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Linear Programming Analysis and Diet Breadth Modeling at Bridge River, British Columbia

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LINEAR PROGRAMMING ANALYSIS AND DIET BREADTH MODELLING AT BRIDGE RIVER, BRITISH COLUMBIA

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Table of Contents

List of Figures

List of Tables

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Abstract:

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Linear Programming Analysis and Diet Breadth Modelling at Bridge River, British Columbia

Chairperson: Dr. Anna Marie Prentiss

Studies in diet breadth modeling and patch choice have been and continue to be a hot topic of interest among practitioners of human behavioral ecology and the set of data available at Bridge River can certainly add to these debates and discussions that have been dominating anthropology in the past few decades. The faunal assemblage of Housepit 54's 17 anthropogenic floors have provided researchers with a plethora of data that clearly indicates periods of resource depletion and partial to full site abandonment. Using Linear Programming and Diet Breadth Modelling I analyze the most represented species in the record and establish an optimal projection for how best to utilize time fishing, hunting and gathering. While optimality is established on the basis of nutrition and time spent processing, correlation coefficients are also used to compare frequencies of salmon versus trout, deer, and other less desirable land vertebrates by floor layer. Establishing how the prehistoric peoples of Bridge River dealt with depletion of their most valued food resource of salmon could prove useful not just in increasing our knowledge of the events that transpired at Bridge River during this time but can also serve as a reference for how best to optimize dwindling resources in the 21st century.

1. Introduction

This thesis aims to contribute to ongoing archaeological investigations of the Bridge River site in British Columbia by focusing on approaches to calculate optimal diet to better interpret the evidence of piscivore vs. carnivore subsistence. Past studies in this area have found there to be a period in time where salmon procurement seemed to be at a low point and questions have arisen as to why this may be. This period is concurrent with further evidence of social inequality and partial to full site abandonment. It is the purpose of this research to further analyze the faunal remains to obtain a better understanding of the breadth diet of these people. From there we can assess the worth of each aquatic and terrestrial fauna what would be needed to sustain the population in the absence of salmon, the most prioritized food source in Lillooet subsistence.

For the accurate ranking of these species, we will rely on diet breadth modelling to rank species in terms of energy expenditure v. energy return and linear programming to assess each animal in terms of protein, fat, and calories. With this data we can compare results to the faunal assemblage from the floors of Housepit 54, the most extensively excavated residential home at Bridge River, to get a better understanding of how well these people were able to supplement salmon during periods of poor salmon harvest (Prentiss et al. 2008). Studies in diet breadth modeling and patch choice have been and continue to be a hot topic of interest among practitioners of human behavioral ecology and the data available at Bridge River can certainly add to these debates and discussions that have been dominating anthropology in the past few decades.

Diet and nutrition studies within the Pacific Northwest (PNW) have been an ongoing archaeological curiosity since Franz Boas first brought attention to the native peoples of this region over a hundred years ago. These studies are prevalent here due to the unique nature of the cultures and ecosystem of this region of the world, which allows for semi-sedentary occupation without the burden of intensive agriculture or pastoralism that seem to go hand in hand with semi-sedentary life in other areas of the world. The abundance of varying food sources within this region and the ability for these hunter-fisher-gatherers to change their diet, when need be, has likely led to this development. Given that much of PNW prehistory suggests resource abundance, archaeologists have been able to study patch choice and decision making among ancient peoples in an environment practically as stable as a laboratory setting.

This stable history is punctuated with periods of social inequality, high stress, and abandonment (Prentiss et al. 2008, 2012, 2014, 2020). Regardless of the region's abundance in resources, archaeological studies and ethnographic evidence still express that there were years of poor production and social stressors such as changes in power, warfare, and unseasonably intense weather conditions. The archaeological excavations of the Bridge River fishing village have uncovered evidence of just these circumstances (Prentiss et al. 2014, 2020). With resource depletion and changing weather conditions being an ongoing, worsening issue throughout the world today it is all the more imperative that we aim to understand the human response to these scenarios in the past.

This study can help construct not just a simple rating system of resources as stated before, but on a deeper level can help us understand how best to react and adapt to resource depletion. Since Bridge River was seen as a primarily egalitarian community up until we see these first signs of social stress, it would be most beneficial for us in the western world to better understand the circumstances surrounding the partial to eventual full site abandonment. Implications of this research will not only affect anthropology but fields such as sociology, politics, and economics as well.

The site being used for this study is specifically that of Housepit 54 in Bridge River, where excavations have opened a total of 17 floors thus far, spanning as far back as 1460 cal. BP (Prentiss 2018). Within these 17 floors there is a clear fluctuation in population density as well as salmon deposits. Much of the salmon collected is of the species *Oncorhynchus nerka* (Sockeye salmon) with a smattering of other Salmonidae and bony fish representing the rest of the fish remains. Given the data presented in applicable ethnographies (Hayden 1992; Teit 1900, 1906) as well as inferences made from basic geography of the site and archaeological data, it is clear that Bridge River, like many of the settlements of interior British Columbia, was home to a community that relied heavily on the annual salmon migrations that ran along the Fraser River.

The history of this site has raised questions regarding wealth-based inequality throughout the community's past given that Housepit sizes, densities, and occupation duration vary in Bridge River (Prentiss et al. 2018). This variation seems to point heavily towards the idea that Malthusian ceilings had been reached during at least two separate occasions in the past resulting in population fluctuation and inequity (Prentiss et al. 2014, 2018, and 2020). This thesis focuses on the species of fish and terrestrial fauna that were used to supplement the losses caused by low salmon numbers to ascertain whether this shift in diet was enough to keep the community in a well fed and economically stable state. It is reasonable to assume that poor salmon collection would have the potential to be extremely detrimental to a society that depended on these annual runs to prepare for long winters and this thesis may better illuminate the true gravity of the situation these people were facing by A) Establishing nutritional tables that can compare and contrast these primary and "fallback" food sources and B) estimating the number of animals that would have been needed to supplement the low salmon numbers and if this would've been feasible during their time. Human Behavioral Ecology has proven itself to be a useful framework in which to view the process of food procurement among past hunter-gatherer-fisher communities and as a result will be used in this research.

Hypotheses

Theories regarding hunting and gathering from an economic, cost/benefit approach are ample and beneficial in their ability to understand decisions regarding food procurement and processing among early peoples. These models and hypotheses are so useful for the field of archaeology because they can help make sense of the archaeological record by not relying solely on the biased information provided by artifact resilience over time (Keene 1981). The basic assumption that human beings are rational and intelligent and would adapt their diet breadth to the given environment they find themselves living in is the backbone of many diet breadth models. The majority of foraging studies in anthropology have utilized contingency modelling due to its simple way of ranking foods based only off nutritional maximizing and time minimizing (Belovsky 1987; Charnov 1976; Krebs et al. 1977; Pulliam 1974; Schoener 1971; Werner and Hall 1974). In this way the researcher need only ascertain the nutritional value per unit of handling time to predict if a resource would be eaten or not. This model, however, assumes that "simultaneous search" would be occurring, whereby a hunter-gatherer would by hunting/gathering for all available items at the same time (Belovsky 1987). This contingency is simply inaccurate to the reality of being a hunter-gatherer. There are times and places for different activities, and this especially applies to the people of Bridge River who would be focusing all their attention on fishing during the salmon runs.

Application of the Diet Breadth and Linear Programming Models have been successful in past studies and seem most appropriate for organizing Bridge River's faunal data in a reliable manner. Our problem is best approached by organizing our study into two separate problem domains. The first objective is to establish an outline for our model and what variables will populate our data. For this research we will be focusing on the carnivorous subsistence of Housepit 54 at Bridge River. Salmon along with other known species of Salmonidae and smaller fish native to the Fraser River as well as deer, rabbit, sheep, and dog, are known to be utilized by the native peoples and will be examined on multiple levels. Each species will be analyzed in terms of protein and caloric yield as well as fat content. From there we can predict what the most efficient versus the least efficient diet breadth would have looked like at Bridge River.

The second problem is to is to assess the faunal assemblage from the floor layers of HP 54 and put together an NISP for salmon versus all other animal remains per floor. With this information a coefficient correlation can determine whether any statistical significance is present between the number of salmon versus other species to establish what relationship (if any) exists between them. Once both problems are tackled, we should be able to obtain reliable answers from the results.

Hypothesis 1: Among the people of the Pacific Northwest salmon is chiefly represented as the primary food source. These salmon were vital to survival in the long winters and processing and storage of hundreds of salmon per family unit needed (Hayden 1997; Teit 1900 and 1906). Salmon was so vital that it was consistently represented in myth, artwork, and political as well as social dealings. While thousands are collected during a season's salmon run it is the nutritional value and utility of these large fish that make them a staple, not just their ample availability. Our assumption is that people are rational and will maximize their food procurement by balancing food quality with procurement time and energy expenditure. This being the case, we can also assume that salmon will rank high on our model. The real question is how well the people of

Bridge River were able to supplement their losses of salmon with other British Columbia species. As far as abundance goes, trout species tend to be prevalent, so it is also likely that trout were not as useful as salmon but could have been used as a secondary fish food source.

Our first hypothesis (H1) is the number of fish species other than salmon will have an inverse relationship during times of low salmon numbers. With virtually all attention being aimed at salmon collection during the annual run, it would not make sense for the Lillooet to be seriously pursuing a lower ranked resource within the same patch simultaneously. This hypothesis seems self-evident given the large gap in fish remains other than salmon in the archaeological record during times of ample salmon availability, however, we do not want to commit the fallacy of treating a biased record as gospel. If salmon numbers are low during a season it would only make sense for fishers to target the next best fish in order to stock up for the winter.

Test Expectations are:

1. Salmon will rank highest in terms of nutritional yield

2. Other fish species will only be abundant when salmon are not.

Hypothesis 2: While the Lillooet are known primarily for their salmon fishing, hunting was still a valuable part of resource procurement in the interior British Columbia. The Lillooet utilized their surrounding terrain for all it had to offer, and the surrounding mountainous regions proved to be especially fruitful in terms of hunting and gathering. Mule deer of the region were an especially valuable resource that allowed the Lillooet to supplement their winter stores with meat other than salmon. Deer meat also had some characteristics which made it better suited for winter storage than salmon meat, mainly its content of saturated fats which salmon meat lacks. These saturated fats prolonged the shelf life of deer meat meaning it was less likely to go rancid before salmon meat (Romanoff 1992).

The hunting of deer always took place right after the end of the sockeye salmon runs in late Autumn, allowing hunters to gauge how much deer would be needed based off how well of a salmon run they had (Romanoff 1992). The activity of hunting was more of an energy expenditure, requiring hunting parties to prepare for an extended stay at camps in the mountains where they would often hunt together, assisted by trained dogs (Alexander 1992). The length of their stay depended heavily on the amount of meat that was needed for the winter months but tended to average about 4-6 weeks. Due to fluctuations in salmon numbers throughout the years, there were many times where last-minute deer hunts saved the day (Romanoff 1992).

It is fair to say that mule deer were a vital resource to the people of Bridge River, given the ample faunal data for deer utilization at Bridge River and the extensive literature on deer hunting among the Lillooet in ethnography. The fact that deer meat was used as a supplement for salmon meat following poor Autumn runs is a compelling enough reason to assume that anthropogenic floors lacking salmon remains might have an increase in deer remains. The second hypothesis (H2) is then that the number of deer remains will be inversely related to the number of salmon remains at HP-54. While the energy expenditure and risk involved with hunting is greater than it is with fishing it only makes sense that poor salmon yield would shift priorities among the Lillooet, making the promise of more meat for winter storage outweigh the risks involved in hunting the mountains.

Test expectations are:

1. Deer meat will prove to be second in nutritional value, behind salmon.

2. The number of deer remains will be inversely related to the number of salmon remains.

Hypothesis 3: Optimal foraging theories depend heavily on the assumption that hunter-gatherers were primarily food driven, but there are several other activities besides food acquisition that could have taken priority at Bridge River. It could very well be that during these salmon runs, food shortage was practically impossible, giving the Lillooet time to engage in activities that may rank higher than fishing during this time (Winterhalder 1983; Hawkes et al. 1985). If we change the way we look at hunter-gatherer life in terms of activity ranking, then our expectations of fishing for salmon taking priority at Bridge River could be completely wrong.

