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NICHE CONSTRUCTION AND BOATING INNOVATION ON THE ALASKA PENINSULA
AND IN THE ALEUTIANS

by

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Table of Contents

List of Figures.....	vii
List of Tables.....	viii
Abstract.....	ix
Chapter One: Introduction.....	1
Chapter Two: Niche Construction & Cultural Innovation.....	6
<i>Niche Construction and Behavioral Ecology.....</i>	<i>13</i>
<i>Criticisms of Niche Construction.....</i>	<i>18</i>
<i>Niche Construction and Innovations in Boating Technology.....</i>	<i>26</i>
Chapter Three: Regional Overview.....	31
<i>Regional Chronology.....</i>	<i>31</i>
<i>Regional Climate.....</i>	<i>38</i>
Chapter Four: Innovation in Boating Technology and Subsistence Change.....	42
<i>Marine Ecosystems and Boating Technology.....</i>	<i>43</i>
<i>Human Predation & Prey Behavior.....</i>	<i>45</i>
<i>History & Ethnography of Aleut Marine Subsistence.....</i>	<i>49</i>
Chapter Five: Changes in the Relative Abundance of Highly Ranked Taxa on Sanak Island.....	52
<i>Method & Theory.....</i>	<i>53</i>
<i>Previous Analysis of Sanak Faunal Record.....</i>	<i>59</i>
<i>Reanalysis of Sanak Faunal Record.....</i>	<i>63</i>
Chapter Six: Regional Interaction, Social Change, and Increasing Social Complexity.....	87
Chapter Seven: Summary and Conclusions.....	99
Bibliography.....	108
Appendix.....	127

Table of Figures

Figure 1: Schematic representation of niche construction.....	13
Figure 2: Regional map.....	32
Figure 3: Sanak map.....	53
Figure 4: Relative Otariid Abundances for Sanak Archaeological Sites.....	66
Figure 5: Otariid/Sea Otter AI migration controlled.....	67
Figure 6: Otariid/Sea Otter AI NISP>100.....	69
Figure7: Otariid/Sea Otter AI NISP>300.....	70
Figure 8: Otariid/Sea Otter AI NISP>500.....	71
Figure 9: Otariid/Sea Otter AI otariid + sea otter NISP>10.....	72
Figure 10: Relationship between climate and otariid/sea otter I.....	76
Figure 11: Temporal changes in point length.....	81
Figure 12: Explanation of Trends NISP > 300.....	86

List of Tables

Table 1: Climate conditions.....	39
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Abstract

Since about 9000 BP, humans inhabiting the physiographic region of the Alaska Peninsula and the Aleutian Islands have adopted an orientation toward marine foraging, making use of bountiful littoral pelagic resources to not only meet caloric needs, but to fashion tools, artwork, and ritual paraphernalia. At the time of Russian contact, ca. 260 BP, Aleut peoples employed sophisticated and highly elaborated foraging tactics, involving the frequent use of closed-hulled, ocean-going kayaks. Because these kayaks and their predecessors were made of archaeologically ephemeral materials – fragments of driftwood and sea mammal skins – studying the patterns of innovation that characterized their development is problematic. Here, the conceptual framework of niche construction – in conjunction with the methodological and theoretical toolkit of human behavioral ecology – is used to search the faunal record of Sanak Island for changes in foraging strategy that might be indicative of boating innovation, with considerable efforts made to situate this approach within a coherent Darwinian understanding of human behavior.

Chapter One: Introduction

At the time of Russian contact in the mid-18th century, the indigenous inhabitants of the Aleutian Islands and Alaska Peninsula were using closed-hulled kayaks to traverse the turbulent waters of the open northeastern Pacific Ocean and Bering Sea. Called *baidarkas* by the Russians, this type of boating technology was a core component of the Aleut foraging strategy and an important mechanism facilitating the establishment and maintenance of patterns of long-distance regional interaction. It was also very likely a significant departure from the rudimentary maritime technology that facilitated the initial colonization of the Aleutian Islands and the islands off the Alaska Peninsula coast at the end of the Pleistocene, with late 19th century Aleut tradition holding that the modern kayak was significantly different from the boats employed by ancestral populations (Turner 2008). The nearly 10,000 year chronology of human habitation, starting with the initial colonization of Umnak Island, continuing through the inception of some of the earliest Aleut cultural traditions, and on to the point of contact with Russian sailors, likely witnessed a number of innovations in boating technology, including the introduction of the ethnographically recognized closed-hulled, ocean-going kayak (CHOGK)¹.

Tracking these changes archaeologically has proven difficult. Ethnographically, red cedar – the preferred material for canoe construction along much of the Northwest Coast – did not grow beyond Kuiu Island, off the southern coast of eastern Alaska (Ames 2002; Maschner 2009a). The few trees locally available in the Alaska Peninsula/Aleutians region are poorly suited to woodworking, rendering boat production

¹ Baidarka is a Russia word for the type of kayak Aleut peoples were using at the time of contact. This paper does not concern the specific invention of the baidarka, but rather something functionally like it. Consequently, the type of boat at issue in this paper will be referred to by the more general term *closed-hulled, ocean-going kayak*, or CHOGK.

largely dependent on the use of perishable secondary raw resources derived from harvested sea mammals (Maschner 2009a). Due to the types of materials available for boat construction in the region, the remnants of these innovations have proven archaeologically ephemeral. Lacking direct evidence for the patterns that characterized the evolution of boating technologies, archaeologists have typically been wary of speculation concerning the precise course of invention and innovation. However, insightful employments of archaeological proxies, such as the relative frequency of faunal remains and indications of regional interaction, have proven useful as measures of seafaring intensity and potential invention (Arnold & Bernard 2005; Fitzhugh & Kennett 2010).

The approaches used by archaeologists like Fitzhugh and Kennett (2010) and Arnold and Bernard (2005) suggest that, though problematic, the lack of material directly indicative of boating technology is not cause for the sort of dismay that would lead researchers to altogether abandon the project of studying innovations in prehistoric boating technology. Rather, it simply necessitates a shift in perspective, such that researchers target archaeologically resilient forms of evidence that might serve as proxies for the development of boating technology. In this regard, adopting the perspective of niche construction offers a route to further insight. Simply framed, niche construction modifies Sewall Wright's (1932) metaphor of the adaptive landscape by highlighting the dynamic interactions between organisms and their environments that modify the shape of adaptive landscapes over time. Viewed from this perspective, the behavior of an organism is recognized as a potential input in a system of evolutionarily significant feedbacks, such that certain behaviors can be expected to produce changes in the

conditions that adjudicate what counts as adaptive in a given context. When properly situated within a larger understanding of social and ecological context of the Aleutians and Alaska Peninsula, the perspective offered by niche construction theory has the benefit of rendering a number of potential variables salient as promising indicators of changes in boating technology.

Of course, the extreme conditionality of what does and does not count as an adaptive response makes deriving precise predictions concerning the specific course of change within a given evolutionary system exceedingly problematic and signally difficult. Nevertheless, it is still possible to derive general expectations concerning the types of changes archaeologists should expect to see as a result of certain innovations in boating technology in the cultural and geographic region that lies at the interface between the Bering Sea and north Pacific ocean, given a sufficient understanding of the patterns of social and ecological interaction that have characterized human habitation of the region over time. By lifting some of the boundaries implicit in the use of less resilient and reliable technologies, the introduction of CHOGK in the region of the Alaska Peninsula represented a clear modification of the Aleut foraging range, likely in partial response to human-induced resource depressions, allowing individuals to harvest prey items that were previously inaccessible due to problems associated with behavioral responses to human predation, distance, changes in seasonal distribution, or storminess. If the introduction of new boating technology resulted in changes in resource accessibility and harvesting strategy, they should be detectable in the relative abundance of faunal remains in archaeological middens and the temporal distribution of harvesting technologies, respectively.

Similar reasoning applies to expectations concerning changes in regional interconnectivity. The development of safer, more reliable, longer range boating technology can be thought of as essentially lowering the costs of long-distance travel. As a consequence, the archaeological record following the advent of said technology should contain signatures of increasing regional interaction, including increases in warfare and raiding, more widespread and homogenous distribution of material culture (particularly raw resources or artifact types that were once more geographically circumscribed), the movement or relocation of individuals, changes in foraging patterns, and increases in socio-economic complexity.

To summarize, innovations in boating technology should be detectible in:

- Changes in foraging patterns as illustrated by zooarchaeological evidence
- Increases in the intensity and frequency of regional interaction
- Increases in socio-economic complexity as a result of interaction and competition

In what follows, the aforementioned expectations are tested using samples of faunal remains collected as part of the Sanak Biocomplexity Project. Using abundances indices derived from the high-resolution faunal record of Sanak, patterns of resource exploitation will be examined through the mutually compatible lenses of optimal foraging theory and niche construction. Specifically, the relative abundances of highly ranked otariids will be situated within the broader context of shifts in regional climate, changes in foraging technology, trends in human occupation of Sanak, and an understanding of otariid behavior in order to identify changes in foraging strategy that might be indicative of boating innovation.

First, space will be dedicated to a discussion of the principles of niche construction theory and its utility in identifying the downstream ecological and social consequences of cultural innovations. This is critical, because the recognition that humans are an important component in a dynamic system of social and ecological feedbacks brings the shifting nature of local foraging strategies and regional interaction into sharper focus while highlighting patterns of reciprocal causation that should both reflect and be reflected in changes in subsistence technology, including boats. Subsequently, I provide an overview of the region's prehistory. This provides an indispensable baseline against which to evaluate the potential signatures of innovations in boating technology. Finally, I review evidence derived from changes in the relative abundances of highly ranked species over time, isotopic signatures indicative of higher trophic level feeding, shifts in the use of harvesting technologies, and increases in regional interconnectivity. Taken together, these lines of evidence can be used to evaluate the hypothesis that innovations in archaeologically transient boating technology should be detectable in retrievable proxies.

Chapter Two: Niche Construction and Cultural Innovation

Simply defined, niche construction posits that organisms play an active role in shaping their selective environments – that is, organisms, through their behavior and metabolism, modify the structure of the mechanisms that sort variation and lead to the long-term evolution of populations (Odling-Smee et al. 1996). That organisms alter the characteristics of the environments they inhabit seems obvious enough to be labeled a truism. Indeed, organism initiated changes in ecosystems are practically ubiquitous: beavers build dams, altering riparian ecosystems; earth worms burrow in the soil, altering its physical and chemical composition; ants aerate and churn soil, circulating nutrients that are essential to the organisms that share their ecosystem (Odling-Smee et al. 1996 & 2003). The fundamental modification to the neo-Darwinian synthesis proffered by niche construction is not that organisms change their environment, but that these types of changes can be conceived of as part of a distinct evolutionary process, rather than merely a direct result or byproduct of prior selection (Day et al. 2003).

Though niche construction represents a relatively recent addition to the conceptual toolkit of evolutionary ecologists, biologists, archaeologists, and anthropologists, insights concerning the potential for evolutionarily significant feedbacks between culture, ecology, and genetic inheritance have been forwarded in various guises for decades. For instance, Frank B. Livingstone noted the critical relationship between cultural processes and ecological variables in the evolution of malaria-resistant sickle-cell anemia among Kwa-speaking agriculturalists in the late 1950s (Livingstone 1958; Odling-Smee et al. 2003). However, it was not until the 1980s, following the publication of a pair of essays by Richard Lewontin (Lewontin 1983 & 1982; Odling-Smee et al.

1996), that ideas concerning these important evolutionary feedbacks began to coalesce into a coherent theoretical framework. Lewontin observed that, “contemporary evolutionary theory implicitly assumes that natural selection pressures in environments are decoupled from the adaptations of the organisms for which they select” (Laland & O’Brien 2010). Thus, with some exceptions, this perspective seems to ignore the possibility that environments are, to varying degrees, shaped by the organisms that inhabit them in ways that might alter the strength or direction of natural selection (Scott-Phillips et al. 2013).

The niche construction perspective seeks to rectify the deficits Lewontin had noted by casting the evolutionarily significant feedbacks between organisms and the selective pressures they experience in sharper relief by positing that the selective environments experienced by organisms are partly a product of the behavior of said organisms, such that past behavior comes to have a non-negligible impact on the structure of extant and future adaptive landscapes. Thus, if organisms can be viewed as “vehicles for genes” (Dawkins 1982 & 2006), then the conceptual modification introduced by niche construction is a recognition that those vehicles include tools capable of altering the environments they traverse in ways that influence the construction of future vehicles. Under the niche construction perspective, individual fitness and the subsequent evolution of populations is brought about through the complex and dynamic interplay of several types of inheritance. Where once natural selection was viewed primarily as a sorting mechanism for heritable genetic information, it becomes a partial product of an ecological inheritance constructed and perpetually modified by the organisms of which any given ecosystem is partially comprised. Proponents of niche construction argue that it

is an important component of the process of evolution and a worthwhile contribution to our understanding thereof, explicitly because it introduces the concept of feedback, between multiple levels of inheritance, into the evolutionary dynamic (Day et al. 2003; Odling-Smee et al. 2003; Laland & O'Brien 2010).

The potential downstream, evolutionarily significant consequences of niche construction are myriad. According to Odling-Smee and colleagues (Odling-Smee et al. 2003; Odling-Smee 2010), the niche constructing behaviors of organisms fall into at least four basic categories of potential ramifications. First, it gives organisms a role to play in controlling the flow of matter and energy through ecosystems, effectively making them “ecosystem engineers”. Matter and energy are, of course, very broad categories (encompassing literally everything known to exist and accessible to scientific investigation), which is precisely the point: ecological engineering is a term that includes everything from the chemical alterations produced in ecosystems as a byproduct of the metabolisms of the organisms that inhabit them, to the more immediately obvious modification to riparian ecosystems that are produced when beavers build dams. Second, niche construction allows organisms to transform their selective environment in ways that generate important forms of feedback with meaningful evolutionary consequences. Ecological engineering need not necessarily directly result in evolutionary change. Its consequences can be entirely ontogenetic, altering the developmental trajectory or behavioral expression of traits as a response to dynamic inputs, absent any change in allele frequency resulting in evolutionary change. However, the feedbacks that modify behavior and development in the short term can ultimately lead to population-wide evolutionary change. Third, it creates a form of ecological inheritance, such that the

selective pressures experienced by descendent populations have been modified by previous generations. Organisms inherit more than just genetic information. Rather, they inherit a set of ecological conditions that have – to varying degrees – been modified by preceding generations, and this ecological inheritance plays a meaningful role in the expression of the phenotypes on which selection acts. Finally, niche construction provides a second process “contributing to the dynamic adaptive match between organism and environment” (Odling-Smee et al. 2003: 3). Inceptive (organism initiated environmental changes) and counteractive (environmentally initiated organism responses) niche construction can be seen as activities that bring an organism’s evolved phenotype, necessarily bounded in its plasticity by some level of developmental and reproductive constraints (Fusco 2001), into a closer adaptive match with the environment (Odling-Smee 2010).

A few brief examples should serve to better illustrate the way niche construction operates. First, as with many deserts, the Negev of Israel is home to a wide range of soil fauna, including communities of cyanobacteria, blue-green algae, and fungi. These organisms secrete polysaccharides that bind sand particles together, creating a crust that insulates them from the desert heat and modulates patterns of runoff and erosion (Jones et al. 1997; Odling-Smee et al. 2003). This crust increases runoff by as much as 30%, causing water to pool in pits dug by native rodents. In these pools, seeds germinate, creating oases that in turn serve as the habitats for other organisms. An additional example can be found in the fossil record, where – from the Devonian onward – an increase in organisms that perturb and turnover oceanic sediments is hypothesized to have lead to a decline in the diversity of immobile suspension feeders (Thayer 1979;

Jones et al. 1994). It is important to note that the feedbacks and interactions at work in the modern Negev and prehistoric Devonian oceans do not depend on some kind of agency or foresight on the part of the cyanobacteria, blue-green algae, fungi, or sediment-perturbing organisms. Furthermore, niche construction need not relate to a cycle of feedbacks that must be traced back to the organism that initiated the change in question. Niche construction is concerned with the consequences of organism initiated changes in both conspecific and heterospecific organisms, often transmitted through complex networks of intermediaries. In both the modern Negev desert and the ocean floor of the Devonian, the persistent ecological engineering carried out by certain organisms is seen to have consequences for the structure and composition of adaptive landscapes, potentially resulting in feedbacks of evolutionary significance.

In genetic terms, niche construction can be framed as a behavior, produced in part by an allele at locus A, that modifies resource R, with the changes in R resulting in new selective pressures that change the expression of an allele at locus B (Odling-Smee 2010). Importantly, the allele at locus B need not be in the niche constructing organism, as illustrated above with the examples from the Negev and Devonian ocean. Dubbed environmentally mediated genotypic associations (EMGAs) (Odling-Smee et al. 2003), this type of change illustrates what niche construction advocates mean when they speak of a feedback relationship between an organism's behavior and the selective pressures it experiences. This is niche construction in the strictest Darwinian sense: a behavior associated with an allele at locus A at time T, that modifies selectively significant resource R, such that the frequency of allele A (or any other allele) at time T+1 is influenced by the modification of resource R. While the precise details vary, this is a

perspective that accords with Elliott Sober's historical definition of adaptation, where "A is an adaptation for task T in population P if and only if A became prevalent in P because there was selection for A, where the selective advantage of A was due to the fact that A helped perform task T" (Sober 1984: 208). This type of evolutionary interaction has been demonstrated through quantitative modeling. Using methods derived from quantitative population genetics, Laland and colleagues (1996 & 1999) used a 2-locus model to demonstrate that niche constructing behavior modifying a resource can produce meaningful impacts on allele frequencies, even in the presence of independent renewal or depletion of the resource in question. The authors propose that, through the modification of certain resources, organisms can shape "new evolutionary trajectories and equilibria, generate and eliminate polymorphisms, and produce time lags in response to selection" (Laland et al. 1999: 10245-10246).

This type of strict Darwinian reasoning might, at first glance, appear irrelevant to any attempt to apply the reasoning of niche construction to the types of questions associated with the advent of new boating technology. This is because technological innovation is primarily a product of ontogenetic and cultural processes. It is by no means entirely divorced from biological processes, but it is not entirely explicable by them either. Evolution by means of naturally selected adaptation is, in the strictest Darwinian sense, a genetic process. The variation that is sorted by natural selection and imbues populations with trans-generational continuity is purely genetic (Dawkins 1982 & 2006). However, a broader – and more accurate – view of evolutionary processes recognizes that the specific manifestation of traits, that is, the specific relationship between a phenotype and the environment in which it is expressed, is a product of the interaction among

multiple tiers of semantic information (Figure 1) (Odling-Smee et al. 2003:177-91; Odling-Smee 2010: 184-189) expressed at various points throughout ontogeny (Fusco 2001). At the most fundamental level, this includes the information encoded in genetic inheritance, but also incorporates information accumulated throughout ontogeny via learning or epigenetic responses to the environment. For humans, semantic information is further expanded to include the massive stores of adaptively useful cumulative cultural information transmitted from generation to generation and among individuals within generations (Odling-Smee et al. 2003; Laland & Brown 2006). In a very real – if generalized – sense, culture (or, specifically, the capacity to create, acquire, store, and transmit vast quantities of cultural information) is the adaptation facilitating human success in a wide variety of ecological niches (Alvard 2003; Boyd & Richerson 2005). Human reaction norms are substantially broadened by the introduction of a capacity to produce and inherit cultural information, allowing behavioral innovations to flourish on a pre-existing scaffold of neurological adaptations (Sterelny 2003). A behavioral reaction norm sensitive to non-genetic inputs is able to more rapidly search a given design space (Dennett 1995) for solutions to problems that might not otherwise be resolved, especially if there is insufficient time for natural selection to produce an adaptive response in genetic terms. In many instances, the specific behaviors of humans have a lot more to do with culturally transmitted information than they have to do with the expression of genetic information. The recognition that phenotypes are constructed in accordance with instructions derived from multiple tiers of genetic, ontogenetic, ecological, and cultural information prevents this recognition from divorcing proximate cultural explanations from a basis in Darwinian thought and evolutionary processes.

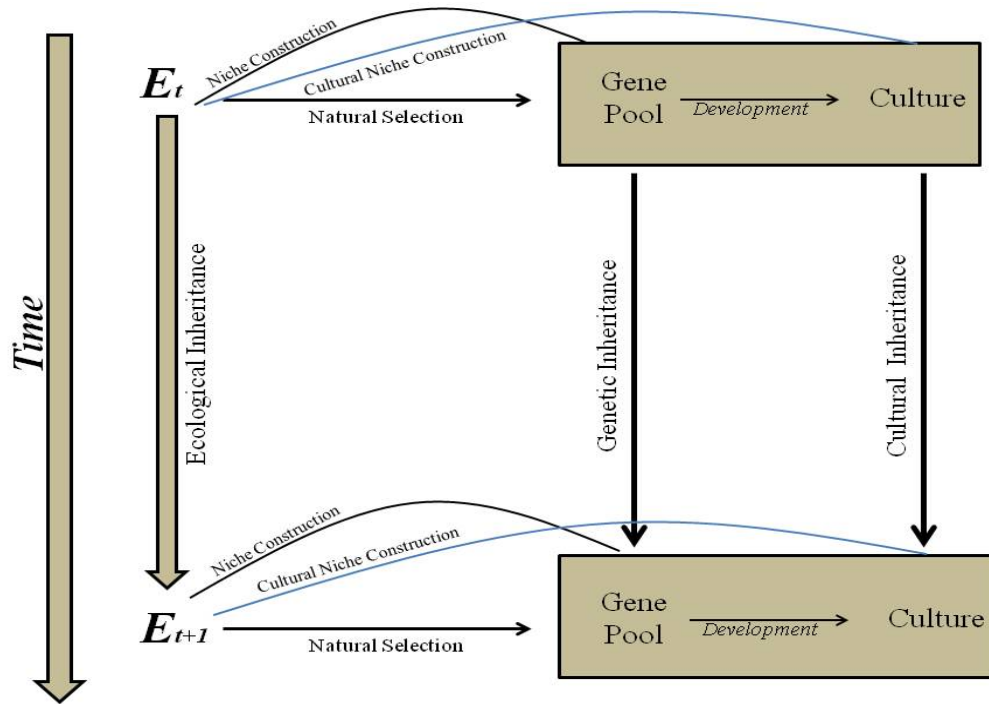


Figure 1: Conceptual illustration of niche construction, adapted from Odling-Smee et al. 2003. Evolutionary processes are seen to involve the interaction of multiple tiers of semantic information.

Niche Construction and Human Behavioral Ecology

In many of the cases addressed by human behavioral ecology, the most salient input in the expression of human behavioral strategies is often cultural (Henrich 2010; Shennan 2013). In instances where human behavioral strategies have important downstream consequences for subsequent generations and the organisms with which they share their environment, we are dealing primarily with cultural niche construction. This demands a relaxation of the historical definition of adaptation to one that deals explicitly with current utility, such that a given trait is considered adaptive simply if it is the best option for solving a given task among plausible alternatives (Fox & Westneat 2010). This type of thinking is, of course, well within the province of behavioral ecology, which analyzes behavior in terms of extant utility, such that foraging behavior or patterns of mating are examined according to the logic of ecological selectionism, meaning that

individual patterns are expected to reflect adaptively plastic responses to variables like resource distribution or trait frequencies. This results in models specific to particular behaviors in specific ecological contexts. Carefully incorporated into niche construction, behavioral ecology provides a tool for analyzing short-term responses to changes in the adaptive landscape, particularly if those changes are initiated by the organism of interest.

