectly onto the model it may be experiencing over-fitting. This could also be caused by poor sample size or lack of environmental variable data.

Predicting Archaeological Sites Using MLAs: A Review

Machine learning is increasingly being applied to archaeological research. In this review, we identified thirteen case studies that evaluate and utilize MLAs for predicting archaeological sites (Ducke 2003; Banks et al. 2008; Fernandes et al. 2011; Galletti et al. 2013; Kirk et al. 2016; Oyarzun 2016; Guyot et al. 2018; Novielo et al. 2018; Wachtel et al. 2018; Zhu et al. 2018; Benner et al. 2019; Walker 2019; Yaworsky et al. 2019). From these, three types of MLAs and two types of MLPs were identified: Logistic Regression (LR; n=2), Random Forest (RF; n=3), Artificial Neural Network (ANN; n=2), Genetic Algorithms for Rule Set Production (GARP; n=1), and MaxEnt (n=7). These represent the current suite of options for archaeologists when implementing MLAs for predictive modelling.

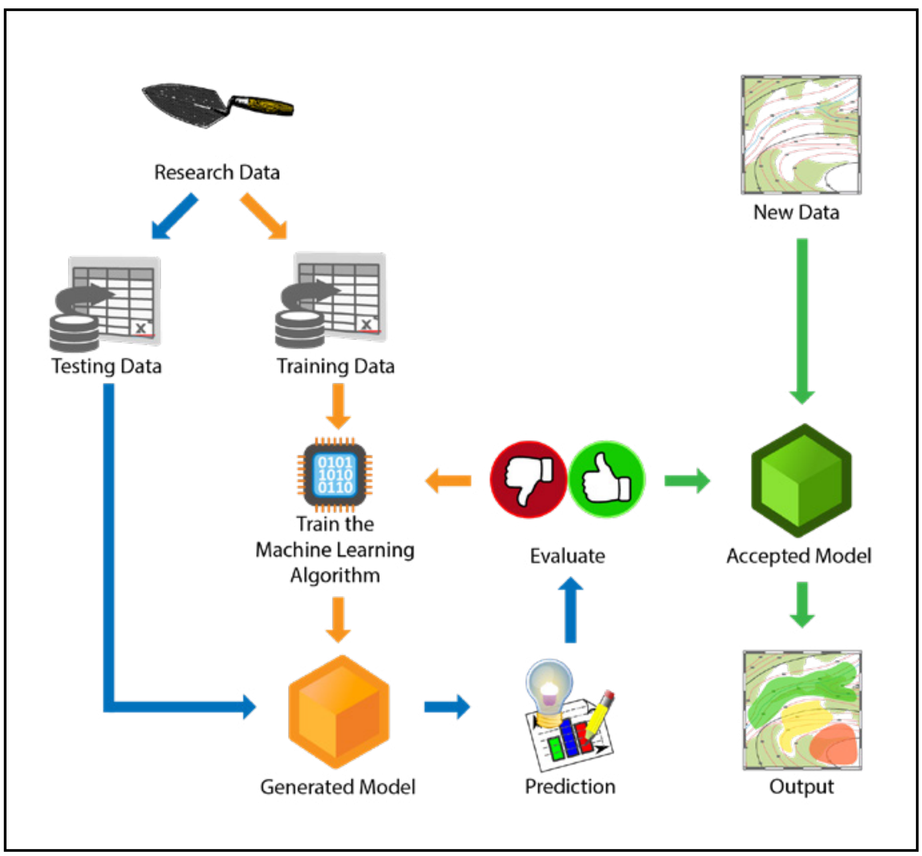

Figure 1. Understanding Supervised Machine Learning Algorithms.

Logistic Regression (LR) is a regression algorithm used for classification problems (Wachtel et al. 2018; Zhu et al. 2018). Created by statisticians, it is a predictive analysis algorithm based on the concept of probability. LR models can be binary (between two groups) or multi-linear (between three or more groups). LR is used to explain relationships between a dependant binary variable (e.g., presence/absence) and a number of independent variables (nominal, ordinal, interval, or ratio). For predicting the probability of archaeological sites, the dependant variable would be site presence (1) or absence (0) while the independent variables would be environmental or cultural data (i.e., distance to water, etc.).

Unfortunately, overfitting (the generation of results that correspond to the sample rather than the population of data) is a common problem with

LR models because increasing the number of independent variables can reduce the ability to generalize the model beyond the data on which the model is fit. This is part of the larger archaeological challenge of representation in archaeology, which is limited because, by definition, archaeologists do not know the range of variability in the population (the archaeological record) from which they produce a sample (archaeological results). Another challenge is the fact that LR models require both true presence and true absence data. This means that we need to know where sites are not as well as where they are to make best use of LR models. In the case studies, Zhu et al. (2018) used a sample size of 350 (56 sites and 294 non-sites) and Wachtel et al. (2018) modeled two areas with known site sample sizes of 54 and 111 respectively and randomly created pseudo-absent data. LR models have value but require a well-studied landscape to be most effective.

Random Forest (RF) is an ensemble algorithm used to make split (yes/no) binary observations (Fernandes et al. 2011; Guyot et al. 2018; Yaworsky et al. 2019). The theory behind RF is that a large number of relatively uncorrelated models (decision trees) operating as a committee will outperform any of the individual constituent models, and that each tree protects each other from their individual errors. While some trees may be wrong, many other trees will be right, so as a group the trees are able to move in the correct direction. For example, a decision tree would ask: 1) is the chosen location a site or not a site? and 2) if it is a site, is it located close to water? and so on.

The downsides to RF are that only one variable (and binary choice) is examined at a time and both presence and absence data are required. In the case studies, Fernandes et al. (2011) used a sample size of 132 known sites and then randomly created pseudo-absent data, while Guyot et al. (2018) used a sample size of 50 (six sites and 44 non-sites). Similar to LR models, RF models work best in well-studied contexts.

Artificial Neural Network (ANN) algorithms were inspired by biological neural networks seen in the brain (Ducke 2003; Kirk et al. 2016). ANNs 'learn' to perform tasks through considering many examples. For example, if data on anthropogenic mounds are inputted to the ANN and identified as mounds, once the ANN sees enough identified mounds (for example from photographs or LiDAR imagery) and of unclassified (i.e. non-mound) landscapes, the network will compile a suite of characteristic traits to identify mound-like landforms that distinguish them from non-mound landforms. ANNs work without being programmed with task-specific rules, giving them great flexibility. The main advantages of ANNs are that they are robust, perform well with noisy data from a range of sources, and can represent both linear and non-linear functions of different forms and complexity levels.

However, ANNs require large datasets, are less transparent than other models, and can be difficult to interpret. They are generally unable to identify the relative importance and effect of the individual environmental variables. ANNs work best when inputs are image-based (areal or LiDAR) and are therefore not as useful for identifying sites without surface topography. In the case studies, Kirk et al. (2016) had 41 known sites, 23 in Galisteo Basin and 18 in the San Manzano Mountains, and used random pseudo-absent sites based on vegetation cover in aerial photos to identify large amalgamated sites. Thus, AANs are flexible, but work best with high-contrast pattern imagery in which the difference between a positive and a negative (i.e., site presence/absence) is clear.

Genetic Algorithms for Rule Set Production (GARP) is an MLP based on evolutionary algorithms that uses op-

Table 3. Comparing MaxEnt to other MLAs.

MaxEnt Predictive Models	**Other MLA Predictive Models**
• Evaluates statistical likelihood that a randomly selected grid location is of the same data population as any provided 'presence' grid location based on environmental attributes	• Requires true absence data or creation of 'mock' pseudo absence data (e.g., random selection, linear models relating input to presence, etc.)
• Only requires 'presence-only' data	• Treats pseudo absences as true absences
• Creates multiple models through trial and error and picks worst performing model that correctly predicts test data under the maximum entropy notion that this model makes the least assumptions • Can output raw, cumulative, and logistic predictions	• Various algorithms generate many models and evaluate best ones • Maps input variables directly to output • Output can be classified (true/false binary) or regression (real number values)

timisation of a combination of ML models (Banks et al. 2008). These were developed to estimate the presence of specific biological species within habitats. Here, independent environmental variables are added to dependent variable occurrence data to create a predicted distribution of species. In archaeology, GARP is used primarily for ecological niche modelling, where human occupation can be modelled onto a landscape. GARP is essentially a non-deterministic approach that produces Binary responses (presence/absence) for each environmental condition and does not need true absence data.

GARP predicts species presence (or archaeological site presence) only if all rules are satisfied for specific environmental conditions. As a result, issues can arise if not enough data exists on the specific conditions necessary for human occupation. These models tend also not to easily account for human agency. The sample size of known archaeological sites utilized in Banks et al. (2008) was 1300 sites. However, in this case study, only 11 Epigravettian and 9 Solutrean sites were used as input to produce the GARP models.

