PARASITES FROM PACIFIC NORTHWEST COAST ARCHAEOLOGICAL SITES

HEALTH AND SETTLEMENT IMPLICATIONS OF PARASITES FROM PACIFIC NORTHWEST COAST ARCHAEOLOGICAL SITES

By

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Doctorate of Philosophy

McMaster University

DOCTOR OF PHILOSOPHY (2005) McMaster University
(Anthropology) Hamilton, Ontario

TITLE: Health and Settlement Implications of Parasites from Pacific Northwest Coast Archaeological Sites

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NUMBER OF PAGES: xiv, 344

ABSTRACT

The aim of this project was to recover archaeological evidence of human parasite infection from the coastal shell middens of British Columbia, Canada. Although the preservation and recovery of intestinal parasites are not new to ancient disease studies, as yet there has been a paucity of investigation for such forms of evidence at temperate, coastal archaeological sites such as those found on the central coast. The reasons for this are threefold, and address some of the long-held assumptions about ancient subsistence economies, diseases in the Americas, and the degree of preservation in shell midden features.

Parasites are often considered a disease of urban societies. Classified on the basis of their subsistence economy, the archaeological populations of the Northwest Coast were non-agrarian hunter-fisher-gatherers. Normative thinking about hunters and gatherers maintain that such cultures were benignly impacted by infectious disease agents. As the level of disease risk is considered low, there has been little expectation of finding pathogen evidence at hunter-gatherer sites.

But consistent and quantifiable microscopic evidence of intestinal parasites, some as much as six thousand years old, was successfully recovered from 11 of 15 shell midden sites tested. Auger samples produced preserved eggs of four parasite taxa, including giant human roundworm (*Ascaris lumbricoides*) and broad fish tapeworm (*Diphyllobothrium* spp.), genera relevant to human health. The ecological, epidemiological and cultural significance of these finds are discussed in relation to health, settlement, behaviour patterns and regional culture history. Methodologically, this project demonstrates a replicable and non-invasive process for retrieving parasite evidence from midden sediments. The results of this study contribute to what is known about hunter-gatherer health, broadening the range of parasite species known in the Americas and confirming the antiquity of the human-parasite relationship.

ACKNOWLEDGEMENTS

Thanks go first and foremost to my supervisor, Aubrey Cannon, who provided the materials, the laboratory, the work space, and the guidance to see this project through. He has been a true mentor from the earliest days of my academic career and was a challenging and outstanding supervisor. My committee members, D. Ann Herring and Laura Finsten provided sound advice and guidance in very different areas of expertise. I am privileged to have had such a diversified anthropological committee. James Alsop and Mohamed Bakr, my external reviewers, provided sage advice and comments, as did Jerome Cybulski, whom I was most privileged to have had present at my defense.

I have been fortunate to receive a great deal of assistance from outside of the Anthropology Department: Patrick Horne, Andrew Jones and Karl Reinhard are the icons of my field. Each has helped me, though none more so than Pat Horne, who was always so generous with guidance and advice. I am immeasurably grateful. Thanks to Rose McQueen and the Regional Parasitology Lab at St. Josephs Hospital in Hamilton for their assistance and counsel in helping me set up the lab in our Fisheries Archaeology Research Centre. I would also like to thank the Heiltsuk Nation, who permitted and participated in the collection of the samples I eventually came to work with in this research project.

I am lucky to have a loving family, both immediate and extended, to support me. Nephews Zachary and Jacob were only just conceived when I started writing this thesis, and were born a month prior to its completion. My husband, Jason, has been my rock and has the strongest, most loving shoulders in the world. I share this accomplishment with him, as there were many occasions through which this was a team effort. And I would truly be remiss if I failed to acknowledge one other warm body who loved me, comforted me, and kept me company through many weary nights and days. Marbles, our cat (AKA Miss Marbles Meeposian Little Litterlegs I). Eighteen years of unconditional love deserves at least a literary pat on the head.

Alisa Dyment started me out on this path. I am here because she wouldn't take no for an answer and because she had more faith in me than I had in myself. My fellow graduate students deserve a nod as well. They broadened my perspective, made me laugh, encouraged me and supported me through all the trials we shared in common. There are a few I must acknowledge formally. Jodi Barta, who took a gamble on a extracurricular project with me that resulted in our first scholarly publication. Brooke Milne was an inspiration and strong role model -

Manitoba was lucky to get you. Beth Finnis and I share alma maters - she is one of the warmest and most genuine people I know, and a good friend. Karen Slonim, who's wisdom and insight is beyond her years - good luck at Missouri. Finally Ben Stride-Darnley, a native Londoner - "the *real* London" - has never failed to serve as an example of patriotism, pride and exuberance. I aim to experience life as lustily as Ben does.

I must also thank the lovely and infinitely patient ladies of the office, the administrators who make life so much easier for all of us: Janis Weir, Rabia Awan, and Rosita Jordan. Thank you for looking after me so kindly and so well. And thanks for sharing your chocolate.

An Ontario Graduate Scholarship, a doctoral fellowship from the Social Sciences and Humanities Research Council of Canada, an internal University Hooker Fellowship and a Departmental scholarship have all helped to support me through this remarkable experience. Without this funding, I simply would not have been here. I have come a long way from where I started, and it is through funding opportunities such as these that so many doors have been opened to me. I am both privileged and honoured to have been considered worthy.

Finally, I'd like to acknowledge two individuals I started my Masters with at the University of Western Ontario, Alexis Dolphin and Joe Parish. We've travelled this road together and despite the distance between us as we pursued our PhD's, we have always managed to stay close. You are the friendship equivalent of "home" for me. I wish you both every success and look forward to many collegial years ahead, looking back on these years that we shared together - so far apart.

I would like to dedicate this work in loving memory of my Nanny, Irene Bathurst, who passed away on May 25th, just two days before my defense. I know she was there in spirit. Merci pour croire en moi.

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Chapter 1:
INTRODUCTION

Whence, thinkest thou, kings and parasites arose?
- Percy Bysshe Shelley, *Queen Mab, Book III*, 1821

1.1 People and Parasites

Humans have always harboured parasites. Today parasitic diseases are among the leading causes of morbidity and mortality in world populations (de Silva et al. 2003; Hotez et al. 2003), yet they remain an issue of relatively low priority in the medical sciences (Sandeman 2001). This lack of interest can be infectious to other disciplines, and subsequently parasitic diseases have been under-represented in anthropological studies as well. As an interdependent species, parasites are reflections of the human cultural and ecological environment in which they develop and flourish. As such, they constitute a form of cultural evidence unrecognized by most archaeologists. Although archaeoparasite analysis has been a specialization of archaeology since the 1960's (Bouchet et al. 2003; Reinhard 1990; 1997), the utilization of parasite evidence in archaeological interpretations is not yet standard practice. This may in part be due to the nature of this biological form of evidence, as parasites are predominantly affiliated with health related issues.

Unless a program of research is specifically interested in health, the broadly interpretive value of parasites as cultural artifacts might be overlooked. Yet this is a line of evidence with the ability to disclose a breadth of cultural, biological, and environmentally relevant information about the populations they have parasitized. From settlement patterns to population density, food preparation, waste disposal/maintenance and ecological reconstruction, it is argued in this thesis that evidence of both zoonotic and human-specific parasites derived from archaeological sites along the central coast of British Columbia offer microscopic insight into the biocultural history of these maritime hunter-gatherers.

1.1.1 *Significance*

In the broadest scale, this project contributes to a growing body of research and interest in ancient health and epidemiology, and specifically how these issues relate to hunting and gathering populations. Empirical evidence of disease pathogens helps to fill the gaps in our knowledge of how diseases develop and are maintained in different types of societies. The current state of scholarship regarding health and disease agents associated with hunting and foraging populations in pre-Columbian North America is particularly vague. Most health related research has been interested in the consequences of agricultural practices or European contact, with little emphasis on what disease agents affected the

populations that inhabited the continents prior to these economic transition periods. This project focusses on North America, specifically the Pacific Coast of British Columbia, Canada, where populations remained dependent on foraged resources for their subsistence up until the era of European contact in the late 18th century (Ames & Maschner 1999). By investigating evidence of intestinal parasites derived from these hunter-fisher-gatherer populations, it became evident that there were differences in parasite density over time and between different types of settlements. This adds to the growing body of evidence that intestinal parasites were a burden borne by the earliest inhabitants of the American continents (Gonçalves et al. 2004).

1.2 Hunter-Gatherers

The influential *Man the Hunter* symposium in 1966, published in 1968 by Lee and Devore, marked a paradigm shift in the anthropological study of hunters and gatherers. The symposium offered a critique of essentialist efforts to define an archetypal hunting and gathering society, recognizing both global and temporal diversity in this mode of production. Relying strongly on ethnographic evidence, the symposium concluded that hunters and gatherers live or lived relatively healthy lives in comparison to agriculturalists (Lee and DeVore 1968). This 'original'

condition, as designated by Sahlins (1972), came to be characterized as the "original affluent society". In general terms, hunter-gatherer group sizes were exemplified as small and frequently mobile, resulting in less accumulated garbage, malnutrition or chronic diseases and more abundance in leisure time (Dunn 1968; Lee 1968; Sahlins 1972; Suttles 1968). These perceptions of hunting and gathering lifestyles, key to the development of primitivist[1] philosophies, heralded back to eighteenth century romanticised concepts of an idyllic, noble and 'natural' condition of humanity, untainted by the trappings of inequality that characterized preceding agricultural and industrial lifestyles.