For example, optimal foraging theory predicts that individuals should maximize the ratio of calories gained over calories expended when searching for food (Borgerhoff-Mulder 2003; Laland & Brown 2011). This is a general expectation that relates to a number of models. Generally formulated, optimal foraging models adhere to the simplified fitness maximizing expectation that $R_{\max} = (E/T_f)_{\max}$, where R_{\max} is net energy return rate, E is the food energy acquired and T_f is the total foraging time (Stephens & Krebs 1986; Kaplan & Hill 1992). The basic assumption is that organisms should work to optimize their net energy return rate by targeting the resources that yield the highest energy returns relative to the costs (time, energy) of acquiring them (Smith & Winterhalder 2003). This simple idea has been elaborated into a variety of models that can be used to examine decisions related to prey choice, diet breadth, and resource patch choice, among others (Winterhalder & Smith 2000; Shennan 2002; Borgerhoff-Mulder 2003; Ydenberg 2010). In prey choice models, one of the key variables determining T_f is encounter rate. If the encounter rate for a highly ranked species decreases as a result of predation, the predator should be expected to either broaden its diet or relocate to an area where the highly ranked prey is more abundant. Both the depression of prey species and the response of predators to said depression can be viewed as niche constructing activities.

It is easy to see how the principles of niche construction and behavioral ecology make natural bedfellows. Indeed, a course-grained harmonization of human behavioral ecology, niche construction, and evolutionary accounts of cultural innovation has the potential to remedy some of the problems these perspectives face individually. In particular, it has been proposed that the niche construction perspective offers at least partial resolution to two long-standing deficits in the application of evolutionary ecological principles to questions of human behavior: the problem of adaptive lag and the informational black box of the phenotypic gambit (Laland & Brown 2006; Broughton *et al.* 2010).

Given sufficient understanding of the processes of biological evolution, the notion of adaptive lag is intuitive. Simply put, the concept of adaptive lag relates to the fact that evolution is not an instantaneous process and environments are rarely – if ever – static (Laland & Brown 2006). Spatial and temporal heterogeneity ensure some degree of mismatch between current selective pressures and evolved traits. This is precisely the problem that motivates the development and deployment of divergent definitions of adaptation – *e.g.* historical and current utility. Because human cultural evolution occurs at a rate roughly fifty times faster than that of genetic evolution (Perrault 2012) and humans colonize new environments more rapidly than can be coped with through the generation and selection of new genetic material (i.e. adaptation), the gap between human environments and genetically produced behavioral phenotypes has the potential to be exceptionally large (Laland & Brown 2006; West *et al.* 2013). This is certainly true of modern, industrialized populations, but is no less true of populations living in the past. The colonization of new habitats – environments remarkably different from those early

humans and their hominid ancestors would have experienced for most of their Plio-Pleistocene evolutionary history – should also result in some level of adaptive mismatch. Resolution to this apparent quandary lies in the recognition that the human ability to succeed across a huge range of habitats is not explicable in terms of specific, genetically encoded adaptations. Rather, it is due to their ability to maximize fitness through social learning and to modify their relationship to environments in ways that produce adaptive matches that would otherwise elude them (Laland & Brown 2006 & 2011). Humans employ counteractive niche construction to minimize the effects of ecological variability while simultaneously reconstructing elements of the environments they colonize to better suit their evolved phenotype (Sterelny 2003; Laland & Brown 2006).

Human behavioral ecologists have been reluctant to specify the mechanisms that facilitate the adaptive match between humans and their environment, in part because there is no reason to assume that any given match should be adaptive in the strict historical sense of the term – that is, as the products of heritable genetic information that proliferated due to its contribution to a phenotype capable of better navigating some form of natural selection (Reznick & Travis 2001). Genetic variation produced in response to natural selection is insufficient to fully explain important elements of humanity's extreme ecological generality. Consequently, human behavioral ecologists have typically avoided specifying what, exactly, is behind humanity's considerable adaptive breadth and have instead chosen to invoke something called the phenotypic gambit, which simply posits that the precise mechanisms (cognitive, cultural, genetic, ontogenetic, or otherwise) are immaterial – humans are expected to behave adaptively, optimality models provide a proximate measure of adaptation and yield testable predictions, and results that either

adhere to or deviate from expectations are empirically informative (Smith 2000; Smith & Winterhalder 2003; Borgerhoff-Mulder 2003;). The answers to questions concerning the proximal mechanisms of human adaptation, of course, lie in the fact that humans are ecological generalists equipped with extreme behavioral plasticity, a remarkable facility with social learning, and the ability to transmit information acquired throughout ontogeny to a wide network of conspecifics (kin and non-kin alike) via language and social learning. Operating in conjunction with our capacity for cumulative cultural evolution, these traits allow humans – in any given context – to rapidly (within the space of a few generations) become ecological specialists (Borgerhoff-Mulder 2003; Henrich 2010; Laland & Brown 2011; Shennan 2013). Part of what humans are up to when they learn how to modify their behavior to better suit an environment and how to modify their environment to better suit their evolved phenotype is, in a very clear sense, niche construction (Broughton *et al.* 2010).

Jack Broughton and colleagues recently employed niche construction to analyze archaeological data pertaining to Central California hunter-gatherers and Mimbres-Mogollon agriculturalists in just this way (Broughton *et al.* 2010). Broughton and colleagues used the abundance of high ranked versus low ranked species in faunal assemblages as an indicator of resource depression, then examined a range of potential variables (e.g. climate change) to determine whether or not the causes of archaeologically detectable resource depressions were anthropogenic. Additionally, they examined human remains for evidence of physiological and behavioral responses to resource stress. Their results indicated that heavy predation of highly ranked game species by Sacramento Valley hunter-gatherers created a resource depression that lead to social and

physiological consequences. Indicators of violence increased in conjunction with indicators of resource depression, suggesting conflict over control of resources. Simultaneously, individuals began to experience deleterious health consequences, indicated by cribra orbitalia, bone lesions, and decreased body size. Similar results were found for data relating to the Mimbres-Mogollon agriculturalists, where resource depression led to the intensification of wild and domesticated resources. In both cases, niche construction helped close informational gaps between inherited genetic variation and extant circumstances. Rather than simply analyzing human responses to changes in resource abundance, Broughton and colleagues were able to establish a potential causal link between human behavior, resource depression, and subsequent changes in human behavior and health outcomes (Broughton *et al.* 2010). It is in precisely this vein of thought that niche construction is deployed in the present paper.

Criticisms of Niche Construction

Since its inception, the concept of niche construction has generated considerable attention – particularly in the realm of anthropological and archaeological thought. While much of this attention has been positive, with researchers enthusiastically concocting new applications for the proposed paradigm, some thoughtful criticisms have been leveled. In their rush to develop and apply a potentially fruitful perspective, some of niche constructions strongest proponents have overstated the generality and applicability of the concept. In some cases, they have argued for niche construction where it might not exist. In others, they have used it to describe phenomena that can be explained with greater focus and clarity by existing theory. As a result, it is important to take a moment to reiterate some of these criticisms and their relationship to the analytical approach

employed in the present work. In particular, it worth pointing out some of the potential pitfalls associated with the application of niche construction theory and explaining the concept is here used in a manner that avoids them.

First among the criticisms leveled against niche construction is that it does not distinguish between organism initiated environmental changes that occur as a byproduct of phenotypes adapted to some other purpose versus those that are the product of a phenotype specifically adapted to initiate the change in question (Dawkins 2004). According to Dawkins, only the latter class of behavior should be viewed as niche construction, which should in turn be viewed as a special class of extended phenotype (Dawkins 1982). Organisms might well alter their environments in evolutionarily meaningful ways, but the process by which they do so can already be understood as either a direct result or accidental byproduct of previous adaptation.

Further criticism stems from the way in which niche construction attempts to place a wide range of phenomena under a broad theoretical umbrella without offering a better explanatory framework than what is offered by existing theory. In describing the ubiquity of niche construction, its proponents attempt to fill theoretical gaps where none exist. Much work in density- and frequency-dependent selection, reciprocal coevolution, and indirect genetic effects already covers much of the ground niche construction seeks to claim (Bodie III 2006). For instance, in a species where mating opportunities are typically secured by dominant males monopolizing access to females, the dominance strategy might be seen to construct a niche in which it may become adaptive for weaker males to adopt a sneakier scramble strategy (Savalli 2001). As defined by Odling-Smee and colleagues, this fits nicely within the niche construction rubric, but is already

sufficiently explained by existing theory on frequency-dependence and sexual selection. The same could be said of the antagonistic relationship of host-parasite coevolution: the observed phenomenon clearly fits the definition of niche construction, but is already well understood via an existing theoretical toolkit (Lively 2001).

A further – though not unrelated – criticism stems from a misrepresentation of the neo-Darwinian understanding of evolution as it stood prior to the advent of the niche construction concept. In their enthusiasm for their new perspective, champions of niche construction have often described the previous evolutionary synthesis as one in which phenotypes are passively selected by an array of abiotic environmental variables (Bodie III 2006). As the previous paragraph demonstrates, this is far from the case. The reciprocal relationship between phenotypes and the selective environments they inhabit was already widely recognized, as well the fact that much of any given organism's selective environment is comprised of the phenotypes of other organisms, both conspecific and heterospecific.

Ultimately, the potential value of niche construction theory can be boiled down to the question of whether or not it offers new insights into a meaningful but previously neglected evolutionary process (Scott-Phillips *et al.* 2013). Standard evolutionary theory is concerned with the interaction of four fundamental processes: natural selection, mutation, genetic drift, and gene flow. Niche construction seeks to introduce the dynamic feedbacks between organisms (both conspecific and heterospecific) and environments, resulting in non-genetic ecological inheritance, as an additional process. In this regard, NC demands particular emphasis on the potential for developmental plasticity to bring organisms into closer accord with their environment.

While none of these criticisms demands that niche construction be tossed aside as a theoretical dead-end, their incorporation into future applications of the theory is necessary if it is to prove its worth. Relative to Dawkins' point that niche construction can only usefully describe behavior adapted for the explicit purpose of niche construction and is simply a special case of the extended phenotype, proponents of the concept counter that niche construction is a distinct and meaningful process whenever the behavior of an organism alters the relationship between an organism's fitness and the environment it occupies – whether or not it is a byproduct or an adaptation shaped by previous selection to fulfill that specific end is irrelevant (Laland & Sterelny 2006). While it is true that adaptive niche construction is a special case of the extended phenotype, it is nonetheless worthy of additional consideration. This is because the extended phenotype perspective, as formulated by Dawkins (1982) considered phenotypic extensions as adaptations – the products of prior selection. Niche construction, on the other hand, places its focus on the downstream evolutionary consequences of environment modifying phenotypes (Laland & Sterelny 2006).

With regard to the claim that, by trespassing into the territory of proven theoretical perspectives, niche construction obfuscates rather than clarifies, its advocates argue that it was never meant to address these areas in the first place. Indeed, Odling-Smee and colleagues (2003) point out that much of what might be classified as niche construction is already explained by existing theory. The authors draw attention to a set of differential equations from one of Lewontin's (1983) early papers. At the time of his writing, Lewontin characterized the Darwinian algorithm as being represented by change in organisms (O) and change in environments (E): $\frac{dO}{dt} = f(O, E)$ and $\frac{dE}{dt} = g(E)$,

respectively. Lewontin argued that while change in organisms is dependent on both organisms and their environment, environmental change is independent of organisms. He suggested change in environment should include organisms as a component, or, $\frac{dE}{dt} = g(O, E)$. Thus, niche construction advocates argue that while niche construction can be viewed as an extremely general process, its theoretical utility is found in specific instances where organisms produce a selectively influential ecological inheritance that is not already explained by existing theory. In this regard, one of niche construction's most fruitful contributions might relate to the concept of environmentally mediated genotypic associations, where evolutionarily important feedbacks are transmitted through intermediary abiotic factors (Odling-Smee *et al.* 2003; Brodie III 2006; Odling-Smee 2010).

Finally, the matter of whether or not niche construction is a distinct evolutionary process is, at one level, arbitrated by one's preference for how stringently the processes of evolution ought to be defined. Traditional evolutionary theory is secure in invoking at the four basic processes of natural selection, mutation, genetic drift, and gene flow (Scott-Phillips *et al.* 2013), but that does not invalidate claims that useful insight can be gained by invoking others (Endler 1986; Laland & Sterelny 2006). This is particularly true when we shift the locus of explanation from the process of biological evolution to individual behaviors, which are inevitably shaped by a variety of ecological and developmental factors (Batseon 2001; Kirschner & Gerhardt 2010; Scott-Phillips *et al.* 2013). This becomes truer still when we shift our attention to human behavior, at which point cumulative cultural evolution becomes a relevant explanatory factor (Odling-Smee *et al.* 2003). Unquestionably, explaining the vast majority of human behavioral variation is

going to involve the invocation of processes beyond mutation, natural selection, genetic drift, and gene flow.

Perhaps no field of inquiry has embraced the niche construction concept as enthusiastically as anthropology. (e.g. Sterelny 2003; Wollstonecroft 2011; Smith 2011; Brown *et al.* 2011; Gignoux *et al.* 2011; Lansing & Fox 2011; Rendell *et al.* 2011; Shennan 2011; Zeder 2012). According to these researchers, human populations are extraordinarily adept niche constructors, engaging in a range of environmental modification that has facilitated their spread to every available habitat (aside from Antarctica), including rather inhospitable places like the high arctic. Like other niche constructing organisms, human infants receive both a genetic and ecological inheritance. Humans are distinct, however, in the massive body of intra-generationally accumulated and continuously modified information they inherit from their progenitors. Various referred to as a semantic (Odling-Smee 2010) and/or an epistemic (Sterelny 2003) inheritance, this body of knowledge has extraordinary adaptive utility, as humans escape many of the costs of trial-and-error learning incurred by many other species throughout ontogeny. Coupled with an ecological inheritance, this informational inheritance opens the door to a type of “cumulative downstream” niche construction (Sterelny 2003) that is both ecological *and* cultural. This facilitates ever more potent forms of niche construction, as human populations directly modify landscapes through intensive agricultural practices, architectural construction, resource extraction, and so on, in such a way that changes accumulate over time. Additionally, the fidelity and longevity of information transmission facilitates innovation at a much faster rate than can be achieved through biological change, allowing both a greater range of niche-constructing behavior

and an increased ability to find more efficient and impactful methods of environmental modification.

Perhaps the most widely cited example of the effects of niche construction on human populations is lactase persistence: the ability to metabolize milk beyond the point of weaning that has been observed in some human populations (Cochran & Harpending 2010). Lactase persistence appears to be an evolutionarily recent phenomenon, resulting from genetic changes that have occurred within the last 10,000 years or so. Prior to that time, the ability to metabolize the lactase enzyme beyond the cessation of breast-feeding had no adaptive utility. However, following the domestication of certain animal species, individuals who were able to consume milk throughout ontogeny had access to a consistent source of caloric energy that was unavailable to individuals who could not metabolize lactase. Consequently, individuals possessing the single-nucleotide polymorphisms (T-13910 and A-22018) associated with lactase persistence were able to outcompete those possessing the competing alleles for lactase non-persistence (those containing single-nucleotide polymorphisms C-13910 and A-22018), resulting in the proliferation of lactase persistence in populations that practiced consistent animal husbandry (Gerbault *et al.* 2011). This is a clear and quantitative example of human niche construction: human populations altered the adaptive landscape through the domestication of certain mammals. In turn, these alterations selected for a set of mutations that would not previously have been advantageous. Presently, lactase persistent phenotypes are quite widespread and tend to be associated with populations that have long histories of interaction with milk-producing species.

In another study (2011) Stephen Shennan put forward the idea that property and wealth inequality could be viewed as a form of niche construction that has the potential to influence gene frequencies – and therefore become impactful on a biological level – given a long enough time frame. According to models put forth by Borgerhoff-Mulder and colleagues (2010), inter-generational resource transfer can be subdivided into three-categories: embodied wealth, relational wealth, and material wealth. Embodied wealth refers to resources transferred from parent to offspring in the form of caloric energy or training in useful skills – it is wealth quite literally embodied by the possessor. Relational wealth refers to the social networks and relationships one might inherit from parents. Material wealth, unsurprisingly, is that wealth embodied in physical objects – livestock, land, slaves, money, and so on. For most of human history, material wealth would not have been an important resource, as frequent movement about the landscape would have limited the accumulation of property and low population density would have mitigated the notion that any given resource or land patch should be subject to ownership and defense. However, at some point conditions changed (the reasons for this change are debated, and are not, in any case, particularly germane to this discussion) and material wealth became an important inter-generational resource. Shennan makes the argument that the accumulation of sufficient quantities of material wealth could result in long-term increases in reproductive success. While the short-term reproductive success of wealthy individuals tends to be relatively low, generations of progeny that reap the benefits of unequal access to property and wealth have a greater degree of long-term reproductive stability. In other words, inter-generational wealth transfer increases inclusive fitness by increasing the likelihood that any given subset of genetic material will survive for many

generations. This is a clear example of positive niche construction, with the accumulation and inter-generational transfer of material wealth increasing the fitness of extant phenotypes.

Though the aforementioned research suggests the niche construction perspective may offer some utility in guiding anthropological and archaeological research, it is worth noting that many of its insights pertaining thereto were preceded by dual inheritance/gene-culture coevolutionary theory. The concept of a system of complex, evolutionarily meaningful feedbacks between the biological and cultural evolution of humans was pioneered in the 1980s (Cavalli-Sforza & Feldman 1981; Rindos 1980 & 1984; Boyd & Richerson 1988) and seems to provide the tools necessary to quite adequately address the evolution of lactase persistence and the potential fitness advantages gleaned through trans-generational wealth accumulation. These overlaps do not rob NC theory of its explanatory merit, but they do highlight the importance of making the relationship between a given theory, the expectations it generates, the phenomena it purports to explain, and pre-existing bodies of relevant theory clear.

Niche Construction and Innovations in Boating Technology

The situation here is somewhat distinct from the aforementioned examples, primarily in that it focuses almost exclusively on culturally and ontogenetically generated variation. Innovation in boating technology in the Aleutian Islands and Alaska Peninsula is not meaningfully explained by genetic variation produced as a result of natural selection or any of the other three universally recognized processes of biological evolution (mutation, genetic drift, gene flow). As explained above, the genetic heritage of

the Aleut certainly played some role, but only insofar as it entails the inheritance of universal human traits that would have evolved during the Plio-Pleistocene – if not earlier. Instead, the meaningful variation at play in the development of the CHOGK was primarily cultural – a product of generations of people living and learning under particular ecological conditions, guided by evolved propensities to pay attention to certain kinds of information, cultivating and transmitting distinct cultural traditions, and consequently developing along distinct trajectories of cultural evolution.

There is nothing revolutionary about this perspective. The vast majority of the behavioral variation that has been investigated by behavioral ecologists – or, for that matter, anthropologists and archaeologists entirely unfamiliar or unsympathetic with Darwinian perspectives – is the product of cultural evolution. The reasons for this are simple – cultural evolution takes place at a rate roughly fifty times greater than biological evolution (Perrault 2012), allowing cultural change to buffer against the effects of natural selection. This is a line of argument not dissimilar to that forwarded by Dawkins (1982) in arguing against the potential for species-level selection (Gould & Eldredge 1977). Because the turnover rate of individual generations vastly exceeds that of entire species, selection at the level of individuals will stimulate adaptive change or extinction long before the relevant selective pressures ever become sensible at the level of the species. Likewise, the rate of cultural evolution is sufficient that most surmountable selective pressures can be navigated by purely cultural means before they have the opportunity to become a meaningful influence on genetic variation. To be absolutely clear, this line of thinking does not support any argument that cultural evolution somehow prevents biological evolution. It certainly has the power to mitigate the effects of natural selection,

but that does not mean that mutation, genetic drift, and gene flow cease to play a meaningful role in shaping the biological composition of human populations. Indeed, the special adaptive utility of cultural variation should not be overstated, as it is really a peculiar – if more highly elaborated – case of a more general rule: that any obstacle to survival or reproduction that can be overcome by a plastic phenotypic response is not likely to influence the frequency of genes in future generations as a selective pressure.

Because the phenomena under investigation here involves processes cultural innovation culminating in advances in boating technology, it is clear that the type of niche construction under consideration involves primarily cultural and ecological feedbacks expressed largely on an ontogenetic scale. The fact that the majority of the explanatory weight falls to processes of cultural evolution allows the arguments presented in this paper to escape some of the more nebulous territory regarding whether or not niche construction is distinct and meaningful process of biological evolution.

Painted broadly, the situation under consideration is as follows: Culturally derived foraging practices facilitate the extirpation of otariid populations from near-shore habitats, and culturally-derived innovations in boating technology allow human hunters to expand their foraging range and fundamentally shift the landscape of optimal foraging solutions. That is, a cultural innovation is seen to fundamentally alter the relationship between human foragers and their ecological niche, as well as the social relationships among neighboring subpopulations. As a consequence, optimality expectations are altered as the costs of acquiring certain resources change and the social landscape shifts as a result of increased region-wide interconnectivity. For purposes of illustration, consider Sewall Wright's metaphor of the adaptive landscape (Wright 1932). Wright

formulated the idea as a means of illustrating his shifting-balance theorem, in which natural selection is imagined to push a population onto a local adaptive peak, where they are stuck until drift pulls the population away and allows it to explore more available evolutionary design space (Wright 1932; Kaplan 2008). As formulated by Wright, the adaptive landscape metaphor was meant to illustrate the relationship between genotypes and fitness, resulting in an extremely high-dimensional (and difficult to visualize) fitness landscape for any realistic genotype (Wright 1932; McCandlish 2011). In terms of the question at hand, the adaptive landscape metaphor has been co-opted and re-deployed as a means of illustrating the relationship between behavioral strategies and optimality, such that peaks represent differentially performing solutions to challenges posed by surviving in a given socio-ecological niche. This is an invocation not dissimilar from that employed by Mesoudi and O'Brien (Mesoudi & O'Brien 2008a & 2008b; Mesoudi 2013) in analyzing projectile point innovation on a simulated fitness landscape. The crucial modification is that innovations have the capacity to precipitate changes in the structure of the fitness landscape in which they are expressed (Mesoudi *et al.* 2013).

According to the traditional view, adaptive landscapes are more or less static. The introduction of niche construction demands a reconsideration of this perspective, suggesting the behaviors of organisms within a given landscape fundamentally alter the shape of that landscape as experienced by future generations. That the notion of a static adaptive landscape can be almost perniciously misleading has been noted elsewhere (Mustonen & Lässig 2009). But where previous emphasis has been placed on the intricacies of molecular evolution, the focus here is on the way cultural innovations might alter the adaptive landscape in the current utility sense of the term (Kauffman 1993;

Mesoudi et al. 2013; Shennan 2013). That is, by decreasing the costs of pursuit and transport (Kennett 2005), the introduction of sophisticated boating technology, capable of reliably traversing long distances over open water in potentially inclement weather, changes the landscape of optimal solutions to foraging dilemmas. It is not that innovations allow human populations to navigate adaptive topography that was previously inaccessible. Rather, human innovations fundamentally change the adaptive topography, creating peaks and valleys that simply did not exist before.