MaxEnt, similar to GARP, is a MLP which runs multiple algorithms and is based on the principle of Maximum Entropy which works to select the model which has the largest entropy (Galletti et al. 2013; Oyarzun 2016; Novielo et al. 2018; Wachtel et al. 2018; Walker 2019; Yaworsky et al. 2019; Benner et al. 2019). The model with the largest entropy is the model that is the least wrong, i.e. which has a distribution that is the most spread out or closest to uniform. This lowers the potential for overfitting. MaxEnt takes a list of locations where species (i.e. sites) are present as its input variable, as well as environmental predictor variables across a landscape that is divided into a grid of cells. MaxEnt evaluates the statistical likelihood that a randomly selected grid location is of the same data population as any provided 'presence' grid location based on the environmental attributes. The output from the MaxEnt program can be interpreted as the predicted probability of presence or as a predicted local abundance.

In comparison to the other MLAs and MLPs discussed, MaxEnt was created specifically to deal with presence-only data and can be run with a small (<50) sample size as it looks at similarity to known grid locations (in this case archaeological sites). The sample size of known archaeological sites utilized in the case studies which applied MaxEnt ranged from 22 to 3,729. MaxEnt works well in archaeological contexts since it does not need known absences and can produce reasonable results from small sample sizes. Since it focuses on traits within spatially determined cells, MaxEnt mimics archaeological judgmental models, but with more quantitative rigour. It can also accommodate a wide range of data types, so can include evidence from beyond material domains, such as curated Indigenous scholarship. A downside to MaxEnt is that it is difficult to compare its output to the outputs of other algorithms.

MaxEnt as the Best-Fit MLA for Archaeological Predictive Modelling in BC

As stated above, a major issue with many MLAs is the need for both true presence and true absence data. In archaeological contexts, true absence data means that an area has been tested and no archaeological material has been found. It can be difficult to both determine and accumulate true absence data in the archaeological record since it requires collecting data on locations that have been tested for archaeological material and held negative results. This type of data can only be gathered through field-based sampling (i.e., test pitting) as even areas which have been previously disturbed may still have portions of intact archaeological sites. It should also be noted that negative data is not accumulated at random. In many archaeological investigations, data is collected in a project-specific way, creating a skewed sample of negative contexts. This means that areas with higher development rates (urban or industrial areas) are more likely to have more positive and negative data than areas which lack development. Areas already ascribed as having high potential are also more likely to be tested than areas which are currently thought, based on previous studies or current assumptions, to have low potential. Likewise, creating pseudo-absence points to run algorithms can hide locations where sites are present and cause over-fitting. These are issues that face BC archaeologists, and which need to be considered when examining common and MLA predictive models.

Out of the thirteen articles reviewed, MaxEnt modelling is the most popular (n=7) and case studies show that MaxEnt is superior to LR and other common MLAs (Table 3).

A brief description of the reviewed case studies which utilize MaxEnt modelling is useful to illustrate this method, required sample sizes, and environmental and cultural variables necessary for MaxEnt modelling. Several of these are tests of MaxEnt against a well-sampled and well-understood archaeological landscape.

1. Galletti et al. (2013) modelled agricultural terraces in Cyprus using MaxEnt, inputting nine environmental variables to find the systematic distinctions between ancient and modern terrace locations and the environmental parameters most influential in modelling these terrace locations. This study used ~200 known sites and utilized elevation, spring veg-

etation, fall vegetation, distance to nearest calcareous sediments, distance to nearest major stream, slope, albedo-radiation, distance to nearest pillow lava, and temperature for modelling variables. The model revealed significant differences between the predicted distributions of the ancient and modern terraces along with different associations of environmental variables.

2. Oyarzun (2016) examined if a site type MaxEnt model can be as good or a better predictor of northeastern California Early Holocene archaeological site probability than the MaxEnt models that do not categorize by site type. A total of 3,729 sites were known in the study region, and the environmental variables slope, aspect, distance to water (springs, waterways and water bodies), geologic mapping, tool stone sources, and large game corridors were used. A lithic scatter model (site type) performed very well while a rock features model performed poorly. The 'kitchen sink' model (all sites) and the ecological region model also performed well.
3. Novielo et al. (2018) modelled the distribution of Neolithic sites in Italy and compared Multiparametric Spatial Analysis (MPSA) in GIS and MaxEnt, inputting environmental features and vegetation indices. This study used 80 known sites for training and 40 for testing. Environmental variables included topographic features: altitude, slope and aspect, geomorphological features: river networks, quarries, and river morphology features (i.e., riverbank edges, river erosion banks), and six satellite vegetation indices. The study found that the MaxEnt approach has higher potential to efficiently improve the prediction of archaeological presences than the MSPA, allowing for a higher overall performance and parsimony (reduced demand in terms of environmental variables). The results also indicated that both subjective and objective modes of variable selection can be implemented, and appropriate model selection procedures can guide the choice of the model with the most effective variable combination.
4. Wachtel et al. (2018) modelled the locations of Bronze and Iron age sites from Israel and Neolithic sites from China comparing LR to MaxEnt inputting environmental variables as well as modern land use information. Known sites included 54 Bronze and Iron ages sites from Israel and 111 Neolithic sites from China. Environmental variables included topography: slope, elevation, aspect, and land curvature; proximity to water sources; modern land uses: agriculture fields, forests (which may have served as pastureland in the past), and modern settlements; and geology: proximity to soft formation (chalk). MaxEnt had a higher performance and stability than LR. Stability was achieved with MaxEnt models even when using a small number of observations. The main advantage of MaxEnt over logistic regression appears to be in its imperviousness to the problem of case-control modelling. Logistic regression requires both positive data and negative data (nonexistent in most cases) while MaxEnt only requires presence data.
5. Benner et al. (2019) modelled Heiltsuk territory using MaxEnt to predict the distribution of monumental western red cedar trees suitable for contemporary cultural modification. The purpose of this study was to firstly identify locations with high potential for old growth, and secondly to identify culturally modified trees (CMTs) for purposes of present-day conservation. Locations for monumental specimens were modelled from Heiltsuk field survey results (68 monumental tree sites), archaeological records (106 CMT sites), and an independent validation dataset from a survey of Chatfield Island (62 sites). Eight environmental variables were used: elevation, distance from ocean, slope, solar radiation, site index, canopy height, leading species, and site series. MaxEnt showcases the different importance of variables for the survey and archaeological models. When tested against the validation dataset, the archaeological model had better predictive performance. When the two models were combined, the highest accuracy was obtained, which the authors suggest was due to the reduction of the most extreme biases associated with either occurrence dataset.
6. Walker (2019) modelled Late Archaic and Middle Woodland mortuary sites in Ontario using MaxEnt, inputting 11 environmental variables: elevation, slope, aspect, ruggedness, soil texture, stoniness, fertile soils, well drained soils, peat and muck, wetlands and distance to water. For this analysis, 22 mortuary sites and 70 non-mortuary sites were used. MaxEnt was utilized to determine which environmental variables predicted the location of mortuary sites. The non-mortuary model appears randomized, while the mortuary model appears to have a high degree of predictive power for determining ecologically suitable site locations. This suggests that key environmental settings of mortuary sites are highly predictable and share distinct qualities separate from other kinds of archaeological sites.
7. Yaworsky et al. (2019) modelled pre-historic land use patterns in Utah and compared regression-based

models (generalized linear and generalized additive) and machine-learning based models (MaxEnt and Random Forest), inputting ten environmental input variables. The environmental variables utilized were aspect, maize growing days, net primary production, temperature, slope, springs (cost distance), streams (cost distance), watershed (size), wetlands (cost distance). They found that the MaxEnt model treated pseudo-absence points correctly while RF overfit the data and misinterpreted pseudo-absence points.

Conclusions

This research suggests that the MaxEnt MLP suite is likely the current best-fit model for archaeological site predictive modelling in BC. The major benefits to MaxEnt modeling versus other MLAs or MLPs are that MaxEnt can be run on relatively small sample sizes (<100); Walker (2019) modeled mortuary site locations with only 22 known sites. In BC, there are many regions which currently have low numbers of known sites. However, that does not mean there not large numbers of unknown sites present. MaxEnt is also particularly beneficial to archaeological modelling because it does not require any absence data. Instead, it evaluates the statistical likelihood that a randomly selected grid location is of the same data population as any provided 'presence' grid location based on environmental attributes. This is useful for BC because true absence data is often not reported on and uploaded; true absence data collection is strongly biased towards areas with increased development, making modelling rural areas very difficult; and creating pseudo-absence is problematic as it treats areas chosen as true absence data, potentially hiding real sites. MaxEnt modelling also creates multiple models through trial and error and picks the worst-performing model that correctly predicts test data. This follows the maximum entropy concept, which choses the model that makes the least assumptions. This creates more accurate models that can continue to increase in accuracy when new sites are inputted. MaxEnt also allows for modelling multiple types. For example, using MaxEnt a model could be created that modelled different site types. In BC, a model could be created which models all site types independently (habitation, CMT, etc.) but within the same model. Links to the MaxEnt software and other reference material can be found below.