The explanations for changes in health and disease patterns in the human past can result in divergent themes, one biologically focussed on the agent, the other behaviourally focussed on the host. The relevance of this project occupies a place at the intersection of these two interpretive themes. While there is considerable overlap, each stream grounds the understanding of ancient diseases upon two different foci: the pathogenic organism and the disease process, respectively. A balanced

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[1]Primitivism is a social, anarchistic critique of the progress of civilization. Primitivist philosophers, such as John Zerzan, argue that the shift from hunter-gatherers to agriculture resulted in hierarchical oppression and alienation.

understanding of ancient disease incorporates both the biological (nature) and cultural (nurture) factors that contribute to the disease process.

With the relatively new introduction of PCR (polymerase chain reaction) to biological anthropology over the last few decades, ancient DNA studies have begun to contribute significantly to evolutionary interpretations of human disease history (Greenblatt 1998; Greeblatt and Spigelman 2003). Molecular analysis can now establish the antiquity and genomic history of specific disease agents. Such studies are beginning to predict and/or demonstrate phylogenies much older than previously demonstrated by macroscopic observations of skeletal pathology. The antiquity of some human-relevant pathogens, such as *Shigella* spp., *Yersinia pestis* (plague), *Mycobacterium tuberculosis* (TB) and *Salmonella typhi* (typhoid fever), are now proposed to extend tens or even hundreds of thousands of years into the past (Achtman et al. 1999; Kidgell et al. 2002; Pupo et al. 2000; Sreevatsan et al. 1997; Zimmer 2001). However, this level of inquiry is primarily interested in the life history of the pathogen. The existence of a pathogenic organism is not sufficient to cause disease (Evans 1995; Timmreck 2002:6). Disease is a harmful condition, or a negative response that a pathogen affects upon another organism. Therefore the study of ancient disease cannot be focussed on

the pathogen alone; it must also consider the organism the pathogen is afflicting and the environment that both organisms inhabit.

By contrast, epidemiological explanations for changes in health are interested in the disease process and understanding how pathogenic agents come to cause harm or affliction to a host or population. Biology, demography, ecology and culture are all recognized as important agents of epidemiological change (Cohen and Crane-Kramer 2003). Bioarchaeological approaches to the interpretation of health and disease utilize skeletal and cultural artifacts to reconstruct epidemiological patterns. However, there has been a penchant to view epidemiological history on an evolutionary trajectory from a period of minimal and benign disease to our current, fully encapsulated state, with a series of recognizable transitions in disease patterns experienced along the way (Armelagos et al. 1996; Barrett et al. 1998; Froment 2001; Omran 1971). Human disease history, therefore, has been broadly categorized into epidemiologic transition periods that became increasingly complicated as they approached the present. A clearer understanding of the nature and diversity of human disease history needs to focus on smaller temporal and spatial scales of analysis.

1.2.1 *Epidemiologic Transitions*

Following the paradigm shift of anthropological thought that resulted from the *Man the Hunter* symposium in the late 1960's, demographer and health scientist Abdel R. Omran (1971) introduced the "Epidemiologic Transition Theory" to the Public Health field. In broad terms, Omran's theory correlated human health and disease history with major stages of cultural evolution, such as agriculture, urbanization and industrialization. Over the years, several researchers (i.e. Armelagos and Brown 2002: 598; Armelagos et al. 1996; Barrett 1998; Cohen 1989; Mitchell 2003) have reevaluated and elaborated on these epidemiological stages. Throughout, two concepts of epidemiologic transition theory have remained the same: 1) that the first major transition in the history of human health was the result of the agricultural revolution and 2) that the period of history before this formed a "Palaeolithic baseline" of human health against which all other epidemiological stages are measured. Hunting and gathering lifestyles prior to the adoption of agriculture were presumed to have been demographically stable, suffering only benign maladies such as those acquired as ancestral pathogens and/or zoonotic infections. It is popularly believed that populations were too small and too mobile to maintain endemic (enduring) or contagious "crowd" diseases (Cohen and Crane-Kramer 2003; Froment 2001; Mitchell 2003;

Waguespack 2002). Therefore it is argued that the diseases of most interest and relevance to humanity did not actually appear in human history until after the adoption of agriculture.

As a result of these over-generalizations, the connection between agriculture and human health and disease has been overemphasized. Some researchers (i.e. Fenner 1982; May and Anderson 1983) have argued that pathogens with long life cycles or periods of latency, those that reproduce by K-strategy such as tuberculosis or chickenpox, also have the capacity to be maintained in the environment for long periods of time. Thus, such "persistent pathogens" may be expected to have impacted ancient hunter-gatherers.

It can be acknowledged that the domestication of plants and animals likely contributed a new suite of pathogens to the human disease pool. But it is the social consequences resulting from domestication, not the practice of domestication itself, that stimulated changes in disease patterns. Population expansion, sedentism, waste accumulation, increased exposure to faecal contamination and less dietary variety are not conditions unique to agricultural populations. There is considerable variability in the lifestyles and cultures of hunters and gatherers (Kelly 1995; Kent 1992; Lee and Daly 1999). The Jomon of Japan and Chulmun of Korea lived in sedentary villages and produced pottery (Akazawa and

Aikens 1986). The Calusa of southern Florida were hierarchical hunter-fisher-gatherers who built monumental earth works and elaborate canal systems (Widmer 1988). Likewise Caral, in the Supe Valley of Peru, is recognized as the oldest planned city in the Americas, and was built replete with monumental architecture and earthworks. And yet this urban site was established more than 4600 years ago without the aid of domestic staple crops such as maize or potatoes (Solis et al. 2001). Similarly, the populations of the Northwest Coast were sedentary, hierarchical, and specialized hunter-fisher-gatherers (Ames 1994; Ames and Maschner 1999; Coupland 1998; Drucker 1955). All of these cultures were densely populated, closely aggregated, and semi-sedentary, cultural conditions typically associated with early agriculturalists. Neglecting to recognize the variability of lifestyles intrinsic to human populations that did not practice agriculture only serves to overlook the range of different circumstances through which diseases might have evolved with their human hosts over time (Merbs 1992; Waldram et al. 1995). Therefore one of the goals in this study was to contribute to a growing body of evidence that challenges such perspectives by establishing the presence of a disease agent among a specific 'hunting and gathering' population of considerable antiquity. From this context, the next phase of research involved addressing the source of the pathogen, why and how it had

persisted within this cultural context and how it may have influenced the humans it parasitized.

1.3 New World Hunter-Gatherers

The perception that the Americas prior to European contact were healthy, unblemished and free from the plagues of "civilization" remains entrenched in common thought. William H. McNeill's popular and influential historical monograph "Plagues and Peoples" has published three editions, one for each of the last three decades: 1977, 1989 and 1998. In it, McNeill reinforces these perceptions, stating "... it seems certain that Amerindian encounters with disease before Columbus had been unimportant from an epidemiological point of view." (McNeill 1998:208). Broadening his perspective, he reflects "... like the human hunting bands that had initially penetrated the Americas, [Amerindians] were incapable of supporting infectious chains of the sort characteristic of *civilized* diseases." (McNeill 1998:211; emphasis mine). The implication here is that "uncivilized", or pre-Colonial America, was therefore "wild"; "wild" is equated with "pristine". This is a fundamental misconception, reinforced in multiple disciplines and venues as the "Frontier myth", the "myth of the pristine environment" or the "Golden Age" (i.e. Echtner and Prasad 2003; Harris 1996; Hessburg and Agee 2003; Jin et al. 2004;

Noakes et al. 2000; Said 1978; Waitt et al. 2003; Wooley 2002). It is chiefly a Western philosophical construction steeped in overarching themes of human stewardship over nature and postcolonial Eurocentrism.

The dogma of the 'virgin continents' has been difficult to dislodge from popular thought, despite sound critique in the literature (i.e. Armelagos et al. 1996; Cohen 1989; Merbs 1992; Steckel and Rose, 2002; Waldram et al. 1995). Likewise, there have been significant skeletal, parasitic and molecular findings that demonstrate the antiquity of pathogens in the Americas thousands of years before European contact or domestication. Treponemal diseases, arboviruses, tuberculosis, Chagas' disease and a host of intestinal parasite species including hookworm, pinworm and tapeworm have been documented from archaeological sites in both North and South America (i.e. Araujo et al. 2000; Gonçalves 2003; Gonçalves and Araugo 2003; Herring 1992; Horne 1985; Martin and Goodman 2002; Ortner and Putschar 1981; Rothschild 2003; Waguespack 2002). Yet two enduring hypotheses of New World disease epidemiology in particular contribute to the maintenance of this pristine perception; the cold screen and virgin soil hypotheses.

T. Dale Stewart, a physical anthropologist, introduced the Cold Screen hypothesis in 1960. This scenario proposed that the high Arctic,

through which the first inhabitants of the Americas were believed to have passed, presented an environment inhospitable to most pathological organisms (Stewart 1960:265). Thus, the theory proposes that as populations moved from the Old world into the New, their pathogens were effectively filtered away through a geographic and evolutionary bottleneck.

The idea that the first inhabitants arrived in North America virtually disease free, or that the harsh living conditions of the Americas selected for "hardy" stock (Sievers and Fisher 1981:196), promoted the perception of a "virgin soil" for pathogens to inhabit in the New World (Crosby 1976). Mobile hunting and gathering populations who are believed to have entered the continent at least 13 000 years ago, were considered to have been too small to maintain acute "crowd diseases" such as smallpox, measles or influenza (Barrett et al. 1998; Froment 2001; Sievers and Fisher 1981). While there is no denying the epidemiological impact of the novel diseases that were introduced with contact, the "virginal" condition of the New World populations has been overstated and misinterpreted.