Chapter Three: Regional Chronology & Climate

Regional Chronology

To understand the evidence here interpreted as a potential signature of innovations in boating technology in the North Pacific, it is first necessary to describe the patterns of settlement, subsistence, and regional interaction that characterized the human niche in the North Pacific in the millennia preceding the likely advent of the closed-hulled, ocean-going kayak (Figure 2). The chronology of human habitation on the greater Aleutian region spans roughly 10000 years. Any record of that temporal depth will, by its very nature, be riddled with social and ecological change. The goal here is to illustrate what was broadly typical of human relationships to the climate and ecology of the Bering Sea and northeastern Pacific. To that end, the chronology employed is that outlined by Allen McCartney (McCartney 1984) and subsequently elaborated and refined by Maschner (Maschner 2012; Maschner in press). It is presented with specific attention to patterns of resource exploitation and regional interaction in the context of long-term climatic variation.

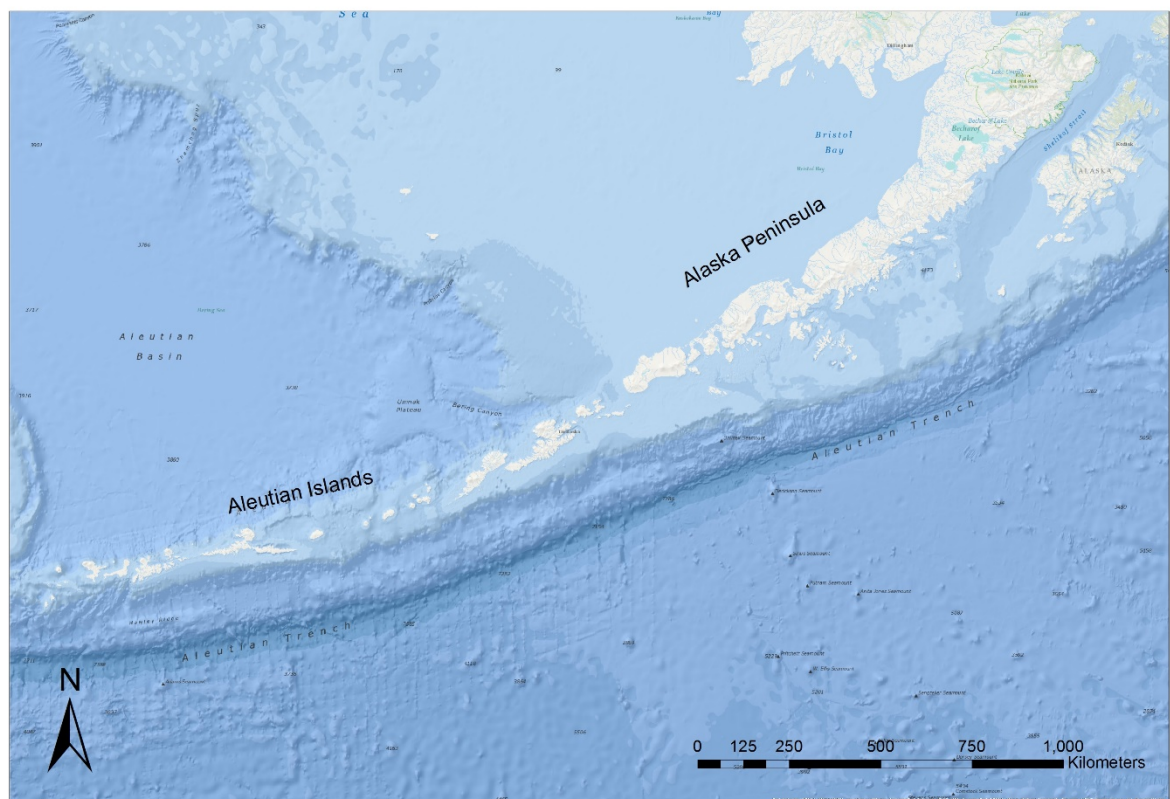


Figure 2: Map of region derived from Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors.

Because coast-lines varied throughout the terminal Pleistocene in concert with the expansion and retreat of glacial ice, it is possible the first colonization of the region predates the earliest known archaeological sites. However, these early sites would have been inundated when coastlines stabilized near their modern limits following the onset of the Holocene (Hoffecker & Elias 2007), and are consequently lost to the archaeological record. Thus, the date of earliest colonization is restricted – beyond the range of speculation – to the Anangula site on the western end of Umnak Island, ca. 9500 BP (McCartney 1984; Maschner 2012 & in press). Extending to around 8000 BP, the Anangula tradition is characterized by a core and prismatic blade technology. Components of the toolkit include large thrusting spears with end-blade insets, ideal for

dispatching large shore-bound sea mammals. The site's coastal setting suggests an orientation toward marine resource based subsistence, but with no indication for the presence of any kind of consistent boat use. In fact, it is not entirely clear whether or not boats were even necessary for the island's initial colonization. It is entirely possible Anangula represents a population stranded after the rise of sea levels roughly 10000 years ago (Maschner in press). Alternatively, the island's inhabitants may have employed any number of expedient technologies to establish their initial occupation (McCarthy 1984; Workman & McCarthy 1998). Superficially boat-like technologies need only exhibit buoyancy and stability sufficient to execute the task of basic transportation. In any event, Anangula seems to have been an isolated phenomenon, both spatially and temporally, representing the only human habitation for 1500 years before terminating in an occupational lull that either represents total depopulation or a sufficient reduction in numbers to render any material signature archaeologically invisible (Maschner in press). There is some suggestion that local extirpation of sea mammal populations led to an expansion to smaller, transitory sites in the area around Unalaska, established in pursuit of highly ranked prey species (Maschner in press).

Following a 1000-year hiatus, sites begin to reappear throughout the region around 7000 BP (McCarthy 1984; Maschner in press), though there is evidence of earlier occupations on Kodiak (Maschner 2012). There is some disagreement about whether these villages represent two different cultural groups: the Aleut in the 1930 kilometer stretch of the Aleutian Islands and the Alaska Peninsula west of a line running from a little east of the Bear River to Ivanof bay in the south, and the Alutiiq-speaking Eskimo peoples to the east, occupying the rest of the Peninsula and Kodiak Island. This was

certainly the case at Russian contact, but there is some evidence that the Alutiiq did not arrive in the region until around 800 BP (Maschner et al. 2009b). Regardless of precise cultural affinities, this phase of occupation has been dubbed the Incipient Aleutian Tradition, lasting from 7000 BP to around 4400-4200 BP (Maschner in press). Flowing out of Kodiak, the Ocean Bay I complex is characterized by large stemmed and lancelet end-blades for harvesting beached sea mammals, followed by the similar Ocean Bay II polished slate complex (Maschner in press). Artifacts associated with the Incipient Aleutian Tradition are found on Walrus Island, along the Sapsuk River, on Unalaska Island, and Sanak Island, showing a distinct regional cline in the frequency distribution of slate implements. Slate tools become fewer and fewer farther and farther west, a pattern simply explained by the fact that the only slate sources in entire region are on Kodiak Island (Maschner in press). By 5800 BP, the assemblages associated with the Ocean Bay Tradition are ubiquitous throughout the Alaska Peninsula, eastern Aleutians, and areas of the Bering Sea (Maschner 2012).

The colonization of previously uninhabited and likely inaccessible islands suggests some improvement in boating technology. This is further bolstered by the introduction of harpoons indicative of off-shore sea mammal harvesting. However, subsequent regional interaction is scarce, suggesting the boating technology available at the time was insufficient to facilitate consistent movement over sizable distances (Maschner in press).

Around 4400 BP, an increase in both the size and number of villages marks the onset of the Early Aleutian Tradition, with a major expansion around 3700-3600 BP accompanied by the harvesting of massive quantities of shellfish (Maschner *et al.* 2009a;

Maschner in press). This period corresponds with the beginning of the neoglacial, ca. 4500 BP, and associated increases in marine productivity (Maschner *et al.* 2009a). Stone end-blades and projectiles decrease in both size and frequency as reliance on sea mammals wanes. It is around this time that eruptions of the volcanoes Aniakchak and Veniaminov split the Aleut. To the west, the Early Aleutian Tradition continues unabated, while the Kachemak tradition takes over in the east. From 3500-2600 BP sites are rare on the Alaska Peninsula, with Hot Springs – abandoned around 2900 BP – representing the only known eastern Aleut occupation. Aside from a widely distributed shamanic complex, suggested by whale bone masks and ivory figures, there is a pattern of regional divergence (Maschner in press). On Sanak, sites show a discontinuous pattern of shellfish exploitation associated with climatic variation, with middens appearing around 3800 BP, disappearing around 3300 BP, and returning around 2600 BP (Maschner *et al.* 2009a).

The Middle Aleutian Tradition begins between 2600 and 2400 BP and carries on through roughly 1000 to 900 BP. A curious gap in chronology, between 1900 and 1500 BP, breaks an otherwise distinctive proliferation of sites. This is a period of village nucleation on Sanak Island, lasting nearly 400 years (Maschner *et al.* 2009a). On the Alaska Peninsula at Adamagan, there are over 1000 surface depressions – the remnants of 30 to 80m² houses – representing the development of a large village in correspondence with the increased productivity associated with cooler sea surface temperatures. The complex and highly specialized toolkit includes the first true toggling harpoons, a clear indicator of open-water sea mammal exploitation. Diet in general seems to be extraordinarily broad, with nearly every harvestable resource in the greater north Pacific

and Bering Sea turning up in the faunal record (Tews 2005; Maschner in press). This period of apparent bounty had a shelf-life: by 2050 BP shellfish harvesting seems to have ceased at Adamagan, and by 1900 Adamagan – and most other sites – have been abandoned (Maschner in press). For the next four hundred years, sites are small and ephemeral, consisting of both fewer and smaller houses – a transition associated with the onset of the Roman Warm Period.

Beginning around 1500 BP, villages once again begin to grow in size, accompanied by the reappearance of massive shell middens (Maschner in press). At the Hot Springs site, the most northerly shell midden site, just west of the boarder of the historically recognized partition between Aleut and Alutiiq cultural groups, there are 100 occupied house depressions, and a cultural repertoire that includes the production of zoomorphic figures and status differentials in burials (Maschner in press). At Hot Springs, harvested species included walrus, rings seals, birds, and cockles – the latter of which form a massive midden deposit covering much of the site’s upper layers to a depth of up to one meter. Elsewhere, on Sanak Island, people were subsisting on a diet of sea lions, harbor seals, and cod. It is at this point, 1500 years ago, that previous research (Betts *et al.* 2011) suggested increased harvesting of large sea mammals, following a substantial lull in harvesting or actual abundance (Betts et al. 2011; Maschner et al. 2014; Maschner in press). At the same time, the length of spear points also begins to increase. Taken together, these two lines of evidence suggest that sea lions and walrus are either becoming more common near shore, or that some innovation in maritime technology is allowing people to get farther off-shore under a wider range of weather conditions (Maschner *et al.* 2014; Maschner in press). Contemporaneously, toggling harpoons

disappear from the archaeological record, further suggesting a change in subsistence practices.

The final three centuries of the Middle Aleutian Tradition see a marked transition in settlement and subsistence practices. Most coastal settlements disappear, leaving areas previously associated with the exploitation of marine resources unoccupied. Instead, the focus seems to have shifted to salmon harvesting, with villages situated in riverine environments along salmon streams (Maschner in press). Except at Adamagan and Hot Springs, villages throughout the region contain more houses of greater size than previously recorded. Interestingly, this period also sees the first occupation of rocks, islets, and other defensible landforms historically associated with warfare (Maschner & Reedy-Maschner 1998). Regional interaction – however acrimonious, competitive, and violent – is the obvious implication.

With the inception of the Late Aleutian Tradition, the region begins a shift toward historically recognized patterns of subsistence, settlement, and regional interaction. This is not to imply a simple, linear progression. By 900 BP the riverine villages have been abandoned. Villages have shifted back to coastal environments and are comprised of a relatively small number (6-8) of very large (150-300m²) houses. These are of the ethnographically recognized nucleus-satellite variety, in which a series of small storage chambers and children's sleeping space were connected by a large, ovoid central hub, representing a communal living space. Excavated houses contained large amounts of whalebone, but the villages were not associated with any middens. This pattern, known from two sites, lasted for around 150 years, before the villages were abandoned (Hoffman 2002; Maschner and Hoffman 2003).

Around 750 BP, populations seem to have collapsed: sites are very small, consisting of three or less houses ranging from 40 to 80m² (Maschner in press). This trend persists for at least 200 years. Then, sometime around 550-500 BP, populations experience an extraordinary rebound. Twelve villages consisting of 7-30 large corporate houses pop up around sockeye salmon streams in the area between Bear River in the east and the northwest end of Unimak Island to the west: previously there had been 7 villages containing only 1-3 small structures. It is estimated that by 400 BP the population has risen from as few as 300 to as many as 15000, such that there were likely as many people living on the Alaska Peninsula and Eastern Aleutians as there were in the previous 4000 years combined (Maschner *et al.* 2009a). Sea mammals are once again a prominent component of the diet, with a particular emphasis on sea lions and whales, accompanied by large amounts of salmon at some locations.

Regional Climate

Archaeological investigations from throughout the Alaska Peninsula and Aleutians have revealed a close relationship between oscillating climatic conditions (Table 1), primary productivity, ecological changes, and patterns of human population growth and resource exploitation (Maschner *et al.* 2009a, 2013; Misarti *et al.* 2009; Betts *et al.* 2011). Because it is impossible to tease out and interpret signals of human-induced changes absent an understanding of the climatic drivers that have played a pivotal role in a variety of long-term trends throughout the region, a brief summary of the relationship between climate and primary productivity is in order.

Period	Age Range	Approximate Climate Conditions
Early Holocene	9000 – 6200 BP	Dry and variable with warmer intervals
	6200 - 5600 BP	Warm and wet
	5600 - 5200 BP	Cooler
Altithermal	5200 - 4000 BP	Warmer
	4000 - 3200 BP	Cool and wet
	3000 - 2600 BP	Perhaps warmer
Neoglacial	2600 - 2000 BP	Cool and wet (increased storminess)
Roman warm interval	2000 - 1800 BP	Warmer
Pre-medieval climatic anomaly	1800 - 1100 BP	Cold
Medieval climate anomaly	1100 - 700 BP	Warmer and dryer, variable
Little Ice Age	700 – 100 BP	Cold and wet
Recent era	100 BP – Present day	Very warm

Table 1: Ten thousand years of climate conditions for the North Pacific. Shading indicates relatively cooler period. Adapted from Maschner et al. 2014, Maschner et al. 2009a, and Misarti et al. 2009.

Long-term climatic conditions in the north Pacific are strongly linked to a phenomenon known as the Pacific Decadal Oscillation (PDO), involving shifting warm and cold regimes over 20-30 year cycles (Misarti *et al.* 2009; Mantua & Hare 2002). The PDO represents a prolonged pattern of Pacific climate variability, similar to El Nino (ENSO) events, but occurring on temporal scales far in excess of the 6-18 month cycles that characterize ENSO events (Mantua & Hare 2002). PDO states are associated with predictable changes in sea surface temperature (SST) (Misarti *et al.* 2009), signaled by sudden alterations in the sign of residual deviations of observed climatic anomalies from mean global average SST anomalies (Mantua & Hare 2002). Additionally, PDO shifts

impact sea level pressure and the strength of a north Pacific low pressure center referred to as the Aleutian Low, which in turn affects oceanic circulation in the Gulf of Alaska Gyre (Misarti *et al.* 2009; Overland *et al.* 1999). As yet, the precise causes of the PDO are unclear, as are the exact causal relationships between it and other climatic phenomena, though a relationship between positive Pacific-North American and negative North Atlantic Oscillation phases suggest an interaction between phases of global atmospheric circulation patterns may be key (Kim *et al.* 2004).

The existence of a relationship between climate and productivity was first noted as a result of changes in Pacific salmon catch (Mantua & Hare 2002). Subsequent research has corroborated the notion of interplay between long-term climatic change and oceanic productivity, revealing a number of interesting trends. A strong Aleutian Low decreases water column stability in the Gulf of Alaska Gyre, increasing vertical mixing via upwelling while simultaneously lowering SST (Misarti *et al.* 2009). Similarly, mesoscale eddies impact the mixing of nutrient-depleted and nutrient rich waters along the north Pacific and Bering Sea interface (Trites *et al.* 2009). These changes impact primary productivity via their affects on seasonal plankton blooms, as illustrated by simulations suggesting 20% decreases in the biomass of spring zooplankton blooms (Trites *et al.* 2009). A relationship between primary productivity and climate has been further substantiated by stable isotope analyses, which uses variations in $\delta^{13}\text{C}$ to identify relevant changes in productivity (Misarti *et al.* 2009). Shifts in primary productivity subsequently ramify up the trophic chain, resulting in ecosystem wide shifts. Of interest here is the potential for decreased primary productivity to result in a proliferation of lean, low energy fish species in the region, which can detrimentally impact the survival

prospects of higher trophic level species, including yearling steller sea lions – a highly ranked prey item for prehistoric Aleutian populations (Trites *et al.* 2009; Maschner *et al.* 2009a).

The point here is not to adopt a stance of overt ecological determinism, but to recognize that ecological variables are nonetheless an important determinant in the shape of adaptive landscapes, putting boundaries on the range of successful strategies. This is a stance of ecological possibilism, wherein exogenous environmental factors are viewed as constraints on the development and evolution of human subsistence practices, demographic patterns, and social systems (Rambo 1983). At issue here is how long-term changes in climatic regime impact the human relationship to prey species, in order to establish a baseline for detecting culturally induced deviations (i.e. niche construction).

Chapter Four: Innovations in Boating Technology and Subsistence Change

Where geography does not render the sea inaccessible, the interface between terrestrial and maritime landscapes is widely recognized as one of the most productive ecological resource zones available for human exploitation (Kennett 2004; Ames 2002; Binford 1990). This is particularly true of coastal environments in high latitude regions like the North Pacific, where access to the bounty of the ocean is absolutely critical to the formation of reliable subsistence strategies, which are then foundational to the establishment and long-term social development of human populations. In this regard, the presence or absence of maritime technology can be a crucial variable, limiting or facilitating access to important resources. Little wonder, then, that the literature on maritime adaptations among hunter-gatherer populations is quite rich and extensive (Yesner 1981 & 1998; Lyman 1989, 1991 & 1995; Hildebrandt & Jones 1992; Veltre 1998; Erlandson 2001; Ames 2002; Arnold & Bernard 2005; Gifford-Gonzalez *et al.* 2005; Kennett 2005; Corbett *et al.* 2008; Fitzhugh & Kennett 2010; Lech *et al.* 2011; Maschner *et al.* 2014; Maschner in press).

Boating technology is an important component of many maritime toolkits. Given its centrality to the argument at hand, it is worth paying some attention to the way boats modify human relationships to aquatic resources. It will be necessary to lay out a number of points, which, taken together, will cohere into an argument for a change in harvesting practices sometime after 1500 BP and continuing into the era directly preceding Russian contact. The first and most basic point is that reliable, ocean-going boating technology should change the relationship between humans and the resources they preferentially target in their subsistence activities (Lyman 1989; Hildebrandt & Jones 1992; Ames

2002). However, it is not evident that harvesting a wide variety of marine resources requires the use of sophisticated boating technology, meaning that evidence must be interpreted with a sharp eye for regional context (Lyman 1989; Hildebrandt & Jones 1992). Second, it is essential for any interpretation of subsistence change to be situated within an understanding of the way the behavior of humans (or any other predator) within an ecosystem changes the behavior of prey species (Lyman 2003; Betts 2011; Maschner 2013). Third, temporal changes in faunal assemblage track actual patterns of exploitation (Betts *et al.* 2011; Lech *et al.* 2011; Maschner *et al.* 2013). The relative abundance of highly ranked taxa can be interpreted in terms of prey choice models of foraging strategy. Fourth, the signature of subsistence change is not strictly limited to the relative abundances of faunal remains, but should be visible in shifts in archaeologically resilient technologies (e.g. stone spear points, bone harpoons) (Maschner 2013; Maschner in press) and the isotopic signatures indicative of changes in trophic feeding level (Misarti & Maschner 2015; Misarti *et al.* 2009). Each of these points requires further elaboration, and so each, in its turn, will be discussed in subsequent sections.

Marine Ecosystems and Boating Technology

Marine ecosystems can be among the most productive on the planet. High primary productivity along coasts, resulting from the mixing of nutrient-rich deep-ocean water with surface water, contributes to high concentrations of resource biomass, diversity, and ecological stability (Kennett 2005). This is particularly true of the geographic region of the Eastern Aleutians and Alaska Peninsula, where the intersection of the North Pacific and Bering Sea stimulates a remarkable abundance of marine resources (Maschner *et al.* 2009; Trites *et al.* 2007). In these environments, where rugged shorelines, high winds,

and harsh climates sometimes render the ocean practically inaccessible, the primary limitations on resource acquisition and production are typically geological, rather than ecological (Kennett 2005; Hildebrandt & Jones 1992). As with purely terrestrial environments, foraging decisions are dictated by the spatially and temporally heterogeneous distribution of resources of varying utility.

Superficially, the presence of any pelagic (open-water) resources or resources associated with off-shore islands, sea-stacks, or particularly rugged coastlines in archaeological assemblages seems a likely indication of the use of boating technology. However, this is not necessarily the case, especially if there is some overlap between littoral and pelagic communities. For instance, Lyman has argued that pinniped (seal) harvesting is not dependent upon the use of any form of open-water technology (Lyman 1989, 1991 & 1995; Hildebrandt & Jones 1992). Indeed, though typically highly ranked in terms of calories per kilo (Kennett 2005), pinnipeds are difficult to capture in the open-water, which is why, ethnographically, clubbing or spearing shore-bound animals at rookeries or haul-outs have often been among preferred harvesting techniques (Lyman 1989, 1991 & 1995; Hildebrandt & Jones 1992; Gifford-Gonzalez *et al.* 2005). Even when haul-outs and rookeries are concentrated off-shore, at locations inaccessible without boats, some animals are bound to show up stranded and within relatively easy grasp of human hunters. Absent calorie rich sea-mammals, aquatically-oriented human populations lacking reliable boating technology still typically maintain access to productive littoral zones containing a variety of resources, including large quantities of easily harvested shell-fish and near shore birds.

Consequently, there is little reason to presume a marine orientation necessitates the regular use of sophisticated boating technology. Instead – following Hildebrandt and Jones (1992) – it is better to view the development and regular deployment of boating technology as a kind of resource intensification. Boating technology changes the relationship between humans and their ecological niche in a number of important ways. Boats are necessary for complex, open-water resource acquisition, and for hauling resources long distances over stretches of water or around coastal geographic features that would otherwise represent impenetrable barriers to access and production. They reduce the costs associated with the pursuit and transport of certain resources (Ames 2002; Kennett 2005) and render previously out-of-reach resources attainable, particularly when inclement weather or rough-seas represent a limiting factor on the use of less resilient technologies (Arnold 1995). Additionally, though the use of boats is not typically thought of as facilitating access to littoral resources, the use of boating technology can be expected to influence patterns of littoral resource exploitation, particularly when said use decreases the costs associated with acquiring more highly ranked, off-shore, open-water resources.