Machine learning applications and requirements are likely to increase for archaeologists in the years ahead, so familiarity with the options and an inventory of successful case studies is valuable. Specifically, utilizing MLAs for predictive modelling can 1) lead to increased accuracy in predicting site locations; 2) identify and rank correlations between site location and environmental, topographical, and cultural variables; 3) model large regions and determine similarities and differences between sites in that region; 4) model lesser known site types; 5) model different time periods; and 6) lead to increased knowledge about precontact site location positional choice. Although such methods can seem intimidating and complex, they provide useful tools for both understanding patterns in existing data and making reasonable predictions about the key traits of material heritage data. These results can then be used to anticipate where heritage sites are likely to exist. While they cannot and should not replace standard methods of site detection, they can assist is locating and protecting heritage data on a scale that can keep pace with development pressures and can continue to be updated and refined as new sites and environmental relationships are uncovered.

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Archaeological Predictive Modelling: The Model Inputs

by Kelly Monteleone

Abstract

Archaeological predictive models are effective tools for site discovery but require multiple steps and inputs to create a useful model. Constructing a predictive model involves many decisions and stages including starting with an appropriate resolution digital elevation model (DEM). The DEM is then used to create or have data mapped onto for the model inputs, such as hydrologic features (streams, lakes, and tributaries), slope, aspect, and coastlines. The choices made while creating the inputs, the intermediate products, and the raster layers significantly impact the model's effectiveness for site discovery. In this paper, questions, decisions, and methods used to create a weighted overlay model are reviewed with a case study from the continental shelf of southeast Alaska. In addition to field testing predictive models, statistical tests are essential for developing robust and competent predictions. With new and faster tools, predictive modelling will become even more popular for students and researchers in archaeology. By sharing model inputs and code via data warehouses with other researchers, when appropriate, and presenting these directions for creating predictive models, modelling will become more accessible to users.

Introduction

Archaeological predictive models have been used by academic researchers, cultural resource managers, and other government agencies for decades to narrow areas for survey of potential archaeological sites. Developing these models is becoming easier with technological improvements. This paper will discuss methods for developing the inputs for predictive models including goal-specific choices. There are numerous methods to create or combine the layers into a predictive model, such as rule-based approaches, regression approaches, and weighted overlays. More recently, machine learning algorithms have arisen as useful methods (Davis 2020; Orengo and Garcia-Molsosa 2019; also see the Johnson, Mason and Martindale article on p. 38 of this issue of The Midden). The weighted overlay method was used in the southeast Alaska continental shelf case study presented here. This method was selected because weighted overlay methods are commonly used in North American archaeology (Bona et al. 1994; Dorshow 2012), it is a simple technique (Verhagen and Whitley 2012), and it is the method the author had been previously taught during CRM work.

The publication of the Late Pleistocene Archaeological Discovery Models on the Pacific Coast of North America (McLaren et al. 2020), lays a framework for future work along the coasts of British Columbia and Alaska. This model identifies five steps to aid in the discovery of Late Pleistocene archaeological sites along the coast. Their five steps are 1) creating local sea level chronology; 2) generating detailed elevation models; 3) creating archaeological predictive models; 4) ground-truthing these models using archaeological survey; and, 5) testing to uncover datable archaeological material. Their discovery model has been tested along the coast of British Columbia from the Gulf Islands (e.g.,. Fedje et al. 2009; Lausanne et al. 2019) to Prince Rupert Harbour (e.g.,. Letham et al. 2016) and numerous places in between (e.g., Martindale et al. 2009; McLaren et al. 2014, 2018). Here we will focus on step three, creating the predictive model.

Numerous stages and decisions are required for the development and testing of an archaeological predictive model. From choosing the appropriate software, determining the specific site types being modelled, or selecting the resolution, these are important. The choices made while creating the inputs, the intermediate products, and the raster layers considerably impact the model's effectiveness for discovering sites. The goal of this paper is to provide a framework for students and archaeologists to follow for creating the inputs of an archaeological predictive model.

Theory

A model is a "hypotheses or sets of hypotheses which simplify complex observations whilst offering a largely accurate predictive framework structuring these observations" (Clark 1968: 32). Thus a model is a hypothesis that needs to be tested and must fit within a larger theoretical framework. Additionally, a model is an abstraction that can be generated inductively or deductively. Predictive modelling is "a technique that, at a minimum, tries to predict the location of archaeological sites or materials (non-site) in a region, based

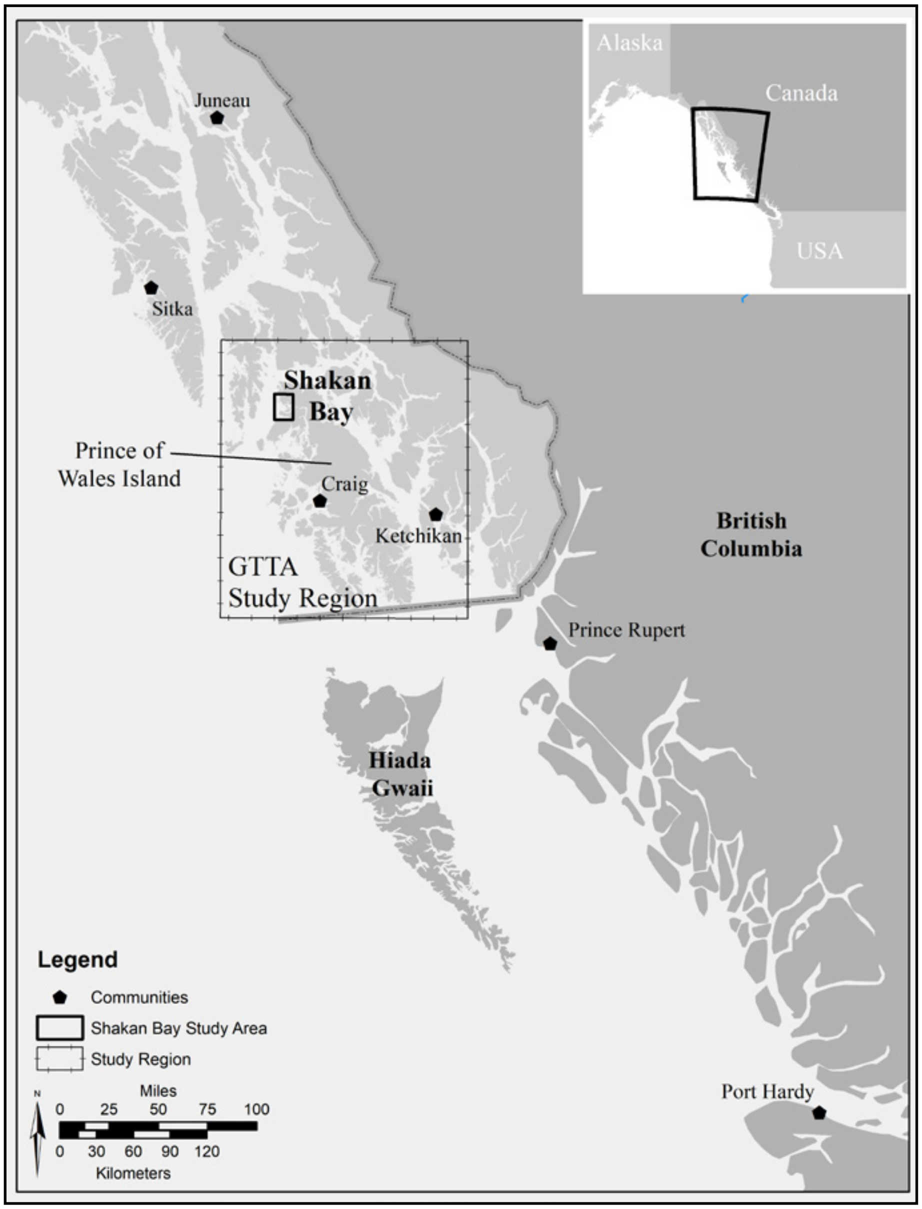

Figure 1: Map of the case study region, west of Prince of Wales Island, and study area, Shakan Bay.

either on a sample of that region or on fundamental notions concerning human behaviour" (Kohler and Parker 1986:400). Verhagen and Whitley (2012:52–53) expand this definition to require the model to have "a quantitative estimate of the probability of encountering archaeological remains outside the zones where they have already been discovered". A predictive model to locate areas of high archeological potential is a bridging function, or middle-range theory, linking high-level theory to data and the archaeological record (Verhagen and Whitley 2012).