One activity that would defy what we'd expect and explain trout and suckerfish in the archaeological record would be that of child rearing and teaching. Ethnography usually only mentions the fishing of trout and other fish when talking about the activities of Lillooet children (Teit 1900; 1906). Fishing for these lesser ranked food sources proves an excellent way to train children in the ways of fishing so that they may hone their skills and prepare themselves for the adult tasks of fishing on a large scale. This being the case, it could be that trout and other smaller fish species only appear in the archaeological record not because of their nutritional yield but because of other, external factors.

Another factor that may defy H1 and H2 is the possibility that our assumptions about the reasons behind the decline in salmon numbers could be wrong. It could very well be that partial abandonment took place before the salmon runs and without the extra manpower, less sockeye salmon was able to be harvested from the river. If this is true, then we could expect to see little correlation between salmon remains numbers and other faunal remains numbers.

Our third hypothesis (H3) would then be the Null Hypothesis, proving the number of other fish or land mammals in the record is completely independent of salmon and has no inverse relationship as far as optimal foraging is concerned.

Test expectations are:

1. Numbers of faunal remains other than salmon will be completely independent of and unrelated to the number of salmon remains.

These three hypotheses should be sufficient in getting to the core of the issues we are aiming to explore. A scramble to substitute nutritional losses from a poor salmon run could very likely help to explain some of the apparent social inequality and resource depletion we see in Bridge River's archaeological record. Better understanding of how the people of Bridge River dealt with a lack of their primary food source can not only help fill the gaps in our knowledge regarding the history of Bridge River but can help us to understand how this band may have reacted to these difficulties in terms of social standing and flow into neighboring groups.

Modelling

This study aims to first create a diet breadth model for the animal species that appear in the anthropogenic floors of Housepit 54 in Bridge River. For this we will use faunal data collected by Steven Simms in the upper Great Basin (Simms 1987) and input data into the formula developed by Charnov and Oriens (1973). This will provide us with a ranked list of resources utilized by the Lillooet of Bridge River based off energy expenditure v. energy gain via calories. From there we can then set up our Linear Programing Analysis. This model will be unique in the sense that multiple considerations need to be adjusted for, making linear programming a most effective method. Linear programming allows for the researcher to consider certain contingencies that the model must incorporate, such as time allotted for an activity, people available to work, etc. (Keene 1981). Fortunately, with the popularity of this type of analysis in business and economics, we can utilize Microsoft Excel Solver and apply our settings to Linear Programming Analysis. Once the variables for the top species are calculated we should be able to rank our species on a scale of most efficient food product to least efficient. We could expect the results to be hardly surprising given the overall size and popularity of salmon versus other resources, but these numbers are important because with them we can also calculate how much of one species would equate to one of the other. In other words, if there were no salmon available, how much trout, deer, mountain goat, etc. would be needed to supplement the loss? With this data we can then focus on the faunal data found at Bridge River.

The following chapters will be laid out in a chronological fashion to give proper background before proceeding with the method, testing, results, and discussion. Chapter 2 will serve to provide the reader with the most prevalent ethnographic and archaeological information regarding the Lillooet of our target region and the site of Housepit 54 in Bridge River, British Columbia. This background is vital in building a proper foundation of understanding for how and why this thesis is important for understanding the prehistory of this region. Chapter 3 will provide the research plan, model, and methods used to put together the diet breadth model and linear programming analysis and explain what variables are being used and why. Chapter 4 will go over the results of our findings and compare them against the faunal record of Housepit 54 to confirm or refute our hypotheses and Chapter 5 will serve as an intellectual discussion of the findings, what they can suggest to us as archaeologists and researchers of resource depletion and conclude this thesis with thoughts and suggestions for future studies in this field.

The problems that plagued the people of Bridge River all those years ago are not too different from the problems facing people all over the world today. As the world around us changes and adapts we find that the things we rely so heavily upon just to function are becoming increasingly depleted. This study can help construct not just a simple rating system of resources, as stated before, but on a deeper level can help us understand how best to react and adapt to resource depletion. We can recognize what happened at Bridge River and compare it to other archaeological sites that experienced similar circumstances. From there we can do what history and archaeology was meant to do: we can understand and learn. This project is not just for the sake of curiosity. Here we have the chance to learn from the past. This study does not only have the benefit of furthering our understanding of human behavioral ecology but has the benefit of furthering our knowledge in such fields as sociology, psychology, nutrition, and politics. What we can learn here may help governments establish programs ahead of resource depletion that can lessen the impact and better prepare future societies for the inevitability of adapting to new norms.

2. Background

The ethnographies of James Teit have managed to paint a vivid picture of the region and the lifeways of these fisher-hunter-gatherers. The Lillooet peoples of interior British Columbia share much of the same practices and beliefs of the more widely popularized coastal Salish groups, since the groups of interior British Columbia trace their descent from the coast. Over the years, however, they've managed to establish several different clans throughout the area. According to these native groups, the boundaries of separate clans have stayed relatively stable over time (Teit 1906).

Material culture was similar to that of Coastal Salish with special attention being given to carving and painting of totems, basketry and weaving, with the fur of mountain sheep and dogs being chiefly used in the making of blankets and clothing (Prentiss et al. 2021; Teit 1900, 1906). Elaborate painting and decorating of wood, bone, and antler objects was another carryover practice from the coast Salish. The Lillooet would use paints made from ochre, vegetable paint, and charcoal to bring life to their totems, ladders, cedar boxes and basic tools. It was common for clans to display their affiliated animal in carvings and paint on their homes (Teit 1900). Much of the symbology used in painting relates to Lillooet conceptions of religion and the creation myths of their world.

In the stories held dear by generations of Lillooet the world was initially inhabited by animal/human hybrids of sort possessing magical gifts. Among these creatures were "transformers" who went about changing these hybrids into the animals that would later inhabit the land. Some animals were attributed with specific phenomena like death, fire, and seasons and most animal "transformers" of note have had clans formed around them for which members proudly claim ancestry to their godly ancestor. Likewise, ceremonial costumes and masks were guarded fiercely by clan leaders and were only permitted to be worn at specific times (Teit 1900, 1906). Ceremony was a vital component to Lillooet lifeways and there was much taboo and tradition that was strictly adhered to.

Taboos surrounding children, infants, menstruation and sexual division of labor were firmly enforced. Starting at the birth of an infant the father would live away from the family and follow rules to ensure no evil befell the newborn child. These rules involved abstaining from carrying any animal he killed, not eating a killed animal for at least one day after its death and ensuring that his wife eats no fresh meat for at least six months after giving birth (Teit 1900). It was strongly believed that deviating from these rules world bring illness and death to the baby. Likewise, it was expected of the mother to follow her own strict set of rules as well. If this were her first child, she would be treated much like when she had first menstruated as a girl. She would live alone for a time in a specially constructed hut, throw away a portion of her first for meals after giving birth, and after one to three months she could return home where a feast celebrating the child's birth would be held (Teit 1900).

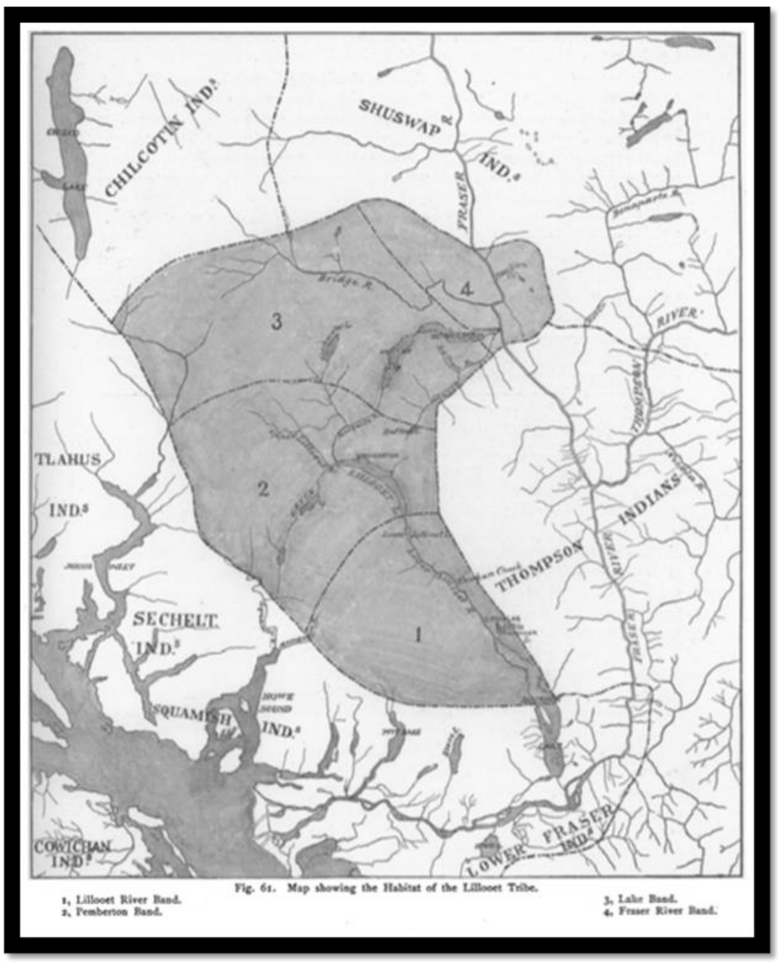

Figure 1. Map of Lillooet lands from Teit 1906

Clans had chiefs and the family of these chief held a sort of aristocracy among the clan but were treated as equals and allowed to marry freely. As reported to Teit, it seems that for much of their history, the Lillooet lived as a fairly egalitarian society with leaders of specific tasks being agreed upon but only holding their positions for a short duration (Teit 1906). A prime example of this type of temporary position would be that of a war chieftain, who would be selected during times of conflict but would then step down and resume their previous role once the fighting had ended. Chief of a hunting party would similarly be in charge of dividing up meat among hunting participants but would not hold any power in the community once hunting was finished. Clan chiefs did, however, hold control over certain seasonal activities that required the cooperation of many people. All berry bushes within the clan lands were protected by the chief and only when the berries were ripe enough for mass harvest did the chief give the go ahead for their gathering. This same principle would hold for the most important event related to sustenance as well: the annual salmon run (Teit 1900 and 1906).

Being as vital to survival as the salmon runs are it was said that thousands of years ago the Lillooet believed that there were no salmon in the river (Hayden 1992). According to the myths and legends of the Lillooet, it wasn’t until the coyote freed the salmon from the grasp of a weir downriver and led the fish up the Fraser that salmon were bestowed upon the people of the region, at which point, salmon forever became a huge part of Lillooet life (Hayden 1992). Salmon fishing was a community wide endeavor that sought to collect and store as much meat as possible to ensure survival in the long winter months. While the initiation of this activity was within the authority of the chief, households collected salmon for themselves as opposed to using communal storage. In this way, it was the responsibility of each family to provision themselves accordingly for the coming winter. This task was accomplished using the combined efforts of strategically placed weirs, nets, hooks on lines, and fishing spears. Wooden platforms were also constructed in key locations along the Fraser River and ownership of these platforms was determined through familial lines (Teit 1900). There is some ethnographic evidence that suggests violence between clans could and had occurred when boundaries were not adhered to (Teit 1906). Such is the unique nature of these fisher-hunter-gatherers, who share many aspects of an egalitarian society while still displaying ideas of ownership and territoriality.