Human Predation and Prey Behavior

In the north Pacific, otariids (eared seals - steller sea lions and northern fur seals) would have been among the most highly ranked prey species regularly available for incorporation into the human diet (Yesner 1981). Usable meat weight for an adult male steller sea lion runs around 508 kg (Yesner 1981) to 660 kg (Betts *et al.* 2011), while that of the smaller northern fur seal comes in at around 160 kg (Yesner 1981) with average weights around 117 kg (Betts *et al.* 2011), still nearly 100% greater than that of an adult

male hair seal. These species exhibit considerable sexual dimorphism, with females offering substantially less usable meat than their male counterparts. Yet even under the reasonable expectation that females and juveniles were both more prevalent and preferentially targeted, they still offer a gross caloric return above and beyond that of most other species inhabiting the North Pacific/Bering Sea interface. Furthermore, otariid rank should be bolstered by their utility in the production of secondary raw resources, including bones useful for constructing a variety of tools, and skins, essential to the production of reliable watercraft and water-resistant clothing (Kennett 2005; Maschner *et al.* 2013; Maschner in press). Where accessible, otariids should be expected to represent a critical component of human diets throughout the Alaskan Peninsula and Aleutian Islands.

Steller sea lions (*Eumetopias jubatus* – hereafter abbreviated SSL) are large pinnipeds with a modern range that encompasses sexually segregated haul-outs throughout the Western Gulf of Alaska, Aleutians, and as far south as Oregon throughout the year (Gifford-Gonzalez *et al.* 2005). Males practice resource-defense polygyny, a form of male-male competition where dominant males seize control of a resource zone that females subsequently visit (Lyman 2003a; Gifford-Gonzalez *et al.* 2005). In early May, males begin occupying and defending rookeries, shortly after which females arrive and give birth to a single pup that is subject to considerable maternal attendance, thus representing a k-selected breeding strategy (Hidebrandt & Jones 1992; Trites & Larkin 1996). Pups typically nurse for about one year, but have been seen nursing at haul-outs and rookeries between the ages of 1-3 (Trites & Larkin 1996; Merrick & Laughlin 1997). Females and pups begin to disperse from rookeries in July-August (Merrick & Laughlin

1997) until rookeries are largely abandoned by October-November (Trites & Larkin 1996; Merrick & Laughlin 1997). Throughout the rest of the year, SSLs occupy haul-outs. Tagging studies have yielded evidence that sexually mature individuals return to the rookeries at which they were birthed, suggesting SSLs show considerable fidelity to rookeries (Calkins & Pitcher 1982; Trites & Larkin 1996). However, SSLs will abandon rookeries and haul-outs if they experience sufficiently high levels of disturbance (Gifford-Gonzalez *et al.* 2005).

Like stellar sea lions, northern fur seals occupy seasonal rookeries. Polygynous males compete to establish harems, where females give birth of a previous season's pups and are subsequently bred – usually within about a week (Rick *et al.* 2011). Females then spend around four to five months weaning their pups, before returning to sea. Juvenile NFS spend a large portion of their early life in open water, roughly from the end of weaning to three or four years of age. In general, NFS differ from SSL in the disproportionate amount of time they spend foraging in open water. This is critical, as it places limits on the range of times these animals can be harvested on land, tending to increase the costs in terms of time, skill, and technology required to harvest NFS throughout much of the year.

As polygynous, k-selected animals, SSL and NFS populations can be particularly susceptible to predation induced depression, depending on the pattern of exploitation adopted by predators, such as over-exploitation of more abundant and more easily captured females (Hildebrandt & Jones 1992; Lyman 2003a). The signature of human-induced depression in highly ranked taxa is common in the zooarchaeological record, but interpreting the precise nature of any given depression can prove problematic (Lyman

2003a). As a result, it is useful to distinguish between several different varieties of depression: exploitation depression, behavioral depression, microhabitat depression, and ecological depression (Lyman 2003a; Betts *et al.* 2011). Exploitation depression occurs when a population experiences an actual decrease as a direct result of predation. Behavioral depression is a result of prey species exhibiting a plastic response to predation, altering their behavior in a manner that decreases encounter rates. Microhabitat depression can be considered a variety of behavioral depression, but involves the relocation of prey species outside the normal range of predators, rather than simply modifying behavior to escape predators within a given extant range. Finally, ecological depression is a decrease in actual population size due to variables unrelated to predation (e.g. climate). In analyzing zooarchaeological evidence for resource depression, it is further useful to distinguish between local populations, which occupy the area around a given archaeological site and contribute the bulk of the faunal material to a given assemblage, and metapopulations that include all local populations in a given region (Lyman 2003; Betts *et al.* 2011). Local population depressions may be masked by an infill of individuals from the surrounding metapopulation.

With the initial colonization of the Alaska Peninsula and Aleutians, beginning ca. 9500 BP with the Anangula Tradition on Umnak Island, humans were harvesting SSLs and other pinnipeds, likely using large stone end-blades to dispatch shore-bound animals at rookeries and haul-outs (Maschner in press). Assuming human populations were either absent or insignificant in the preceding years (an assumption not unwarranted, considering the variations in sea level that would have accompanied preceding years) the local SSL populations would have been predator-naïve with respect to humans. The same

can likely be said of SSL populations occupying rookeries and haul-outs in any local area where human incursions represent a novel threat. Depending on the intensity of harvesting, initial contact with human predators can be expected to produce an exploitation depression. As populations become accustomed to patterns of human predation, behavioral/microhabitat exploitation should be more common, as individuals adjust to the new threat via ontogenetic processes (e.g. learning), given the assumption that some mechanism for identifying and avoiding novel threats is likely highly conserved and widespread in the animal kingdom (Frid & Dill 2002). Indeed, because flexible behavioral responses are cheaper than fixed traits or morphological adaptations – which should only arise when predation risk is both significant and consistent across a large number of generations – the typical anti-predator response for many organisms should be behavioral (Novacs & Blumstein 2010). The succeeding section explores these relationships in greater depth, via an exploration of the relative abundances of faunal remains in an archaeological assemblage from Sanak Island.

History and Ethnography of Aleut Marine Subsistence

The subsistence strategies employed by the prehistoric Aleut are hidden from direct observation by temporal expanses measured in centuries. This has always been the fundamental epistemological problem faced by archaeology as a discipline, toward which massive amounts of intellectual effort have been bent over the past the several decades. The material remains recovered from throughout the greater Aleutian region can paint a partial picture – indeed, their contribution to our understanding is indispensable. But because of the gaps that remain in understanding based on material evidence, it is often useful to supplement these findings with information derived from early ethnographic

accounts of Aleut subsistence strategies. These give researchers important insight into an otherwise inaccessible body of knowledge - the set of beliefs, customs, and strategies that shaped the Aleut relationship to the sea.

Ethnographic accounts roundly corroborate what might be broadly construed as the central finding of archaeological investigations of Aleut subsistence: that their lifestyle was inextricably linked to resources derived from marine ecosystems (Laughlin 1980; Veniaminov 1984; Jochelson 2002; Turner 2008). Early boating technology is reported to have been substantively different from ethnographically observed technologies – at the turn of the 20th century, Aleuts reported that their ancestors were at some point restricted to near shore foraging by the use of unstable, open-hulled vessels (Turner 2008). Technology resembling the sophisticated closed-hulled, ocean-going baidarkas of the historical record was apparently not developed until a later date. Turner (2008) reports that the Aleut did not make war upon one prior to the development of something along the lines of the CHOGK, giving us a rough indication of where to look for the signal of its introduction, since consistent and widespread evidence for violent conflict does not turn up in the archaeological record until after about 1500 BP (Maschner in press).

The kayaks recorded in ethnographic accounts were extraordinarily resilient and expertly crafted elements of a sophisticated marine subsistence strategy. Upwards of three meters in length, they came in one, two, and three passenger varieties² (Jochelson 2002; Turner 2008). The outer hull was sewn from sea mammal skins, with Steller sea lion providing the preferred working material (Laughlin 1980). For ballast, 25 kilogram

² Turner (2008) reports that the two and three holed varieties were of Russian invention.

stones were placed inside the craft (Jochelson 2002). A three piece keelson increased flexibility, improving the crafts durability when buffeted by rough seas (Laughlin 1980). Kayak construction was both labor intensive and time consuming, involving specialized knowledge and specific resources (Turner 2008).

Various species of marine mammal were hunted from these kayaks using a throwing board (atlatl) and dart system (Laughlin 1980; Jochelson 2002) which allowed hunters to successfully target animals with one hand while stabilizing their boat with the other. However, other prey species, including the otariids of interest in this paper, are reported to have been preferentially targeted on land (Laughlin 1980; Veniaminov 1984; Jochelson 2002). The specific reasons for doing this different from species to species – northern fur seals, for instance, are agile and difficult to capture in open water, while adult Steller sea lions could be extremely dangerous to a hunter in open water – but they can all be boiled down to the ease of capturing and dispatching these animals on shore versus open water.

Ethnographically, otariid hunting is reported to have involved a two-fold strategy. First, hunters in kayaks worked to corral the animals, cutting off their access to the sea and driving them inland (Jochelson 2002). Second – once driven inland, clubs were used to incapacitate the animals, at which point they were dispatched with thrusting spears or deep cuts across the throat (Veniaminov 1984; Jochelson 2002). Hunters preferentially targeted smaller adult male Steller sea lions, avoiding the difficulty and danger involved in capturing the largest males and hauling them from a rookery or haul-out back to the village site while simultaneously allowing them to secure better meat and hides free of the tissue damage inflicted by a lifetime of territorial skirmishes (Laughlin 1980).

Chapter 5: Changes in the Relative Abundance of Highly Ranked Taxa on Sanak Island

Three seasons of archaeological excavation on Sanak Island (Figure 3) – located off the southern coast of the western Alaska Peninsula – have yielded a continuous sequence of faunal remains, spanning from roughly 5000 BP to 200 BP (Maschner *et al.* 2009a; Betts *et al.* 2011), representing a remarkable fount of information. The sequence tracks nearly 5000 years of human occupation and subsistence change in the North Pacific. Using abundance indices, deployed within the framework of optimal foraging theory, archaeologists and zooarchaeologists can tease important insights out of the primary raw data derived from the Sanak faunal assemblage. However, because additional variables relating to climatic oscillations, social change, ecological variation, technological change, and so forth complicate matters beyond a one-to-one correspondence between the relative abundance of taxa in a given assemblage and the absolute abundance of taxa inhabiting the contemporaneous landscape, deriving robust interpretations from the Sanak assemblage requires some effort (Betts & Friesen 2006; Betts *et al.* 2011). In order to get a sense of the forces shaping patterns of subsistence, interpretations must be meticulously constructed and rigorously compared against a variety of variables.

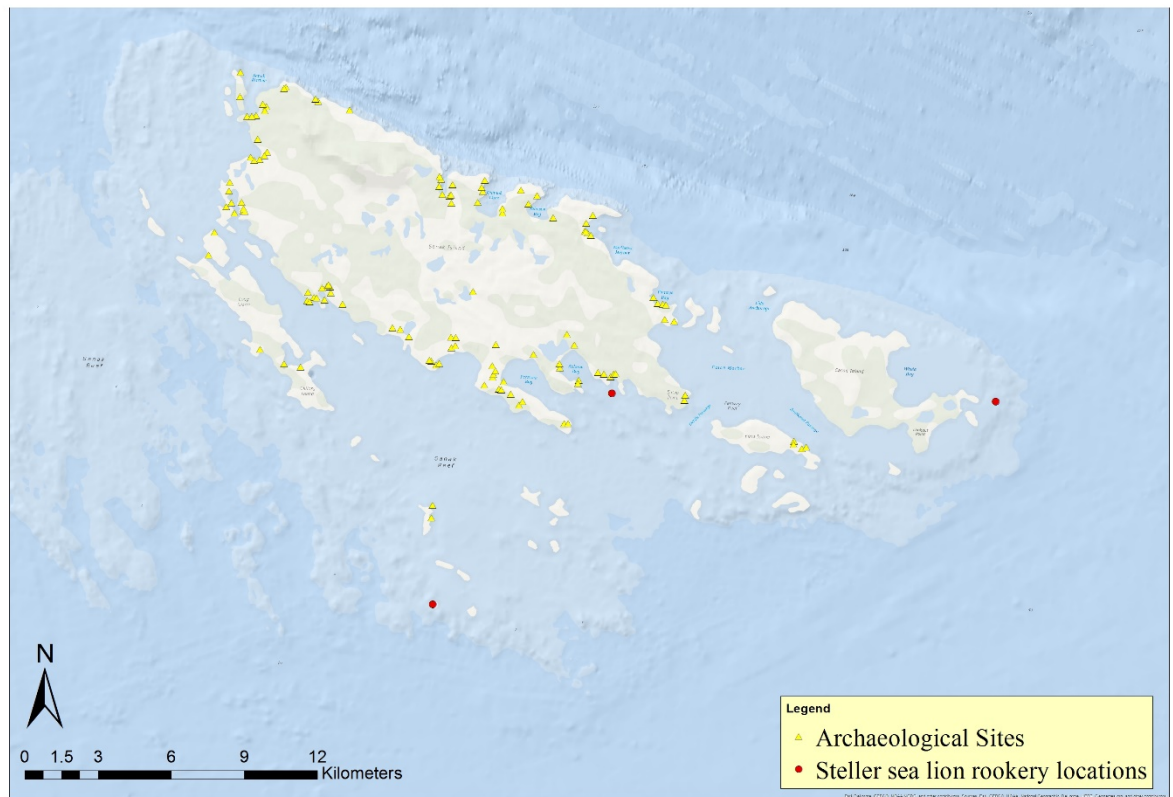


Figure 3: Location of archaeological sites and Steller sea lion rookeries around Sanak Island. Rookery data for NOAA.

Method and Theory

Abundance indices have proven a useful tool in the analysis of prehistoric subsistence trends, but their results must be situated within a broader understanding of the additional variables that might be influencing changes in subsistence practices. Moreover, abundance indices involve a number of assumptions that must be unpacked before they can be fruitfully employed. But before this work can be done, it is worthwhile to take a moment to explore exactly what abundance indices are. Put briefly, abundance indices reflect the normalized ratio of large-bodied, highly ranked taxa to smaller, lower ranked taxa (Betts & Friesen 2006). This is given by the equation $AI = A / (A + B)$, where A is the

frequency of highly ranked taxa in a given assemblage and B , the frequency of some lower ranked species. That is, it is the sum of the number of identified specimens (NISP) of highly ranked game, divided by the sum of the NISPs for the highly ranked game species and some species that, under diet breadth assumptions, should only be targeted when the highly ranked species is unavailable (Betts & Friesen 2004; Betts & Friesen 2006). Abundance indices are considered a reliable measure of the relative abundance of animals under the assumption that humans are targeting them in a manner consistent with prey choice and diet breadth models of optimal foraging theory (Betts *et al.* 2011) That said, it is important to keep in mind that abundance indices are actually meant to reflect encounter rates, which – in the case of behavioral or microhabitat depressions – might not be directly indicative of the actual abundance of animals in a given region over a certain time frame (Betts *et al.* 2011). Because understanding abundance indices requires some understanding of prey choice and diet breadth models, these models and their core assumptions will be briefly reviewed.

Regarding patterns of resource acquisition on the Alaska Peninsula, prey choice and diet breadth models are of particular relevance. Something of the nature of these models can be surmised from their monikers: prey choice deals with the things organisms should chose to consume among available alternatives (i.e. what prey to chose) and diet breadth relates to how expansive an assemblage of resources an organism should incorporate into its diet in order to meet the nutritional needs associated with somatic maintenance and reproduction (Bird & O'Connell 2006; Ydenberg 2010). In a significant sense, the latter is more or less a restatement of the former. The difference is primarily in the question one chooses to emphasize. Interested in which organisms a

forager should preferentially target, and in what order, the researcher is interested in questions of prey choice. Questions relating to what organisms a forager should consider as conditions deviate from those in which subsistence needs can be met through exploitation of resources highly ranked according to prey choice models, they begin to ask questions of diet breadth – that is, what should individuals eat to counter-balance depressions in the abundance of preferred food items? Put simply, prey choice is a matter of what is best to eat, relative the costs and benefits of acquisitions, whereas diet breadth is a matter of how many things should be included in the diet (Kaplan & Hill 1992).

Decisions about what to eat are governed by three variables: (1) the average net energy acquired from an encounter e_i , (2) expected/average handling costs – the amount of time and energy expended capturing or harvesting the prey item – h_i , and (3) the abundance of the item, as given by encounter rate λ_i (Ydenberg 2010; Kaplan & Hill 1992). For two resources, the net energy gain is given by...

$$\frac{\lambda_1 e_1 + \lambda_2 e_2}{1 + \lambda_1 h_1 + \lambda_2 e_2}$$

A forager should be expected to incorporate resource 2 into the diet when the abundance of resource 1 declines, such that...

$$\frac{e_2}{h_2} > \frac{e_1}{1/\lambda_1 + h_1}$$

Otherwise referred to as generalization, this type of behavior is expressly predicated upon the abundance of highly ranked resources – as long as there is plenty of resource 1 around, it does not pay to add resource 2 to the diet (Ydenberg 2010). The recognition

that the incorporation of lower ranked resources into the diet is dependent upon the encounter rate with more highly ranked resources is essential to an accurate interpretation of abundance indices (Kennett 2005).

There are, unsurprisingly, a number of complications that arise when attempting to assess the putative optimality of prehistoric foraging strategies. Foremost among these is the simple fact that archaeologists have no way to directly assess rates of return or determine the relative costs of procurement and handling for any given resource (Kennett 2005). Costs of procurement, for instance, can be influenced by a number of variables like local knowledge of prey behavior and context-dependent hunting strategies that are difficult – if not altogether impossible – to measure archaeologically. In a similar vein, return rates do not necessarily correspond directly to the meat-weight of captured animals: depending on processing strategy, such as those associated with the logistical tactics of collectors, hunters may bring back significantly less than the total meat-weight of a captured animal (Ames 2002).

Further problems stem from the level of resolution offered by the archaeological record. Necessarily and (almost) ubiquitously invisible, individuals do not make a reasonable target for archaeological investigation, particularly when it comes to the application of optimality models. However, foraging theory was initially developed as a method to assess the extant utility of the resource-acquisition strategies employed by modern populations, involving direct observations of the behavior of *individual* organisms in well-defined ecological contexts (Winterhalder & Smith 2000; Bird & O'Connell 2006). This opens up important questions relating to whether or not the use of abundance indices to track human foraging behavior might disguise important individual

level heterogeneity and whether averaging assemblages over a wide expanse of time and space might mask important variation at finer scales (Lyman 2003b). Concerns regarding the former can be alleviated with the recognition that foraging theory has proven useful in elucidating the nature of subsistence strategies among extant populations of humans (Bettinger 1987; Winterhalder & Smith 2000), suggesting that remarkably suboptimal foraging would require more explanation than broad adherence to model expectations. In terms of the latter, the potential pitfalls associated with time-space averaging can be avoided by carefully specifying the temporal-spatial scale of analysis and asking questions relevant to that scale (Lyman 2003b). Finally, the invisibility (or, at the very least, extremely low resolution) of the individual mandates a locus of analysis focused on the typical strategies (Dawkins 1982) employed by many individuals over long periods of time. Hence, the information derived from abundance indices relates to the aggregate behavior of a group of individuals, typically over a long stretch of time. This is not particularly problematic, especially when the specific question being asked relates to long-term changes in foraging strategy, rather than the day-to-day success of individual hunters.

Ultimately, abundance indices are only informative if researchers are willing to assume, *a priori*, that the prehistoric population under investigation is adhering to the expectations of optimal foraging theory. Precisely how reasonable this is remains a matter for serious debate. Optimality, evolutionarily speaking, must be defined with a sharp eye for context (El Mouden *et al.* 2014). Different environments offer different constraints and opportunities, which organisms are bound to negotiate through trade-offs and limitations of the phenotype they have inherited from their ancestors. Furthermore,

environmental stochasticity – both on the scale of an individual life and over many thousands of generations – prevents organisms from homing in on an optimal solution to every problem they might face. This is because adaptation can only drive a population toward an optimal state for the average or typical conditions experienced by that population and because adaptive lag ensures some gap between past selective environments and extant circumstances. Consequently, true optimality may be entirely illusory – or at the least difficult to detect – even without the widely recognized epistemological limits of the archaeological record. Natural selection does not guarantee optimality – only that organisms will be inexorably pushed in that direction (El Mouden *et al.* 2014).

When applying abundance indices to the archaeological record, it is typically unreasonable to assume that patterns – optimal or otherwise – can be sufficiently explained by natural selection. Whatever optimality prehistoric populations exhibit, it is likely to be more frequently attributable to purely ontogenetic and cultural processes – learning and social transmission – than changes in the frequency of traits brought about by natural selection. Thus, the precise mechanistic details shaping human foraging in the archaeological record are different from those assumed to be at work for non-human foragers. Nevertheless, roughly the same caveats apply, and the result is that the closest researchers can reasonably assume study populations might get to optimality is some ad hoc compromise dictated by extant constraints and opportunities. This is by no means crippling. Here, it is not assumed that the prehistoric inhabitants of Sanak were preternaturally capable of tracking ecological conditions, allowing them to remain at a local optimum throughout the chronology of human habitation on the island. Rather, it is

merely assumed that people were actively *trying* to optimize the ratio of benefits to costs of subsistence behavior relative to the informational, cultural, and ecological constraints they faced.

Though some flaws may remain inherent to the use of abundance indices, they should not suffice to erode confidence in their empirical utility. In terms of time-space averaging, the trends of interest in the present work should be manifest across a large geographic area and over relatively long stretches of time, so the analysis here is regionally focused and targeted at determining long-term patterns in sea mammal exploitation on Sanak Island.

Previous Analysis of Sanak Faunal Record

Matthew Betts and colleagues analyzed a migration-controlled sample of faunal remains derived from eight distinct shell middens, together representing a nearly continuous sequence of resource exploitation stretching from ca. 4550 BP to 200 BP (Betts *et al.* 2011; Maschner *et al.* 2014). Based on body weight, otariids likely represent the highest ranked taxa regularly harvested by the Sanak population, and thus represent the taxa of interest in their analysis. Because of some difficulty in distinguishing between elements, Betts and colleagues grouped Steller sea lions with the considerably smaller northern fur seal (Betts *et al.* 2011). Though smaller and more difficult to catch due to the amount of time spent in open water, the size and accessibility of NFS relative to the various species of phocids inhabiting the area around Sanak likely made them a highly ranked prey source for marine-based foragers on the Alaska Peninsula and throughout the Aleutians (Betts *et al.* 2011). Comparison taxa *B* were

selected on the basis of return rates that shift slower than those of otariids, such that increases or decreases in the relative frequency of *B* were reliably indicative of changes in otariid encounter rates, and multiple comparison taxa (sea otters, phocids, and all other sea mammals) were used to control for additional variables (e.g. intensification) (Betts *et al.* 2011).

The results of Betts and colleague's analysis (Betts *et al.* 2011) pointed toward a number of interesting trends and a few anomalies. Following the initial colonization of Sanak, the relative abundance of otariids increased sharply along all three indices, a trend lasting through roughly the first millennium of occupation, 4500-3500 BP, with a peak around 3600 BP (Maschner *et al.* 2014). Otariid abundance declined over the succeeding millennium, before stabilizing for the subsequent 500 years. Around 2000 BP the abundance of otariids began to experience an uptick relative to that of sea otters, but decreased in proportion to phocids, resulting in an anomaly around 1480 BP in which the three indices no longer track one another. Following this, otariid encounter rates seem to decrease, suggesting a resource depression that reaches its nadir around 970 BP, corresponding with the onset of the Medieval Climatic Anomaly, a pronounced regime shift associated with a potential ecosystem collapse (Maschner *et al.* 2014; Maschner *et al.* 2009b). Subsequently, otariid abundances once again increase up to the end of the faunal sequence, around 460 BP, during which time all three indices are once again synchronized.