The theory behind archaeological predictive modelling is based on the biological concept of the niche (Kvamme 2006; Kondo and Oguchi 2012; Kondo, Omori, and Verhagen 2012; Monteleone 2013, 2019b). Archaeologically, a niche is "the total range of conditions in the environment under which a population lives and replaces itself" (Kvamme 2006:14). This is a simplification. According to Hutchinson, a niche "could be represented quantitatively in terms of the multidimensional combination of abiotic and biotic variables required for an individual to survive and reproduce" (Brown 1995:30). Species exhibit distinctive patterns of abundance and distribution that reflect a species' environmental requirements; humans are no different. Ideal habitats can be represented by measurements of specific variables, often environmental variables. Culturally determined variability can be mapped and associated with environmental variables using Human Behavioural Ecology (HBE) as a theoretical framework (Bettinger, Garvey, and Tushingham 2015; Bird and Codding 2008:396; Kantner 2008:61). People's choices may not be based exclusively on environmental variables, called environmental determinism, but the pattern of how these decisions are reflected on the landscape can be mapped and reproduced like any other quantitative dimensions within the human niche. This means each predictive model must incorporate cultural attributes into the decisions about variables used, such as resource locations. More recently, Supernant (2017) has demonstrated that cultural landscapes, including Indigenous Traditional Knowledge, can be spatially located onto archaeological landscapes and produce better models (Benner et al. 2019; Deroy 2019). Every predictive model is uniquely designed for a specific culture, both temporally and spatially. Decision-making processes make hunter-gatherer subsistence economies, such as Northwest Coast (NWC) cultures, well-suited to predictive models, as their main focus is on food procurement, which can be spatially located (Boaz and Uleberg 2000).

The landscape is the scale of analysis for using HBE to investigate the archaeological site locations. A landscape is an ecosystem where humans interact with other species and the environment (Jochim 1981:4); essentially the scope of the niche. This is often termed "landscape ecology" (Anschuetz, Wilshusen, and Scheick

2001; Bender 2002; Casey 2008; Kantner 2008; Wandsnider 1992). Landscape archaeology provides a conceptual framework to address all contexts of past human behaviour and goes beyond an "environmental" approach. It is focused on things that locate humans spatially (David and Thomas 2008:38). Landscape archaeology is about "place" as a basic unit of lived experience (Casey 2008:44). Community engagement and collaborative approaches to landscapes ensure that these lived places incorporate oral histories and Indigenous Knowledge (Laluk 2017; Ross, Prangnell, and Coghill 2010; Stump 2013).

Case Study

The methods discussed here have been applied to a land-use predictive model to identify areas of high archaeological potential on the continental shelf of southeast Alaska (Dixon and Monteleone 2014; Monteleone, Dixon, and Wickert 2013; Monteleone 2013, 2019b). This research was part of the Gateway to the Americas (GTTA) I and II projects (Dixon and Monteleone 2011; Monteleone and Dixon 2018). Southeast Alaska has a sheltered environment where archaeological sites could be preserved and identified on the continental shelf from the end of the Pleistocene. The GTTA predictive model was developed to narrow the survey and testing areas in the over 40,000 km2 study region (Figure 1). The focus has been the western continental shelf off Prince of Wales Island. The stages followed during the GTTA project are similar to the framework created by McLaren et al. (2020), however, the research was conducted independently and before the publication of the discovery model.

Methods

Developing a predictive model can be divided into stages: inputs into the model, intermediate products, raster outputs, final products or the model outputs, and model testing (see figure 2 for the stages for the GTTA model). The intermediate products are those derived from the inputs, such as creating streams from an elevation model. Raster outputs are the amal-

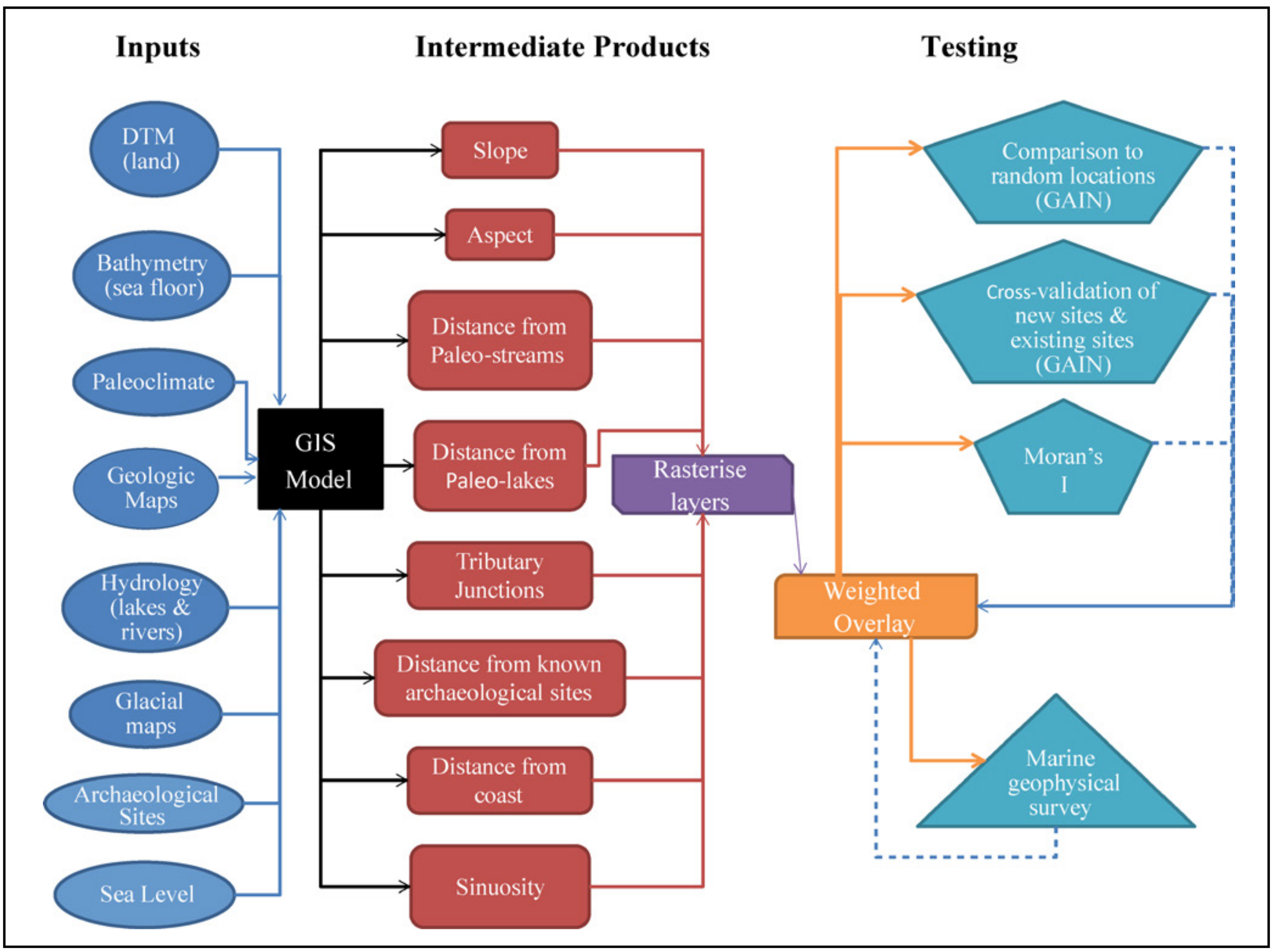

Figure 2: GTTA methods flow chart (Monteleone 2019b, 57).

gamation of the intermediate products into a format that the modelling method can utilize. The example here is a weighted overlay; therefore, the raster outputs are ranked buffers.

When investigating a time range with significant environmental or cultural changes, such as sea level, time-slices are a useful tool to capture the changes. For the final products, the time slices are combined using raster math or mosaic functions. After developing the final products, testing the model is conducted including field survey and statistical testing.

Before Starting

There are a few steps to consider before starting the analysis. These include software choices, site types to include, and the resolution for the analysis and inputs.