Hunting around Bridge River

While the Lillooet are known primarily for their salmon fishing, hunting was still a valuable part of resource procurement in the interior British Columbia. The two activities go hand in hand and often a poor season of fishing could be supplemented with extra effort being put into hunting (Hayden 1992). The majority of Lillooet hunting took place in the surrounding mountainous terrain where the primary target of hunting parties were mule deer (*Odocoileus hemionus*) (Romanoff 1992). In addition to mule deer, big game such as mountain goat (*Oreamnos americanus*), bighorn sheep (*Ovis canadensis*), black bear (*Ursus americanus*), and caribou (*Rangifer taerandus*) in the northern Lillooet territories (Teit 1906). While other animals in the region were hunted for their meat and pelts, it was the mule deer that proved most valuable in terms of quantity and calories. Just after the Fall salmon runs, hunting parties would head to the mountains (around late September and up until early November) where they would establish a small camp and hunt the terrain for mule deer to complement the salmon meat stored for winter (Romanoff 1992).

Among the Lillooet hunting was primarily a group activity with the killing of animals being undertaken by specially trained and recognized “hunters”, while the processing and carrying back to the village being done by the women (Teit 1900). In pre-contact times arrow points used for hunting were made from stone, beaver tooth, and deer bone but following European contact copper and eventually iron were utilized (Teit 1906). Bows were not always used for hunting, however, with certain game requiring different methods of procurement. Beavers were often harpooned after being driven from their lodges, bears were more commonly caught in elaborate deadfalls, and pitfalls or corrals could be used for catching deer (Teit 1906). For many of these hunts specially trained dogs were used to direct prey towards the hunters. Hunters themselves were a sort of guild within Lillooet society that not just anyone could be a part of. At a young age boys would be trained in geography through the telling of stories and myths, weapon training and endurance running, often requiring them to run for miles in unsteady terrain (Romanoff 1992). Hunters were also expected to choose and train for the qualities of a 'guardian spirit', giving them a sort of Shamanistic respect (Romanoff 1992).

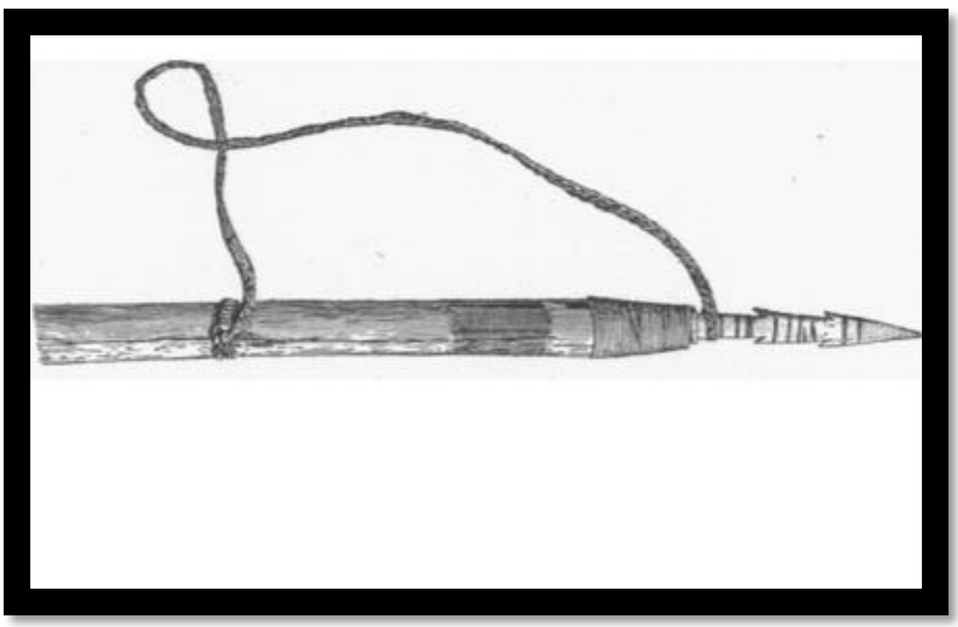

Figure 2: Beaver Harpoon from Teit 1906

The primary concern of this thesis as far as hunting is concerned is that although several different species and methods were utilized for the procurement of meat, it would not have been enough to sustain the population with hunting alone. The population size of deer within the region that would have been hunted by the Lillooet of Bridge River would've been small with only an estimated ten to forty deer being taken per year (Alexander 1992). When this is taken into consideration it makes much more sense why buck skin clothing was considered such a premium item that not a lot of Lillooet had the privilege of owning (Romanoff 1992). Plus, the Lillooet of Bridge River were not just competing for deer with other clans but competing against natural predators like cougars, wolves, and bears as well (Hayden 1992). The number of available deer would vary greatly from season to season and if hunting were to be intensified due to poor salmon runs there is no guarantee that enough meat could be procured to outlast the winter months.

Fishing in the Fraser River

Within the Fraser River there are five species of salmon that were caught and utilized by indigenous peoples: Sockeye salmon (*Oncorhynchus nerka*), Chinook salmon(*Oncorhynchus tshawitscha*), Pink salmon (*Oncorhynchus gorbuscha*), Coho salmon (*Oncorhynchus kisutch*) and Chum salmon (*Oncorhynchus keta*). It is important to note that while all five other these species were present in the Fraser River, their availability was not simultaneous or equal spread throughout the river system, making specific locations and times of the year suitable for catching specific species (Kew 1992). Chinook, or "Spring Salmon", as they were called by the Lillooet, were the largest of salmon species and were caught during the Spring run where they were eaten and traded quickly due to their fat content making them difficult to store (Hayden 1992). It was when sagebrush buttercup began to bloom in April that people would prepare for Spring salmon runs that would last until late May or early June (Kennedy and Bouchard 1992). They tend to arrive again in late July but are overshadowed by the far more abundant and easier to catch Sockeye salmon by this time.

Pink salmon also tend to show up around August and are comparably small to the other four species with an average weight of around 4 lbs (Neave 1966a). It is perhaps due to their lack of size, as well as contemporary sources not preferring its flavor compared to fattier salmon, that it these fish were often only taken if other salmon weren't as plentiful (Kennedy and Bouchard 1992). Last to arrive are the Coho salmon in October which were often obtained while people were still prioritizing Sockeye, which by this time are nearing the end of their fall run and are coming in on the thinner, more depleted side. Chum salmon have the shortest of migrations up the Fraser River and as a result do not make it to Bridge River (Kennedy and Bouchard 1992; Kew 1992).

The Sockeye salmon runs of late summer were thus most important in preparing for the long winter due to their abundance in fall and their lean, non-fatty flesh which was easiest to dry for storage. As salmon migrate upriver, they do not eat and whatever energy they burn is not being replaced. Because of this, the catching of sockeye around late August and early September proved to be the perfect time for fat stores to be burned off so fillets were lean enough for drying and storage (Romanoff1992). Sockeyes are primarily concentrated in areas of the river closer to the lakes where they spawn and while they are usually plentiful operate on a four-year cycle whereby one year will experience a large boom in numbers, followed by three years severely depleted of sockeye (Kew 1992). The difference in high versus low sockeye years varies and is further compounded by external factors such as weather, flow rate, and river depth. These salmon were the target of the major runs, but it has been recorded that smaller, less-desirable fish were taken from time to time as well, mostly in periods of low salmon numbers (Hayden 1992, 1997; Kennedy and Bouchard 1992; Teit 1906).

Many of the lesser desired, but still utilized, freshwater fish species of the Fraser River had runs and seasons that tended to not coincide with winter harvest. Rainbow trout, while decently sized and plentiful in the river system, were primarily caught near lakes in early spring and tended to be consumed on the spot (Kennedy and Bouchard 1992). Dolly Varden char were caught year-round in streams but are not known to have been cured and stored like salmon. Squawfish and Suckerfish were caught in lakes and usually eaten fresh and many other small fish such as lamprey, sculpin, and peamouth chub were caught by children for fun but never eaten. Curiously, white sturgeon which are prevalent throughout the area were not known to be eaten by the people of Bridge River, according to ethnography and modern-day informants but they were targeted by neighboring plateau groups (Kennedy and Bouchard 1992). Of the smaller fish caught, it was very rare that any would be kept for winter storage.

Methods of Catching Fish

Given the fact that many of these fish vary in size, seasonality, and river ecosystem, there were several techniques that the Lillooet employed to catch them. Scaffolds, set nets, and weirs were often most employed for salmon runs. Scaffolds were constructed along step rocky shores and usually suspended above rapids, in areas where fishing without scaffolding was practically impossible (Kennedy and Bouchard 1992). From these platforms set nets could be used given their far reach to scoop salmon from the rushing water. The fibrous innards of Indian Hemp stems were used to construct a net which was then connected to a bent, fir hoop attached to a long pole and a line was attached to the rings and the net was held open with the line. When a fish entered the net, the line would be released and the net would close around the fish, ensuring it could not escape and that it could be safely lifted from the water without dropping (Kennedy and Bouchard 1992).

Weirs were essentially a lattice work of sticks constructed and placed in parts of a stream to corral salmon into shallow waters. From there the Lillooet could spear them, scoop them out, or trap them with basket traps set in the water. Basket traps were cylindrical contraptions made from pliable sticks with an opening facing downstream that could trap fish as they sought shelter (Teit 1906). These were usually best used for salmon smolt and trout. The three-pronged spear was another common method of catching trout near lakes. This technique required a clear line of sight and was usually not employed in the deep, opaque waters of the rushing river. The three prongs would pin the fish on both flanks with the center prong piercing the spine. While usually done from land it has been noted that this technique was also employed via canoe with the help of a torch as a light source (Teit 1906).

Line fishing was another common means of catching fish and had the added benefit of being a passive trap, meaning it could be set and left overnight. A long line was anchored on one end into the water while the other end was tied off on shore. From this singular line several small lines hung at close to equal intervals, each bated with a hook adorning fish eyes, fish eggs, or smaller fish (Kennedy and Bouchard 1992). Several fish could be caught overnight while this was employed, or at the very least, the chances of catching a fish were much higher with the several lines attached. This also seems to have been the primary method used when ice fishing on lakes in the winter months (Kennedy and Bouchard 1992).

Processing

Once caught, the preferred method of preparation was to remove the heads at the river side and create "neck ties" whereby the fish was split the length of the spine, keeping the very tail end intact so they could be transported back to the village either by wearing the fillets around the neck or hanging them on a long branch and carrying them back with the assistance of another person (Teit 1900, 1906). Heads were occasionally processed as well, being used to make rich stews and even being used ceremonially in the bathing of newborn babies (Teit 1906). Whether salmon was being stored for winter or eaten immediately, there were a number of ways in which it could have been prepared.

Barbecuing of salmon is understood by most researchers to be the most common cooking method for the immediate eating of meat (Kennedy and Bouchard 1992). Halves of salmon or steaks were placed on a branch of red cedar or ironwood and held over a fire, usually anchored so it did not need someone constantly holding it. Salmon heads were also regularly consumed in this manner by piercing the head, or half of a head cut sagittal, with a sharpened stick and holding it over a fire. For either immediate consumption or food on the go, powdered salmon was processed and mixed in a basket with fish oil and dried, crushed saskatoon berries. These were rolled into small mounds, similar to the way pemmican was made on the Great Plains, and carried in a pouch by hunters and gatherers (Kennedy and Bouchard 1992). Salmon eggs were also eaten fresh or buried and left until Spring where they were then dug up and mixed with tiger lily bulbs and bitterroot and boiled together (Kennedy and Bouchard 1992). The main objective of the Autumn salmon run, however, was still focused around drying and storing salmon for the upcoming winter.

Drying and storage of fillets varied depending on weather conditions of the area but what has primarily been understood is that drier regions stored their fillets in cellars beneath family homes and wetter regions constructed sheds for their fillets to dry in (Teit 1900). Being part of the British Columbian plateau, the Lillooet of Bridge River had ideal conditions for the drying of meat for storage, utilizing the still hot dry winds of late summer to prepare sockeye neckties for winter (Hayden 1992). Within the British Columbian plateau there were a number of ways in which fillets could be properly cured. Depending on location and weather, salmon could be dried in the sun, in the wind, be the heat of a fire, or in a smokehouse (Alexander 1992). To ensure that insects would not spoil the meat it was also common for the utilization of juniper berries, hung up with the fish, to be used as a sort of insect repellant (Alexander 1992). Fish caught on mountain excursions were most often cured depending on length of stay. If time was of the essence, meat would be dried out using fire, which could reportedly make the meat edible for a length of about 6 months to roughly two years before going rancid.