1.4 Pacific Northwest Coast Hunter-Fisher-Gatherers

Considering one of the aims of this project was to explore the presence of pathogens among non-agrarian populations in the Americas,

the Northwest Coast was a logical place to begin the search. By the early 1970's, archaeological studies recognized that hunting and gathering cultures could express varying degrees of economic and social complexity (Lee and Devore 1968; Price and Brown 1985; Renouf 1984). Hunter-gatherers were no longer considered to be one generalized "type" of society (Testart 1982; Yesner 1980). The hunter-gatherer cultures of the Pacific Northwest Coast were often endorsed as an illustration of such diversity (Suttles 1968; Testart 1982), demonstrating many of the features typically associated with agricultural societies such as intensive resource exploitation, storage, sedentism, high population density, and socioeconomic inequalities (Fitzhugh 2003; Johnson and Earle 1987:4; Matson 1992:367; Testart 1982:524).

As the North Pacific region was glaciated during the Pleistocene, particularly the mainland coast, most of the archaeological record only represents occupation from the Holocene epoch (ca. 10 000 BP) onward (Yesner 1998:207). The Bering Land Bridge to the north is typically considered the gateway of New World migration, therefore the Northwest Coast falls within the geographical boundaries of interest for early hunter-gatherer research.

According to archaeological evidence over 9000 years old, the cultures of the Pacific Coast of Canada had always been intensive fisher-

foragers (Carlson 1998; Cannon 1991; Stein et al. 2003; Suttles 1990). They continued to rely on this subsistence base through European contact in the 18th century and to the present day. Their only domesticate was the dog (Ames and Maschner 2000; Schwartz 1997). Populations were seasonally sedentary, utilizing a spectrum of maritime species and concentrating on a few specific resources that were reliably available in abundance at regular seasonal intervals. Dense and permanently settled populations accumulate waste and increase their exposure time with the local environment and one another, amplifying their susceptibility to infectious pathogens (Herring 1992; Larsen 1997).

On the Northwest Coast, all matter of cultural wastes were accumulated in shell middens (Hobler 1990). Stratified midden deposits provide a means of investigating and comparing cultural patterns of considerable time depth, allowing for the investigation of relative changes in parasite burden over time. All of the 15 sites investigated in this study were shell middens, some over five metres in depth. There was also variability in the type of sites that were examined, allowing for spatial comparisons of parasite evidence in relation to site use and activity.

Aside from broadening the knowledge of local health patterns, the study of parasitic evidence can contribute to a number of different issues relevant to Northwest Coast studies. At the local level, the variety of

species of parasite present and the quantity found are an indication of variability in settlement patterns and site types, a measure of environmental modification, mobility, population density and the anthropogenic consequences of mass resource harvesting. Such evidence is also valuable in interpreting patterns of waste disposal and residential site maintenance. All such findings broaden our knowledge of the complexity of the Northwest Coast cultures and demonstrate the antiquity of parasitic pathogens in the Americas.

1.5 Parasites and Local Site Variability

In the studies that have investigated disease experienced by hunter-gatherers, parasites are frequently hypothesized to be a common source of morbidity (i.e. Cohen 1989; Cohen and Crane-Kramer 2003; Dunn 1968; Froment 2001; Ubelaker 1992; Walker 1986; Waguespack 2002). However, the primary unit of analysis in most health related studies of past populations has been human skeletal material. Preservation, representation and access to human remains can limit the scope of skeletal analyses. Studies were once restricted to investigating only what can be seen on preserved bone. Molecular, chemical and histological methods of analysing bone are changing this reliance on morphological evidence (Greenblatt 1998; Greenblatt et al. 2003). However, we are far

from an era in which broad scale and destructive molecular testing is a standard procedure on all skeletal material, leaving us reliant on visual cues to alert us to bone changes and disease processes. These morphological changes are also restricted in their interpretive value, as there are limits in the ways in which bone tissue responds to stress, and skeletal changes may have a host of potential causes (Goodman et al. 1984; Ortner and Putschar 1981; Rothschild and Martin 1993). Nor do all diseases involve bone tissue. Numerous human pathogens leave no trace of their presence on the skeleton, and most parasitic diseases can be counted among them. Furthermore, only a portion of a population is likely to be represented in burials or skeletal populations. The incidence of a pathological condition within a skeletal population is a measure of how it affected those who died, not those who were living (Wood et al. 1992). Supplementary lines of health evidence that are readily accessible, such as parasites, can broaden the interpretive value of skeletal studies.

Parasite analysis provides a complement to skeletal studies as an independent means of seeing the disease agent actually engaged within its terrain. As parasite evidence is deposited by living individuals, it is a reflection of host morbidity rather than mortality. A disease variable that interacts with a living community allows for interpretations about what may have made people ill, not just what killed them. Thus, parasite evidence

provides a more holistic understanding of the epidemiological process by which a disease develops, is sustained, and wanes within a community.

Human skeletal remains from a number of coastal sites throughout the Americas have demonstrated evidence of pathological conditions commonly considered to be indicative of iron deficiency: cribra orbitalia and porotic hyperostosis (Curtin 1984; Cybulski 1990 and 1992; Dale 1994; Ubelaker 1992; Walker 1986; Wright and Chew 1998). But the presence of these conditions in coastal populations has presented an anomaly to researchers. Hereditary anaemias were not present in New World populations prior to European contact (Stuart-Macadam 1992), and the maritime diet of these populations should have provided sufficient dietary iron to stave off acquired anaemia. This led researchers such as those listed above to suggest that parasite burden might, at least in part, account for these skeletal conditions. Consequently, this project focussed on finding evidence of parasites that were likely to cause anaemia. Four species in particular, are capable of causing or contributing to anaemia in humans: hookworm (*Necator americanus/ Ancyclostoma duodena*), whipworm (*Trichuris trichiura*), threadworm (*Strongyloides stercoralis*), and broad fish tapeworm (*Diphyllobothrium latum*) (Crompton 2000; de Silva 2003; Horton 2003). While no evidence of hookworm, whipworm or threadworm was recovered in this study, there was evidence of fish

tapeworm (*Diphyllobothrium spp.*) in considerable abundance. Evidence of three other parasite species was also recovered: human roundworm (*Ascaris lumbricoides*), salmon poisoning fluke (*Nanophyetus salmincola*), and dwarf tapeworm and/or hydatid cyst disease (Cyclophyllidea).

Skeletal evidence from several sites along the Northwest Coast demonstrate an unexpectedly high incidence of anaemic indicators (Curtin 1984; Cybulski 1990 and 1992; Dale 1994). The marine and riverine diet of these populations was high in sources of protein and heme iron (Chisholm et al. 1983), which is more readily absorbed than the iron from plant sources. Therefore, researchers such as Dale (1994) and Stuart-Macadam (1992) have implicated intestinal parasites as a potential explanation for this skeletal pattern. But a lack of empirical evidence to support this scenario has weakened this hypothesis.

There are likely several interrelated explanations that can account for this lack of parasite evidence at coastal North American archaeological sites. Primarily, there has been a lack of investigation for this type of evidence. It has been assumed, based on modern patterns of parasite distribution which find the majority of parasitic infections in tropical or economically depressed countries, that there is a limited variety of parasite fauna likely to be encountered in temperate regions of North America (Markell et al. 1999:16-23). Furthermore, the likelihood of

finding any parasite evidence at non-urban sites in the absence of discrete faecal deposits such as coprolites or latrines seemed remote (Reinhard 1992). It was further assumed that the risk of pathogens among foraging cultures was limited or benign. Finally, there was no 'epidemiologic transition' that occurred among these coastal populations until the arrival of European explorers in the 18th century. Therefore, based on long-held assumptions, the hunting-fishing-gathering populations could be assumed to have been living in a healthy and relatively risk-free coexistence with their environment. In other words, there has been a lack of attention to parasites because the likelihood of finding them has seemed doubtful.

1.6 Summary

This research project was initiated as a means of broadening what is known of human health in pre-agrarian, hunting and gathering populations. It focuses specifically on the coastal hunter-fisher-gatherers of the Pacific Coast of Canada, as a means of demonstrating the antiquity of disease agents in the Americas prior to European contact. The dense, sheltered, and sedentary living circumstances of the coastal inhabitants provided circumstances ideal for the dissemination of infectious disease. These living conditions resulted in the disposal of waste products in shell

middens, which were subsequently tested for evidence of parasitic pathogens. The positive recovery of parasite eggs from these midden contexts demonstrated significant patterns in the distribution of evidence between different types of settlements. Both cultural and taphonomic processes influenced the size and diversity of the recovered parasite assemblage. As an independent and supporting form of archaeological evidence, the parasites recovered in this project provide depth to research questions interested in health and disease, site ecology and species interaction, site use, food choice and methods of food preparation.

This thesis is structured as follows. Chapter two is dedicated to parasites. It provides a definition, discusses what parasites are of relevance to hunter-gatherer studies and the modes by which they are transmitted. A brief history of the specialization of archaeoparasitology follows, detailing what sorts of archaeological evidence parasites leave behind. As the array of parasitic diseases that relate to hunters and gatherers is so broad, this section concludes with a biological background narrowly focussed on those parasite taxa that were recovered in this project.

Chapter three provides a background on Northwest Coast archaeology. It sets this project within a geographical context and

discusses issues of relevance to Northwest Coast culture history. The nature of the archaeological record in the region is detailed and a brief background is provided for each of the sites that were tested for parasite evidence.

Chapter four details the methods that were used to recover parasite evidence, including the protocol that was specifically developed for testing shell midden material. The results of these procedures and the measures taken to account for taphonomic or depositional bias are outlined in Chapter five. Details of which taxa were recovered and the patterns they elucidate are presented along with statistical analyses. The chapter concludes with a site-by-site account of parasite findings.

Following the scales of analysis first outlined in this introduction, chapter six discusses the results of this study. Starting with the broad relevance of these findings to issues of hunter-gatherer health, focus then moves to the significance of these findings to issues relating to disease in pre-contact North America. This is followed by a discussion of the archaeological significance of parasites and patterns of distribution in relation to the region of the Pacific Northwest Coast. It concludes with an examination of the evidence in relation to the smallest scale of analysis this project could address, the local community. Chapter seven

summarizes the findings of this project, detailing its most significant contributions and recommending future lines of inquiry.