Software

There are many good, high-quality software options to choose from. Sometimes, one software is better for a specific task. Academic work in North America is primarily conducted using ESRI's ArcGIS or ArcPro (the latest version). This includes options to use a python library specific to ESRI, ArcPy. The programing language R and the associated R-Studio has numerous robust libraries for completing complicated spatial analyses. The software programs gvSIG and Quantum GIS (QGIS) use interfaces that are comparable to ArcGIS's push-button format (Lock, Kormann, and Pouncett 2014). Geographic Resource Analysis Support System (GRASS) is a powerhouse for processing and, like R, has libraries that include published references explaining how the tools are coded. In the end, most people work with what they have been trained in. Online courses are an excellent way to quickly become competent in other software. For GTTA, most of the work was conducted in ArcGIS 9 and 10, but some processes were run in GRASS.

Site Types and Time Slices

Predictive models are more efficient if they focus on specific site types or landforms (Kvamme 2006). This means a model will be different for caves or rockshelters vs. terraces or flat areas. Modelling for cave or rockshelters will focus on steeper areas. Focusing on caves used for hunting means water sources could be further away. This is where cultural and archaeological knowledge becomes important in the modelling process.

As archaeological sites are temporal, the time period(s) being investigated also affect the predictive model, especially if the site types or locations change over time, or do not change (Monteleone 2016). When looking for Pleistocene age sites, environmental reconstruction is important, especially sea level and glacial chronologies. This becomes a trade-off between the temporal resolution and the resolution needed for the research question(s).

With the GTTA model, the focus was on any prehistoric site, so culturally modified trees, historic cabins, and rock art were removed from the analysis. Because of the significant environmental change through time, 500 cal BP (calendar years before present) time slices were created from 16,000 to 10,000 cal BP (Monteleone 2013, 2019b).

Resolution

The site type or landform to be identified will also affect the resolution for the analysis. If the features or landforms to be identified are only one to five meters, a resolution of 10 meters will not identify archaeologically significant features. However, smaller resolutions can increase the noise or bad data in the analysis. A smaller resolution can also increase the file size, possibly requiring a supercomputer. ESRI's ArcMap and R both are not equipped to handle analysis on large files. ESRI's created ArcPro, which uses multiple cores and processing threads to assist in the analysis of larger files. For the case study, most of the analysis was done in the ArcGIS python shell using ArcPy (all python scripts used are available in Appendix B of Monteleone 2013). The ideal situation is the smallest resolution appropriate to the landforms or features being identified with the smallest file size the workstation used computationally manage. Decisions about resolution and site types need to be made before creating the model inputs.

Model Inputs

This stage involves gathering data, formatting or standardizing the data, and incorporating the data into a GIS database. The data available to input into the model is very important. As more data is put into repositories and shared online, these model inputs could become the equivalent of intermediate products and even raster outputs, i.e., a stream file that extends onto the continental shelf readily available for download. However, building layers from raw data aids in understanding the data, its units, and its intricacies.

Digital Elevation Model (DEM)

The basis of the model is the DEM or Digital Terrain Model (DTM) as this is how many of the other layers are derived and the layer on which analyses of currently known site locations are conducted. Many of the intermediate products will be derived from the DEM. The accuracy and precision of this layer will affect the analysis more than any other input. Step 2 in McLaren et al. (2020) process is generating a detailed DEM, specifically a bare earth model, which is a term derived from lidar (Light Detection and Ranging) analysis where the point-cloud includes all surfaces, such as trees and other vegetation (Wang and Glenn 2009; Lu et al. 2008). Bare earth models in lidar are just that, a model of the expected land surface with the trees and vegetation removed. Any DEM is a model, and therefore, a representation of data. For analyzes, the projection of the DEM needs to be meter based, such as Universal Transverse Mercator (UTM) and not degree-based.

Satellite remote sensed images such as Landsat, National Elevation Data (NED), and the Shuttle Radar Topography (SRTM) image files are readily available for most of the globe. These larger-scale files will be useful for statistical analysis at the region or landscape extent. Locally remotely sensed data such as lidar and bathymetry are extremely useful, can be high resolution (less than 1-meter resolution or several points per square meter), and can be expensive. The quality of these data varies for each survey.

GIS tools allow for combining multiple points or XYZ data sets. Combining elevational point data from multiple sources allows for the generation of even higher resolution DEMs. For the GTTA model, NED data were converted to point data (originally at 25-m resolution and down-sampled to 5-m resolution), NOAA charts were included as point data, marine survey data were gathered in XYZ formats, and lidar data were purchased from Scientific Fishers Inc. These datasets were all combined to create the seamless DEM. All the point data combined into a single point file of over 40 million points that was then converted to a DEM via Inverse Distance Weighted (IDW) method, where each value is determined by using a linearly weighted combination of sample points. The IDW method was compared against the Spline method, which uses a mathematical function that minimizes surface curvature, but found the results comparable, if not better quality (Monteleone 2013:110–11). The DEM is also the base map that other data sources are mapped onto.

Selecting Model Inputs

Identifying data sets that will categorize the cultural behaviours being modelled is essential to a successful predictive model (Kvamme 2006:21). These can vary depending on site types, landforms, culture groups, time periods, and many more factors. For example, a map of streams with salmon runs will help identify harvest or procurement sites. Sometimes digitization of the data from published maps or working with local communities is required to build the datasets (Supernant 2017). Data repositories are becoming extremely useful sources of already digitized data.

Another model input that is helpful for an archaeological predictive model is known archaeological site locations. This data is available from the British Columbia Archaeology Branch or any other state, provincial, or territorial government agency (with appropriate permissions). The resolution of the site locations can be highly variable. Some issues arise from older site locations that were mapped by hand as the locations are not accurate, such as terrestrial sites in the middle of water bodies or on mountainsides that are described on land or flat surfaces. Despite these issues, this is often the best source of information about the archaeological sites types being modelled. It is recommended that the archaeological site data be split into training and test datasets. Randomly select a percentage of the sites in the study area to be used to test the model (for example 20%) and use the remaining percentage to build the model.

Selecting Model Inputs for Case Study

For the GTTA model, there were eight inputs (figure 2): terrestrial DTM, bathymetry (seafloor DEM), paleoclimate data, geologic maps, hydrology, glacial maps, archaeological sites, and sea level. The DEM including both land and bathymetry data were developed from point data. Three DEMs were created: (1) a 25-m resolution DEM for the entire northern NWC; (2) a 5-m resolution DEM for the GTTA study area in southeast Alaska; and (3) a 1-m resolution DEM for the area around Shakan Bay. The various resolutions are products of the file size and computer processing ability. As the area increases, the resolution also has to increase. Archaeological site data were compiled for the outer coast from Juneau, Alaska to the northern tip of Vancouver Island. Paleoclimate was used as an input in developing the hydrology (lakes and rivers). Geologic maps, glacial maps, and paleoclimate were used as limiting factors to determine if each area could have been habitable from 10,000 to 16,000 cal BP. All of these data were gathered into an ArcGIS database and used to create the intermediate products (Monteleone, Dixon, and Wickert 2013; Monteleone 2013, 2019b).

Intermediate Products

Intermediate products are created from the inputs. For the GTTA there were two stages of intermediate products (Figure 2), the derived variables like slope, aspect, and hydrology, and the buffered and classified raster files.

Slope and Aspect

Slope and aspect are easily derived from the DEM input in any GIS software. Slope is the elevation change over the distance; hence, the slope has to be calculated at a resolution larger than the DEM. ArcGIS, and other tools, use an averaging function to calculate the slope between the elevation of the cell and the surrounding cells, thus generalizing the data or resolution. All of the outputs need to be the same resolution, so this new resolution becomes the project resolution. For the 5-m DEM for GTTA, a 10-m resolution model was used. That was why a 1-m DEM was created for Shakan Bay and a 2-m resolution model generated (Monteleone 2019b).

Hydrology

ArcGIS has very detailed instructions to create rivers or streams, but the module in GRASS is preferred as the tool has been developed and regularly updated by hydrologists (Callaghan and Wickert 2019; Barnes, Callaghan, and Wickert 2020b, 2020a). With the rapid advancement in this field of research, the GTTA hydrology methods are becoming outdated. For GTTA, streams or drainage paths (Monteleone, Dixon, and Wickert 2013) were calculated from the DEM using an improved, highly efficient least-cost-path search (Metz, Mitasova, and Harmon 2011) in GRASS GIS 7 (GRASS Development Team 2015). Flow accumulation was calculated using a constant value for precipitation minus evapotranspiration (of 4×10-5 mm/s, which is characteristic of the region based on the TraCE-21K paleoclimate model) (He 2011; Liu et al. 2009). A 0.1 m3/s discharge threshold was used to define streams. This value, based on records from gauging stations in southeast Alaska from CUASHI Hydrodesktop (Ames et al. 2012), was used to define the headwaters of streams. This work was conducted with a hydrologist, which is highly recommended.