For the deer that were taken in late fall smoking and drying was the most common method of processing. Once taken back to the hunting camps, deer were quartered out and the ribs along with the front section of the deer were propped up with sticks around a fire (Romanoff 1992). Once sufficiently dried, the meat was hung in strips over the fire to be smoked, which could preserve the meat for upwards of six months (Romanoff 1992). While the hides were processed for the manufacturing of a number of different items, the sinew was processed to be used as thread and deer bones were utilized in the construction of multiple separate tools (Kennedy and Bouchard 1978).

Whatever the method of procurement or storage, the overall goal was for each family unit to store enough salmon to outlast the winter. There is evidence of sharing between households but much like the famed potlatches of the coast, this was done in the form of feasting to display wealth and status among the community (Hayden 1992; Teit 1906). These fillets were the key to survival once winter set in and harsh conditions made tasks like hunting and gathering dangerously difficult.

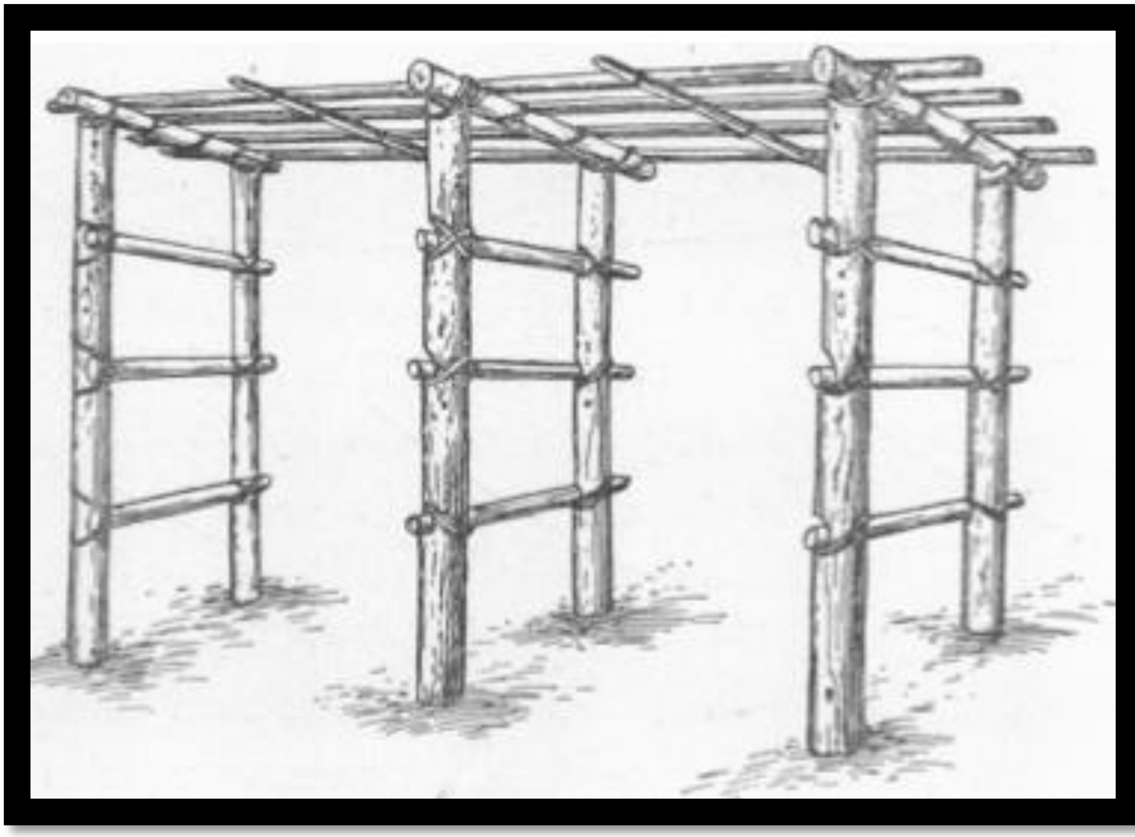

Figure 3: Fish drying rack utilized by the Lillooet from Teit 1906

These "housepits" that archaeologists in the region study are the remains of the winter dwellings of the Lillooet. These were semi-subterranean lodges of sorts with fire pits and rooftop entries that were navigated with the use of ladders. Storage of food was accomplished with the use of cedar bark containers placed in the ground while specially made shelving for other supplies was installed along support beams holding up the ceiling. In some reconstructions, the walls of these lodges were lined with long, bench-like beds that could accommodate the families that would be living inside. Other reconstructions have theorized bed spaces under the eaves of the roof or on wooden platforms over the floor. Once winter was in full swing families would spend the vast majority of the day inside their lodges.

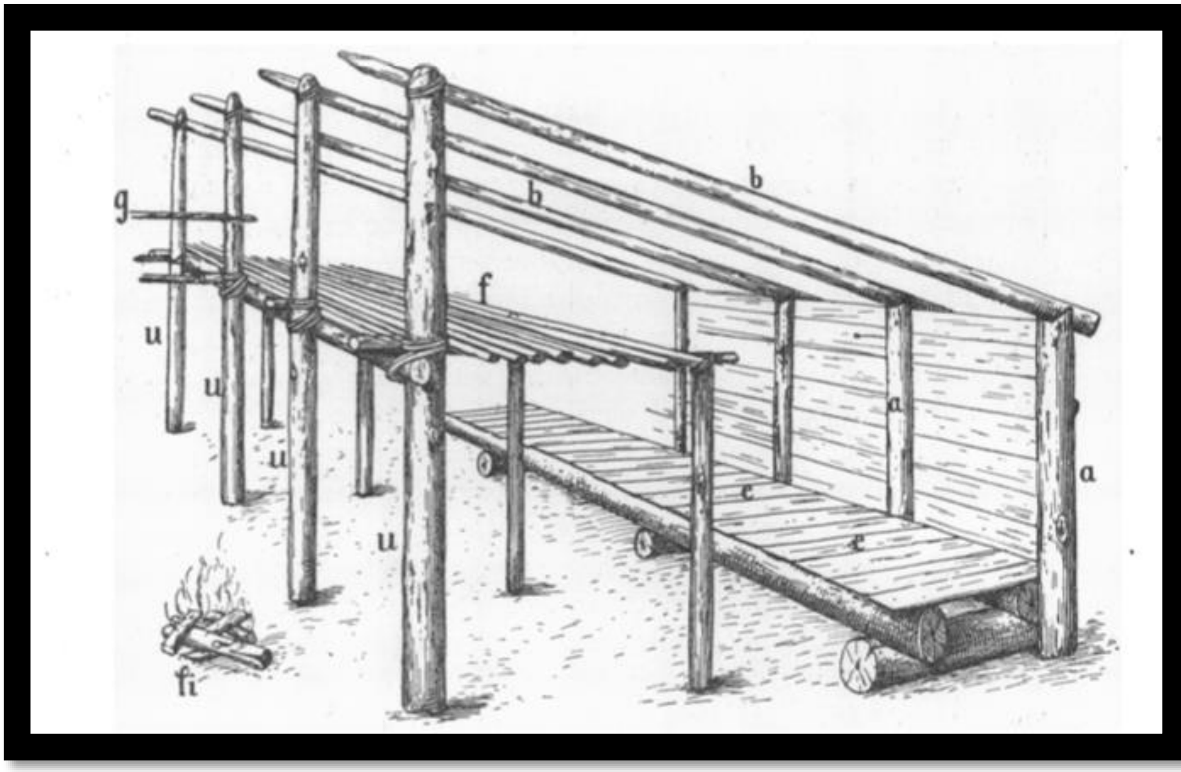

Figure 4: Interior depiction of Lillooet winter lodge from Teit 1906

It is the remains of materials left behind in these housepits that have provided the bulk of knowledge for archaeologists studying these villages. Faunal remains are abundant within the anthropogenic floor layers and can provide insight as to not just the diet of occupants but how much of these food sources were being utilized. The abundance of salmon remains within these layers is no surprise given the ethnographic evidence for reliance on salmon but what is puzzling in these layers is the disparity of salmon remains between different time periods. Teit has acknowledged in his writings that seasonality played a crucial part in survival and the Lillooet have reported times where ancestors have had to dip into winter stores early or even years of poor salmon numbers swimming up river (Teit 1906).

There is only slight mention by Teit of the Lillooet utilizing smaller fish species but Brian Hayden manages to elucidate more on the topic. Smaller fish such as trout, the freshwater ling, suckerfish, squawfish, lamprey, and sculpin were eaten fresh when they were in season, usually around late spring (Hayden 1992). While trout were captured with similar methods as salmon, they were usually not found in the same locations as salmon and were instead caught regularly in small streams and lakes. Hayden's work on nearby Keatley Creek explains that the Lillooet had vast fluctuation in salmon run returns. Hundreds of salmon were needed just to sustain one family lodge through the winter, with modern Lillooet claiming the average number taken each year per family is around 300 salmon, and it seems that on a rough cycle of every four years the Lillooet would experience heavy salmon runs but would occasionally see years of virtually no salmon (Hayden 1992, 1997). In these times the Lillooet would have to rely more heavily on deer meat and geophytes (roots) while also attempting to make up for the lack of salmon with trout fishing in nearby lakes and rivers (Hayden 1992, 1997). This is further reflected in the archaeological excavations that have been undergone at Bridge River over the years.

Archaeology of Bridge River

At Bridge River, Dr. Anna Prentiss and others have been able to put together a chronology of residence in the village that appears to show variation in occupation over four distinct periods (Prentiss et al. 2008). At the village's oldest point (1800-1600 cal. YBP) only seven housepits are evident. This period shows evidence of a more egalitarian style system through the arrangement of housepits and lack of evidence for individual/family-based wealth. From 1300-1100 cal. YBP the size of the village grows to around 30 households and at this point appears to shift to a more material wealth-based system, but from 1100-500 cal. YBP Bridge River is mostly abandoned until reoccupation appears just before the colonial period starts up (Prentiss et al. 2008; 2018).

This fluctuation in population accompanied with apparent changes in social stratification is exactly what intrigues archaeologists about this site. When viewed through the perspective of Human Behavioral Ecology it appears that the people of Bridge River could have reached what is called a Malthusian ceiling from which they could not recuperate (Lee 1986; Malthus 1778). This is essentially an idea born of predicting societal economic complications based off the sociodynamics of a small population and their resources. With plentiful resources we see an increase in population and in turn an increase in demand for resources. As time goes on there is a plateau where resources and consumers seem to find equilibrium, however, if the population grows too quickly when resources drop, then a Malthusian Ceiling is reached and we can expect site abandonment, resource defense, and occasionally violence (Malthus 1778; Puleston et al. 2014).

Given the evidence of fluctuation in population and wealth ending with abrupt abandonment it is anything but unfounded to suspect that the past peoples of Bridge River had befallen this scenario. Annual salmon runs worked practically like clockwork in this region of North America and these anadromous fish were a fairly reliable resource... Most of the time. Ethnographers of the region have found that when past starvation or famine is brought up it is in direct relation to lack of salmon (Kennedy and Bouchard 1992; Romanoff 1992). Resource patches were scarce during winter months and given the sense of territoriality displayed by the

Lillooet peoples, many patches were inaccessible having belonged to other groups. The only viable option was to stock up in the summer and fall on the most abundant of resources: salmon.

When studying fisher-hunter-gatherers it becomes absolutely paramount that a researcher thoroughly understands the relationship between the community and their food source. This requires that we as archaeologists take a slight caveat into the realm of studies produced by biologists and animal behaviorists concerned with the animal species in question. Humans do not exist in a void and are certainly not solely responsible for their fate. Hunter-gatherers rely on their ecosystem and their understanding of the species that share this space with them in order to survive. So to understand why salmon numbers fluctuate to the point of borderline societal collapse, we need to understand the biology and behavior of the salmon themselves. Both Teit and Hayden mention there being recorded times of extremely low salmon numbers and given what has been learned from studies of sockeye salmon it is understandable that this trend is possible.