Changes in otariid encounter rate are clear throughout the temporal sequence of the Sanak Island faunal assemblage, but the potential causes of these trends need to be teased out by situating the abundance indices within a wider ecological context.

Comparison with climatic data from a number of sources revealed a clear correlation between sea surface temperature and otariid abundance (Maschner *et al.* 2009a; Maschner *et al.* 2014; Betts *et al.* 2011). Modern research indicates that cooler periods are associated with higher levels of primary productivity and increases in the number of calorically rich fish species preferentially targeted by Steller sea lions (Trites *et al.* 2009). Conversely, warm periods are subject to a decline in primary productivity and a resurgence in the numbers of leaner fish species. These conditions are particularly stressful for young Steller sea lions, which require around twice the relative energy as adults and may not be able to meet daily caloric needs feeding on low quality prey (Trites *et al.* 2009; Rosen & Trites 2004). Peak otariid abundances in the Betts *et al.* study of the Sanak assemblage were nested well within the temporal bounds of cool, high productivity climatic oscillations. Thus, the work of Betts and colleagues seemed to corroborate the hypothesis that climate has been a primary driver of otariid abundance in the seas around Sanak, suggesting some portion of warm period declines may be attributable to ecological depression.

Throughout much of the sequence, human population estimates track well with both otariid abundances and climate regime. However, the early part of the sequence reveals discordant trends in otariid abundance and human population, suggesting human harvesting at this time is particularly pronounced (Betts *et al.* 2011). Betts and colleagues suggested the elevated abundances at this time may have been a product of a predator-naïve population colonizing a novel microhabitat following the isostatic rebound of coasts with the onset of the neoglacial (Betts *et al.* 2011). Newly exposed rookeries and haul-outs were subsequently infilled by the regional metapopulation, creating a new local

population entirely unfamiliar with the predation risks posed by humans. Of course, the causal arrow could easily point the other direction, if human population following the initial colonization of Sanak, ca. 5500 BP, were low enough that predation risk was low for surrounding otariid populations. In any event, the otariid population from ca. 4550 BP to 3500 BP likely represented a high-return resource whose naivety and close proximity likely played a role in lowering pursuit and handling costs.

Betts and colleagues continue to suggest that human predation may account for the subsequent decline from the 3600 BP peak to the lower encounter rates experienced around 2590 BP. The climate around this time was still cool and concurrent productivity likely high, making conditions ripe for a flourishing otariid population. Absent evidence for a corresponding climatic, demographic, or technological change, Betts and colleagues argue in favor of a hypothesis relating to human-induced behavioral/microhabitat populations. With prolonged exposure to human predation, it is reasonable to expect otariid populations to respond with behavioral adjustments, either adopting more successful evasive strategies or moving to rookeries and haul-outs outside the range of human hunters (Frid & Dill 2002; Gifford-Gonzalez *et al.* 2005; Novacs & Blumstein 2010; Betts *et al.* 2011). In this case, the subsequent period of relative stasis can be interpreted as a time of strategic equilibrium, with otariid behavioral adaptations offsetting human predation.

The subsequent uptick in harvesting, peaking around 1480 BP, is more difficult to interpret. It is here that the confusing deviation in abundance indices occurs, with the otariid/sea-otter indices indicating an increased abundance of highly ranked prey, while the otariid/phocid index suggests a relative decrease, and the otariid/other sea mammal

index exhibits relative stasis. The implication here is that people are harvesting more and more phocids at a time when higher-ranked otariids are also abundant. It is possible the increased abundance of otariids relates exclusively to increased primary productivity following the onset of another cooler regime. This would conform to the general trend in prey abundance tracking primary productivity through favorable climatic regimes, and is the explanation favored by Betts et al. (2011). However, a reanalysis of the Sanak Island faunal data complicates this relationship, and suggests some other variable may be needed to explain long-term trends in the relative abundance of otariid remains.

Reanalysis of Sanak Faunal Record

In the spring of 2015, the Sanak Island faunal data were subjected to several new analyses. In the years following the analysis presented in Betts et al. (2011), additional faunal remains were discovered within the collections and analyzed by staff working on the Sanak Island project in Maschner's Arctic Archaeology Laboratory. Here, I present the results of several fresh analyses I conducted on material derived from the complete sample of skeletal material recovered three field seasons on Sanak Island, representing over 500,000 individual skeletal elements distributed across dozens of individual sites and a period of occupation spanning nearly five thousand years.

The Sanak faunal data were analyzed for the purpose of identifying long-term changes in subsistence that might be attributable to innovations in boating technology. There was no obvious reason to presume the analysis would reveal results that differed significantly from those outlined by Betts and colleagues (Betts *et al.* 2011). However, I employ an approach that involves a different set of analytical tools and have the

advantage of access to the complete set of faunal data derived from Sanak Island. This results in an understanding of the Sanak Island faunal sequence that not only deploys a somewhat different analytical strategy, but offers a number of potential improvements in terms of reliability and long-term temporal resolution.

In order to assess long-term trends in the relative abundance of otariids on the Alaska Peninsula, I employed number of identified specimens (NISP) to account for the relative frequency of faunal remains. NISP reflects specimen count, or the number of individual elements retrieved from a faunal assemblage, and is thus often considered a form of primary data (Reitz & Wing 2008). However, the use of NISP as form of secondary data to track the relative frequency of taxa is sometimes favored due to its high level of replicability (Reitz & Wing 2008). Furthermore, because NISP is the method of taxonomical accounting employed by previous researchers, it was deemed best to use it here to facilitate direct comparison between analyses.

Though NISP is considered highly replicable, it is nonetheless influenced by discretionary decisions about what to count (Reitz & Wing 2008). Here, the concern relates to what, precisely, should count as an identified specimen. For complete elements, such as a mandible or femur, the decision is clear, but things become more ambiguous when dealing with something along the lines of highly eroded rib fragment. For the purposes of this analysis, each individual bone, fragmentary or otherwise, is counted as a single specimen. The assumption here is that each taxa was subjected to the same taphonomic processes, such that the reliability of the NISP as a measure of relative frequency is preserved. It is furthered assumed that cultural inputs have not significantly biased the faunal record, though it should be recognized that the use of Steller sea lion

remains as secondary raw resources for tool production may depress otariid abundance estimates below an actual representation of prehistoric abundance (Bunn et al. 1988; Kent 1993; Kennett 2005; Reitz & Wing 2008).

In line with previous research, abundance indices are used to track long-term changes in resource exploitation, under the expectation that human-induced changes in the landscape of optimal foraging solutions should leave detectable changes in the faunal record. Steller sea lions represent the primary taxa of interest, A in the abundance measure $AI = A/(A + B)$, but the large taxonomic grouping otariid was used to avoid issues stemming from the ambiguity of differentiating between northern fur seal and Steller sea lion remains. Sea otters were used as the comparison taxa, B , both because their relatively low meat-weight and difficulty of capture render them suboptimal prey. Additionally, ethnographic accounts record some amount of cultural aversion to the consumption of sea otter meat – not only was their meat widely agreed to present an unpleasant flavor, their skins were of little use and they were perceived to be of human origin (Laughlin 1980). Sea otter hunting was practically non-existent prior to the introduction of commercial fur hunting by the Russians. The resulting abundance measures are presented for each Sanak Island archaeological site in Figure 4.

Betts and colleagues employed a migration-controlled sample, limiting their analysis to sites lacking migratory fauna, under the assumption that this would mitigate the potential noise produced by seasonal variation in the frequencies of taxa (Betts *et al.* 2011). Because the trends of interest are manifest over long periods of time and could be potentially masked by seasonal variation in the availability of prey species, this seems a reasonable decision. Indeed, lacking migration-control, patterns of relative abundance can

in fact be very noisy and difficult to interpret. Consequently, the first analysis presented here follows the lead of Betts and colleagues, focusing on remains derived from sites XFP-111, XFP-110, XFP-096, XFP-067, XFP-058, XFP-056 (Upper and Lower), and XFP-054 (Figure 5).

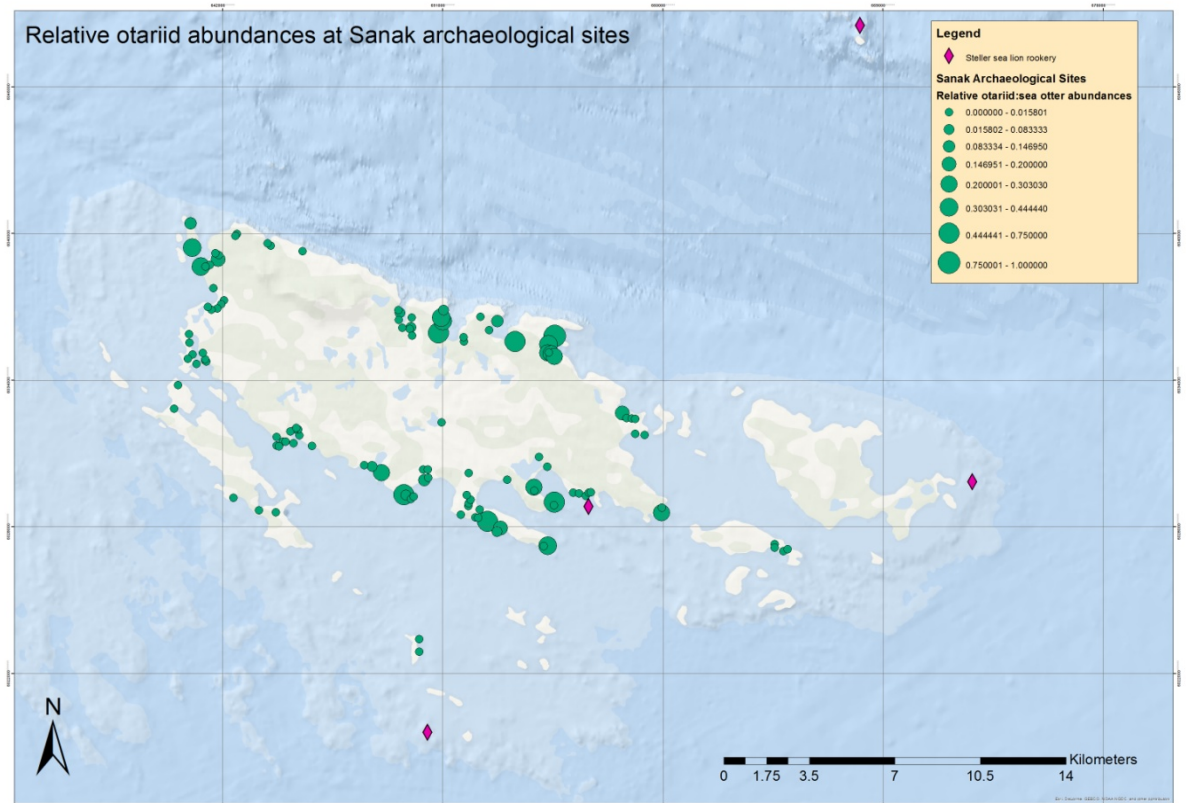


Figure 4: Relative otariid abundances for Sanak Island archaeological sites. Abundance measures averaged for sites with multiple dated components for purposes of representation. Dated components are treated separately in analyses.

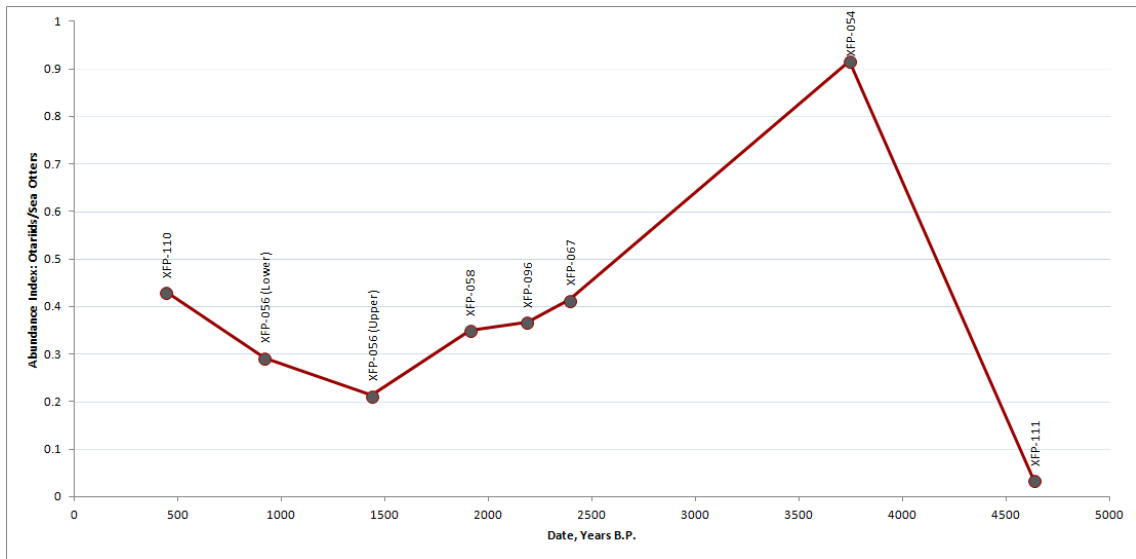


Figure 5: Migration controlled sample, using the same sites employed by Betts et al. 2011. Relative otariid abundance tracks will with their analysis in the years between ca. 4600 BP and ca. 2000 BP. The apparent depression around 1500 BP, however, is absent from previous analyses.

During the first 2500 years of the Sanak faunal sequence, from ca. 4500 BP to 2000 BP, the relative abundance of otariids tracks closely with that presented by Betts et al. (2011). Deviations are likely explicable as products of error associated with counting decisions. Between 3800 and 3700 BP, relative otariid abundance peaks at 0.833. Encounters with highly ranked prey during this period are clearly frequent, allowing the human population of Sanak to forage efficiently on a narrower range of prey species. Otariid abundances decline thereafter, but whereas Betts and colleagues found a decline that terminated around 2000 to 1900 BP, followed by a peak in relative otariid abundances between 1500 and 1400 BP, the present analysis reveals a clear depression – a continuation of the trend in otariid declines that began around 3700 BP. Methodologically, the cause of this disparity is clear: Betts and colleagues were not working with a complete record of Sanak fauna. The newly analyzed samples included significant amounts of material from Upper XFP-056, which contained large quantities of otter bone. While the previous analysis accounted for 49 sea otter elements, the present

analysis accounts for 196. The clear indication is that the inhabitants of Sanak Island ca. 1500-1300 BP were harvesting large amounts of sea otters relative to otariids, precisely the type of signature commonly interpreted as a depression in the encounter rate with higher ranked resources.

Adopting a migration controlled sample as a target for analysis is a pragmatic choice, primarily because it greatly minimizes the noise that might be introduced by seasonal variation. However, it also has the effect of substantially reducing overall sample size. In an analysis of temporal variation in animal abundance on Sanak Island, it reduces the number of data points from 96 potential sites to 7. Because such a reduction in sample size has the potential to introduce distortion of its own, a number of analyses are here presented that use a larger number of Sanak Island sites and regression analysis with a LOESS smoothing technique to understand long-term patterns in subsistence change. LOESS was chosen specifically because its method of locally weighted polynomial regression should paint a clear picture of temporal variation.

For the purposes of the present analysis, there are two interrelated samples of interest. The first is the sample of faunal elements that comprise the entire assemblage for any given site. The second is the sample of individual abundance indices yielded by each site. In an attempt to understand the influence of sample size on the resulting LOESS curves, several analyses were carried out, using all sites with a total NISP greater than 100 ($n = 55$) (Figure 6), a total NISP greater than 300 ($n = 54$) (Figure 7), and a total NISP greater than 500 ($n = 48$) (Figure 8). An additional analysis looks at all sites with a total combined otariid and sea otter NISP greater than 10 (Figure 9). For the analyses based on total NISP, three different abundance indices were employed, each targeted at tracking

the relative abundance of otariids over time. As with the migration controlled sample, the first abundance index is that tracking otariid exploitation relative to sea otter. This analysis was supplemented with an analysis of otariid/phocids AI and otariid/all other sea mammal AI.

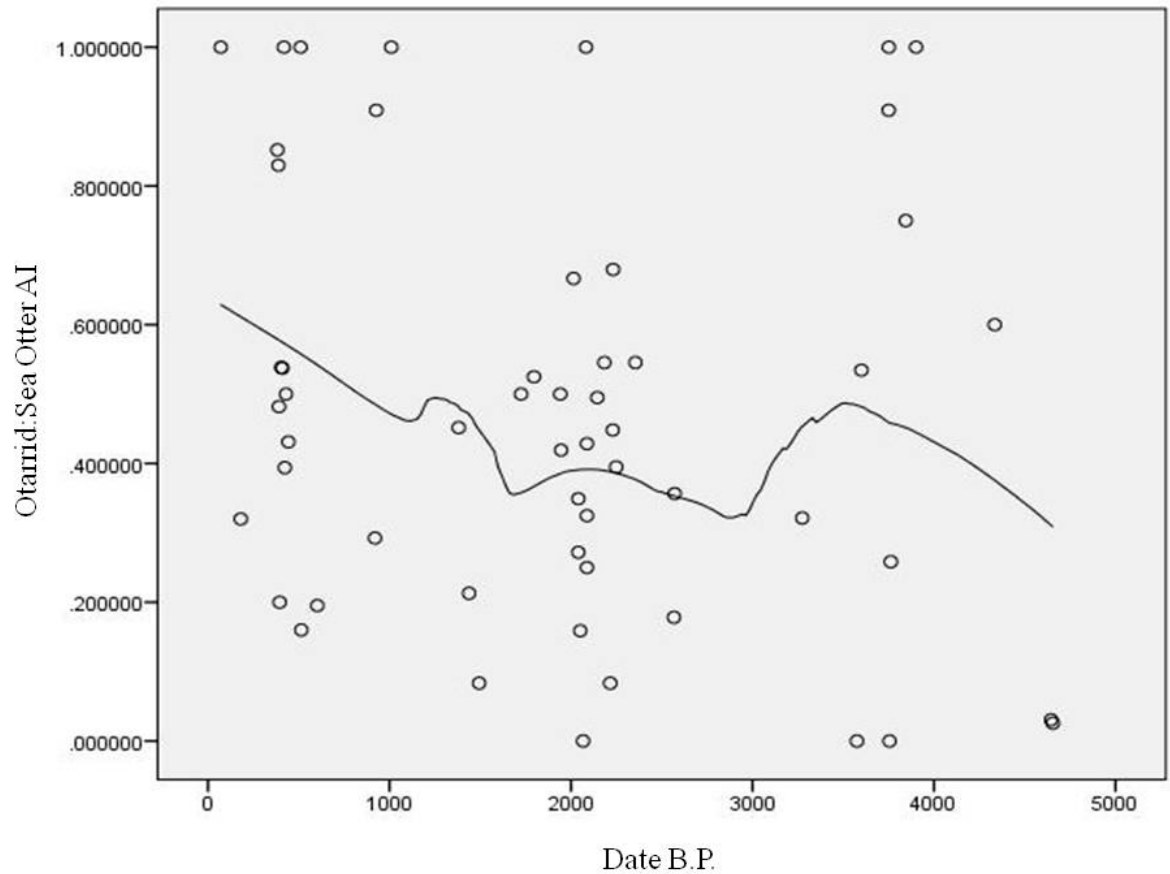


Figure 6: Otariid:sea otter abundances for the NISP >100 sample.

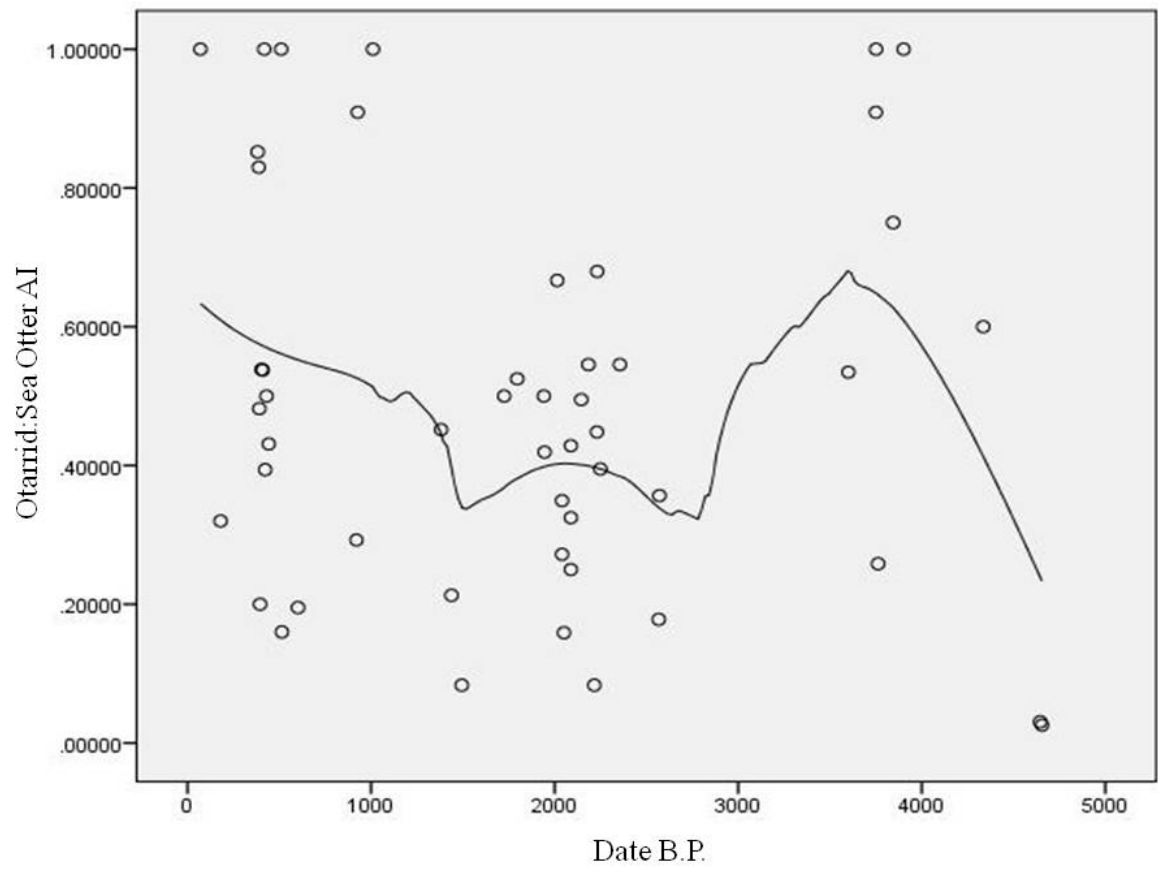


Figure 7: Otariid:sea otter adundance indices for the NISP > 300 sample.