Possible paleo-lake locations can be generated in a two-step process; this is useful for reconstructing the continental shelf and for paleoenvironments where the modern lakes may not be equivalent. First, depressions are identified in ArcGIS 10 with the basin fill algorithm (Spatial Analyst Toolbox). This algorithm typically is used to fill pits caused by data errors in the DEM but also fills enclosed depressions that may have been lake basins. Hence, these lakes are depressions in the landscape that could have been lakes, marshes, peat bogs, or simply depressions. The second step is removing small areas that are not feasible as lakes from the basin-fill output. An area of 200 m2 was selected as the minimum value for the GTTA model. This was an arbitrary value to remove small errors in the file outputted by basin fill (Monteleone 2013, 2019a).

Reconstructing the position of the shoreline, where the land and water met, can be complicated as the location changes with tides and waves. Here, the shorelines are defined as the zero contour or 0-meter elevation of the DEM for each time slice. The stream file was clipped to the paleoshorelines from the original stream file. Paleo-tributaries were calculated as the intersection of streams with other streams, lakes, and the coastline. All of these steps were conducted using ArcGIS's Data Management - Features toolbox.

Sinuosity

It is not just the proximity to the coast, but the shape of the coast and character of the offshore environment that is important for resource locations. Mackie and Sumpter (2005) utilize shoreline intricacy (similar to sinuosity) to analyze site distribution patterns on Haida Gwaii. Lausanne et al. (2019) and Vogelaar (2017) refers to this as coastline complexity. For GTTA, an ArcPy python script was created that calculated sinuosity based on a defined diameter using clipping and buffer tools in ArcGIS. The shoreline was converted to a series of points and clipped to the 3 km (diameter) buffer at each point along the coast. The distance along the coast was calculated for each clipped shoreline length. The first and last points for each length of shoreline were used to calculate the linear or Euclidean distance. The sinuosity of each length of shoreline was then calculated as the actual distance along the coast divided by the Euclidean distance. The mean sinuosity value was then used for each point along the coast. The values range from linear (1) to sinuous (values greater than 5) (Monteleone 2013:125–26, 2019b).

Statistics to Determine Variable Ranks

For GTTA, statistical analysis and ethnographic research were used to determine the most appropriate ranked distances, used to create the buffer distances for the rasters. Statistical analysis, ANOVA and t-test, of each variable to known archaeological sites was conducted to determine the highest probable locations (Monteleone 2016, 2013, 2019b). Interestingly, sites were not within 100 m of stream files. They were within 500 m, specifically 418 m was the median distance to known archaeologist sites from a water source. The hypothesis is that the issue is due partly to the width of streams not being incorporated into the streamlined file; measurements are to a line, which has no thickness.

Raster Layers

The final inputs to the models are raster files (Figure 2). Most of the inputs and intermediate products are shapefiles. There are two steps to creating the raster files from the shapefiles. First, the files need to be buffered to create the ranked variables. The buffers create areas of probability ranges for uncovering archaeological sites around the line and point features. Each buffer represents a rank used in the final method. Secondly, the buffered shapefiles are converted to raster files of the same resolution using ArcGIS Conversion Tools

Slope and aspect, for GTTA, were already raster files. Each of the other intermediate products (streams, lakes, tributary junctions, known archaeological sites, and sinuosity-coastline) were converted from shapefile to rasters. Sinuosity and coastlines were combined but split into three categories (high, medium, and low) based on how similar they were to the average sinuosity near known archaeological sites in the region before they were buffered. The shapefiles were then converted to raster files at 10 m resolution.

GTTA Final Model

For the GTTA project, the ArcGIS 10 weighted overlay in the raster toolbox was used. To find the best fit, over 13 models were created of various weights and tested against new and known sites versus random locations. Originally, the weights were finalized based on visual inspection. Subsequently, Kvamme's Gain (outlined below) was used to determine the final model weights. Model weights are ratios applied to each variable; these weights are multiplied by the ranking for each buffer to determine the final model value or output. Future iterations of the model will use machine learning and artificial intelligence to refine the ranks, weights, and variables.

Once the weights were finalized, fifteen different time-slices were created of the model. The final model had values from zero to four, with moderately high potential set as value 3 and high potential set as value 4. To refine the potential locations of archaeological sites on the continental shelf, these layers were combined using "mosaic to new raster" in ArcGIS 10. This method preserved the values of zero to four. Only layers created for periods of lower sea level were incorporated into this mosaic. This final model was then used for statistical analysis, marine geophysical survey, and subsurface testing.

Testing Predictability

The traditional method to test an archaeological predictive model is via field survey or ground-truthing (Kohler and Parker 1986). Ground-truthing both provides the key archaeological data needed and confirms the accuracy of the proposed model. McLaren et al. (2020) discuss the need for ground-truthing to test the predictive model and to locate archaeologically dated material. Kvamme's Gain is a statistical analysis of the model's overall predictability and is often used for archaeological predictive model testing (Kvamme 2006).

Kvamme's Gain has not been used by some archaeologists who believe it is only testing the model against itself. By incorporating sites that were not included in the development of the model, the test site locations, Kvamme's Gain provides a robust statistical assessment of the model. The formula is (Mink II, Stokes, and Pollack 2006:215):

$$Gain = 1 - \frac{\textit{percent of total area covered by model}}{\textit{percent of total sites within the model area}}$$

The result is a value between -1 and 1 that is the ratio of the number of sites to the percent of the predicted area from the total area. If the results are negative or less than 0.5, the model is not predictive. If it is negatively predictive (result below 0), areas that are not high potential could and likely have archaeological sites. If the value is between 0 and 0.5, it means that it is close to equally likely that archaeological sites are in the high potential area or the low potential area. When the gain value is over 0.5, it means that more than 50% of the archaeological sites are likely within the high potential areas (Kvamme 1988; Mink II, Stokes, and Pollack 2006). The current GTTA model is over 90% (or 0.9) predictive (Monteleone 2013:137).

Getis-Ord General G and Moran's I were explored as statistical tests (both available in ArcGIS) during the GTTA project; they are tests of clustering or spatial grouping of data (Getis and Ord 1992). These statistics were not beneficial as they did not demonstrate variability between model versions or provide information for evaluating the effectiveness of the model (Monteleone 2019b).

For the GTTA project, four years of subsurface testing resulted in less than the equivalent of 50 shovel tests in a terrestrial setting. No archaeological materials were recovered from the continental shelf; however, several archaeological sites were discovered on Prince of Wales Island (Williams and Dixon 2014). Initially, testing was conducted with a very small clam-shell like grab sampler that did not penetrate the sediment surface. The remainder of the project was spent developing and testing a suction dredge that allowed us to reach depths of over a meter. More work is still needed to test and refine the GTTA model.

Looking to the Future

Archaeological predictive models have been the standard for many years in British Columbia as part of archaeological overview assessments. They are commonly used by archaeological companies to minimize the survey of low archaeological potential areas designated for development. Presented here is one method to create such a model; there are many ways to create an archaeological predictive model. The methods presented focus on the development of the input layers to ensure shared knowledge and processes as the methods become more complicated and advanced.

Data warehouses are the future of finding ready-to-use data sources or model inputs. If archaeologists start to provide base layers and code after publication, then there will be an increase in the reproducibility and the scientific merit of the models and will allow for others to build on the research. These are standard practices for many scientific fields, and as such, data is available for archaeologists as consumers. Archaeologists need to work on becoming better data producers, with non-culturally sensitive data sets. The geophysical and video data from the GTTA project is available from the Arctic Data Center (Monteleone 2019a). Repositories such as DataOne (https://www.dataone.org/) would welcome archaeologically derived data sets in collaboration with the Indigenous communities and when appropriate, and provide a template for metadata collection.

The next phase in archaeological predictive modelling is leveraging artificial intelligence and machine learning. These processes can iterate through options and test accuracy at speeds significantly faster than any graduate student sitting at a workstation. This future has potential but requires archaeologists to learn more programming skills.

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Flagship Archaeologists in a Flagship Archaeological Region: Remembering George MacDonald and Ken Ames through the archaeology of the Prince Rupert Harbour, British Columbia, Canada

by Bryn Letham

In the last year, two significant figures in North American archaeology, Dr. George MacDonald (1938-2020) and Dr. Ken Ames (1945-2019) sadly passed away. Near the beginnings of their illustrious careers both were instrumental in one of the largest archaeological research programs ever conducted in Canada: The North Coast Prehistory Project. This project explored several locations in northern British Columbia, though focused on archaeologically-spectacular landscape of the Prince Rupert Harbour. In the decades that followed, George and Ken expanded their work along the Northwest Coast, and their research impacted many around the globe. These men led the way for a fleet of archaeologists (such as myself) in exploring the Indigenous history of North America, they fought for the rights of Indigenous peoples to own and manage their cultural heritage, and their research addressed broad anthropological questions that lead us to reassess how we understand non-agricultural societies.