Of the five Pacific Salmon species that exist, it was primarily the migrating Sockeye salmon that the people of Bridge River utilized. Sockeyes are one of the few species of Pacific salmon that display a sensitivity to temperature and river conditions, and may all together postpone their migrations upstream if conditions are unfavorable (Blackbourn 1987; Hodgson et al. 2006; Tully and Barber 1960; Quinn and Adams 1996). It is for this reason that climate has had such an influence on the shaping of ecosystems and human habitats throughout history. Within the Pacific Northwest alone it has been hypothesized that uncharacteristic occurrences of draught and high temperatures have been the driving force behind everything from budworm infestations in coniferous tree species (Flowers et al. 2014) to widespread forest fires termed the Fraser Valley Fire Period (*sensu* Lepofsky et al. 2005). These bouts of unseasonably warm weather have been further confirmed through dendroclimatological studies that found there to be a sort of cyclical regularity in periods of draught occurring roughly once a century within the area of study (Graumlich 1987). A variety of paleo-climate proxies have projected what appears to be a likely cooler period in the Pacific Northwest from 1700-1200 cal. BP leading up to a warmer period from 1200-600 cal. BP (Allen and Smith 2007; Patterson et al. 2005; Tunnicliffe et al. 2001). There have also been population proxies created based on radiocarbon dates from the Mid-Fraser that suggest climate factors would have affected human populations, quite possibly through the productivity and availability of salmon populations (Prentiss et al. 2022).

These environmental stressors affect everything from microbes in the forest soil to anadromous fish getting ready to make their migrations upriver. The bulk of freshwater fish rely on environmental cues such as temperature, flow rate, and rainfall when preparing for migration (Quinn and Adams 1996). Sockeye salmon are one of the few salmonids that also display this sensitivity to water temperature and levels (Blackbourn 1987). The effects of temperature on sockeye salmon migrations have been well documented over the years and it has become clear that temperatures at sea will even determine which route they will take on their return to the Fraser River (Groot and Quinn 1987). Sockeye salmon will tend to take either a northerly or a southerly route when migrating inland and these routes seem to correspond with years characterized by El Nino conditions. The northern route, taking salmon from Queen Charlotte Strait to Johnstone Strait, to the Strait of Georgia to the Fraser River, seems to be favored in warmer than usual years and as a result the sockeye tend to arrive later to their spawning grounds than in non-El Nino years (Groot and Quinn 1987).

While this information can help us clarify a most likely scenario as to what happened at Bridge River, the main concern for this thesis is to analyze not what happened, but how events could have affected the diet of the inhabitants of Housepit 54. With the drop in salmon numbers, would people have been able to make up for the losses in protein, calories, and fat with back up fish species and hunted animals when weather permitted? The population at Bridge River would have been fairly large before the fall in salmon numbers which raises obvious concerns of whether or not the households would be able to support themselves during the bad salmon runs to come. Fortunately, the faunal data from Housepit 54 is plentiful enough for a mathematical model to tackle and with the appropriate model we can ascertain some answers to these questions.

3. Methods and Materials

Diet Breadth Modelling among hunter-gatherer communities has been a popular method of assessing human behavior in relation to the ecosystem for over fifty years (Hawkes Hill and O'Connell 1985; Lee 1979; Pulliam 1974; Pyke, Pulliam, and Charnov 1977; Simms 1987; Winterhalder 1983). The model allows for the researcher to find the best combination of resources in terms of energy expenditure v. calories (or any nutritional value) gained. The idea of a mathematical model predicting human behavior has been argued by many to be unrealistic and incapable of appreciating the complexity and randomness of humanity throughout the years, but diet breadth modelling has proven to be a useful method for interpreting archaeological data. While ancient peoples may not have been counting calories or making complex equations to figure out how best to spend their time foraging, they were still masters of their environment and they understood how best to spend their time in the pursuit of resources. It is the evolution inspired idea that organisms innately pursue resources whose benefits outweigh costs that are central to the theory of diet breadth and optimal foraging. These models are merely representations of what foraging "should" look like in a given area if the community is trying to be as proficient as possible. It is for this reason why diet breadth modelling is still used in archaeological studies and why it will be used to assess the subsistence activities of the people of Bridge River.

For this model to work, certain key assumptions must be made. One of these assumptions is that an environment rich with the most profitable food source will show evidence of a narrower diet whereas an environment with lower numbers of that resource will show evidence of a wider range in diet (Pyke et al. 1977). Bridge River is a prime example of this. With such a high reliability and density of salmon during annual runs we see that much of the daily activity during these periods is centered around the procurement of salmon. There is little reason to go hunting or foraging when hundreds of salmon could be caught and processed in one day.

Another assumption for Diet Breadth Modelling is that where a hunter decides to hunt (Patch Choice) can be assumed to be a cost-benefit analysis between energy expenditure v. resources gained. I believe the specialization of hunting and the subculture surrounding it as an esteemed position among the Lillooet proves this assumption is vital in resource procurement. From a young age, Lillooet children raised as hunters are trained in local geography, tracking, animal behaviors and movement, and hot spots for animal activity (Romanoff 1992). Hunters are well respected and rewarded for their abilities to locate game in an environment where deer population ebbs and flows from season to season. With so much time and effort being put into training competent hunters I think it is safe to say that patch choice plays a key role in a Lillooet hunters decision making process.

Diet Breadth Modelling, if done correctly, should vary depending on the available game. In other words, it is a concept that is heavily dependent on environmental conditions. A study of diet breadth conducted by Steven Simms in the upper Great Basin of North America was vital to this research because many of the fauna he used in his calculations are also present in the interior of British Columbia. In his study he was able to breakdown important factors like pursuit time, processing time, and net calories per species (Simms 1987). With this data he could determine an optimal diet for the hunter-gatherers of the region and assess evidence from multiple archaeological sites in the area to compare his results to real world evidence. This is the essential plan for my use of Diet Breadth Modelling at Bridge River, but in addition to this we will also use Linear Programming to bolster our results.

Linear Programming Analysis first came into practice with economists and business sciences as a useful way to analyze multiple resources with multiple variables but was quickly picked up by archaeologists to analyze cost benefit problems in optimal foraging. Linear Programming in archaeology was demonstrated as a viable tool by Arthur Keene (1981) while also cautioning that it is not a "cure all" for every economic problem related to hunter-gatherers. The problem and constraints being tackled in this thesis should be perfect for the use of Linear Programming without overextending the program's abilities. Fortunately for us it has been well documented that hunter-gatherers were well practiced in cost benefit analysis and optimization of time and energy (Belovsky 1978; Dorfman et al. 1958; Keene 1981; Spivey and Thrall 1970; Wagner 1975; Walters and Hilborn 1978) so it goes without saying that we can be sure that the residents of Housepit 54 in Bridge River were doing the same thing.

Hunter-gatherers understood on some level that they required a varied diet to survive, and archaeological studies have confirmed this through the lack of evidence in health issues related to malnutrition among ancient hunter-gathering peoples (Ackerknecht 1948; Bronte-Stewart et al. 1960; Davidson et al. 1975; Dunn 2007; Hoygaard 1941; Keene 1981; Krogh and Krogh 1914; MacArthur 1960; Mann et al. 1962; Sinclair 1953; Trusswell and Hansen 1976) and we know that the Lillooet of Bridge River also utilized a varied diet of fish, deer, rabbit, berries, and geophytes. However, to take on every possible piece of the Lillooet diet would be far too much for Linear Programming to handle and seeing as the bulk of the winter diet was in salmon fillets, I will focus only on the "piscivore" diet of Housepit 54. In this way we can get a good idea of how well this household would fare in the long winter months where floors deficient in salmon numbers were concerned.

The idea is that we can use a diet breadth model to determine the most highly ranked resources of the Lillooet and then assess three different nutrients from each species (calories, proteins, and fat), input the data and calculate on a scale which of these species would be most beneficial to least beneficial. With this information, we could then look at the faunal evidence in our anthropogenic floors of Housepit 54 and get an idea of how effective species other than salmon were at bringing in these nutrients. By establishing a ranking system and being able to put a set of numbers on the efficacy in sustenance of these species we can better understand the role aquatic food stuffs (or lack there in) would play in social stress and population dynamics of the region. It is also important to note that this method, while reliable, is accounting only for nutritional value of resources and does not take into account cultural preference as far as taste is concerned. Often times fat content contributes to a food item being preferred due to taste and with fat being one of the factors considered in this research due to its importance to a hunter-gatherer societies diet, we can expect some crossover between nutritionally and culturally valued food resources (Prentiss 2022).

Diet Breadth and Linear Programming in Archaeology

Since the first use of Diet Breadth Modelling in archaeological studies there have been differing opinions on what resources are most likely to be exploited by early hunter-gatherers.

Given the need for logical balance between energy expenditure v. energy gain from resources, some archaeologists have argued that plant resources should be prioritized over meat (Lee 1979). The reason for this is that plants are more abundant and while they cost more to process, they offer the hunter-gatherers a low-risk option as opposed to hunting (Lee 1979). This can only be true, however, in areas where plant resources truly are more abundant and regions where this is not the case hunter-gatherers should pursue hunting and fishing. Other archaeologists side more with the theory that meat should be prioritized due to its hefty nutritional returns (Harris 1979). In addition to their returns, there is also a cultural aspect to the hunter-gatherer societies that needs to be considered, which Lee even contends, that meat may be prioritized despite its high risk due to taste preferences and the prestige that comes with a successful hunt (Lee 1979).

This is where the true difficulty comes in assessing the optimal diet of past hunter-gatherers. While we can find evidence of resources exploited and put together predictive models we cannot account for human preference and random decision making. It is only in ethnographic studies that these factors can be observed. A study of the Ache of Paraguay conducted in 1982 was able to bring light to some of these concerns while still expressing the efficiency of Diet Breadth Modelling (Hawkes, Hill, and O'Connell 1982). Here researchers found that most of the time the Ache hunter-gatherers pursued expected resources based off high return but would unexpectedly make decisions while hunting and foraging that could only be chalked up to human preference. While hunting and foraging, the Ache would consume resources on the go as they were encountered but researchers observed that at times, resources like palm fruit were taken and at other times, inexplicably ignored. These decisions had nothing to do with energy expenditure v. energy gained but rather random, on the spot, human decision making based off preference (Hawkes, Hill, and O'Connell 1982). In addition to palm fruit, monkeys were also mostly ignored despite the fact that they ranked third highest in terms of caloric return. According to the Ache hunters, this decision was made because monkeys “were not fat enough”. There were also times where the collared peccary, which ranked sixth highest in calories was preferred over the white lipped peccary, ranking first in calories, because it was easier to hunt the collared peccary (Hawkes, Hill, and O’Connell 1982). It is my hope that the use of Diet Breadth Modelling and Linnear Programming will be a more accurate approach due to the Linear Programing Analysis’ ability to rank resources based not just off calories but a multitude of other nutritional attributes like fat and protein as well.

There have been several studies in archaeology that have utilized the Linear Program model with varying success. In the Saginaw Valley of Canada, a study in Linear Programming was used to analyze the plant diet of the pre-contact people of the region. Researchers first had to establish which plant species were available and utilized at the time period that the study was looking into, which was established using palynological data (Bernabo and Webb 1977; Davis 1976; Kapp 1977). This study had a number of complications associated with it which involved not only the mentioned issues of establishing which species were available but also involved forest reconstruction in order to understand how different the area would have been that far back and as well as estimation of shrub and tree density to predict where these species would’ve grown (Autin 1941; Cain 1932, 1935; Curtis 1959; Griffin 1948; Stearns 1956; Zager and Pippin 1977).

The study collected data from their model on available nuts, fruit, seeds, roots, and tree sap. From there researchers calculated labor and travel costs in addition to the nutritional profiles of these foods and plugged them into their model. Altogether, ten separate species were used for the study with varying levels of procurement difficulty, processing time, yield, and nutritional benefits and with this information a reliable model was constructed using Linear Programming with greens being the most cost effective and beneficial and Beechnuts being the least (Keene 1981).