Chapter 2:
PARASITES AND ARCHAEOPARASITOLOGY

So, naturalists observe, a flea
Hath smaller fleas that on him prey;
And these have smaller still to bite 'em;
And so proceed *ad infinitum*.
- Jonathan Swift, *On Poetry, a Rhapsody*, 1733

2.1 An Introduction to Parasites

A parasite is recognized in this study as an organism that lives in or on a host from which it derives nourishment at the host's expense (Markell et al. 1999:7). Gastrointestinal parasites are theorized to be among the most common infectious agents to have plagued hunter-gatherers (Cohen 1989; Cohen and Crane-Kramer 2003; Diamond 1999:204; Dunn 1968; Froment 2001; Huss-Ashmore 1992; Mitchell 2003; Waguespack 2002). In spite of this, the relevance and history of parasitic infections experienced by ancient hunting and gathering populations has been relatively unexplored. This chapter elaborates more specifically on what is known, rather than what is not, about hunter-gatherer parasitoses. It introduces some biological aspects of parasites and parasitic infection relevant for drawing interpretations from archaeoparasite evidence. A review of the current literature on ancient hunter-gatherer parasitoses will be followed with a brief synopsis of the specialization of

archaeoparasitology. Finally, the life cycle, morphological characteristics and epidemiological pattern of each of the parasite taxon that have been recovered are introduced as background information pertinent to the interpretations that are drawn from this study.

2.2 Perceptions of Hunter-Gatherer Health

Those who have studied hunter-gatherer health in any depth have recognized the problems with defining all hunting and gathering populations as one inclusive type (i.e. Dunn 1968; Froment 2001). While such a broad definition may suit some circumstances, the range of habitats, resources and lifestyles experienced by these populations make it difficult to present a single, defining pattern of "hunter-gatherer health". Yet consistently, hunters and gatherers have been used as an optimal baseline with which to compare the health of agricultural or industrial populations (Cohen 1989; Dunn 1968; Newman 1976). Small group size, low population density, frequent mobility and the utilization of a diverse range of resources are factors that are argued to contribute to the well nourished, fit and healthy lifestyle associated with hunting and gathering (Cordain et al. 2000; Eaton and Eaton 1999; 2003; Lindeberg et al. 2003).

2.2.1 *Group size and density*

A pathogenic species that requires human to human transmission also requires a constant supply of humans susceptible to infection, and such population parameters are not believed to have been reached by early hunting and gathering bands (Cohen 1989; Diamond 2002:268; Froment 2001; St. Hoyme 1969). In a small population, an acute and virulent human-specific pathogen could eliminate the reproductive pool of its host population, thus truncating its own life cycle and limiting its transmissibility. If the density of human populations within a particular region is low, and contact between small groups is limited, the pathogen will lack an environment in which it can be maintained. This perception provided justification for believing acute "crowd diseases" did not develop in human populations until after the adoption of agriculture and the inferred subsequent growth of human populations (Cohen and Crane-Kramer 2003; Newman 1976; St. Hoyme 1969).

2.2.2 *Group mobility*

The mobility of hunting and gathering groups is also considered to be a determining factor in the transmission of infectious disease. Mobility limits the amount of time spent in contact with an environmental pathogen, decreasing the likelihood that the pathogen will develop a human specialization, unless the period of transmissibility is lengthy (Cockburn

1971). It may also prevent the ready dissemination of pathogens from those severely ill and rendered immobile to others in the community (Ewald 2003). The frequent relocation of residences and temporary nature of dwellings would also avoid the accumulation of faeces and other forms of cess that might attract vectors of disease or transmit pathogens by faecal-oral contamination (Cohen and Crane-Kramer 2003; Froment 2001; Herring 1992).

2.2.3 *Nutrition*

There is the perception that hunters and gatherers suffered infrequently from starvation and enjoyed superior nutritional status based on the diversity and abundance of naturally occurring resources (Cohen and Crane-Kramer 2003; Dunn 1968; Hume et al. 2003; McNeill 1998; Sahlins 1972). Health is directly correlated with the nutritional status of the host, as malnutrition and weakened constitution can both increase and compound a host's susceptibility to infection (Cohen 2000; Danforth 1999; Horton 2003; Koski and Scott 2001; Markell et al. 1999; Olsen et al. 2001a; Stephenson 1980; Thompson 2001). While the foraged food supply may have been limited periodically, overall the varied contribution to the diet is commonly considered adequate or even optimal (Walker et al. 2003) for human metabolic requirements.

However, the assumption that all hunters and gatherers experience healthy living conditions ignores the environmental context which may also affect health and disease exposure experienced by different populations. Based on a survey of modern and historic hunter-gatherers, Dunn (1968) proposed that the variety of parasitic diseases could be correlated with the complexity of an ecosystem; thus tropical hunter-gatherers were likely to be exposed to a greater variety of pathogenic species than those in 'less complex' environments such as the Arctic. Although these differences are likely to have more to do with the socioeconomic status of these geographical regions of the world than Dunn appreciated at the time, resource availability in different environments will also influence the nutritional status of a population and its ability to produce clothing or shelter (Martin and Goodman 2002).

Biological dissimilarities in hunter-gatherer group size or demography, such as age, sex, responsiveness, and acquired immunity are also bound to vary in different environments and among different social settings. Genetic constitution, sex and age are important variables that shape a parasitic relationship both at the individual and population levels (Markell et al. 1999:10).

Differences in human behaviour may also dramatically influence the health profile of a hunting and gathering population. For example,

variations in mobility or sedentism, forms of shelter, sexual activity, frequency of contact with other groups, patterns of food preparation, choice of food consumed, hygiene, avoidance strategies, and differences in technology may all shape the health profile of a population, regardless of the form of subsistence they practice.

Finally, hunter-gatherers are rarely recognized as dynamic, living human populations that experience change. Change is considered a primary factor in the emergence of disease (Cohen 2000; Dobson and Carper 1992; Huss-Ashmore 1992; Petney 2001; Thompson 2001), be it change in the environment, biology or behaviour of a population. Faced with changing conditions, organisms adapt and modify their relationships to one another and their environment (Ewald 1998; Martin and Rothschild 1998). Thus changes in climate, season, population, residence, technology, diet or even those changes experienced over the lifetime of an individual are all bound to have contributed to a diverse and complex profile of health in ancient human populations. Studying health in past societies requires a smaller scale of analysis than the economic classification of "hunter-gatherer".

2.3 Diseases of Hunter-Gatherers

2.3.1 *Zoonoses*

Of the diseases believed to have afflicted hunters and gatherers, zoonotic diseases, those adapted to other species but acquired from intimate interaction with animals or their remains, are considered among humanity's most ancient pathogens (Armelagos et al. 1996; Cohen 1989:33; Cohen and Crane-Kramer 2003; Froment 2001; Huss-Ashmore 1992; Nelson 1972; Thompson 2001; Waguespack 2002). Often overlooked are soil-borne diseases such as coccidioidomycosis, tetanus, hookworm, or tuberculosis. But the intimate, daily relationship of hunters and gatherers with a variety of animal species is believed to have afforded greater exposure to zoonoses. Zoonotic species are not specifically adapted to humans. As they are not reliant on a pool of human hosts for their transmission, a virulent zoonotic pathogen could effectively eliminate the productive adults of a population with little or no consequence to the reproductive cycle of the parasite (Cohen and Crane-Kramer 2003; Cohen 1989:135). It is estimated that over 100 species of parasites such as fleas, tapeworm or leishmaniasis are known to infect both humans and other vertebrates (Schwabe 1982). Three of the four taxonomic orders of parasites recovered in this project, Pseudophyllidea

(*Diphyllobothrium spp.*), Cyclophyllidea and Digenea (*Nanophyetus salmincola*) are of zoonotic origin.

2.3.2 *Chronic disease*

Chronic diseases are those which persist for long periods of time or with low intensity within an individual or a population. There is some disagreement in the role of such diseases in hunting and gathering populations. Based on surveys of modern and historic hunter-gatherers, Dunn (1968) and Froment (2001) gauged chronic diseases to be a relatively low risk. Life expectancy at birth was typically short among the societies surveyed, and thus there was less time for the development of persistent infections, such as those commonly found in contemporary, aged, western industrialized nations. Group mobility was also considered a limiting factor in the lingering survival of the chronically ill, as such individuals would be dispatched or abandoned in order to allow the group to move on and utilize fresh resources. In opposition to this, other researchers (i.e. Cohen and Crane-Kramer 2003; Fenner 1982; Martin and Goodman 2002; Waguespack, 2002) have suggested chronic diseases, particularly those that reproduce slowly, are acquired early in life or are of low intensity, are likely to have afflicted early hunter-gatherers. Persistent or latent infections can be maintained within a population or sustained environmentally within other animals or soil for

long periods of time, increasing the opportunity for disease transmission (Ewald 2003). Many parasite species, such as those recovered in this study, are likely to be acquired at an early age and can persist both within an individual and/or the environment for extended periods of time.

2.3.3 *Hunter-gatherer Disease Summary*

Group mobility, small population size, low population density and a varied diet are commonly considered the main characteristics that kept hunter-gatherer health at a premium and infectious disease at bay. However, close and intimate contact with animals, mobility into novel territory, exposure to a broad range of different foods and changes in the ecological, biological or social environment can also increase the risk of transmission of zoonotic, novel or food borne pathogens. While 3 of the 4 genera recovered in this study were hypothetically predictable zoonotic species, one of the parasites recovered was a human specific pathogen (*Ascaris lumbricoides*). All of the species recovered are disseminated by faecal waste, and all have life-cycles that depend on a period of development outside of the definitive host, allowing the persistence of the parasite within the environment for long periods of time. The parasites recovered in this project are a testament to the diversity in hunting and gathering lifestyles that could have shaped the history of disease profiles

and demonstrate the shortcomings of drawing broad assumptions about hunter-gatherer health.