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The Prince Rupert Harbour has an enigmatic charm; there is a certain magnetism that draws people together into its fog and mist and history. The city of Prince Rupert itself is an inauspicious rainy coastal community of a little over 12,000 people, situated where the early Grand Trunk Pa-

Figure 1: Al McMillan, David Archer, Richard Inglis, George MacDonald, Ken Ames (from left to right) at the Boardwalk Site in Dodge Cove, Prince Rupert Harbour, 1969. George is conferring with his field supervisors on excavation plans at the beginning of the excavation season. The Boardwalk Site is now the feature of a major exhibit designed by George at the Canadian Museum of History. (Photo: George MacDonald).

cific Railway (now part of Canadian National Railway) meets the deepest natural harbour in North America. With this configuration the city has drawn people and industry and continents together for 150 years. The city serves as the western-most major international shipping port in North America and key nexus point for commerce with East Asia. However, before the arrival of the railroad in the early 1900s — or more accurately, before the arrival of colonial-settlers and the Hudson's Bay Company to the north coast in the early 1800s — the Prince Rupert Harbour was a nexus for the Tsimshian Indigenous peoples. For thousands of years before European colonialism the Harbour was a hub of human occupation, and was likely one of the most densely populated locations in western North America.

Tsimshian peoples' broader territories extend from the southern Alaskan Panhandle and the mouth of the Nass River, up the Skeena River and south beyond the entrance to the Douglas Channel. There are hundreds if not thousands of ancient settlements throughout this territory, but the Prince Rupert Harbour has gained archaeological renown given the concentration of sites in the ~250 km^2 area, setting it apart from elsewhere on the coast in sheer site density. 1500 years ago, the population living in the Harbour itself would have been in the thousands: archaeological survey and radiocarbon dating has demonstrated that dozens of villages, each contemporaneously occupied by several hundred people, dotted the shorelines leading into the harbour. This remarkable archaeological record is little-known beyond the Canadian archaeological community and local Tsimshian inhabitants, but is foundational to our understanding of Northwest Coast culture and the dynamic history of coastal fisher-hunter-gatherers.

The archaeological significance has been recognized by researchers for over 50 years — and indeed, the magnetism of the Harbour has drawn generations of archaeologists. In the 1960s and 1970s the Canadian Museum of History (then the Museum of Man) undertook the North Coast Prehistory Project (NCPP). This included investigating the ancient settlements along the Skeena River, offshore Haida Gwaii, and in the Prince Rupert Harbour. It resulted in thorough surveys and excavations of many major sites – a dozen of which were in the Harbour area. George MacDonald was the director of the NCPP and Ken Ames worked as a field supervisor and wrote his PhD on the excavations. Both would go on to become giants in their field: MacDonald's NCPP work was grand in scope and he drew together archaeology, ethnohistory, and Indigenous oral history for the entire North Coast. He became the director of the Museum where he designed novel exhibits for bringing ancient history and Indigenous culture to the public and published extensively on Northwest Coast art and cosmology (e.g., MacDonald 1976, 1983). Through his work along the Skeena River he had the ar-

Figure 2: A reconstruction of a Tsimshian plank house in the Northwest Coast First Peoples Grand Hall at the Canadian Museum of History. The exhibit was designed by George MacDonald. (Photo: Bryn Letham).

chaeological landscapes of Kitselas Canyon near Terrace and Gitwangak Battle Hill near Hazelton protected and designated as National Historic Sites. Ames became a Professor at Portland State University, made a career directing excavations of some of the largest ancient plank houses on the Northwest Coast on the Lower Columbia River, and became one of the most prolific researchers of the region, including co-authoring one of the most authoritative textbooks on the subject (Ames and Maschner 1999).

Most importantly though, George and Ken are both fondly remembered as being humble geniuses of immense personability. Their lives were dedicated to sharing their brilliance with colleagues, students, and the general public. Their research was built on respectful relationships with the many Indigenous communities with whom they worked. In an attempt to honour these amazing anthropologists and to continue their lives' missions of educating about the rich history of North America's Indigenous past, it is fitting to explore their work specifically in the Prince Rupert Harbour and its legacy for researchers today – which is how I became acquainted with George and Ken in various ways, and how I too fell sway to the region's enchantment.

A 50 Year Legacy of Developing Research

The methods used to unearth aspects of ancient lives in the Prince Rupert Harbour transformed significantly over George's and Ken's careers. The months-long NCPP excavations directed by George from 1966-1973 involved the removal of massive amounts of dirt, shoveled out by crews sometimes upwards of 50 people down to depths of several meters. From these large trenches, the excavators recovered stone, bone, and wood artifacts, along with shell and bone remains from foods harvested and consumed by the ancient occupants. Prince Rupert is infamously recognized as the rainiest city in Canada; not even the dense rainforest canopy could protect those digging, screening, and sorting through greasy black sludge in torrential downpours typical of a Rupert summer. Adding to the saturation, sometimes the archaeologists used hoses to blast away layers of mud from artifacts and architectural features. But, emerging from that mucky toil was a detailed window into how ancient people lived in the Harbour: how they harvested food and what they ate, how they built their houses and how they buried their dead.

The NCPP laid the foundation for understanding the culture history of the Prince Rupert Harbour (Ames 2005; MacDonald and Cybulski 2001; MacDonald and Inglis 1981), which subsequent efforts built upon in the following decades through systematic archaeological surveys and more refined excavation techniques. The recognition of the vast numbers of sites in the area encouraged researchers to document as many as possible and investigate the breadth of types of archaeological features. The discovery of traces of houses and architectural features at ancient villages encouraged excavations focused on exploring the roles of households as political and economic units of ancient Tsimshian life. Furthermore, the expansion of the port and other industries in Prince Rupert necessitated salvage excavations and Cultural Resource Management archaeology.

In 2011 I began my PhD at the University of British Columbia as part of a research project designed to expand on the work of the NCPP around Prince Rupert using current innovative methods. The project was co-directed by Andrew Martindale of UBC and Ken Ames, who both became co-supervisors of my PhD. Using George's, Ken's, and others' field notes from the NCPP as a guide we revisited the sites they had excavated and investigated those

Figure 3: One of the NCPP's early 1970s excavation units at what is now the location of the modern shipping port in Prince Rupert. The entire mound in the photo is an accumulation of anthropogenically-deposited shell, visible in the excavation backdirt piles on the right side, and in the stratigraphy of the excavation unit in the center. These are some of the largest shell midden sites documented in North America. (Photo: George MacDonald).

Figure 4: A scene harking back to 1969 at Boardwalk: Ken Ames, David Archer, Kisha Supernant, and Andrew Martindale conferring about field plans at the beginning of the 2011 season. (Photo: Bryn Letham).

they had not. That summer, Ken flew from Portland, Oregon, to Prince Rupert, almost 40 years since his last visit working with the NCPP. Fittingly, the Harbour is where Ken both began and concluded his illustrious career in Northwest Coast archaeology. The spell of the Harbour drew him back — as one of my colleagues heard him describe it — "like a siren's call". I never met George MacDonald in person. But I analysed his publications, reports, and excavation notes, and through these and by walking with Ken over the sites that the two had excavated together half a century earlier, George's influence on our work was palpable.

Rather than large-scale excavations, we took small-diameter cores from the ancient villages to quickly assess the depth of archaeological deposits and collect samples for radiocarbon dating from a much larger number of sites. This meant we spent less time in the rain. We also used geological methods to document long-term trends of sea level change to explore settlement patterns relative to shifting shorelines and to consider how the archaeological record documented by the NCPP might be affected by erosion. We then looked for new, undocumented sites associated with different sea level elevations in the past. I oversaw this latter part, and it involved digging through mud in the rain, so I can at least partially empathize with the NCPP crew.

Figure 5: Carved wooden bowl handle excavated by George MacDonald and his team from the Lachane site, which is now beneath the shipping port facility in Prince Rupert. (Photo: George MacDonald).

The different approaches employed by the NCPP and our project complemented each other: MacDonald and his team unearthed impressive aspects of Tsimshian material culture on a grand scale from a small number of sites – everything from tools, to weapons, to art, to houses, and cemeteries. Our work elucidated subtle and less tangible patterns of Tsimshian history from a broader swath of sites – what were population numbers like at different times, how and when did settlement patterns change, how did coastal landscapes change through time and how did these changes affect population and settlement? Together, along with other work of Indigenous and non-Indigenous scholars, we have developed vivid snapshots of the remarkable ancient occupation of the Prince Rupert Harbour.