Another study that focused heavily on using Linear Programming to assess correlations between constraints was one conducted by Richard Lee (1979) focusing on the !Kung San. The !Kung do not store food like many other hunter-gatherers so what resources they can obtain throughout the day matter so much more because they cannot save food for times when weather limits them in their hunting and gathering (Lee 1979). It was Lee's objective in this study to find out if foraging time would be constrained by the physical environment of the !Kung. Past studies in physiology and the assessment of !Kung load carrying in adverse weather were utilized by Lee along with his own research into cold weather hunting and foraging times to put together a simple Linear Programming problem (Blurton, Jones, and Sibley 1978; Wyndham 1956; Wyndham et al. 1964). Lee input data on human thermal physiology, air temperature and solar radiation reports, and a thermal model to solve his equation (Finch 1972a, 1972b; Gates 1980; Lee 1979; Porter and Gates 1969). What he ended up finding was that while weather limited the !Kung in how much time they would spend foraging, the ample water in their diet and the warmth induced by physical activity was more than enough to keep them within thermal equilibrium, showing Lee that the weather was not a constraint on diet (Lee 1979).

Since then, other researchers have established smaller, more manageable data sets for Linear Programming. A more recent study by Gremillion (2002) used Linear Programming to assess the use of Mast Harvesting tree species at the Cold Oak Shelter site in eastern Kentucky. Instead of taking on the large variety of food stuffs, Gremillion found that using Linear Programming Analysis on just four species (hickory, acorn, black walnut and chestnut) was much more manageable and reliable. While being fairly small scale as archaeological studies go, Gremillion (2002) was able to tackle a problem that simpler models would not have been able to handle and provide feasible results that further propelled the knowledge of the Cold Oak Shelter site.

Bridge River Dataset

It is not my intention to stretch the capabilities of Linear Programming too far by considering the entirety of the Lillooet diet in one calculation. We will instead use Linear Programming to first assess the fish species utilized by the Lillooet of Bridge River and then use Diet Breadth modelling and Linear Programming to look at hunting resources of the area. There is also ample information on the exact fish species and land mammals eaten at Bridge River, so I have not had to deal with Keene's complications in the Saginaw Valley regarding species availability and forest reconstruction, but this is not to say that there have been no complications. Ethnographic and archaeological evidence of salmon and trout consumption are plentiful but there is not much documented on the consumption of smaller fish. Housepit 54's faunal record, however, has turned up many remains of what can only be classified as "small bony fish", since not enough of the skeletal remains were present to identify the exact species (Prentiss et al. "XY Fauna Total Database" https://scholarworks.umt.edu/household_archaeology_supplemental_data/1/ 13 April 2022). From the outlet of the Fraser River into the Strait of Georgia all the way up to the Bridge River site there are a possible 17 separate species of fish that could have been utilized by the native peoples.

These include one species of lamprey (*Petromyzontidae*), one species of sturgeon (*Acipenseridae*), two species of suckers (*Catostomidae*), two species of smelt (*Osmeridae*), eight species of salmon and their subfamilies (*Salmonidae* and *Salmoninae*), three species of whitefish (*Salmonaidae* and subfamily, *Coregoninae*), and four species of sculpin (*Cottidae*). Most if not all of these species were likely utilized by the native peoples of the area, but if we rely on the ample faunal data of the Bridge River site then we can identify three distinct families for sure: *Salmonidae*, *Salmoninae*, and *Catostomidae*. This makes the target fish for this study salmon, trout, and suckerfish. Given this data we can infer that the "small bony fish" are likely suckerfish of some variety, documented in ethnography as often being the target of young children fishing in streams and lakes (Hayden 1992; Teit 1906). I feel that their large spread throughout the northwest of North America with the Columbia and Fraser rivers being especially conducive to their life cycles justifies this assumption (Dauble 1986).

Animals hunted by the Lillooet following the Autumn salmon runs are a little easier to ascertain than fish. Mule Deer (*Odocoileus hemionus*) was the primary target of these hunts but it has been noted in ethnography that other animals like mountain sheep (*Ovis canadensis*) may have been taken if encountered (Hayden 1992; Teit 1900). Practically all birds and rodents native to the area were also utilized by the Lillooet and present in the faunal record of Bridge River but seeing as these were not specifically targeted for storage during winter months, I would not expect their impact to be very high. Black bear was also noted as being a prey item in ethnography but the record of Housepit 54 is absent of their remains.

For the nutritional values of fish and mammals being used in this thesis the USDA and Alaska Department of Fish and Game were consulted as well as data collected in Simms 1982. It is their data that has determined the levels of protein, fat, and calories for each species.

Table 1: Nutritional breakdown of top food species using USDA and Alaska Department of Fish and Game data.

Per 3oz Portion	**Protein**	**Calories**	**Fat**
Salmon	37g	261	10g
Deer	24g	145	1.3g
Sheep	23g	122	3g
Trout	16g	111	4.9g
Suckerfish	14g	78	2g

The Bridge River faunal data of Housepit 54 has provided a plethora of information for archaeologists to dissect. Of the 17 floors uncovered and of the 31 species and genus identified in the layers, we will be focusing on 5 of these anthropogenic floors and 5 of the species. These layers span what Dr. Prentiss has identified as four separate periods in Bridge River's history. BR 1 (1800-1600 cal. BP) is characterized by one or two housepit congregations but provides archaeologists with little else as far as evidence is concerned. BR 2 (1600-1300 cal. BP) witnesses' immediate growth at first but nearing the end of this period only a handful of households remained occupied. BR 3 (1300-1000cal. BP) sees yet another population boom, this time reaching a maximum capacity around halfway through its life, but the end of BR 3 is characterized by full site abandonment. The most recent of phases is BR 4 (500-100 cal. BP) where reoccupation occurs shortly before colonists show up for the first time (Prentiss et al. 2018). Housepit 54 (HP 54) itself begins in at BR 2 around 1460 BP ending in BR 4.

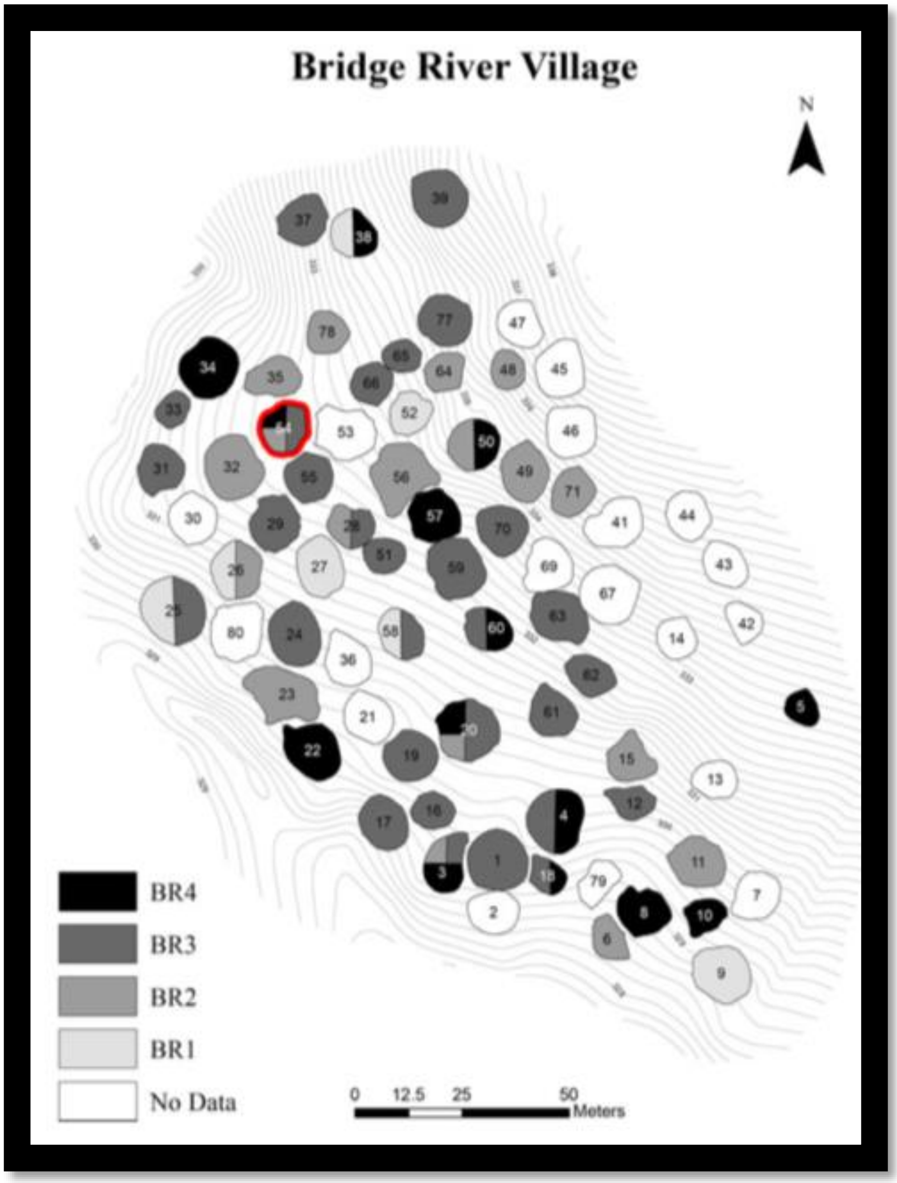

Figure 5: Bridge River Housepit occupations BR1-BR4 (Prentiss et al. 2018)

Table 2: Amount of faunal remains per floor of Housepit 54

Floor	All Remains	# and % of Aquatic Animal Remains	# and % of Terrestrial Animal Remains	# and % of Indeterminate Remains
IIa	934	342 (36.7%)	59 (6.3%)	532 (57%)
IIb	6434	3,835 (59.6%)	96.5 (1.5%)	2,503 (38.9%)

IIc	3116	947 (30.4%)	427 (13.7%)	1,742 (55.9%)
IId	2579	511 (19.8%)	77 (3%	1,991 (77.2%)
IIe	6624	1,497 (22.6%)	99 (1.5%)	5,028 (75.9%)
IIf	1238	615 (49.7%)	74 (6%)	548 (44.3%)
IIg	868	430 (49.6%)	64 (7.4%)	373 (43%)
IIh	2229	537 (24.1%)	96 (4.3%)	1,596 (71.6%)
IIi	991	206 (20.8%)	28 (2.8%)	757 (76.4%)
IIj	932	121 (13%)	19 (2%)	792 (85%)
IIk	6945	597 (8.6%)	76 (1.1%)	6,271 (90.3%)
IIL	3889	222 (5.7%)	19 (.5%)	3,648 (93.8%)
IIm	519	171 (32.9%)	37 (7.1%)	311 (60%)
IIn	3	1 (33.3%)	2 (66.7%)	0
IIo	3	1 (33.3%)	2 (66.7%)	0

What is important to remember is that the farther down we go, the farther back in time we are looking. What we observe in the above table is that fish make up the bulk of the diet through the majority HP 54’s timeline. However, we also see that the deeper we dig, the more fragmented and indeterminate faunal remains are. These numbers can help us understand the past history of Bridge River but we have to be careful with how we go about using this data. Does a layer with 100 pieces of salmon remains and 2 pieces of deer remains mean that there were more salmon than deer? Not at all. Salmon remains could be far more fragmented with the remains of one salmon amounting to hundreds of pieces and we already know from ethnography that deer bones were utilized in tool making, meaning the remains thrown away are what could not be used (Hayden 1992; Teit 1900). These numbers when comparing all floor layers against each other can be useful in giving us a general idea of diet during these periods of time within this household and that is really what we are looking at. Given what we understand from the Bridge River site and Lillooet ethnographies I aim to confirm or refute my three Hypotheses:

Hypothesis 1 (H1): The number of trout and other fish remains will be higher when salmon remains are low.