2.4 Parasite Biology

It is estimated that over half of all living organisms are parasitic at some or all stages of their life-cycle, and that parasites have been found in almost every environmental niche on earth (Pietrock and Marcogliese 2003:293). Parasites can be plants or animals, therefore a biological background encompassing all forms of parasites would be unwieldy and distracting. In order to narrow the scope of this dissertation, this section will provide a background on parasite biology relevant only to those taxa that were recovered in this project (Table 2.1).

Parasite species are characterized on the basis of size as either microparasites or macroparasites (Anderson 1979; Dobson and Carper 1992; Petney 2001). Microparasites, or parasitic microorganisms which rapidly reproduce within a host include protozoa, viruses, rickettsia, bacteria, or single-celled fungi that are too small to be seen with the naked eye. Macroparasites, however, are readily visible without microscopic aid, though it should be noted that this classification is based on the size of the mature adult worm. Typically, macroparasitic infections are persistent and chronic, being maintained over long periods of time,

with common reinfection rates (Petney and Andrews 1998). Macroparasites reproduce sexually through transmission stages in the external environment rather than within their definitive host. As such, their life-cycle is largely contingent on environmental conditions (Cockburn 1971; Fenner 1982). Such organisms include helminths (worms) and arthropods (biting insects), though it is the former category of pathogenic macroparasites which live *in* humans that are of interest to this project. In their adult stage, helminths, or intestinal roundworms (Nematoda), tapeworms (Cestoda) and flukes (Trematoda) can range in size from half a millimetre to over 14 metres in length. Helminth eggs are too small to be seen with the naked eye and require a microscope for analysis. Many species can be distinguished from the morphological characteristics of their egg shells (Davis 1987).

Nematodes (non-segmented roundworms) are the most common form of helminthic parasite to affect vertebrates (Faust 1963). Human pathogenic nematodes produce eggs or larvae that are either free-living or require incubation outside of their host to become infective. Eggs are produced and fertilized by separate sexes within the host and voided with faeces (Markell et al. 1999). They shed continuously from infected individuals and may be excreted with every faecal specimen produced (Brooke and Melvin 1989). Mature nematodes feed on blood and compete

for nutrients from within the intestines of their hosts. Minor nematode infections are usually tolerated with little or no morbidity, though major infections can interfere with nutrition, cause gastrointestinal maladies, migrate through the host or illicit an immune response (Horton 2003). Common human nematodes include *Ascaris lumbricoides* (human roundworm), *Necator americanus* and/or *Ancylostoma duodenal* (hookworm) and *Enterobius vermicularis* (pinworm). The only nematode recovered from this study was *Ascaris lumbricoides* (see Results and Analysis).

Cestodes (tapeworms and cystic worms) are flat, ribbon-like, and segmented worms. They are the largest of the intestinal worms to parasitize humans, some reaching as much as 15 metres in length (Raether and Hänel 2003; von Bonsdorff 1977). Tapeworms have no digestive system of their own, so nourishment is derived by absorption of blood, mucus and epithelial cells in the host's small intestine (Halton 2004; Markell et al. 1999; Muller 2001). The body of the tapeworm is made up of individual segments, or proglottids, that are formed throughout the life of the tapeworm (Markell et al. 1999; Muller 2001). Each proglottid is hermaphroditic, containing both male and female organs. Eggs are produced at the terminal end, and proglottids are shed with the host's faeces as they become gravid. The life cycle of most tapeworms is

indirect, involving several species of intermediary hosts. Cestode infections are frequently tolerated without any outward signs of morbidity, though they can cause gastrointestinal distress, emaciation, localized pain, diarrhea or in some cases, cystercercosis (the development of cysts) (Muller 2001). Over 40 species of tapeworm are estimated to parasitize humans (Cox 2002). Clinically important human cestodes include *Diphyllobothrium latum* (broad fish tapeworm), *Taenia saginata* (beef tapeworm) and *Taenia solium* (pork tapeworm). Two orders of tapeworm were recovered in this study; Pseuedophyllidea (*Diphyllobothrium spp.*) and Cyclophyllidea (see Results and Analysis).

Trematodes (flukes) are flatworms that use suckers or hooks to attach to their definitive host and derive nourishment by absorbing nutrients straight into their gut (Halton 2004; Markell et al. 1999). Fertilized eggs are passed with the host's faeces, though they are usually shed at irregular intervals (Brooke and Melvin 1989:7). Digenetic trematodes, those that cause infection in humans, require mollusks as intermediary hosts (Cox 2002; Faust 1963). Larvae develop and are expelled in water, where they penetrate a host through the skin or through ingestion. Minor infections, as with other helminths, are usually asymptomatic, though severe infections can cause edema or swelling of extremities, pain, or diarrhea (Markell et al. 1999). Clinically important

trematodes include intestinal flukes such as *Fasciolopsis buski* and blood flukes such as *Schistosoma mansoni*. The only trematode recovered in this study, *Nanophyetus salmincola* (see Results and Analysis), is more commonly associated with canid species, though it can parasitize humans as indirect hosts as well.

2.4.1 *Transmission*

The range of modes by which helminthic parasites are transmitted from one host to another varies in complexity, but transmission strategies can be broadly categorized as either direct or indirect (Anderson 1982; Warren et al. 1982; Woolhouse et al. 2001). Direct transmission is the result of close contact between hosts, and provides limited opportunity for the parasite to transfer itself between them. Most directly transferred pathogens are specialized in their host preferences (Woolhouse et al. 2001). Indirect routes of transmission are the most common and most diverse, enabling parasites to be passed from one host to another in a variety of ways, such as foodborne, waterborne, soilborne, free-living infectious stages, or through the incorporation of intermediate host species (Woolhouse et al. 2001). Indirect pathogens may come into contact with a variety of possible hosts and are not likely to limit their transmissibility by specializing in any one, thus they are able to infect a variety of different species.

Pathogens may be transferred between hosts by means of respiratory, alimentary, skin penetration or sexual activity (Fenner 1982). Respiratory transmission is a direct means of infection, by which the pathogen is passed from host to host through inhaled droplets or excretions. Contaminated soil or dust with eggs/larvae may also be indirectly transmitted to a host by respiration. Some infectious agents such as trematode larvae can penetrate directly through the skin (Fenner 1982). Alimentary routes are associated with both direct and indirect modes of transmission. They include any activity that brings contaminated substances including air, fingers, soil, food, and water to any possible portal of entry or exit (Fenner 1982). The parasites recovered in this study are most readily transmitted indirectly by the alimentary route due to faecal-oral contamination.

Animals can act as important mechanisms of helminth dissemination, either as mechanical vectors or by acting as reservoir hosts of infection. Humans may intercept the zoonotic cycle of transmission as alternative hosts. Zoonotic parasites such as fish, pork or beef tapeworm can be unwittingly transferred to humans by consuming the flesh of an intermediary or definitive host that has been embedded or encysted with infective larvae. Transmission can also be facilitated during the dismemberment or processing of contaminated carcasses or

interacting with infected animals (Faust 1963; Fortuine 1989:59). Due to their close and frequent contact with humans, domestic animals are particularly important as reservoir hosts for a number of zoonotic helminths (Cohen and Crane-Kramer 2003; Conway and Roper 2000; Cook 1990; Schwabe 1982). The only domestic animal kept by the Pacific coastal populations was the dog (Crockford 1997). Dogs share a number of pathogens with humans and can act as reservoirs or mechanical vectors of several human-specific infections (Cohen and Crane-Kramer 2003), including those taxa recovered in this project.

While humans of all ages are at risk of parasitic infection, children have the least developed immunity and are the most susceptible (Noble and Noble 1982:488). Children's activities and dubious hygiene bring them into frequent and intimate contact with contaminated soil, fomites (contaminated objects) and animal vectors (Hotez et al. 2003; Olsen et al. 2001b; Vecchiato 1997). Faecal-oral transmission is particularly common among children, as soiled hands from water, dirt, dogs, other animals and even other children come in contact with a child's mouth or other points of entry (Jung and Jelliffe 1970; Olsen et al. 2001a). Between the ages of one and three, when a child is most susceptible to malnutrition due to weaning stress and an immature immune system, they are also the most vulnerable to parasitic infection (Vecchiato 1997; Williams 1970).

Some of the numerous circumstances that can lead to the dissemination of helminthic species include changes in the host's population size, migration, contact, conflict, as well as environmental, behavioural or evolutionary change (Cohen 2000; Dobson and Carper 1992; Dunn 1968; Noble and Noble 1982; Petney 2001; Thompson 2001). An increase or decrease in host population size will affect the size of the parasite population as well, as larger populations provide more susceptible hosts at a greater regeneration rate (Noble and Noble 1982:487). Host migration effectively moves a pathogen from one environment into another; likewise, contact between hosts allows for the transmission of pathogens into a new pool of resources (Schwabe 1982). While conflict provides an opportunity for novel host contact, it also affords new opportunities for pathogens. Stress and disease frequently accompany conflict, as weak or wounded individuals suffer compromised immunity and often less mobility, readily promoting the establishment and spread of infectious diseases (Diamond 1999; Ewald 1994). Environmental change, both long and short term phenomena, such as seasonal shifts, flooding or the warming of the coastal Pacific waters that accompany cyclical *El Niño* events, can also dramatically alter the environment in which both the parasite and potential hosts flourish (Dobson and Carper 1992; Harvell et al. 2002; Pietrock and Marcogliese

2003). Abiotic environmental factors such as temperature, light and humidity can affect the growth and viability of helminthic life stages (Noble and Noble 1982:485). Changes in host behaviour, such as the use of latrines or preparation of food may also have an influence on the biological cycle of disease. Finally, selective evolutionary change can take place rapidly in parasitic species, because they have much shorter reproductive cycles than humans and other mammals (Ewald 2003), which in turn may have a dramatic effect on the biology of the parasite and its host population.