Dozens of Villages, Thousands of People, Millennia of Occupation

Between the NCPP and subsequent survey by local Prince Rupert archaeologist David Archer (who is also an NCPP alumnus), over 475 archaeological sites have been documented in the Prince Rupert Harbour area. 150 of these are occupation sites (villages or camps), and up to 60 of these are villages that had multiple plank houses. NCPP excavations revealed that these villages were characterized by large mounds of shell and other cultural debris.

Many villages stretch several hundred meters along the coast and at some these shell deposits are nearly 10 meters deep, forming striking protrusions against the natural topography. While the productive coastal rainforest rapidly decomposes most of the wooden material that formed the mainstay of Northwest Coast technology, in some lucky cases the NCPP located waterlogged areas where anaerobic conditions allowed for the preservation of basketry, paddles, tools, weapons, and even the planks from houses, giving a rare glimpse at the master craftsmanship of the ancient woodworkers.

The large houses were impressive feats of carpentry, constructed of planks and beams split with wedges from standing or fallen cedar trees, and monumental hand-hewn cedar posts moved into place and levered upright with human power. In most cases, however, the remains of these houses are only indicated by rectangular depressions in the ground from where the now-decayed wooden structures once stood. Some house depressions are upwards of 20 meters in length, and by comparison with accounts from early European colonial-explorers and ethnographers in the area, we know that these structures would have housed several dozen people each. Villages with 15 plank houses could easily have had 200–300 occupants. Nearly every beach where you could land a canoe in the Prince Rupert Harbour has an archaeological site, and in the narrow passes leading into the harbour multiple large villages are a mere stone's throw from each other.

Some of the villages are in unlikely places. The site of Garden Island at the end of one of the main passes into the harbour, where Ken Ames' PhD was focused, is essentially an island of shell constructed by its inhabitants. Prior to the deposition of 2–3 m of shell, charcoal, and fire-altered rock, this location was a gravel bar that would have been inundated by high tides. Through the build-up of shell people constructed a new place to live at a very strategic location.

It is a common assumption that the shell accumulations associated with Northwest Coast villages are simply food refuse deposits that slowly accumulate around living areas. Locations like Garden Island provide clear evidence that this is not always the case, and ancient peoples also used bulky shell to actively build land and extend habitable area at villages while providing well-drained surfaces to live upon in the wet coastal climate. In our recent research we have empirically demonstrated this to be the case by radiocarbon dating the top and bottom of massive shell accumulations and finding very similar ages bracketing the deposits: indications that sometimes meters of shell accumulated very rapidly or in single dumping events (Letham et al. 2019). In the Prince Rupert Harbour people significantly modified the shape of coastlines to create ideal living surfaces.

Another striking feature of these villages is that they have been persistently occupied for thousands of years. The NCPP was cutting edge for its time in that MacDonald and colleagues radiocarbon dated a lot of samples from their excavations. Their results indicated 5000 years of habitation among the 12 sites that they studied. Through analysing the artifacts from bottom to top at these sites, George and Ken observed remarkable stability in technological styles; the evidence suggested resilient populations of people that were well adapted to coastal life from an early time. Indeed, George argued against early models that proposed that the occupants of the coast were recent arrivals who migrated from the interior, and emphasized that Tsimshian culture developed continuously and *in situ* for thousands of years. Adding to the potential time-depth of these processes, in our recent research we discovered that sea level was higher in the harbour further back in time, and with that knowledge I worked to discover occupation sites over 9000 years old on shorelines that are now stranded back in the forest behind the more recent archaeological sites (Letham et al. 2018).

Our research also focused on dating additional settlement sites to those excavated by the NCPP to assess if they were contemporaneously occupied — potentially indicating a very large population living in the area at one time — or if they were occupied at different times, and therefore just indicative of people moving around a lot over the millennia.

We found that around 2700 years ago there was a fluorescence of occupation in the Harbour, and that over the next 1500 years dozens of villages were occupied, most of which have overlapping dates (Martindale et al. 2017). In the last 1000 years fewer villages overall were occupied, but those that were are significantly larger and are more densely clustered around each other. In several cases where we intensively dated single sites we found a broad and even spread of ages of samples within the overall range of dates, supporting persistent, long-term occupation of these villages. Taken together with the observations that these were large villages involving significant investments in housing, it is apparent that the Prince Rupert Harbour was occupied by thousands of people by at least as early as 2700 years ago.

During these times, the waterways would have been filled with dugout canoes, smoke would have peeled upwards from hundreds of plank houses commanding the waterfront, and the beaches would have been burgeoning with activity: playing, carving, harvesting, socializing, processing and preparing food, greeting neighbours or visitors from afar.

Figure 6: Garden Island, an island made up entirely of human-deposited shell and other cultural debris, and location of a strategically-placed village. It was the location of a major NCPP excavation and the focus of Ken Ames' PhD dissertation. Photo courtesy of Coastal and Ocean Resources and the Prince Rupert Port Authority (http://www.rupertport.com/port-authority/sustainability/shoreline-habitat).

Figure 7: NCPP Excavations at Garden Island in 1967. Excavators cleared the face of half of the island to expose the archaeological stratigraphy, which indicates layers of human-deposited shell and other debris to the base of the island. (Photo: Alan McMillan).

This population density is much higher than typically expected for ancient societies without agriculture, and challenges the impressions and implications of the concepts of "fisher-hunter-gatherers" (e.g., mobile bands eking out an existence on the hostile rugged coast). Occupants of the Harbour were living contrary to the "expectations" of early anthropologists: large populations were living sedentary lifestyles in villages with monumental architecture and engineering the landscape in exceptional ways — all in the absence of an agricultural economic base. This is not necessarily a new finding; it has been observed to various degrees by many Northwest Coast anthropologists and archaeologists. Indeed, both George and Ken helped champion the notion more generally through their research and explorations of Indigenous art, ceremony, economy and social organization. However, the Prince Rupert Harbour appears to be an exceptional case even for the Northwest Coast and indicates numbers of people living together at a scale above any other area of the region yet documented archaeologically. Ken even dared to call the Prince Rupert Harbour occupation "urban-like" based on the proximity at which contemporaneously occupied villages were located, a provocative proclamation for societies usually used as examples defined in contrast to urban city-dwelling societies.

Flagship Archaeologists for a Flagship Region

Ken, along with friend and colleague Andrew Martindale, also declared the Prince Rupert Harbour a “flagship region” for archaeology (Ames and Martindale 2014). By this they mean that it should be considered one of those locations with global significance for shaping how we understand ancient history and past societies, based on both the spectacular and well-preserved archaeological record as well as the long legacy of cutting-edge research that has helped uncover and interpret this record. Additionally, they emphasize the importance of the Tsimshian people in contributing to region’s flagship significance. Tsimshian ancestors thrived on these shorelines for thousands of years, and the Prince Rupert Harbour is still a central place for Tsimshian today, who are currently managing and protecting this significant landscape. Undoubtedly, the magnetic power of the place — drawing people, and plants and animals, and fur traders, and missionaries, and railways, and industries, and commerce, and histories together — plays a key role in generating this flagship status.

Even in very literally their last days of life, George was sharing on social media a treasure trove of archival photographs of people and places from his lifetime of research on the Northwest Coast, and Ken was writing and editing scientific papers that our team was preparing for publication. They were still enchanted by the Harbour’s misty spell, even if they could not physically be present there. George MacDonald and Ken Ames, who dedicated their lives to bringing so many aspects of past Tsimshian life, culture, and history into the present and into public conscious, were themselves flagship archaeologists who inspired future generations of us and have left an immutable foundation of research on which to build.

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The picture of life in the ancient Prince Rupert Harbour sketched above is the culmination of the research of dozens of people who worked with or followed in the footsteps of George and Ken. Of course it is also the product of the Tsimshian Peoples, past and present, who have occupied and stewarded their territories for millennia. George and Ken’s influence is far-reaching, and it would be impossible to list all the amazing people who have been part of this work, never mind those beyond the Harbour who they have impacted. That said, in addition to the individuals mentioned above, Richard Inglis must be acknowledged for being George’s right-hand man in the NCPP; he still works closely with the Tsimshian today. Jerry Cybulski worked with the bioarchaeological remains from the NCPP and has contributed fascinating findings on burial practices and warfare in the region. David Archer’s thorough surveys of the Harbour have been essential for interpreting settlement patterns of the area, and Susan Marsden has dedicated a life’s work to understanding Tsimshian oral histories. Gary Coupland’s work in the area has defined how we understand life in ancient households at the Harbour’s villages. Colleagues, students, and friends of George and Ken all deserve recognition but would fill a book longer than the pages of NCPP excavation notes.

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Figure 8: A massive shell ridge at the back of a village site. The person in the foreground stands on the natural forest surface, and the person in the background stands on top of an 8-meter-deep mound of shell. (Photo: Bryn Letham).

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