Hypothesis 2 (H2): The number of deer and land mammal remains will be higher when salmon numbers are low.

Hypothesis 3 (H3): The number of fish other than salmon and land mammal remains will be completely independent of salmon numbers.

4. Analysis and Results

In this chapter we will go over the ranked resources of the Lillooet, discuss our methods being used, test our data and compare our results to the floor layers of Housepit 54. Ranking of resources will be established using data from ethnography past archaeological studies in Diet Breadth Modelling, and nutritional breakdown of each resource. Through the use of our statistical models I prove that salmon is the top resource at Bridge River followed by deer, goat/sheep and smaller fish. From there my hypotheses on prey choice at Housepit 54 are tested and our final results are obtained.

For each resource, diet breadth modelling is broken down into factors of total calories, pursuit time, processing time, handling time, and return rate. Pursuit time is the estimated time from when a hunter spots his prey to when he can take it down. Processing time is calculated as the amount of time it takes to gut, skin, and fillet the animal, handling time is the sum of pursuit and processing time, and return rate is shown as total calories per hour. (Simms 1987). Unless it is very well documented in ethnography, a researcher must find alternative means of establishing these factors if they hope to use this model for an archaeological site.

Simms (1987) used interviews with experienced hunters to find his pursuit and processing costs, which vary from 20 minutes to 1 hour to encompass situations where a hunter was able to kill the animal immediately or situations where the animal had to be stalked or chased down after wounding. His processing times were calculated based off Ache hunter-gatherers techniques for skinning, gutting, and filleting meat which seem to be applicable across many hunter-gatherer groups. It is also interesting to note that Simms decided to categorize deer and bighorn sheep together given their size and seemingly equal availability, making them equal in terms of most optimal resource for the Great Basin.

Table 3: Resource Ranking from Simms (1987)

	Total cal/ind	**Pursuit Time (hrs/ind)**	**Pursuit Time (hrs/kg)**	**Processing Time (hrs/ind)**	**Processing Time (hrs/kg)**	**Handling Time (hrs/kg)**	**Return Rate (cal/hr)**
Deer and Bighorn Sheep	42,900	.02-1.0	.0006-.03	1.5	.04	.04-.07	17,971-31,450

At Bridge River we know that Autumn hunting was mainly focused on deer procurement and mountain goats were taken when available, not just for their meat but for their shaggy pelts which the Lillooet used for clothing, trade, and blankets. Bighorn sheep and mountain goat are essentially the same size and contain virtually the same nutrients, so Simms (1987) results are certainly comparable to the interior of British Columbia. With winter approaching near Bridge River, mountain goats would be found in lower elevation areas, around the same spots mule deer would be grazing, so their equal availability to deer in the Great Basin can certainly translate to British Columbia as well. Using data from the Alaska Department of Fish and Wildlife we can also compare mule deer and mountain goat using linear programming, comparing these species based off their caloric, fat, and protein content as well.

When putting together the mathematical model I have decided to utilize the Solver function in Microsoft Excel. Setting solver to LP (Linear Programming) we can effectively and reliably calculate the data at hand. The variables that needed to be considered for this study consisted of our three fish species (salmon, trout, and suckerfish) and two terrestrial species (mountain goat and mule deer), nutritional values for proteins, fat, and calories, and labor hours needed to process a set number of these species. Since hunting and fishing to prepare for winter storage were conducted at different times and in different seasons, I will run one analysis for hunting and another for fishing. For Linear Programing to work we need to first find our processing time per unit and then set our constraints to account for fat, calories, and protein. Values for processing time are taken from Simms (1987) and nutritional information on mountain goat and mule deer were provided by the Alaska Department of Fish and Game.

Table 4: Data to input into the linear programing analysis for terrestrial fauna

	Deer	**Goat**
Processing Amount	1	1
Required Input		
Labor Time (min. per kill)	90	90
Yield		
Protein	24	23
Calories	145	122
Fat	1.3	3

With this data input into our linear programing analysis the results unsurprisingly predicted that in a 12 hour day, it is most optimal to ignore mountain goat and focus all attention on hunting deer for a total optimal return (best case scenario) of 8 deer in a day, amounting to 192g of protein, 1160 calories, and 10.4g fat. When data is manually input in the linear program model, and we omit deer and instead calculate for goat we find that 8 mountain goats in a 12 hour period will provide hunters with a total of 184g of protein, 976 calories, and 24g of fat. Although fat yield is over double that of deer, optimality projects that it would be more profitable in terms of calories and protein to focus entirely on deer.

Table 5: Linear Programing results for Mule Deer v. Mountain Goat, showing a focus on deer to be the most optimal choice.

Food Source	Processing Amount	Labor Time (in min.)	Protein	Calories	Fat
Mule Deer	1	90	24g	145	1.3g
Mountain Goat	1	90	23g	122	3g
Most Optimal					
Mule Deer	8	720	192g	1160	10.4
* Limited to 720 minutes of Labor Time (12 hour period)					

Ethnographic records relay that a Lillooet woman could process up to 50 salmon a day, so I used this to determine that it would take 14.28 minutes to fully process one average sized sockeye salmon (Hayden 1997). I then broke that down further to determine that this amounted to about 3.07 minutes per kilogram. Given that processing methods would have differed little between salmon, trout, and suckerfish I then calculated, based on 3.07 minutes per kilogram, that it would take 12.28 minutes to process an average sized rainbow or brown trout (the most abundant type of trout in the Fraser River) and 9.8 minutes to process an average sized suckerfish. These "average" sizes were determined by British Columbia's Fish and Game website. It is possible that these species varied in size during our specific time period at Bridge River but there is no way to know for certain.

Table 6: Data to input into the linear programing analysis for fish

	Salmon	Trout	Suckerfish
Processing Amount	1	1	1
Required Input			
Labor Time (min. per 1 fish)	14.28	12.28	9.8
Yield			
Protein	39	16	14
Calories	269	111	78
Fat	10	4.9	2

With salmon, trout, and suckerfish being compared against each other based on their protein, fat, and caloric content we need to set our constraint of 720 minutes (12-hour period) so that processing time must be equal to or less than that amount of time. As predicted, salmon is largest of the species and yields the highest amounts of protein, fat, and calories, but also takes the longest to process. It could be that focusing on a mixture of the species could prove to be more effective.

Table 7: Linear Programming results displaying highest optimal use of fishing time. Results suggest that trout and suckerfish are poor choices compared to salmon.

Food Source	**Processing Amount**	**Labor Time** (in min.)	**Protein**	**Calories**	**Fat**
Salmon	1	14.28	39g	269	10g
Trout	1	12.28	16g	111	4.9g
Suckerfish	1	9.8	14g	78	2g
Most Optimal					
Salmon	50	720	1,966g	13,563	504g
* Limited to 720 minutes of Labor Time (12 hour period)					

What we end up with after our optimality calculations are run is a result that predicts the most optimal use of fishing and processing time being solely focused on salmon. Despite the time saving element of processing trout or suckerfish, salmon comes out as most optimal given the large yield of nutrients that is practically double that of trout. These results are not all too surprising given the ethnographic evidence for the massive importance of the annual salmon runs. Sockeye salmon run from July to late September and with Sockeye being the leanest of salmon, best for drying and storage, this run would have been the last chance for the people of Bridge River to top off their winter stores (Hayden 1992). During this time salmon collection was a household wide endeavor with all attention going towards the procurement and processing of salmon. Following the end of this run, hunters and their families would head up to the mountains to hunt deer in order to top off their winter food storages. This ethnographic data is also reflected in the linear programing analysis which projected a hunting focus on deer to be most optimal. It is interesting to note, however, that while deer is the most optimal *hunted* species, it is still outranked by salmon according to our modelling. This is hardly surprising given the massive abundance of salmon during their annual runs compared to the trickle of deer that pass through the mountains every hunting season following an Autumn salmon run.

We want to understand the impact this would have had on the occupants of HP 54 during this time, so to do so we will first assume that the number of residents is the same as it was before the drop in salmon numbers and see if the amount of lower ranked fish, deer or goat meat would be enough to make up for losses in nutrients from salmon. Prentiss et al. (2018) used studies of fire cracked rock (FCR) in the layers of HP 54 to determine likely population size based on hearth locations and workspaces. With these calculations it was determined that during the occupation of IIf-IIl residency could have fluctuated from as small as 5 to as many as 30 occupants (Prentiss et al. 2018).

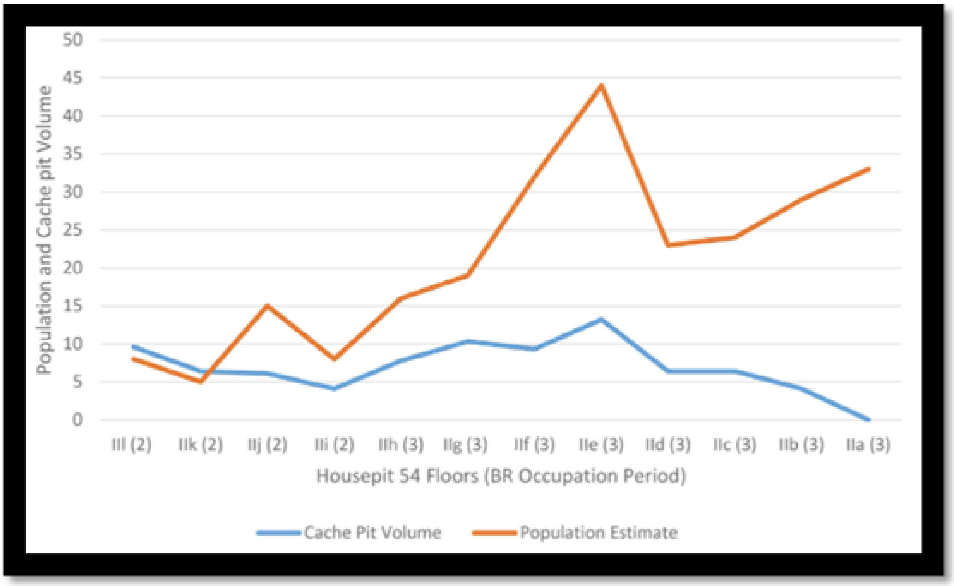

Figure 6: Graph displaying population v. cache pit volume (Prentiss 2018)

Within the floor layers themselves we can now run a correlation coefficient between the ratios of NISP of salmon remains and deer remains. With linear programming determining what should be the most optimal decision, we still need to examine the faunal record of HP 54 itself to determine whether there is any significance between the differences of salmon and deer remains. For this I run a correlation coefficient based off of volume density of remains per layer, which should ultimately be a more accurate assessment than going off of number of remains alone.

Table 8: Volume densities of remains per floor level of HP 54 from Prentiss (2020)

	Excavated	ONC	ART	CA
Floor	Volume (m^3)	D	D	D
IIa	1.304	179	38	4.6
IIb	1.238	3119	59	4.8
IIc	0.928	1023	61	6.5
IId	1.068	484	61	3.7
IIe	0.831	1940	78	12
IIf	0.721	892	76	9.7
IIg	0.6	715	98	1.7
IIh	0.923	584	44	23.8
IIi	0.573	360	35	0
IIj	0.393	489	36	2.5
IIk	1.305	475	30	6.9
IIl	0.52	508	25	7.7

ONC D = *Oncorhynchus* sp. density; ART D = Artiodactyl density; CA D = Canid density.