2.5 Archaeoparasitology

2.5.1 *Parasite Preservation*

Parasitic worms lack skeletal features, therefore they only preserve archaeologically in mummified or desiccated conditions. It is the evacuated stage of a parasite's development that is of greatest interest to archaeologists, as many parasites produce eggs that are enclosed within a chitinous or sclerotinous shell (Christenson 1974; Smyth 1969; Wharton, 1980). These materials are impervious to decay in the open environment, a feature suited to allow the species to survive developmental stages outside of its host(s). The same qualitites that make parasite egg shells so resilient to environmental decay also make

them recoverable archaeological evidence. Eggs have most typically been recovered from coprolites, mummies and discrete faecal deposits such as latrine features. They preserve well in a variety of depositional environments (Jones et al. 1988; Jones 1982b), and have been recovered in circumstances as diverse as cave sites in the American desert southwest (Reinhard 1988) and pathways in Viking-occupied Jorvik, England (Jones 1982b). However, prolific evidence for eggs is most often recovered from sites with optimal organic preservation, such as desiccated, mummified, wet, frozen or anaerobic environments (Bouchet et al. 2003; Jones 1982b; Reinhard 1990; Reinhard 1992). The diagenic changes and taphonomic conditions in which parasite eggs do *not* preserve is still poorly understood, though fluctuations in temperature and water saturation are believed to enhance the decay process (Bouchet et al. 2003; Jones 1982a; Reinhard et al. 1986). There is also considerable difference between taxa in the size, shape and structural composition of egg shells, factors that may result in differential preservation.

2.5.2 *Development of Archaeoparasitology*

Ruffer (1910) is credited with the first published paper on archaeologically recovered parasite remains, printed in a medical journal at the turn of the 20th century. It took several decades before comparable studies or a defined methodology began to appear with any regularity in

the literature. Initially, most papers focussed on the discovery of parasite genera and the refinement of methodological extraction (Araujo et al. 1998), and were found dispersed in a wide array of published media, from site report appendices to veterinary journals (Horne 1985). Reinhard first coined the phrase "archaeoparasitology" over a decade ago in order to differentiate evidence of the human relationship with ancient parasites from the more generalized study of "paleoparasitology", which could include non-human or palaeontological material (Reinhard 1990). Archaeoparasitology labs specialized in the extraction and analysis of parasite remains were first established in the 1970's and 1980's and focussed primarily on coprolite remains (Araujo et al. 1998; Reinhard and Bryant 1992). In the decades since, Reinhard has described the development of the speciality as occurring on 4 separate fronts; in Germany, the United Kingdom, and North and South America, respectively (Reinhard 1992). Each region has a particular research focus and theoretical orientation that guides the interpretations of these biological artifacts.

In the UK, most parasite studies have been conducted by A.K.G. Jones and colleagues out of the Environmental Archaeology Unit at the University of York, England. Environmental archaeology, therefore, has had a prominent role in shaping the interpretive use of parasite evidence.

Archaeoparasite recovery has focused primarily on soil deposits, as coprolite remains or concretions have rarely been recovered in wet and temperate environments. Parasite remains have been used as 'biomarkers' to identify features such as latrines, fertilized farmer's fields or gardens, urban streets and domestic animal enclosures (Jones 1987). Therefore, there has been a strong emphasis in UK studies to quantify and compare the relative distribution of parasite remains between site features. The quantification of evidence is not used as a measure of disease incidence or health burden. This is because it is impossible to control for the number of organisms, human and otherwise, that have contributed to an assemblage or the range of time over which a deposit has accumulated (Jones 1982a; Jones 1985; Jones 1987; Jones 1988). Rather, quantification is used as a relative means of comparing activity areas, to determine where faeces were deposited, how they were disseminated across a site, and as a measure of environmental contamination and standards of hygiene.

In Germany, most archaeoparasite studies have been carried out at the Institut für Anthropologie at the Universität Göttingen, and have focused on epidemiological issues of disease transmission and site formation processes (Reinhard 1992). The consequences of parasite burden on human hosts has been their primary focus. Therefore they

examine patterns of parasite distribution over time and between site features. Their comparative approach also requires methods of analysis that allow for quantitative study (Reinhard 1986).

Karl Reinhard of the University of Nebraska-Lincoln has been instrumental in the development of archaeoparasite studies in North America, particularly in the desert southwest of the continental United States. As a trained anthropologist, Reinhard's studies have focused on how human behaviour shapes or is shaped by a relationship with parasites. His work has been integrative, eliciting more than one form of interpretation from parasite evidence. Human behaviour, disease epidemiology, site ecology, and seasonality are issues that have been addressed in North American studies (Bouchet et al. 2003). The main line of evidence has been coprolites, as the dry environment of the desert southwest desiccates organic remains such as faeces, providing optimal preservation of both form and content.

Reinhard has collaborated on archaeoparasite studies that have been conducted in South America, primarily by researchers such as Araújo and Ferreira of the Fundaçao Oswaldo Cruz, Brazil (Reinhard 1992). Research questions in South American studies are more interested in the antiquity of parasite organisms, their distribution and the host-parasite relationship (Bouchet et al. 2003). Much of the research from

South America has focused on revising methods of identification and applying new technologies, such as PCR extraction, as precise diagnostic tools. Studies have been heavily influenced by evolutionary frameworks, with particular interest in human migration and the use of parasite species to monitor the movement of populations into and through the Americas. Due to the exceptional preservation conditions in the cold and arid Andes mountains, many parasite studies have had the opportunity to utilize human and faunal mummied remains, examining everything from ectoparasites such as fleas from dogs and guinea pigs (Dittmar et al. 2003) to protozoan parasites responsible for Chagas' disease from human tissue (Aufderheide et al. 2004; Guhl et al. 2000).

2.5.3 *Limitations of Archaeoparasitology*

To date, most archaeoparasite studies in the Americas have functioned in tandem with coprolite analysis, and have been chiefly limited to regions conducive to coprolite preservation such as the North American desert southwest and the mountainous and coastal Andean region of South America. However, there are limitations to such studies, as a coprolite represents a single faecal event deposited by a single organism formed over a very brief period of time (Callen 1967; Jones 1982a; Sobolik 1996). As a human can produce anywhere from 20 to 1500 grams of faeces per day (Lewin 1999:25), a coprolite may only represent a small

fraction of an individual's total faecal burden. The depth of time represented by a single coprolite can be restricted to as little as one meal or the accumulation of several meals over a period of days (Callen 1967:263). Furthermore, recognizable coprolites represent properly formed faeces. Diarrhea, which is a common symptom of intestinal worm burden, is much more difficult to isolate archaeologically. Therefore, the range of interpretations that can be made from coprolite evidence is limited and interpretations based on such material need to take these limitations into consideration.

The ability to clearly associate recovered parasite evidence with human activity may be another limiting aspect of archaeoparasite interpretation (Fry 1985; Reinhard 1992). There are numerous species of free-living, non-pathogenic parasites that live within the soil and a variety of free-range fauna that could contribute to a pathogen assemblage. Therefore, it is important to establish a human context for the material being analyzed. In the early days of archaeoparasite analysis, when the academic climate was reluctant to accept evidence of ancient parasites, there was a particular focus on methodological studies that could definitively prove human associations (Araújo et al. 2000; Bryant and Williams-Dean 1975; Fry 1985; Wilke and Hall 1975). Today, an accepted and replicable methodology has established the validity of

archaeoparasite studies. Circumstantial evidence, such as the presence of cultural artifacts or human-specific parasites, help to establish the human origin of the archaeological material.

Finally, one of the greatest advances in archaeoparasite studies in the last decade – ancient DNA – may also, ironically, be holding back its recognition as a significant line of archaeological evidence. Ancient DNA studies have been invaluable in the precise identification of parasite species, and are instrumental to elucidating evolutionary patterns of human-parasite history (Baum and Bar-Gal 2003; Herrmann and Hummel 1998; Loreille and Bouchet 2003; Loreille et al. 2001; Zimmer 2001). However, the excitement engendered by this relatively new technological advancement has masked the interpretive value of less complicated methods of analysis. Molecular studies are complex, costly, destructive, time consuming and consequently not yet quantifiable. They do not provide information about patterns of distribution over time or space. While they are a powerful line of supporting evidence, molecular methods should not be considered a replacement for microscopic analyses, which are practical, economical and measurable.

2.5.4 *Archaeoparasitology Summary*

Archaeoparasitology has developed as a specialization in different regional centres of the world, each with its own theoretical objectives. As

the discipline grows and develops, these regional specialties and researchers are coming together, providing a more comprehensive framework for parasite analysis. Archaeoparasite studies are broadening in scope, as independent and collaborative researchers from countries such as France (Françoise Bouchet, Laboratoire de Paléoparasitologie, Université de Reims), Korea (Seoul National University Medical Research Centre and the Foundation for the Preservation of Cultural Properties, Seoul), Japan (Nara University) and Canada (Patrick Horne, University of Toronto) inspire new colleagues and contribute to a growing body of literature. This study aims to incorporate the regional strengths of each school of research into one study. The strength of the environmental framework and quantification methods utilized by UK researchers is applied to compare the relative distribution of parasite evidence over time and between sites. This framework provides a means of measuring site activity and ecology. The methods inspired by German studies provide a framework for the interpretation of health and disease, based on the cultural and ecological context of the recovered parasite remains. Findings recovered in this project are also considered within the context of the broadly regional and historical framework of South American studies, contributing to a growing database of New World pathogens and expanding their known range of distribution. Finally, the methodology

used in this study is an application of the advances made in the North American school of analysis. A behavioural approach is used to interpret parasite remains within their environmental and cultural context, in order to evaluate the consequences of parasite burden amongst coastal hunter-fisher-gatherers. This thesis, therefore, is an amalgamation of the strengths of these different theoretical and methodological schools of archaeoparasite studies.