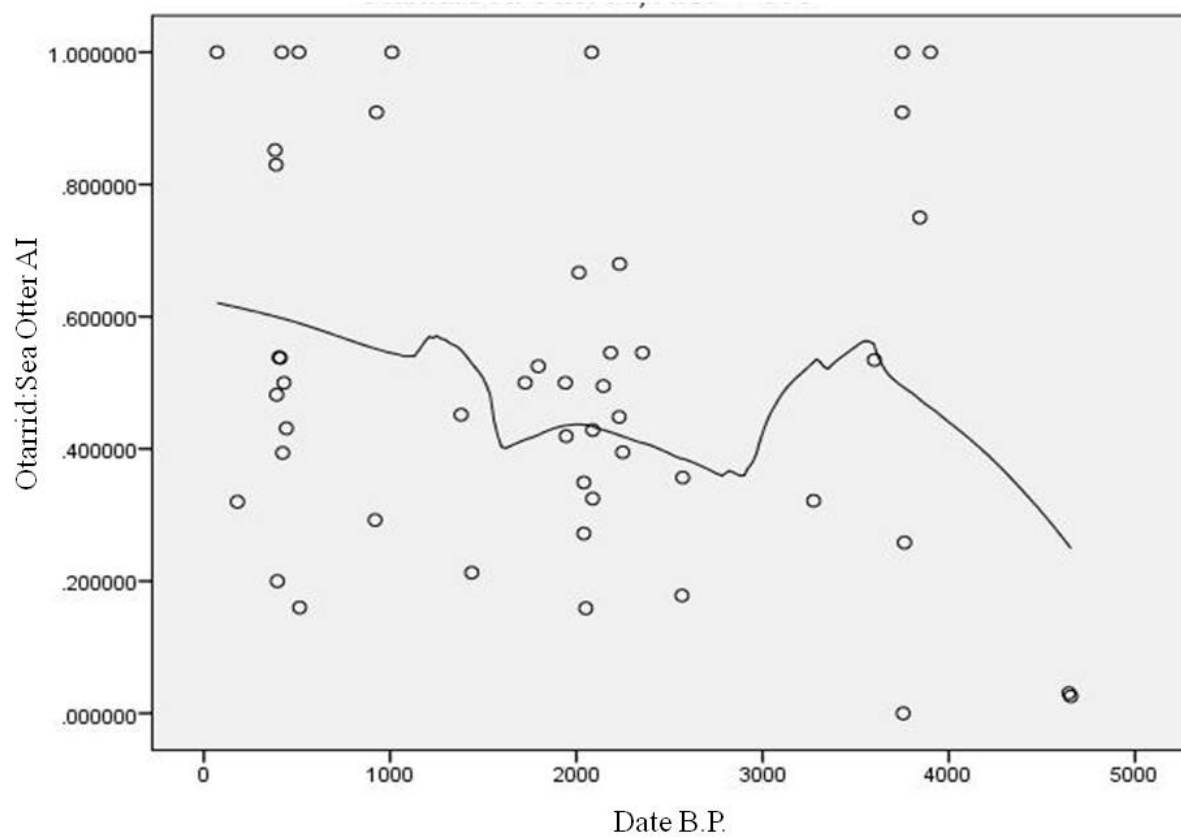


Figure 8: Otariid:sea otter abundance indices for the NISP > 500 sample.

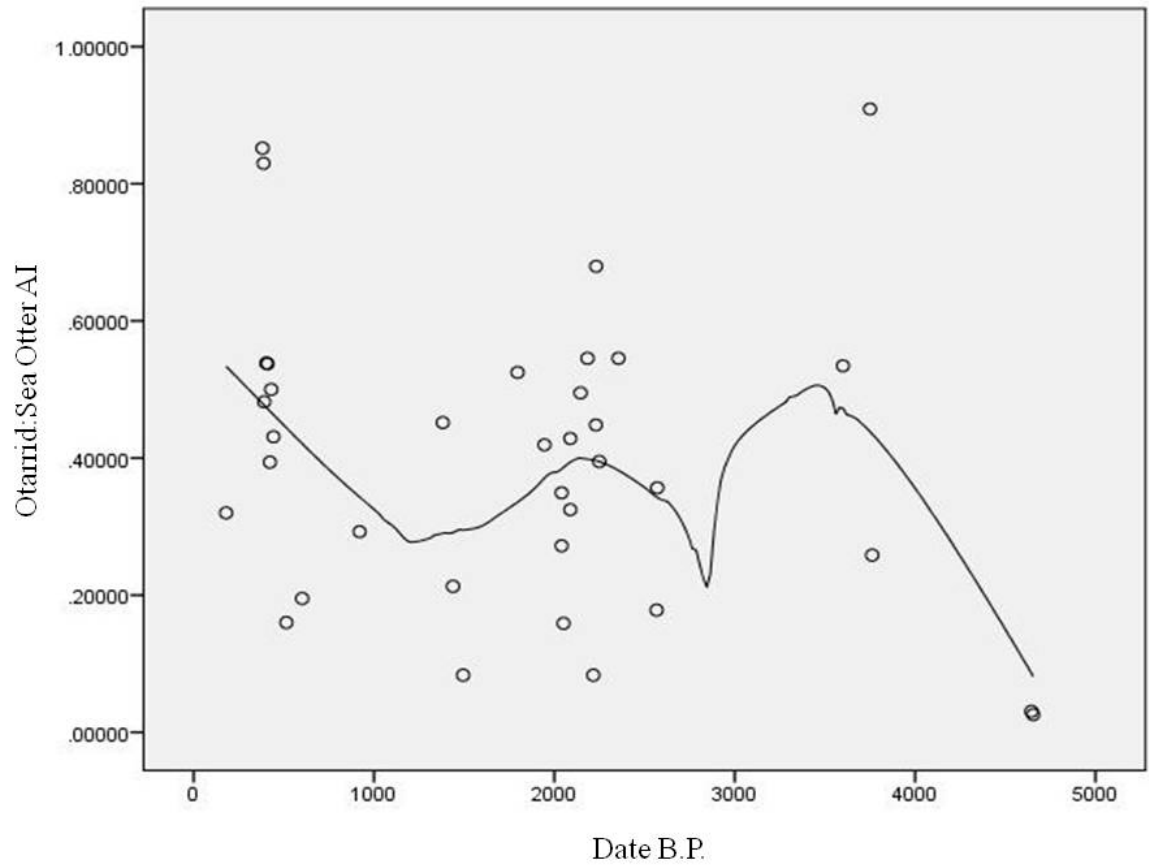


Figure 9: Otariid:sea otter abundances for the summed otariid, sea otter NISP > 10 sample.

Looking at the resulting curves for otariid/sea otter abundance, the most striking feature is how similar their general form is to that derived from looking only at the migration controlled sites. Year-to-year (or, more precisely, date-to-date), the larger samples display considerable variation. But the long-term trends revealed indicate the centuries following the initial colonization of Sanak were marked by increasing returns from investment in the pursuit and capture of large, highly ranked otariids. Returns peaked around 3500 BP, at which point they began to decline, reaching a nadir sometime around 3000 BP.

Less surprising than the similarity between the migration-controlled sampled and the larger samples employed for the analyses here is their mutual similarity. The primary purpose of repeating the same analysis with the relatively minor variations in total site sample-size achieved between a total NISP of 100, 300, and 500 was to test whether or not sample-size played a strong role in dictating the final shape of the curve. If this were the case, one would expect each successive weeding of the total sample of Sanak sites according to increasing NISP to remove some of the results that might be most directly attributable to low sample size: sites with an AI of 1.00 or 0.00, in particular. This did not occur. Instead, there is substantial similarity between the curves produced with each sample. Foraging on otariids appears to yield ever increasing returns in the first millennia following the colonization of Sanak before declining to nadir around 3000 BP. At this point, foraging returns remain low for around 1500 years, with a minor uptick ca. 2000 BP. Then, around 1500-1300 BP, there is sudden resurgence in otariid harvesting. This trend continues to increase into the era just preceding Russian contact.

A final test of the effects of sample size used the sum of otariid and sea otter elements ($\text{otariid NISP} + \text{sea otter NISP} > 10$) as the selection criteria (Figure 9). This is reasonable, given that these are the taxa of interest. Nevertheless, this does run the risk of introducing undue artificiality, granting that AIs researchers perceive as aberrant (1.00 and 0.00) are within the realm of possibility. Again, there is an upward trend in otariid exploitation, peaking around 3500 BP and declining until 3000 BP. However, there is resurgence in harvesting that deviates considerably from the previous three analyses, with AIs in excess of 0.40 just prior to 2000 BP. Thereafter, harvesting declines until around

1300-1100 BP, at which point otariids are harvested in greater and greater numbers relative to sea otters well into the historic period.

The deviation between the analysis based on sum of otariid and sea otter remains and the analyses based on total NISP clearly indicates that the choice of sample size plays a role in sculpting the shape of the results. Yet it is difficult to discern which way the error cuts. Potentially, the otariid + sea otter > 10 sample is a more accurate reflection of the foraging patterns on Sanak Island. Another possibility is that this analysis biases the result toward one that matches the researcher's preference for AIs that *seem* more natural. Lacking an independent baseline for comparison, it is difficult to tell one way or the other.

That being the case, there is still much to be gleaned from the places where the results from all of these analyses align. In every case, the earliest inhabitants of Sanak seem to be getting a very good living from otariid harvesting in the first 10 to 12 centuries following their arrival – sufficient, in any case, that they need to invest less and less effort in pursuing a smaller, less calorically rich prey species like sea otters. This lasts until about 3500 BP, at which point otariid remains began to decrease relative to those of sea otters. In four out of the five analyses (migration controlled, NISP > 100, NISP > 300, NISP 500), there is a signature of a depression in otariid abundances that terminates sometime around 1500 to 1300 BP – broken by a small hump between 2400 and 2200 BP. The otariid + sea otter NISP based sample deviates, indicating depressions around 2900 to 2800 BP and 1300 to 1100 BP. All these analyses realign with otariid abundances increasing into the historic period.

Though there is some discrepancy regarding its date of onset and duration, the signature of a prehistoric depression in otariid abundance is clear. Identifying its precise cause is problematic. Previous analyses demonstrated a clear association between otariid abundance and climatic regime, with otariid populations peaking during colder periods characterized by high primary productivity. With these fresh analyses, that pattern remains throughout much of the sequence, suggesting climate was often a critical driver in the relationship between humans and otariid abundances. However, there is a point at which the overall pattern is disrupted. The 1500-1300 BP depression in otariid abundances, followed by a sharp increase in otariid abundances, occurs during a high productivity cool period, making the relationship between otariid population patterns, climate, and primary productivity during this phase a bit more nebulous. On the one hand, the points of overlap among the above analyses strongly suggests the patterns they reveal are real. On the other, they expose a situation in which the relationship between prey abundance and climatic regime becomes less straightforward during the final 1500 years of the sequence. Irrespective of the analysis in focus, the 1500-1300 BP depression in otariid abundance occurs during a presumed cold period when productivity is likely high and conditions should be ripe for supporting healthy otariid populations (Figure 10). Because the general pattern of decline that terminates around 1500-1300 BP extends into a cold, high productivity period, the implication that the depression in relative otariid abundances during this phase is at least partially attributable to human behavior is compelling. Nevertheless, three additional points are worth stressing: (1) that the 1500-1300 BP depression appears to be a continuation of a trend that began in the preceding period of relatively warmer climatic conditions, (2) that the steep climb out of the

depression also takes place during a period of relatively cooler temperatures, and (3) that the error range for the ^{14}C is sufficiently large (± 150 years) that the apparent overlaps between patterns of otariid exploitation and climate regime should be approached with circumspection.

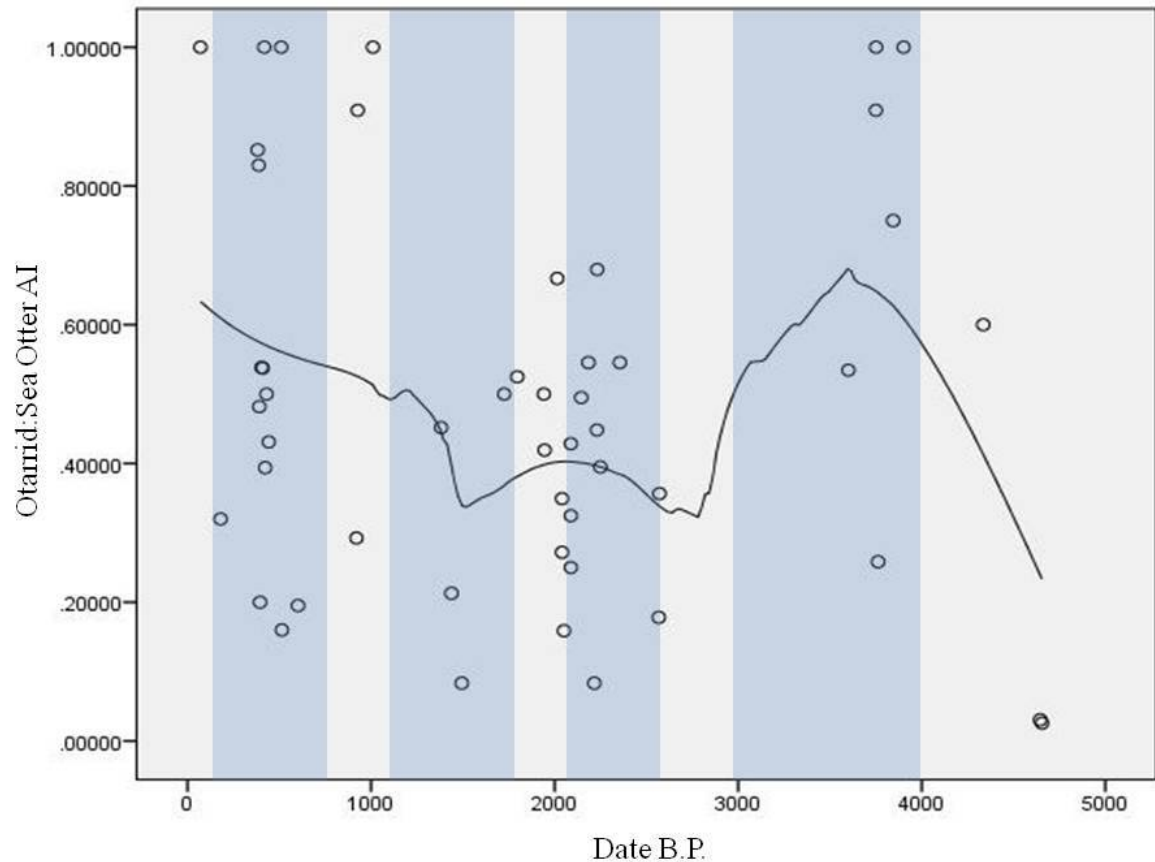


Figure 10: Climate regime and relative abundances for the NISP > 300 sample. Shaded blue bars indicate periods when sea surface temperatures were cooler and primary productivity higher.

Following the interpretation forwarded by Betts *et al.* (2011), it is reasonable to explain the initial peak in otariid abundance as the result of a naïve population heavily exploited by novel predators. Unfamiliar with humans and the predation risks they posed, Stellar sea lions and northern fur seals frequenting the haulouts and rookeries around

Sanak were initially ill-prepared to cope with the new threat. Over time, it is reasonable to expect that this would have eventually resulted in a depression in the otariid population around Sanak. In this regard, it is worth keeping in mind that the types of depression are not mutually exclusive. Otariids very likely would have declined in actual numbers as a result of human predation. At the same time, otariids would likely have adopted behavioral strategies that would have reduced encounter rates, moving to rookeries and haul-outs outside the range of human foragers and employing escape tactics more effective against human hunting techniques. This is particularly true if populations maintain some level of long-term fidelity to rookery locations, such that knowledge of human predation is more or less continuous (Calkins & Pitcher 1982). That is, individuals would be familiarized with human predation risk through purely ontogenetic processes shortly after birth, and would carry that knowledge with them when they return to rookeries at sexual maturity. Given some consistency in human predation, overlap between generations would encourage long-term behavioral adjustments, even in the absence of strictly genetic adaptations to the selective pressures associated with human predation.

Under these conditions, one can expect the following:

- Decline in absolute otariid abundances around Sanak Island as the local population declines, buffered by infill from the surrounding metapopulation as a product of male-male competition for rookery locations

- Changes in otariid behavior, including trends in movement to more distant rookeries and haul-out locations, as well as the adoption of escape tactics more effective against human predation

These points are critical to the development of a coherent explanation for the depression in otariid numbers evident in the updated analysis of the Sanak faunal record. However, absent contextualization with additional lines of evidence, their information content remains – in many respects – largely ambiguous. It is clear that climate is not a prime mover in dictating patterns of otariid exploitation on Sanak, and this alone is enough to suggest that it is worth looking to the human population for an explanation. However, it is unclear precisely what humans might have been doing – how their behavior or pursuit tactics might have changed – to produce the patterns apparent in the faunal record. Consequently, it is worth taking a moment to discuss archaeological evidence pertaining to regional patterns in human occupation, changes in archaeologically resilient harvesting technology, and trends in subsistence as illuminated by isotopic analyses of human skeletal remains.

The prehistory of human occupation of Sanak Island is characterized by intervals of population expansion and decline that have tended to covary with cold and warm climatic regimes (Maschner *et al.* 2009a & 2014; Betts *et al.* 2011). Using the number and area of house floors, village areas, and the distribution of radiocarbon dates, Joseph Cornell developed a probabilistic method of estimating the population of Sanak Island (Maschner *et al.* 2009a). These estimates, in comparison with the LOESS curves presented in above, immediately reveal a curious trend. Beginning around 5000 BP, populations – as indicated by the house floors, village areas, and radiocarbon date

distributions in a probabilistic population estimate (Maschner *et al.* 2009a) – are relatively low. They increase over the next 1500 years, roughly in sync with the relative abundance of otariid remains in the faunal record. It is important to keep in mind, however, that the actual human population during this period is low in comparison to later periods. Though there is considerable variation in the occupation index, the general trend from ca. 3500 BP and around 3000 BP is one of decline, at which point they experience another uptick. Another decline runs from ca. 2000 BP to 1700-1600 BP, at which point populations again increase steeply, followed by a large and rapid decrease around 900-700 BP and a pronounced resurgence around 700-600 BP, at which point the human occupation index indicates populations several times larger than those experienced around the point of peak otariid abundance, ca. 3500 BP, and roughly twice those experienced during the 2500-2000 BP peak.

The 1500-1300 BP depression in otariid abundances coincides with a general increase in human populations. In the behavioral ecology literature, such a divergence is typically interpreted as a signal of a broadening of the dietary spectrum, precipitated by the pressures an expanding population exerts on the resource base (Kaplan & Hill 1992; Winterhalder & Kennett 2006). An interpretation along these lines is not unreasonable – humans have a remarkable facility to respond flexibly to changing ecological conditions. Nevertheless, the fact that otariid abundances increase over the subsequent centuries, reaching a peak not seen since 3700 BP between 500-400 BP – when human populations are at their highest – suggests a less unequivocal explanation. This is not to suggest that a broadening of the diet does not partially explain long-term changes in foraging patterns on Sanak, but rather that there is more at work than people simply eating more a wider

variety of taxa to buffer population induced resource stress. Indeed, prominent peaks in the human population index (i.e. ca. 4500-3000 BP, ca. 700-400 BP) correspond with higher than average relative otariid abundances ($\bar{X} = 0.471638$ for the NISP > 100 sample). This defies interpretations that would link diet breadth with population size and resource pressure resulting from the same, because the population of Sanak seems to have harvested relatively *fewer* lower ranked species during periods when population size would have presumably created the highest levels of resource stress.

In the earliest phases of occupation, the explanation is obvious. Though there is a peak in population, the actual number of people living on Sanak remains relatively low. There are plenty of otariids to go around and – as previously discussed – they are largely ignorant to the threat posed by humans. However, during the latter phase of the sequence, the alignment between relative otariid abundance and markedly increased population size is mysterious. Here, data derived from changes in hunting technology (Maschner *et al.* 2014) and the isotopic signature of human remains (Coltrain *et al.* 2006; Maschner *et al.* 2013; Misarti & Maschner 2014) proves most instructive.

Beginning with the colonization of the North Pacific, ca. 5000 BP, the prehistoric toolkit includes large, thrusting spears, over 120 mm in length (Figure 10). This is a point design consistent with the harvesting of large, shore-bound animals. During this period and the succeeding centuries, the human population of Sanak is low and, as indicated by the faunal record, otariids are increasingly plentiful. Assuming – as reported in 19th century ethnographic accounts (Turner 2008) – that marine transport technology is limited to boats incapable of reliably navigating rough waters or making long trips out

into deep water, the preferred harvesting strategy would have been killing easily accessible, shore-bound animals at nearby rookery and haul-out locations.

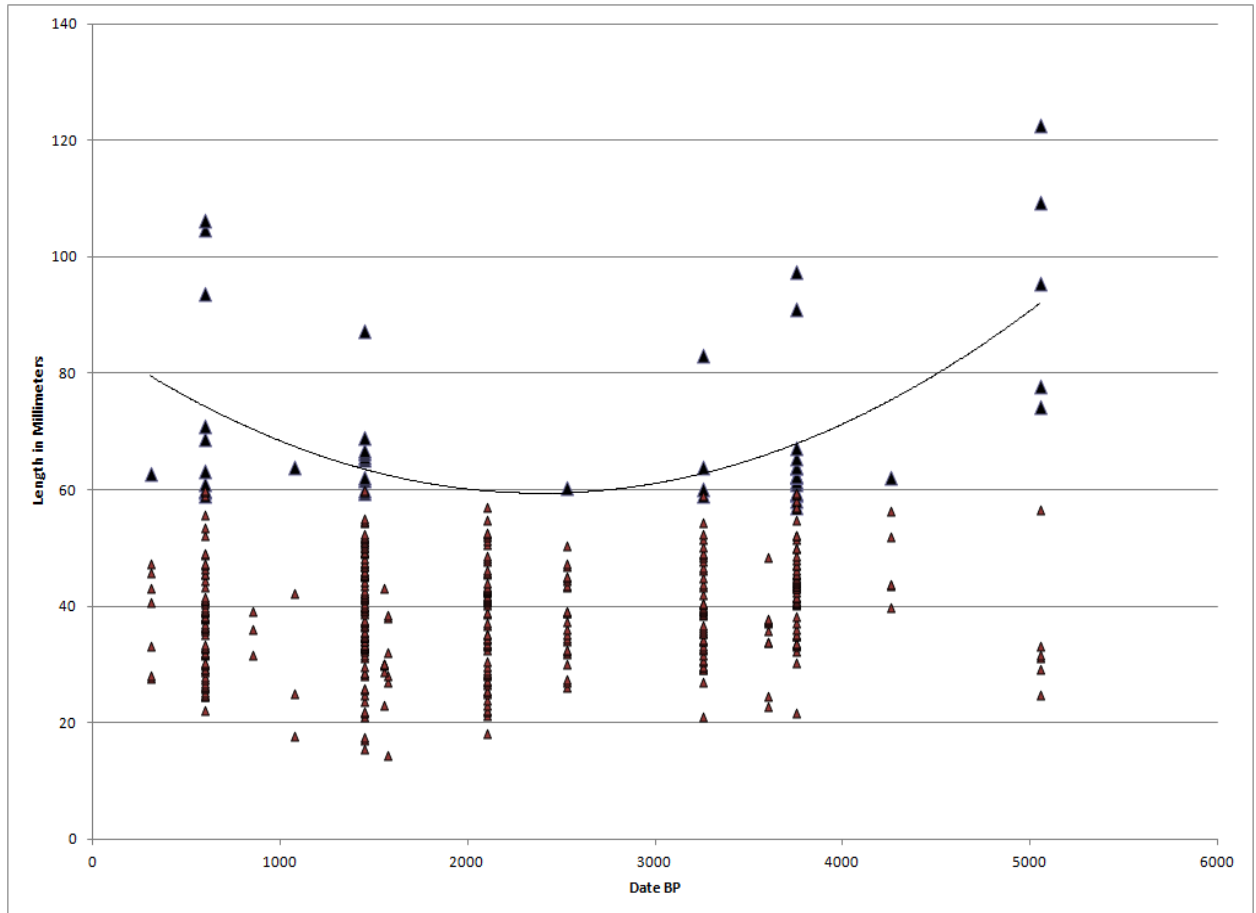


Figure 11: Temporal changes in stone point length. Projectiles above 60mm in length are considered likely thrusting blades. They are presented in black, with a curve tracing the temporal frequency of points of different length. Smaller points are likely projectiles (arrow or atlatl dart points). They are presented in red.