The correlation coefficients used were a Pearson r and Spearman's rho. These were chosen because while Pearson r correlations are useful in analyzing the linear relationship of raw data the Spearman's rho is best with analyzing ranked data, giving the two of these tests their own differential utility in crunching data. The Pearson correlation test found that there was no correlation between the number of identifiable specimens (NISP) of salmon v. trout, providing us with an r number of -0.09287 and a p-value of 0.381423. The Spearman's rho was then run and further confirmed this finding with a coefficient of 0.245784 and a p-value of 0.790865. There appears to be no correlation between the two suggesting that even in times of salmon scarcity as we see in late BR 2 through BR 3 (floors IIj-IIf), trout remained a food source that was sought after independently of salmon and seemingly not for the purpose of replacing salmon. The same test was then run again for salmon v. deer NISP volumes, which should be a more accurate measurement since it is a calculated ratio of how much of the known volume of a floor is associated with specific remains. In doing this it was found that the two correlated with each other positively, with a Pearson correlation r number equaling 0.385663 and our p-value being 0.2156638, and the Spearman's rho providing a coefficient of 0.6164633 and a p-value of 0.032776. Ethnographies describe periods of time where a failed salmon run was made up for with an increase in hunting of deer, but statistically speaking it looks as if this was not the case at HP 54 during BR 2 and BR 3. Instead it appears that periods of plentiful salmon were complimented further with plentiful deer.

With these results I was curious to see what other species within the layers of HP 54 would correlate and given the data from Prentiss (2020) I was able to look into the influence of beaver, dog, and small rodents as well. Dogs were used in hunting, hauling of gear, and protection but were also known to be a feast food during large gatherings and celebrations (Hayden 1992; Prentiss et al. 2021; Teit 1900 and 1906). Canine remains are present throughout the floor layers and it is quite possible that periods flush with salmon and deer would correlate with dog as well. Beaver was another regular food source for the Lillooet, though not a staple, that appears throughout the record of HP 54 and while they are only briefly mentioned in ethnography as being consumed they are prevalent enough to warrant testing (Hayden 1992; Teit 1900 and 1906). Lastly, I wanted to look at the remains of small rodents, which are on virtually every layer but not highly sought after. It is likely that these remains were not eaten by people but rather dragged in by dogs, contributing to the faunal assemblage to the chagrin of archaeologists attempting to understand the diet of Housepit residents (Prentiss 2020.

Volumes for the NISP of these three species were established and the same correlation tests were run again. Dogs received a Pearson r number of 0.07080073 and a p value of

0.82692313 and a Spearman's rho of 0.36140573 with a p value of 0.87580531. Beaver results were a Pearson r of 0.40133665 and a p value of 0.19598379 and a Spearman's rho of 0.65258269 with a p value of 0.02143099. Small rodent remains were tested lasted and received a Pearson r of 0.00351516 with a p value of 0.99134954 and a Spearman's rho of -0.1022967 with a p value of 0.75173375. From these results we can see that while dogs and small rodents do not correlate, beaver seems to correlate well with deer and salmon. I wanted to put together a table based off of nutritional attributes of all species ranked in descending order but there is unfortunately little information on dog (since the species utilized is now extinct) and rodents. However, if we assume that the nutritional composition of the dogs utilized would be similar to that of wolves, then based off of animal sizes we could expect a ranking of most nutritious to least nutritious to show salmon, deer, beaver, dogs, and lastly small rodents. Beaver, while usually being smaller than dog, have large reserves of fat and seeing as they were eaten more regularly in ethnography than dogs were, it makes sense to place them above dogs in the ranking.

While not confirming our H1 and H2, this data makes sense given the known ethnographic information regarding Lillooet diet. Fishing and hunting were both important aspects of survival and it makes sense that periods of high salmon yield would be accompanied by high hunting yield. While I originally thought the periods of lower salmon numbers were reflective of poor salmon runs, the results would suggest instead that it was quite possibly more telling of population size at the time of collection. The fact that other food items like deer and beaver were highly present when salmon were as well seems to suggest that this is the case. With more mouths to feed, more food is needed but when less people are residing in a home, less food is needed. After running these tests we can safely refute H1, H2 and H3, since the numbers of deer and other faunal remains are not entirely independent of salmon numbers but instead correlate positively with them, not in an inverse manner.

5. Discussion

The problems facing the people of Bridge River during the 4 phases identified by Dr. Prentiss were varied and compounded upon one another as time went on. Past studies have uncovered evidence of resource depletion, social stress, inequality, and site abandonment and it was my hope to add to these studies by looking into the effects of salmon depletion on the residence of HP 54. We know that the floors of IIf-IIj display the largest signs of salmon depletion and that this period was marked by population changes and stress indications. What this thesis has been able to show is that with the drop in salmon numbers, backup river fish and some faunal remains were not as prevalent during times of high, or low salmon yield, but the number of deer and beaver were higher when salmon were more available as well. The amount that would have been needed to make up for this deficit would be unrealistic to sustain the population if that population were of equal size as when salmon were more present, but given the fact that other hunted species outside the seasonal limitations of salmon were also low during these periods it seems more likely that population change is the reason behind these differences and not unfavorable weather conditions.

The PNW with the Bridge River region in particular would experience warmer and dryer than usual conditions every few decades or so that would've had an impactful result on the people of the region (Graumlich 1987; Lepofsky et al. 2005). During the autumn salmon run it was the sockeye salmon that made up the bulk of the catch and it has been documented in recent years that this species of salmon is most susceptible to changing water conditions (Blackbourn 1987; Hodgson et al. 2006; Tully and Barber 1960; Quinn et al 2007b). With an entire society built on the foundation of an annual salmon run to supply them with enough food to get through the long winter, something like a poor late summer run could be detrimental to the health and wellbeing of a household. We would expect that if this were the case at Bridge River, other hunted animals would be more present when salmon numbers were low but that is not what my tests have shown.

The diet breadth and linear programming models that were used calculated the most optimal plan for the procurement and processing of the top five most utilized species found in the faunal assemblage of HP 54. Salmon was largest, most available, and had the highest nutritional yield of our fish species but from the outset of our research it was unclear if maybe a combination of different species would prove most optimal. What the model ended up telling us was that despite the processing time, the best course of action would have been to process as much salmon as possible to achieve the highest yield in nutrients. Given the faunal data of an average season this result makes sense and mirrors what we see and what past ethnographies have documented. While salmon are plenty, it's best to ignore all other fish and go for the gold!

It was my suspicion that perhaps in these times of low salmon density we would see an increase in the number of trout remains or hunted species in the faunal record, given their abundance in the area. This was proven to be incorrect once the correlation coefficient was run against the NISP of salmon v. trout and salmon v. deer through HP 54's floors. Ethnography expressed trout fishing as being altogether different from the annual salmon runs and the results suggest that even in a time of salmon scarcity trout were not pursued as an alternative. It was not uncommon for low salmon return to be supplemented with hunted deer just before winter, but it seems that according to our statistical testing there is also no inverse correlation between salmon numbers and deer numbers during this period of time. The major concern here is that BR 2 to BR 3 at HP 54 demonstrate a drop in the top three most optimal meat resources. If the occupancy was on the higher end of Prentiss et al.'s 2018 projection for this period in Bridge River history, then we could expect major nutritional stressors among the people. I suggest that it is most likely that the HP 54 household was on the lower end of its occupancy during this time, which would likely explain the poor resource yield in their winter stores.

Dr. Prentiss and others have found that it was in BR 3 that major shifts were occurring within Bridge River and the population started to fluctuate. By analyzing the faunal data from floors IIf-IIj of BR 2, we saw a sharp contrast in salmon remains during this period compared to times before. With salmon yield at a high most of the time, population would max out over time and begin to plateau, but if bad years of salmon runs started to become more common, this small society would reach a Malthusian Ceiling. With what we have seen in past studies at Bridge River and now with the addition of these thesis results I believe that lack of salmon and hunted resources played a major role in the partial to full site abandonment.

There are of course concerns I have with the data of this thesis that prevent me from putting too much merit into these results. We cannot ignore the fact that much of the faunal assemblage of HP 54 is severely fragmented making species identification impossible for many of the pieces. Unfortunately, this problem is not unique to the site of Bridge River but is a constant thorn in the side of many an archaeologist at sites throughout the world, and until we can develop a better way of identifying these fragments of bone we are stuck with doing the best we can with what we've got. Utilizing volumetric data to establish exactly how much of the available space was occupied by remains of a particular species, however, certainly helps give a clearer picture of resource abundance during the 25-50 year periods in these layers. Our diet breadth and linear programing models have also allowed us to establish an ideal, ranked system for the pursuit of top ranked resources that I am particularly happy about because they lend credit to the field of human behavioral ecology.

Central to Optimal Foraging theory is that hunter-gatherers way the pros and cons of resources when hunting and foraging and will aim to find balance between energy expenditure and energy gain in the form of nutrients. Our results for what an optimal diet should be reflect ethnography and the archaeological record perfectly. While exact numbers regarding pursuit time and processing time of beaver are not available, nutritional data also helps explain the higher presence of this species remains during abundant times given their high concentration of needed fat and overall yield of edible meat given their average size. The most nutritious of prey was the salmon which make up the bulk of the diet and according to ethnography, are prioritized above all else during the annual runs (Hayden 1992; Teit 1900). After the Autumn salmon run, hunting of deer begins in the mountains, with mountain goat being taken if encountered. It isn't specified exactly when beaver were more likely to be taken but their high population and spread throughout the study area imply that they were readily available for hunting when desired. Our diet breadth model indeed shows that deer and goat were equal in most respects with deer being a slightly more nutritious option. If anything, our results here act to confirm the theory of optimal diet in hunter-gatherer communities.

While this thesis aimed to draw conclusions from the faunal assemblage of HP 54 it was also developed to better understand the implications of dependency on resources that are of a finite supply and may ebb and flow with change. This is a scenario of growing concern in the world of the 21st century where dependency on fossil fuels, commercial farming, and destruction of forests is becoming a much less stable way to live. What we can learn from the archaeology of Bridge River can help give researchers some insight into what we can expect to see throughout the world if proper precautions are not taken.

Future Research

It is clear that resource depletion, social inequity, and abandonment became the eventual norm at Bridge River over time but what is still yet unclear is why. I believe strongly that environmental conditions slowly altered the ecosystem to the point that seasonality and rainfall changed enough for formally dependable food sources to become less stable over time. This is a theory that is yet to be proven and future studies in paleoclimate in the vicinity of Bridge River could quite possibly explain what we see in the archaeological record. Studies at Bridge River continue with recent focus being on geochemical analysis of soil which can also prove to help clear up many of the questions regarding climate.

I believe that isotope analysis can also prove to be quite beneficial at Bridge River. Nitrogen 15 (N15) is an isotope absorbed into the collagen of animals that subsist from a marine diet, like anadromous fish that spend a good portion of the year feeding at sea before their late summer migrations. Further research into isotope analysis may prove useful in assessing how long the salmon found in HP 54's layers IIf-IIj were at sea, which could help confirm or refute the theory of these sockeye postponing their upriver migrations. As of now, however, the sensitivity of isotope analysis is still being fine-tuned and may not be able to find a difference between salmon who were at sea for four months or six months.

Other valuable answers could be obtained if processing and butchery locations could be established for our Bridge River site. It is mainly believed that while processing salmon, the heads and entrails were either tossed back into the river or tossed nearby the banks in a pile where dogs and other scavengers would pick them apart, but if we could find one of these refuse pits containing salmon heads then we could develop a much more accurate understanding of how many salmon were being processed through the years by examining otoliths. These otoliths (literally "ear stones") are small structures within the skulls of fish like salmon that consist of roughly 95% calcium carbonate, making them more stone than bone (Volk, Schroder, and Grimm 1999). Not only does this make them more apt to survive the tests of time and a much more reliable marker for salmon numbers, but otoliths develop something like tree rings in dendroclimatology over time which can be analyzed to find evidence for anything from environmental temperature changes to starvation episodes (Campana and Neilson 1985; Mosegaard et al. 1987; Brothers 1990; Volk et al. 1990 and 1994; Munk et al. 1993). If a refuse pit containing these otoliths could be found, then we could not only gauge annual salmon yield but have a valuable predictor of the ancient weather conditions of the time.

Whatever approach future researchers take in building off the archaeological record at Bridge River we can at least be sure that there is much to be learned from this site. Years of research into the prehistory ancestors of the Lillooet in this region have uncovered a plethora of data that has enabled archaeologists to further lift the vail of uncertainty that shadows our understanding of the past. With resource depletion being an ever-growing issue in the world today I foresee studies in human behavioral ecology in locations such as Bridge River becoming even more valuable.

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