2.6 Life-Cycle and Epidemiology of Recovered Taxa

Taxonomic classification of Recovered Parasites					
Kingdom	Phylum	Class	Order	Family	Genus/ species
Animalia	Platyhelminthes (flatworms)	Trematoda (fluke)	Digenea	Troglotrematidea	*Nanophyetus salmincola*
		Cestoidea (tapeworm)	Pseudophyllidea	Diphyllobothriidae	*Diphyllobothrium spp.*
			Cyclophyllidea	Hymenolepididae?	*Hymenolepis nana?*
				Taeniidae?	*Echinococcus spp.? Taenia spp.?*
	Nemahelminthes (roundworms)	Nematoda (roundworm)	Ascaridae	Ascarididae	*Ascaris lumbricoides*

Table 2.1: Taxonomic classification of recovered parasites. Cyclophyllidean eggs could not be confidently identified below taxonomic Order (see Results and Analysis chapter).

This study recovered four taxonomic orders of intestinal parasites: Pseudophyllidea *(Diphyllobothrium spp.)*, Digenea (*Nanophyetus salmincola*), Ascaridae *(Ascaris lumbricoides)*, Cyclophyllidea (Table 2.1;

see Results and Analysis). The complicated life cycle experienced by these parasites can be a mixed advantage; it can over-complicate a research question with seemingly innumerable, uncontrollable variables just as it can provide very precise information about site ecology and human behaviour. Certain conditions must be in place through each stage of the parasite's development in order for that parasite to reproduce. A change in any one of these conditions can be disastrous to the parasite. So the very presence of a particular parasite is evidence of a precise set of conditions that must have been met in order for that species to exist and proliferate. The following will provide a brief introduction to the life cycle of each of the recovered taxa and how they may be transmitted within human populations.

2.6.1 Phylum: Platyhelminthes
Class: Cestoidea
Order: Pseudophyllidea
Genus: *Diphyllobothrium spp.*

The broad fish tapeworm, *Diphyllobothrium spp.*, is the largest cestode to parasitize humans. Taxonomically, it is classified within the Order Pseudophyllidea, those tapeworms that develop through an aquatic life-cycle. *Diphyllobothrium* has a complicated life-cycle involving two intermediary hosts and one definitive host. It is a zoonotic infection with a worldwide distribution, but is particularly common in the northern latitudes

and temperate regions (Bylund 1982; Curtis and Bylund 1991; Ching 1984). Humans and other piscivorus animals are infected upon consuming raw fish that contain the tapeworm larvae. Anaemia due to vitamin B_{12} deficiency may result in individuals with heavy infestations.

The life-cycle of *Diphyllobothrium* spp. starts as fertilized eggs are expelled with faeces from a mammalian or avian host (Figure 2.1). There are a number of *Diphyllobothrium* species that may infect humans, some of which are restricted by geography and some of which are restricted to specific intermediary hosts (Bylund 1982; Hilliard 1960; Rausch et al. 1967). Eggs embryonate in water after 10-20 days at temperatures between 4 and 25°C (von Bonsdorff 1977). Although ideal temperatures for optimal development range from 18-20°C, eggs can also remain viable for several months in zero degree temperatures (Bylund 1982; Smyth 1969). The coracidium, the first stage of development, requires a light source in order to develop and hatch from the egg case. Therefore, shallow littoral environments with temperatures that range between 15-20°C are ideal developmental conditions for this species (Smyth 1969). The sclerotinous shell of the egg (Smyth 1969) preserves well archaeologically.

The coracidium is an embryo covered in fine, ciliated hairs that allow it to propel through the water in a motion designed to attract the first

intermediary host, a copepod (aquatic crustacean, i.e. waterflea). The coracidia must be consumed by a copepod such as Cyclops, 12-72 hours after hatching (Bylund 1982). Disguised as a meal, the devoured coracidium makes its way to the gut where after 2-6 weeks it develops into a first stage, or procercoid larva (Bylund 1982).

When the copepod is, in turn, devoured by a planktivorous or carnivorous minnow or fry, the first stage procercoid larva leaves the gut of the fish and migrates into the organs or flesh where it embeds and develops into a second stage, or plerocercoid larva. Plerocercoid larvae will survive being successively consumed through several paratenic hosts, but will not mature until it has reached a definitive mammalian or avian host (Bylund 1982; Rausch and Adams 2000). These second stage larvae can be visible to the naked eye and can reach a maximum of 4-5 cm in length. Studies have found older and larger fish to harbour more larvae (Ching 1984; Torres et al. 2004; 1998). Potential intermediary hosts for plerocercoid larvae include species of fish from Esocidae, Percidae, Lotidae, and particularly, Salmonidae families. They can survive for several years within a host, and are capable of withstanding the transition from fresh to salt water, as experienced by anadromous fish (Ching 1984; Margolis et al. 1973).

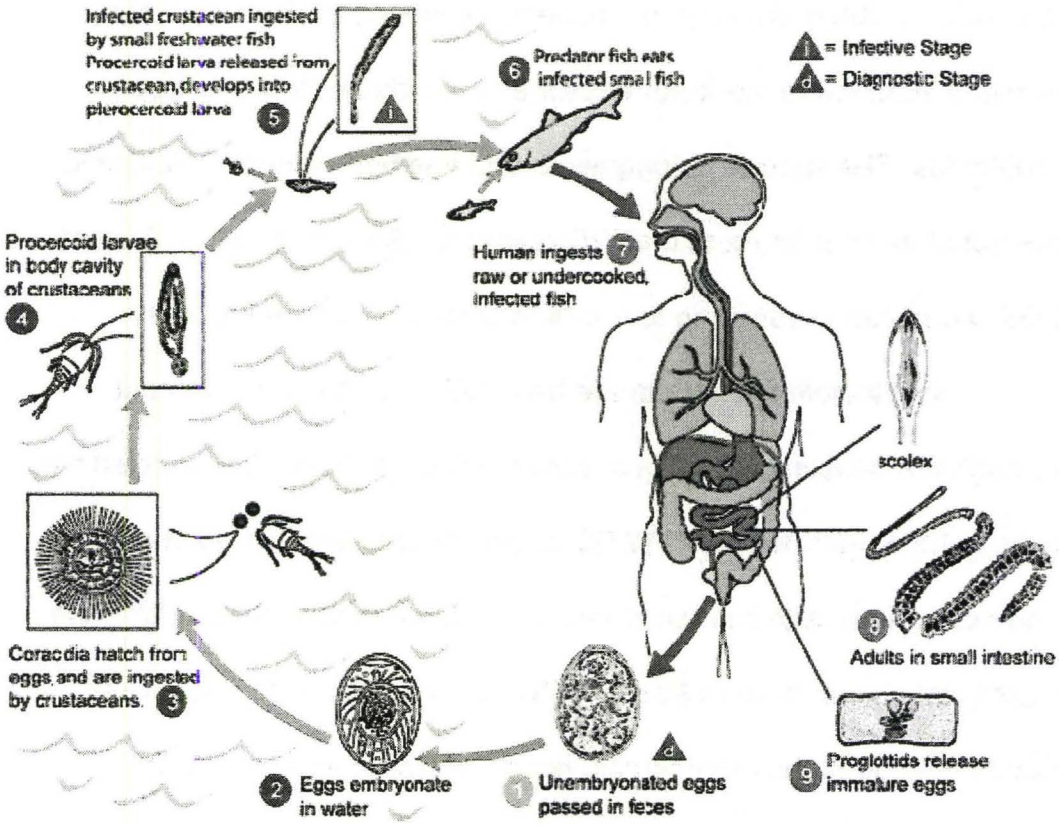

Figure 2.1: *Diphyllobothrium* spp. life-cycle (CDC 2001).

When the second intermediary host, the fish, is consumed by a definitive mammalian or avian host, the embedded or encysted larvae are deposited in the stomach and move to the lower intestine, where they develop into sexually mature adults. *Diphyllobothrium* is a hermaphroditic genus, so only one worm is necessary to produce eggs, and eggs are first produced 3-6 weeks after ingestion of the plerocercoid larva (Bylund 1982). Usually, mammalian or avian hosts are only infected with one worm. The tapeworm averages 5-10 metres in length but can grow much larger, leaving little room in the small intestine for more than one of its

kind (Muller 2001). As long as the head, or scolex, of the tapeworm remains attached to the lower intestine, it will continue to produce proglottids. The species is long-lived, and has been known to reside in the gut of its host for more than 25 years (von Bonsdorff 1977). A single adult worm can produce up to 1 million eggs per day (Muller 2001).

Diphyllobothrium larvae are transmitted to the definitive host through the consumption of raw, undercooked, dried or cold-smoked fish (Ching 1984; von Bonsdorff 1977). Drying or smoking fish, as was commonly done with salmon stores by cultures such as those along the Northwest Coast of North America (Ames and Maschner, 1999:127), does not destroy the plerocercoid larvae (Beldsoe and Oria, 2001; Cockburn, 1971:49). Symptoms can range from benign to gastrointestinal complaints, weight loss or, in the case of *D. latum*, pernicious anaemia (Curtis and Bylund 1991; Jenkerson 1984; von Bonsdorff 1977; Wolfgang 1954). Diagnosis of the condition is usually based on finding eggs in a patient's stool sample. Fortuine (1989:315), an authority on the history of medicine in Alaska, suggests that gastrointestinal upset due to food contaminated by intestinal parasites was likely to have afflicted Native Alaskans throughout antiquity. The wide geographic distribution of *Diphyllobothrium* spp. throughout the Arctic is considered an indication of its endemic nature in the region (Fortuine 1989:62).