Over time, as human population numbers increased and the threat of human predation became more and more consistent, otariid populations likely responded by both moving to less accessible rookery and haul-out locations and adopting more effective escape tactics. Depending on the precise harvesting strategy used (targeting female vs. male otariids), human exploitation could also have depressed the actual number of animals in the local population. With fewer large animals within reach, the length of end-

blades declines steadily, resulting in a trough that corresponds with the decreased relative otariid abundances shown from ca. 2900-2800 BP to 1500-1300 BP in the NISP > 100, NISP > 300, and NISP > 500 samples. Maximum end-blade length during this time is just in excess of 60 mm.

After 1500-1300 BP, end-blades lengths once again trend upward – with a brief decrease around 1000 BP – following the trend in otariid abundances seen in the Sanak Island faunal record. By 1300-1200 BP, end-blades in excess of 120 mm reappear. This yields two obvious potential explanations. First, that there has been resurgence in the otariid population around Sanak Island. Second, that the people occupying Sanak Island during the centuries preceding the historical period have access to a population of shore-bound animals that they did not have access to previously. Given what we know of otariid behavior, the latter seems most likely. There is at least one point at which the human occupation index suggests Sanak might have been entirely abandoned by humans (Maschner *et al.* 2009a), temporarily releasing the local otariid population from the threat of predation, but this is at a point well before the 1500-1300 BP climb in relative otariid abundances and end-blade lengths. In the preceding centuries, human populations were very likely high enough to maintain consistent pressure on any otariids occupying any nearby rookeries and haulouts. It is therefore reasonable to assume that the pattern of depression evident in the faunal record, induced as a direct product of local population depletion (buffered by infill from the surrounding metapopulation) or behavioral adjustment in the form of improved escape tactics and relocation, would have remained consistent throughout this period. Otariids around Sanak Island remained as difficult to locate and/or capture after 1500-1300 BP as they did previously. In conjunction with the

pattern of increasing relative otariid abundances, the changes in end-blade length signify access to a source of shore-bound animals that the inhabitants of Sanak did not have access to in preceding centuries.

The argument here is that the newfound access to previously unavailable otariid populations was facilitated by innovations in boating technology, in particular the development of the historically recognized, closed-hulled, ocean-going kayak (or something like it). The development of such a craft would have lifted some of the foraging limitations implicit in less stable and resilient technologies, allowing people to travel farther under a wider variety of conditions – including inclement weather that would have rendered previous maritime craft untenably dangerous. By alleviating a number of the constraints and costs associated with the use of less stable precursors, the invention and widespread adoption of closed-hulled, ocean-going kayaks represented a fundamental modification of the Aleut optimal foraging landscape. The signature of these changes is apparent in the steady increase in relative otariid abundances over the final 10 or 12 centuries preceding the historical period and the reintroduction of a toolkit consistent with reliable access to rookeries and haul-outs.

That Aleut peoples living on the Alaska Peninsula experienced a pronounced shift in foraging tactics around 1500-1300 BP is further corroborated by data derived from stable isotope analyses of human remains uncovered in 80 burials in the Umnak Island region in the Aleutians, several hundred kilometers west of Sanak (Coltrain *et al.* 2006; Maschner *et al.* 2014; Misarti & Maschner 2015). Variations in the proportion of stable isotopes present in animal tissues have been shown to provide a reliable measure of trophic position (DeNiro & Epstein 1984; Michener & Kaufman 2007; Misarti *et al.*

2009; Middelburg 2014). In marine environments, levels of $\delta^{15}\text{N}$ increase roughly 3% for each step up the chain of trophic interaction (Misarti *et al.* 2009). Higher $\delta^{15}\text{N}$ are therefore indicative of higher trophic level feeding, and can be used to gain invaluable insight into the nature and composition of prehistoric diets.

The skeletal material collected from the area around Umnak Island includes remains that date from 3600-3500 BP up to the just before the onset of historical period, ca. 300 BP. Stable isotope analyses conducted on these remains paint a picture of long-term subsistence trends that corresponds remarkably well with the trends revealed in the Sanak faunal data (Maschner *et al.* 2014). At the beginning of the sequence, $\delta^{15}\text{N}$ values start out relatively high and then consistently decline, reaching a nadir sometime around 1500-1300 BP. Thereafter, $\delta^{15}\text{N}$ values trend upwards, increasing steadily and steeply until around 500-400 BP, at which point they begin to taper off. This is precisely what one should expect to see if high trophic level otariids – in particular Stellar sea lions – are making up a larger and larger proportion of the Aleut diet. These data, should, of course, be interpreted with appropriate circumspection. Temporal variation in within species isotope ratios can be produced entirely by ecological factors and may in fact exceed the level of variation seen between the 1500-1300 BP nadir and 600-500 BP zenith (Misarti *et al.* 2009; Misarti & Maschner 2014), suggesting the increased $\delta^{15}\text{N}$ ratios could be attributable to factors entirely external to the predator-prey relationship between humans and otariids.

Notwithstanding, the correspondence between the increase in trophic level feeding apparent in the isotopic data and the increased relative abundance of otariids in the Sanak faunal record is difficult to ignore. The relationship is rendered even more

compelling when one notes that the upward trend in $\delta^{15}\text{N}$ ratios and relative otariid abundances cut across different climate regimes, with the increases beginning in cooler regimes and carrying steadily through subsequent phases of warm and cool temperatures, thus discounting the explanatory significance of climate. Coupled with the distance between Umnak and Sanak, this represents evidence of a pronounced, region-wide shift in foraging behavior. This is precisely the kind of change one should expect to see following the invention or introduction of a competitively advantageous addition to the toolkit, such as was seen with the rapid diffusion of new bow and arrow technology following the introduction of the Asian War Complex in North America (Maschner & Mason 2013).

To reiterate, the Sanak faunal record provides an index of temporal subsistence change, revealing long-term patterns of decline and increase in the relative abundance of highly ranked prey species (Figure 12). Given what is known of otariid behavior, it is reasonable to interpret decreases in their relative abundance beginning around 3500 BP as resulting from ontogenetic responses to the increasing threat of human predation. Otariids would have adopted more effective escape tactics and relocated to less accessible rookeries and haulouts to avoid human hunters, resulting in a general trend of mutually reinforcing behavioral and microhabitat depression, culminating in a relative low around 1500-1300 BP, after which relative otariid abundances increase steadily. This can be interpreted one of two ways: either the actual population of otariids has increased, or the Aleut living on Sanak are exploiting populations of otariids to which they did not previously have access. Changes in harvesting technology, in particular increases in the length of thrusting spear points used to dispatch large shore-bound animals, lends

credence to the latter hypothesis. Finally, increased ratios of $\delta^{15}\text{N}$ indicative of a shift toward higher trophic level feeding further corroborates the hypothesis that the people of the Aleutian Islands and Alaska Peninsula are able to more consistently access highly ranked otariids than they had in the centuries preceding the 1500-1300 BP. Adjustments in foraging tactics precipitated by innovations in boating technology, allowing hunters to travel farther under a wider range of conditions, are a strong candidate explanation for the aforementioned trends.

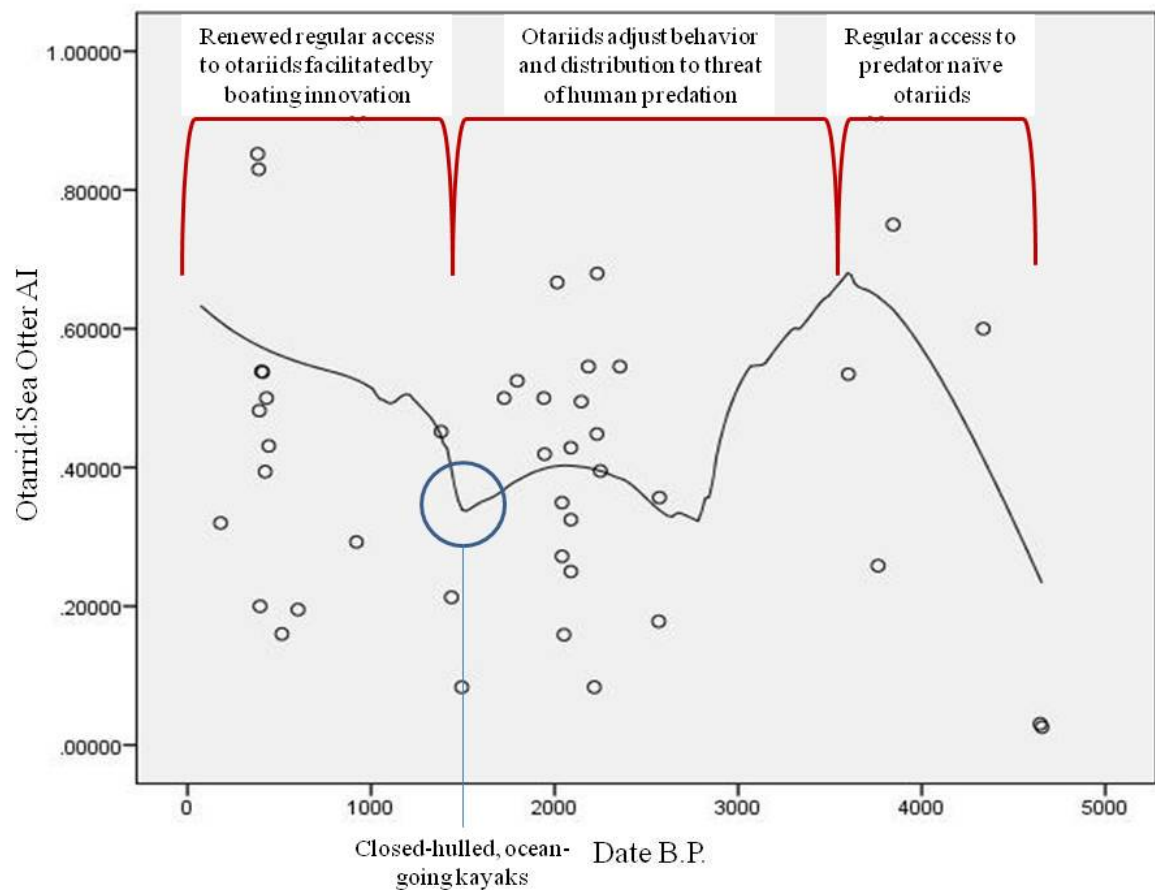


Figure 12: Changes in relative otariid abundance from NISP > 300 sample. Red bars indicate patterns of otariid behavior and changes in human foraging strategy that would have influenced encounter rates.

Chapter Six: Regional Interaction, Social Change, and Increasing Social Complexity

Beginning around 1000-900 BP with the transition to the Late Aleutian Tradition, the archaeological record of the Aleutian Islands and Alaska Peninsula provides evidence for marked increases in regional interconnectivity and socioeconomic complexity. These are region-wide changes, from the far islands of the Western Aleutians (Corbett *et al.* 1997) to Kodiak Island in the Gulf of Alaska to the east (Maschner & Reedy-Maschner 1998; Fitzhugh & Kennett 2009). Broadly speaking, material culture across the Alaska Peninsula and throughout the Aleutians begins to exhibit some early affinity with that recognized in the pertinent ethnographic literature (Maschner 2000).

Among the more pronounced and archaeologically salient changes to occur around this time is a shift in settlement patterns and village organization (Maschner 1997). Villages in some places are smaller, but the houses of which they are comprised are larger – in the range of 150-300m² (Maschner in press). This is not an isolated change, with house sizes throughout the region quadrupling within a relatively short range of time (Fitzhugh 1996; Maschner & Reedy-Maschner 1998; Hatfield 2010). These are large nucleus-satellite houses, likely inhabited by single lineages (Maschner & Hoffman 2003) and reliably interpreted as indicative of an increase in social complexity (Maschner & Patton 1996).

Elevated levels of regional interaction – often acrimonious in nature - are evident in a roughly contemporaneous increase in the number of fortifications throughout the region and increased incidences of skeletal trauma (Maschner & Reedy-Maschner 1998; Hatfield 2010). Fortifications predate the 1000-900 BP shift in settlement organization,

but become much more frequent thereafter (Maschner & Mason 2013). These are often structured around some inherently defensible feature of the natural landscape, offering both superior views of the surrounding area and decreased accessibility for aggressors (Maschner & Reedy-Maschner 1998). Human skeletal remains display evidence of scalping, decapitation, depressed skull fractures and other signals of violence (Maschner & Reedy-Maschner 1998). A concurrent increase in the number of arrow points, likely associated with the recurve and backed bows of the Asian War Complex – highly effective against humans, less-so for hunting marine resources from boats – further corroborates the emerging picture of violent regional conflict (Maschner & Reedy-Maschner 1998; Maschner & Mason 2013).

Social interaction is further evident in the changing distribution of material culture. Prior to 1000 BP, sites in adjacent regions develop along relatively distinct trajectories (Misarti & Maschner 2015). Thereafter, sites display increasing levels of regional continuity in the use of raw materials and ceremonial objects (Corbett *et al.* 1997; Misarti & Maschner 2014), as well as elevated levels of within-site variation (Hatfield 2010). In particular, there is an influx of characteristic ground slate artifacts from Kodiak in the east, including semilunar ulu blades (Hatfield 2010; Misarti & Maschner 2014).

The influx of tools and raw materials from Kodiak is accompanied by an influx of new genetic material. Based on craniometric variation, Hrdlička suggested a distinction between Paleo and Neo-Aleut populations, beginning around 1000 BP – an argument that seemed to be further substantiated by stable isotope (Coltrain *et al.* 2006) and mtDNA analyses (Smith *et al.* 2009). However, it is not necessary to postulate anything like a

large scale migration or population replacement event to explain these changes. When carefully contextualized with contemporaneous archaeological evidence, it seems just as likely that the minute changes in the frequency of mtDNA haplogroups on the Alaska Peninsula and Eastern Aleutians could result from increases in regional interaction and altered marriage practices that facilitate and influx of women from the east (Misarti & Maschner 2015).

The relationship between seafaring practices, regional interaction, and social change has been discussed elsewhere (Arnold 1995; Arnold & Bernard 2005; Fitzhugh & Kennett 20010). Fitzhugh and Kennett (2010) in particular link increasing seafaring intensity with demographic processes and associated rises in social, political, and economic complexity, arguing that elevated levels of intra- and inter-community competition might have served to mitigate the potential risks involved in persistent maritime activity by effectively increasing the potential status rewards gleaned from behaviors like high-risk open-water hunting. They posit that mutually reinforcing trends involving growing levels of regional interaction and social complexity stimulated previously unseen levels of marine resource exploitation, particularly in the last 900 years of human activity around Kodiak.

Fitzhugh and Kennett make a compelling case. The exploitation of marine resources is a risky endeavor, regardless of technology, and it makes good sense to argue that infusing said practices with the additional social value associated with status-seeking behavior would shift the balance of costs and benefits beyond what might be observed under purely economic considerations. However, unless the status rewards are immense, it is also reasonable to posit a minimum safety threshold, beyond which the presumed

benefits of risky hunting strategies are offset by the potential costs. This is particularly true in the regions of the north Pacific and Bering Sea surrounding the Aleutians and Alaska Peninsula, where cold waters and rough seas decrease survivability in the event of capsize or some other calamity considerably. That elevated levels of social complexity and competition might precipitate increased seafaring intensity is not in dispute. Rather, the argument here is that lacking reliable boating technology, levels of regional interaction and marine resource exploitation are capped by environmental and geographical feature like storminess and distance.

It might be easy to fall into the trap of giving the aforementioned innovations in boating technology undue causal heft. This would be a mistake for any number of reasons, not least of which being that we lack the capacity to manipulate the relevant variables in manner that would provide compelling evidence for causation. But more fundamentally, for the argument at hand, it is simply worth clarifying that the development or introduction of closed-hulled, ocean-going kayaks did not cause the Aleut inhabiting Sanak to harvest more otariids – it simply opened up the possibility of doing so, and the people of Sanak seemed to have pursued it.

More foolhardy still would be any claim that the development of the closed-hulled kayak caused the elevated levels of regional interaction evident in the archaeological record in the centuries after 1500-1300 BP. Indeed, a number of potential explanations – most of which are not mutually exclusive – stand to offer valuable insight into the processes that both precipitated social change in the Aleutians and across the Alaska Peninsula after about 1000 BP. Prior to this time, levels of regional interaction and social complexity are relatively low (Maschner in press; Misarti & Maschner 2014). Thereafter,

they tended to increase – though not without interruption (Maschner *et al.* 2009b). Innovations in boating technology did not cause any of these changes. Nevertheless, there is a strong argument to be made that the development of maritime technology capable of reliably transporting people over long distances played a critical role in facilitating mutual reinforcing patterns of increasing social interaction and social complexity.

Identifying the precise patterns and processes that led to the development of the CHOGK in the Aleutians and on the Alaska Peninsula is, of course, problematic – as stressed earlier, the materials available for boat construction throughout the region were limited. Because boats were built of secondary raw resources derived from captured animals, they did not preserve well in the highly acidic soils that characterize most archaeological sites in the region, and as a result, there is no material record of chronological change available to directly assess the processes of invention and innovation at work. Nevertheless, it is worth taking some time to spell out some assumptions about the basic character of processes of technological change, as viewed through the lens of Darwinian theory.

Among the central themes of the current work is the ongoing program of attempting to situate cultural phenomena like technological change within a coherent Darwinian framework. This is a prospect that has generated considerable academic interest in recent decades and an accompanying host of theoretical insights and methodological advances (Boyd & Richerson 1988; Shennan 2002; Shennan 2009; O'Brien & Shennan 2010; Laland & Brown 2011; Mesoudi 2011; Richerson & Christiansen 2013; Okasha & Binmore 2014). The resulting literature is by turns broad and deep. Little surprise, then, that few (if any) researchers have been able to familiarize

themselves with – let alone master – all of it. A partial consequence of this is that academic discourse in relevant fields has been plagued with terminological and conceptual inconsistencies, such that terms like *fitness* and *adaptation* are sometimes employed in a manner that lacks coherence within the larger framework of Darwinian thought (e.g. referring to cultural traits as adaptations and attributing their persistence or success to fitness) or fail to gain explanatory traction when applied to specific phenomena like cultural change (Shennan 2013).

Considering the nascence of some of the pertinent fields of inquiry and the novelty of the questions they seek to answer, none of this should be cause for alarm – even in the realm of biological phenomena, terms like fitness and adaptation are subject to variety of interpretations, some differing subtly, others more meaningfully (Dawkins 1982; Fox & Westneat 2010). But central to any process of scientific discovery is the capacity for researchers within a field to operate within a shared paradigm, articulated with mutually compatible understandings of central concepts (Hull 1988 & 2001; Kuhn 2012). As a result, a central challenge for those concerned with articulating successful Darwinian explanations of human behavior is the task of being precise about what is meant by a term like *adaptation* in scenarios that often depend on multiple tiers of semantic information – ecological, ontogenetic, cultural, and genetic – for the development of comprehensive explanations.

Here, that has meant wielding the conceptual framework of niche construction and the powerful analytic tools of behavioral ecology to investigate a phenomenon with few direct causal linkages to variation in heritable genetic information. That is, natural selection and adaptation – in the strict Darwinian sense – do not have a meaningful role

to play in explaining the development of new technology or subsequent changes in foraging technology in the Aleutians and on the Alaska Peninsula. To be clear, that is not to say explanations for human behavior can ever be entirely divorced from genetic variation. Reduced to its most fundamental and general form, any given innovative process is bound to be guided by preferences that are, in the strictest Darwinian sense, *evolved*. Humans find certain behaviors psychologically rewarding and others outright unpleasant, and this basic array of positive and negative emotional responses to social and ecological stimuli almost certainly evolved because these responses have tended to serve as reliable proxies for determining which behaviors translate into positive or negative fitness outcomes (El Mouden *et al.* 2014). However, because these traits are practically universal (absent some kind of pathological condition) they do not make good candidates for explaining specific instances of behavioral variation (Bateson 2001). They are an indispensable component of the process by which non-genetic behavioral variation is generated, but their ubiquity robs them of the counter-factual quality (Woodward 2003) that would make them useful components of a conditional explanation for the development and consequences of boating innovation in prehistoric Alaska. Explanations of this kind are most fruitfully constructed of predominantly ontogenetic and cultural components.

This perhaps begs the question: if natural selection, adaptation, and genetic variation are not among the more important moving parts of a given explanatory framework, how then can it be properly described as Darwinian? On the most rudimentary level, the answer echoes a point spelled out above – absent an understanding of the suite of adaptations and evolved preferences that characterize the human animal,

explanations about why human beings behave the way they do lack the theoretical context necessary to imbue them with coherence. Human traits that exist because they are either highly conserved components of mammalian biology or adaptations resulting from selective pressure experienced throughout the Plio-Pleistocene are fundamental ingredients – along with historical contingency and the vicissitudes of cultural inheritance – in myriad recipes for human behavior. In other words, without our biological inheritance, the very existence of phenomena like status-seeking behavior (Maschner & Patton 1996) or a basic capacity for cumulative cultural evolution (Alvard 2003) would be inexplicable. Of course, this type of argument risks treading the potentially fraught ground of tautological truism – essentially reducible to something like “if certain initial conditions were different, subsequent things would also be different.” This is only true if one neglects to fully contextualize a given claim, removing it from the ether of pure theory and situating it within a set of potential causal relationships and empirical expectations (Sober 1984). That is, it still remains to be explained why humans exhibit the specific suite of evolved psychological propensities they do, and what the consequences of those propensities are in any given situation. Moreover, it is worth remembering that tautology is something of a framing problem. It has to do with how researchers view and describe the targets of their investigation and does not actually impinge on the reality or behavior of the phenomena in question (Dawkins 1982; Sober 1984).

On a more pragmatic level, explanations of the kind at issue here export Darwinian principles – variation, inheritance, competition – from the realm of purely biological evolution and generalize them in a way that can be fruitfully applied to an

investigation of any process that involves variation in transmissible traits that cannot proliferate indefinitely (Mesoudi 2011). Natural selection might not fully explain innovation in boating technology and subsequent foraging decisions, but selection of a more general kind almost certainly does. In the abstract, human agents have a multitude of options for learning and behavioral expression, but in the physical execution of any given task that multitude is inevitably narrowed down to a relatively small subset – usually just one. Any given individual might start her day with dozens of potential tasks she might accomplish, hundreds of sources of information to which she might turn her attention, but the finitude of time ensures she will only get to a few of them. Processes of selection therefore narrow possibilities, which are themselves built from variation in knowledge, behavior, inclination, and opportunity that have been shaped by the inheritance and transmission of vast stores of cultural information, ecological conditions, and genetic variation – including evolved predispositions that, in aggregate, tend to guide patterns of cultural innovation and evolution down adaptive pathways (Boyd *et al.* 2013).

Presumably, the suite of individual insights and inventions that bridge the gap between expedient boating technologies to more reliable open-hulled craft to something like the ethnographically recognized CHOGK accumulated gradually. Though colloquial understandings of innovation are filled with accounts of the lone geniuses making startling advances in relatively short order, these are typically – if not in fact universally – apocryphal (Basalla 1988; Arthur 2009). Instead, technological development is typically characterized by patterns of incremental change (Roux 2010), varying in rate and intensity depending on conditions like population size and interconnectivity, resource security, and extant levels of variation in traits and ideas (Henrich 2010; Powell *et al.*

2010; Boyd *et al.* 2013; Mesoudi 2013). The process of invention and innovation can be risky, particularly in situations where the costs of failure are significant. For the prehistoric Aleut, the potential costs entailed by meddling with existing technology in order to venture farther and farther from shore under a wider variety of conditions were high, so it is reasonable to expect patterns of invention to have been relatively conservative, biased toward social learning and imitation (Henrich 2010). Attending to and copying what already works is a strategy that minimizes risk and, depending on the sophistication and complexity of the skill-set being learned, guarantees some minimum level of success. This strategy also lends itself to behavioral homogeneity, which might at least partially explain why ocean-going craft of the kind under investigation here were developed sooner.

Adopting a Darwinian stance offers further insight into the conditions under which novel technologies are most likely to develop and perpetuate. Once again, the realities of invention and innovation seem to run counter to colloquial interpretations and “common sense” understandings. Necessity, in most cases, is not the metaphorical mother of invention. A population experiencing resource stress may in fact be in greater need of innovations that extend their foraging range or otherwise enhance their resource-acquisition prospects, but that does not mean they will produce them. Indeed, the very stressors that might elevate the value of a given set of inventions and innovations also limit a population’s capacity to invest in the processes that produce them (Henrich 2010) – a point that runs contrary to the risk-sensitive interpretations occasionally forwarded and favored by behavioral ecologists (Fitzhugh 2001). The implication here is that one ought to expect a suite of insights and inventions to coalesce into a novel form of boating

technology during a period of relative ecological stability, when resources were plentiful and people could afford to invest time and energy into the business of tinkering with existing variation.

Similarly, there are demographic conditions that are more likely to nurture innovation than others. In general, innovation is more and more likely to occur as populations grow larger and larger and the individuals of which they are comprised become increasingly interconnected (Henrich 2010; Powell *et al.* 2010; Shennan 2013). To begin with, smaller populations are more likely to experience the deleterious effects of sampling error as ineffectual techniques rise to fixation and become more or less locked-in as traditional components of the cultural repertoire (Powell *et al.* 2013). This is less likely to happen in larger populations, where there are more potential innovators and therefore more opportunities for novel insights to arise. As with genetic variation, cultural variation should be higher in larger populations. Network density – the interconnectedness of a population, both internally and with neighboring groups – likewise plays a role in processes of innovation, facilitating the proliferation and persistence of new ideas (Shennan 2013).

Taken together, these elements paint a coarse-grained picture of what to look for when searching for the potential locus – both temporal and spatial – for the development of the CHOGK. That is, all things being equal, innovations in boating technology (or any other technology) should arise when conditions are good and populations are both large and relatively well interconnected. During the years preceding the 1500-1300 BP increase in otariid harvesting, populations on the Alaska Peninsula were growing (Maschner 2009 & Maschner in press). These changes also took place during a stretch of several centuries

when the climate was relatively cool, and primary productivity likely high (Maschner *et al.* 2009). Thus, two of the conditions thought optimal for innovation (larger populations and resource stability) are potentially satisfied. This by no means represents conclusive evidence that new boating technologies were developed during this time frame, but it is suggestive that conditions may have been ripe for such an innovation to develop. Once developed, the CHOGK would have allowed the people inhabit the region to extent existing social networks and establish new ones, thereby facilitating levels of regional interaction and interconnectivity amenable to the proliferation and persistence of the technology.

Chapter Seven: Summary and Conclusions

Archaeology is a science perpetually limited by the kinds of evidence to which researchers have recourse. Naturally, the kinds of evidence that preserve in the archaeological record varies depending on depositional conditions and subsequent taphonomic processes, and are typically limited to particularly resilient materials like bone, stone, and wood. Any behavior that does not leave some kind of material evidence in its wake is a reasonable target for careful speculation, but is, at best, a difficult target for empirical inquiry. Nevertheless, many aspects of the human past that have left little or no direct evidence of their presence still manage to stimulate scientific curiosity. This is precisely the situation faced by researchers interested in patterns of prehistoric boating innovation in the Aleutians and on the Alaska Peninsula. Lacking the red cedar used for ocean-going boat construction by populations all along the Northwest and Californian coast of North America, the prehistoric Aleut made their boats from locally available woods and the skins of captured sea mammals – neither of which preserved in the acidic soils of the region. Consequently, the precise patterns of invention, modification, and innovation that characterized the evolution of boating technology in the region are forever hidden from the direct scrutiny of interested researchers.

Niche construction theory offers a remedy for some of these informational deficits. Niche construction shifts the focus of attention away from a demand for direct observations of temporal trends in boating innovation to the potential downstream consequences human populations might both experience and precipitate as innovations in boating technology allow them to create and explore new social and ecological niches and fundamentally alter their adaptive landscape. As a result, a host of data are rendered

freshly germane to an investigation of prehistoric boating innovation. The fundamental handicap inherent in our inability to directly study the patterns of invention and innovation that characterized the evolution of boating technology in the Aleutians and on the Alaska Peninsula can be circumvented by using temporal changes in the relative abundance of faunal remains as a proxy measure for human-initiated changes in foraging strategy. This approach requires only a handful of fundamental assumptions: (1) that maritime technologies will be subject to processes of cumulative cultural evolution, (2) that the people who initially colonized the Aleutians and Alaska Peninsula did not have boats exhibiting the versatility and reliability of ethnographically recognized craft, (3) that the development or introduction of craft with said qualities will result changes in foraging strategy, and (4) that these changes should leave an intelligible signature in the faunal record.

These assumptions rest on an understanding of the human capacity to influence their environments - often in unpredictable ways - and both develop and deploy adaptive responses to novel exogenous challenges in shorter periods of time than can be attributed solely to biological change. Here, the term *adaptive* is used in reference to current utility, rather than adaptation that can be directly attributed to genetic variation (Fox & Westneat 2010). It applies to whatever strategy might be deemed best among plausible alternatives. In this light, concepts derived from optimal foraging theory can be fruitfully applied to questions pertaining to the causes and consequences of cultural variation - like those at the core of the processes that produce technological innovation. The human capacity to actively construct aspects of their world or buffer themselves against the often unpredictable hazards associated with social or ecological change

through processes of cultural evolution represents a novel mechanism for increasing the adaptive match between organism and environment. Apparent cases of severe adaptive lag, wherein the genetically inherited limitations of human physiology are poorly suited for the business of survival and reproduction in novel environments (Laland & Brown 2006), are bridged by an ability to search available design space (Dennett 1995), arrive at, and subsequently transmit solutions to adaptive challenges at a rate far in excess of what might be achievable through processes of natural selection, genetic drift, gene flow, and genetic mutation alone. Through the creation, storage, and transmission of ontogenetically acquired information, humans have access to unique routes toward adaptive specialization across a wide variety of environments. In the vernacular of human behavioral ecology, humans are able to home in optimal solutions to prey choice dilemmas or problems associated with resource patch choice considerably more rapidly than might be accomplished through the action of mutation, natural selection, genetic drift, and gene flow alone. Not limited to facilitating the rapid navigation of adaptive landscapes, the human capacity for cumulative cultural evolution also enhances their efficacy as niche constructing organisms, signally elevating their potential to create new landscapes that present otherwise unreachable or previously nonexistent adaptive peaks. That is, humans have to the power to initiate changes - both deliberately and accidentally - that substantially alter the array of optimal strategies for solving adaptive challenges.

Recognizing that humans are master niche constructors, both deliberately and accidentally modifying their environments, this paper posits that the development of an ocean going craft with the resilience and stability of the ethnographically recognized kayaks used by Aleut peoples across the Alaska Peninsula and throughout the Aleutians

should be expected to produce archaeologically detectable changes in the set of available set of optimal foraging strategies. That is, the adaptive landscape for foragers employing boating technology that largely limits them to near-shore resources is different from that experienced by foragers employing boating technology that can carry them farther under a wider variety of conditions, significantly expanding their foraging range and the array of resources available at any given point in time. In a very literal sense, the development of the closed-hulled, ocean-going kayak represents a fundamental, human-initiated change in the adaptive landscape. Moreover, it is a change that should be detectable in the faunal record – well preserved in shell middens throughout the region.

To that end, I conducted several analyses on the high-resolution faunal-record recovered after three seasons of archaeological excavation on Sanak Island, off the southern coast of the Alaska Peninsula. Because the introduction or development of the CHOGK is expected to have stimulated region-wide changes, a core assumption here is that Sanak can serve as proxy for the rest of the Alaska Peninsula and Aleutian Islands. Nowhere is it assumed that the CHOGK was developed on Sanak – of course, it may have been, but the likelihood that the place where the critical insights and inventions originated is the same place targeted in this analysis seems low.

Building on previous analyses (Betts & Friesen 2006; Betts *et al.* 2011), patterns in resource exploitation were analyzed using abundances indices, under the assumption that the people who produced the faunal record were generally adhering to optimal foraging expectations for any given set of conditions. The expectation here was that any change in optimal foraging strategy associated with the development or introduction of the CHOGK should be discernible within the faunal record, as humans flexibly modify

their foraging tactics to accommodate the advantages associated with the novel technology. Highly ranked otariids were selected as the taxa of interest, compared against smaller, lower ranked sea otters. Five analyses were conducted: one using a migration-controlled sample based off previous work (Betts *et al.* 2011), three using different minimum total NISPs for the purpose of investigating the influence of sample size, and one using the sum of otariid and sea otter NISPs. Individual AIs were calculated for each date and site in the Sanak faunal record, these were plotted, and LOESS curves were used to expose long-term trends in resource use. Taken together, these analyses revealed mutually consistent patterns of otariid exploitation on Sanak. The otariid-sea otter NISP based sample exhibited a peak that deviated from the other LOESS curves which is difficult to interpret, requiring a judgment call as to whether or not it reveals something of critical importance. This potential anomaly aside, the AIs corresponded at two important points: high otariid foraging efficiency in the first millennia following the initial colonization of Sanak, peaking around 3500 BP and declining thereafter, a substantial depression in otariid encounter rates around 1500-1300 BP, followed by steady increases up into the historic period.

Niche construction theory, together with the principles of optimal foraging theory, renders these trends salient as potential signatures of boating innovation. The initial colonists of Sanak enjoyed access to populations of otariids naive to the potential threat posed by human hunters. As a result, the faunal record for the earliest phases of the faunal record of Sanak Island reveals a trend of increasing foraging efficiency - human hunters are able to meet their caloric needs via the exploitation of highly ranked Steller sea lions and northern fur seals, with limited recourse to lower ranked species like sea

otters. Over time, otariid encounter rates decreased and people began to incorporate increasing amounts of sea otters into their diet. The implications here are twofold. First, by driving otariids to adopt more effective escape tactics and pushing them onto more distant rookeries and haul-outs, human predation depressed local otariid abundances and, as a result, encounter rates. Second, humans responded to these changes flexibly, changing their foraging strategy to compensate for decreased access to preferred game.

Despite an uptick during a cool period lasting from 2600 to 2100 BP, otariid abundances remain relatively low until around 1300 BP, at which point they increase substantially, trending upward until just prior to the historical period. There is no reason to assume otariid behavior or distributions would have changed at this point. However, a change in human foraging strategy, both precipitated and facilitated by the introduction or development of maritime technology that allowed human hunters to travel farther under a wider variety of conditions should be expected to produce precisely this type of signature. That is, novel boating technology allowed humans to reach rookeries and haul-outs that were previously inaccessible. This would have represented a substantial modification of the range of optimal foraging strategies, expanding them to include regular forays to more distant rookeries and haul-outs under conditions that would have made a similar trip - using less sophisticated and reliable technologies - unbearably risky. Organism initiated and largely attributable to ontogenetically generated and culturally transmitted variation, this is niche construction unburdened by most of the deficits that have hobbled prior applications.

To contextualize these trends, they were compared against oscillations in regional climate. The purpose here was to determine if the patterns revealed in the faunal record

were attributable to variations in primary productivity. Throughout much of the sequence, peak otariid abundances correlate with cooler climatic regimes. However, one discontinuity was apparent between foraging patterns and regional climate, such that an apparent depression in otariid encounter rates - ca. 1500-1300 BP - occurred during a potentially high productivity cold period when conditions should have been best for supporting large otariid populations. This supports an interpretation of human-induced resource depression, with human hunting driving otariids to more distant rookeries and haulouts and encouraging them to adopt more effective escape tactics. This in turn opens up the question of why relative otariid abundances increase after the 1500-1300 BP depression. Human population trends upward during this time, meaning the pressure of human predation was never lifted, encouraging local otariids to maintain the behavioral adjustments that likely stimulated the depression in the first place. By alleviating previous restrictions on foraging range and allowing hunters to venture out under a wider variety of conditions, the development or introduction of the CHOGK is therefore a compelling candidate explanation for these trends.

This idea is further corroborated by changes in the harvesting toolkit. After the initial colonization of Sanak, when colonies of shore-bound animals would almost certainly have been within reach, large thrusting spears reach lengths in excess of 12 centimeters. These lengths decline over time as shore-bound animals become less and less accessible. Then, around 1500-1300 BP, the lengths of large thrusting spears start to increase, once more reaching lengths in excess of 12 centimeters. This is parsimoniously explained if Aleut hunters have access to a new source of large, shore-bound animals. That both thrusting spear lengths and relative otariid abundances continue to increase into

the historical error strongly suggests that whatever limitation resulted in previous depressions has been permanently lifted.

This explanation is not unequivocal. Though there is a strong and compelling case to be made for the introduction or development of something closely resembling ethnographically recognized forms of marine transportation sometime in the range of 1500-1300 BP, it is difficult to exhaustively eliminate other options. To an extent, this is not surprising – fully exhaustive explanations are something of a rarity in science, even for disciplines with access to the powerful tools of manipulative experimentation. Ad hoc variations on established explanations can be multiplied indefinitely without detracting from their empirical content (Maxwell 1974), which is precisely why scientists employ value criteria like parsimony to adjudicate certain kinds theoretical disputes (Kuhn 1977). While the boating innovation hypothesis is parsimonious, it remains difficult to say that is firmly conclusive.

It is, for instance, quite possible that increased predation by orcas could have produced the apparent depression in otariid numbers evident around 1500-1300 BP. This is a very real possibility that is difficult to rule out, but the fact that patterns of regional interaction increase substantially in the centuries after 1500-1300 BP argues strongly for the existence of some form of reliable ocean-going technology – a minimum condition for consistent and intense regional interaction.

A similar problem arises when broad trends in human population growth on Sanak are compared with changes in relative otariid abundance. Set against the LOESS curves derived from the present study, the temporal trends in population paint a picture

that superficially resembles the dynamics of Lotka-Volterra predator-prey interactions – except on a much longer temporal scale. Such an interpretation is rendered suspect by comparatively vast swaths of time over which these trends are expressed – typical Lotka-Volterra predator-prey population dynamics play out on the scale of generations, and these trends play out on the scale of centuries. Nevertheless, it is difficult to rule out the possibility that the trends examined in this paper are the product of the dynamic interplay between the relative abundances of human predators and their prey.

That being said, a judicious deployment of concepts derived from niche construction and human behavioral ecology, taken in conjunction with principles of cultural evolution, sculpts a compelling case that the CHOGK was introduced around 1500-1300 BP. That these changes are expected to be region wide, with the faunal record of Sanak merely serving as a high temporal resolution proxy for an entire region, places these ideas firmly within the realm of a corroborated hypothesis with strong potential for future testing. If the CHOGK was introduced around 1500-1300 BP, similarly high resolution faunal records should show roughly contemporaneous changes. If they do not, this hypothesis is rendered suspect and new explanations for the changes apparent in the Sanak faunal record must be explored.

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Appendix

Table of Data:

Site	XFP-031	XFP-031	XFP-033	XFP-034	XFP-035	XFP-036	XFP-037	XFP-038	XFP-050	XFP-052	XFP-052	XFP-052
Site Date	2184	2230	70	395	2088	2355	1381	1796	180	391	410	418
Bearded seal	1											
Harbour seal	2		2			4			5	1	13	
Northern fur seal	5				9	3		9	4	2	7	
Otariidae	1	21	1	1	1	8	7	5	1	33	22	3
Phocidae	13	24	5	3	27	40	6	31	22	19	177	
Pinnepedia		119	3	3			4		6	11	5	
Porpoise sp.						5			1			
Ribbon Seal												
Ringed seal	1					2					3	
Sea otter	5	32		4	16	15	17	19	17	43	37	
Steller's sea lion		5	1		2	7	7	7	3	5	14	1
Toothed whale												
Walrus		2				5			1	10		
Whale sp.	16	30			2	5		3	4	8	2	
Bird Total	109	45	310	283	323	1801	163	193	164	441	2703	13
Mammal Total	1351	786	1276	107	229	363	97	192	308	380	753	15
Fish Total	8471	1589	404	33417	3365	21990	4304	11750	1537	3053	15182	1126
Grand Total	9931	2420	1990	33807	3917	24154	4564	12135	2009	3874	18638	1154
Otariid/Sea Otter AI	0.545455	0.448276	1	0.2	0.428571	0.545455	0.451613	0.525	0.32	0.481928	0.5375	1
Otariid + Sea Otter NISP	11	58	2	5	28	33	31	40	25	83	80	4

Site	XFP-052	XFP-053	XFP-054	XFP-054	XFP-054	XFP-056	XFP-056	XFP-058	XFP-058	XFP-061	XFP-061	XFP-061
Site Date	430	1143	3663	3750	3755	1438	920	2040	514	2051	2567	3762
Bearded seal										2		
Harbour seal	1			5		6	11	2	3	4	9	5
Northern fur seal	3					10	9	12	2	17	4	1
Otariidae	44	2	1	10		37	58	69	1	31	13	21
Phocidae	63	1		14	15	193	453	133	17	337	398	174
Pinnepedia	56		1	50	20	175	48	89	7	45	15	7
Porpoise sp.								2			1	
Ribbon Seal										2		
Ringed seal							7		5		3	
Sea otter	56	1		1	1	196	208	177	21	344	83	66
Steller's sea lion	9					6	19	14	1	17	1	1
Toothed whale												
Walrus	25			3	1	6	1	3		3		
Whale sp.	14	4	5	10		33	48	9		21	6	
Bird Total	585	15	84	352	223	854	865	1124	335	2170	798	332
Mammal Total	404	10	10	180	436	956	1606	907	198	2139	1281	516
Fish Total	2841		1	2470	2019	10145	27264	22155	2835	11989	3824	535
Grand Total	3830	25	95	3002	2678	11955	29735	24186	3368	16298	5903	1383
Otariid/Sea Otter AI	0.5	0.666667	1	0.909091	0	0.212851	0.292517	0.349265	0.16	0.158924	0.178218	0.258427
Otariid + Sea Otter NISP	112	3	1	11	1	249	294	272	25	409	101	89

Site	XFP-062	XFP-062	XFP-063	XFP-063	XFP-064	XFP-064	XFP-066	XFP-067	XFP-067	XFP-067	XFP-067	XFP-071
Site Date	1941	3274	2232	3600	3751	3901	510	2145	2571	3280	Surface	1010
Bearded seal			1						1			
Harbour seal		2	5	1			5		3		2	
Northern fur seal			30	1	6	3		18	6		4	
Otariidae	1	9	27	20	2	1	7	23	38			1
Phocidae	5	36	89	23	2	6	3	45	65		2	
Pinnepedia	8			5			2	1	49			
Porpoise sp.												
Ribbon Seal												
Ringed seal							5	4				
Sea otter	4	19	33	27				51	92	1	10	
Steller's sea lion	3		13	10			2	9	7		2	
Toothed whale									1			
Walrus		1	2	3					1			
Whale sp.		3	2	2		1	9	3	17			
Bird Total	28	749	719	17	324	209	126	1002	335		91	9
Mammal Total	41	372	675	177	104	59	86	457	390	1	91	2
Fish Total	3302	36431	13840	1216	6826	7764	3241	10396	1311		22	3061
Grand Total	3371	37552	15234	1410	7254	8032	3453	11855	2036	1	204	3072
Otariid/Sea Otter AI	0.5	0.321429	0.679612	0.534483	1	1	1	0.49505	0.356643	0	0.375	1
Otariid + Sea Otter NISP	8	28	103	58	8	4	9	101	143	1	16	1

Site	XFP-078	XFP-080	XFP-095	XFP-096	XFP-096	XFP-097	XFP-099	XFP-101	XFP-103	XFP-103	XFP-104	XFP-110
Site Date		1494	927	2088	2249	No Date	382	No Date	2082	3844	388	443
Bearded seal							2					
Harbour seal					2		3	1			5	4
Northern fur seal		1	3	2	7	2	9				5	1
Otariidae		1	4	22	38	3	22	2	1	3	28	11
Phocidae			4	14	68	3	40	10		6	192	44
Pinnepedia				19	56	2	8			119	29	19
Porpoise sp.				1								
Ribbon Seal												
Ringed seal											7	
Sea otter	1	22	1	52	72	5	8			1	8	33
Steller's sea lion			3	1	2		15	2			6	13
Toothed whale												
Walrus					1	1	11	2				
Whale sp.			3	8	9	1	2	2		1	2	16
Bird Total		64	236	47	228		329	16	7	242	2008	764
Mammal Total	1	38	61	150	347	18	271	23	48	219	3085	449
Fish Total		272	2547	346	755		15507	472	1599	8476	24375	11718
Grand Total	1	374	2844	543	1330	18	16107	511	1654	8937	29468	12931
Otariid/Sea Otter AI	0	0.083333	0.909091	0.324675	0.394958	0.5	0.851852	1	1	0.75	0.829787	0.431034
Otariid + Sea Otter NISP	1	24	11	77	119	10	54	4	1	4	47	58

Site	XFP-111	XFP-111	XFP-111	XFP-111	XFP-113	XFP-114	XFP-115	XFP-119	XFP-119	XFP-119	XFP-121	XFP-131	XFP-133	XFP-138
Site Date	1725	4335	4645	4655	2067	2216	2088	1945	2040	602	403	2014	423	400
Bearded seal														
Harbour seal			4	7					1		3		1	
Northern fur seal	1		3					2	37		8	1	10	
Otariidae		3	1	5		1	1	8	30	7	13		1	
Phocidae		18	52	141	2	6	6	6	89	12	40	2	23	2
Pinnepedia	1	38	22	6				3	26	4	23		1	
Porpoise sp.													1	
Ribbon Seal														
Ringed seal			2						2					
Sea otter	1	2	159	265	3	11	3	18	249	33	18	1	20	3
Steller's sea lion			1	2				3	26	1		1	2	
Toothed whale														
Walrus														
Whale sp.		5	8				2		7	5	1	2	15	
Bird Total	250	135	1597	4235	22	93	51	273	1349	43	275	250	135	1
Mammal Total	42	66	1041	1257	11	30	17	171	931	70	300	232	279	10
Fish Total	362	232	934	1660	135	261	236	3738	15537	323	22264	1015	4536	
Grand Total	654	433	3572	7152	168	384	304	4182	17817	436	22839	1497	4950	11
Otariid/Sea Otter AI	0.5	0.6	0.030488	0.025735	0	0.083333	0.25	0.419355	0.27193	0.195122	0.538462	0.666667	0.393939	0
Otariid + Sea Otter NISP	2	5	164	272	3	12	4	31	342	41	39	3	33	3