Operculated ('capped') eggs are golden-brown in colour with a smooth, ovoid shell. Egg dimensions are species dependent with considerable overlap, though the genus average ranges from 40-76 µm x 35-56 µm in size (Baer 1969; Bylund 1982; Foreyt 2001; Meyer and Olsen 1980; Noble and Noble 1982; Rausch and Hilliard 1970). The epidemiology of the disease, therefore, requires an appropriate water biotope, the presence of suitable intermediary species, particular feeding habits of the definitive host and sewage disposal close to or within access of the water biotope in order to perpetuate the life-cycle.

The taxonomic differentiation of *Diphyllobothrium* species has been based on the size of the adult tapeworm, larvae or eggs, the species of intermediary host or definitive host, the environment in which the embryo develops or the location that the larvae embed within an intermediary host (Bylund 1982; Hilliard 1960; Rausch and Hilliard 1970). A clear and conclusive taxonomy for this genera has yet to be established (Bylund 1982; Muller, 2001). However, based on the historic precedence of those species that have already been identified in the Northwest Coast region and those that have not, the most likely species to have been recovered in this project are *D. dendriticum*, *D. ursi* and *D. latum* (see Table 2.2) (Ching 1984). No evidence of *D. pacificum*, the only entirely salt-water species, have been identified as far north as the Canadian Pacific Coast,

therefore all recovered species likely developed in freshwater sources such as lakes and rivers.

Diphyllobothrium Species	Definitive Host(s)	2nd Intermediary Host(s)	Transmission
D. latum	*Human*, dog, bear	Esox (pike), Perca (perch), Salmonidae (salmon)	Embeds in fish flesh
D. dendriticum	*Gull*, dog, fox, wolf, human	Salmonidae and Coregonidae	Encysts in fish viscera or body wall
D. ursi	*Bear*, human	Salmonidae	Encysts in fish viscera
D. pacificum (strictly marine)	*Sea lion*, human, dog	Marine fish	Embeds in fish flesh

Table 2.2: Mode of transmission of different *Diphyllobothrium* species (Andersen and Halvorsen, 1978; Ching, 1984; Wolfgang, 1954; Wright and Curtis, 2000).

The oldest archaeological evidence of *Diphyllobothrium* spp. yet recovered dates to 4110 BC and has been documented along the Pacific Coast as far south as Chile (Ferreira et al. 1984). There have also been several findings in Peru (Callen and Camaron 1960; Holiday et al. 2003; Patrucco et al. 1983; see Gonçalves et al. 2003 for review). All evidence recovered in South America has been identified as *D. pacificum*, the species currently recognized as endemic to the region. *Diphyllobothrium pacificum* is dependent on a fully marine life-cycle involving pinnipeds (seals and sea-lions) as typical definitive hosts. The recovery of the species has been attributed to the use of intermediary hosts, marine fish, in the customary preparation of the raw dish, *ceviche* (Cabrera et al. 2001; Torres et al. 2000). The northernmost prehistoric evidence for

Diphyllobothrium has been recovered from the Aleutian islands in Alaska (Bouchett et al. 2001). Dickson and colleagues (2004) have recently recovered eggs from the intestinal contents of a mummy found in northwest British Columbia. The only evidence from the interior has been documented as far east as Michigan, in the Great Lakes region (Horne 1985; MacClary 1972). All recovered North American evidence is considered to represent *D. latum*, though this specific diagnosis is inconclusive.

2.6.2 Phylum: Platyhelminthes
Class: Cestoidea
Order: Cyclophyllidea
Family: Hymenolepididae and Taeniidae
Taeniidae Subfamily: Taenia and Echinococcus

The Cyclophyllidea (frequently know as Taenioidea) are a zoonotic order of cestode that produce non-operculated, round eggs (Muller 2001). Most of the medically important tapeworms are classified in this order, as they are source of significant morbidity and mortality in human populations worldwide (Hoberg 2002; Raether and Hänel 2003). For some of the recovered parasite evidence, this was the lowest level of confident classification that was possible. Based on the general morphological characteristics of the recovered eggs, there are two possible families in which the evidence could be classified: Hymenoleidadae (Figure 2.3) and

Taeniidae (Figure 2.2). As cestodes, their biology is similar to that described for *Diphyllobothrium*; they are segmented, live within the gut of their definitive host and fertilized eggs are passed with proglottids in stool (Arambulo 1982; Muller 2001).

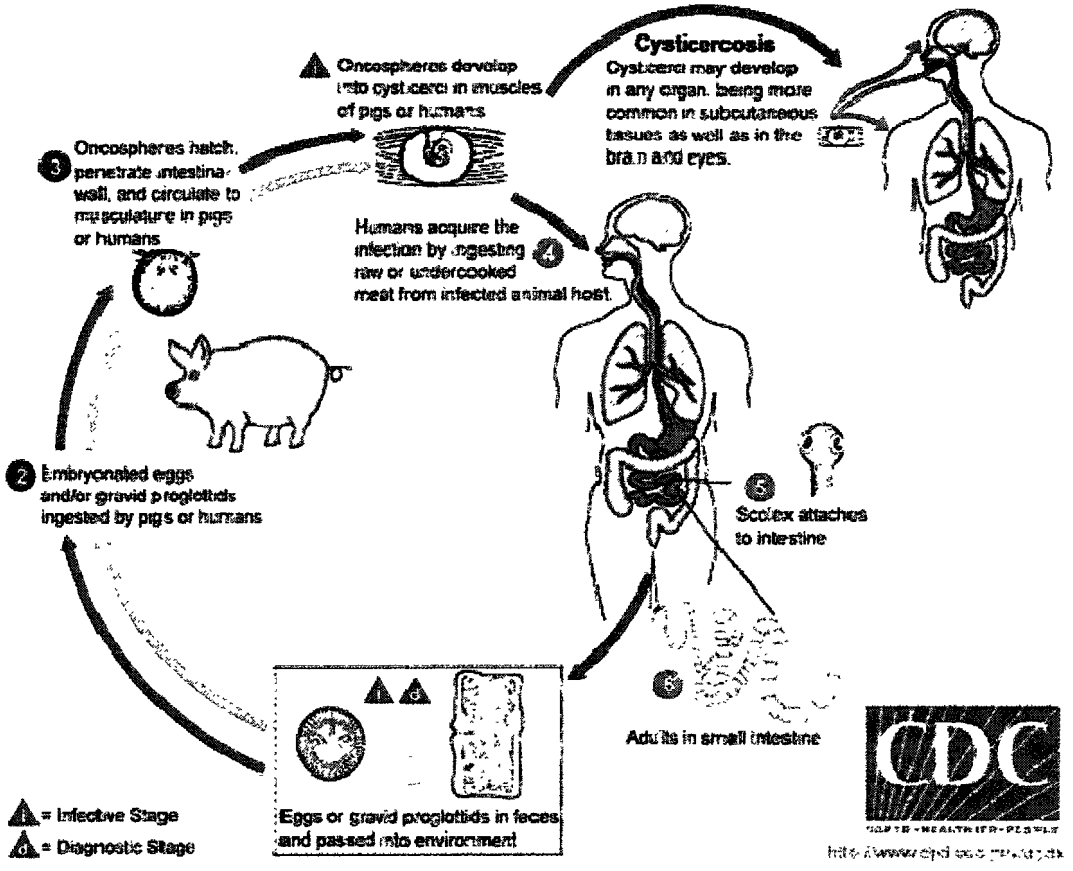

Figure 2.2: Cysticercosis infection by Taeniids (CDC 2001).

Cyclophyllid tapeworms range in size from 3 mm to 10 m (Muller 2001), and eggs can be just as variable, ranging from 30-80 µm in diameter (WHO 1980). *Hymenolepis* tapeworms parasitize mammals and birds and require an insect as an intermediary host, whereas Taeniids only parasitize mammals. Transmission occurs when the flesh of an intermediary host encysted with infective larvae is consumed (Arambulo 1982). Clinical manifestations of either family of infection are highly variable and can range from abdominal discomfort to the life-threatening development and rupture of cysts (Arambulo 1982; Raether and Hänel 2003). *Taenia solium* (pork tapeworm) and *T. saginata* (beef tapeworm) are most commonly associated with domesticated species (swine and cattle). However, using phylogenetic and divergent date analysis, Hoberg and colleagues (2000) have modelled an ancestry for these parasites that links them to ancient hominids (Hoberg et al. 2000), so the presence of this genus in the Americas should not be ruled improbable. Others, such as *T. multiceps* (gid tapeworm), *T. pisiformis* (canine tapeworm), *Echinococcus granulosus* (hydatid disease) or *E. multilocularis* (alveolar hydatid disease) are natural parasites of dogs and other canids, and could potentially have been present on the coast prehistorically. The eggs of the Taeniids *Echinococcus* and *Taenia* cannot be distinguished (Georgi 1974:145). *Hymenolepis nana* (dwarf tapeworm) is a parasite that

commonly afflicts children. Its current worldwide distribution, along with *H. diminuta* (rat tapeworm) qualify them both as potential parasites of this region (Muller 2001).

Taeniid eggs have been recovered from coprolites in the desert southwest (Fry 1977; Reinhard 1990). Evidence of *Hymenolepis spp.* has been recovered in South America, the desert southwest and Michigan (Gonçalves et al. 2003; Horne 1985; McClary 1972; Reinhard et al. 1987), with evidence from Utah dating as old as 5330 BC (Fry 1977).

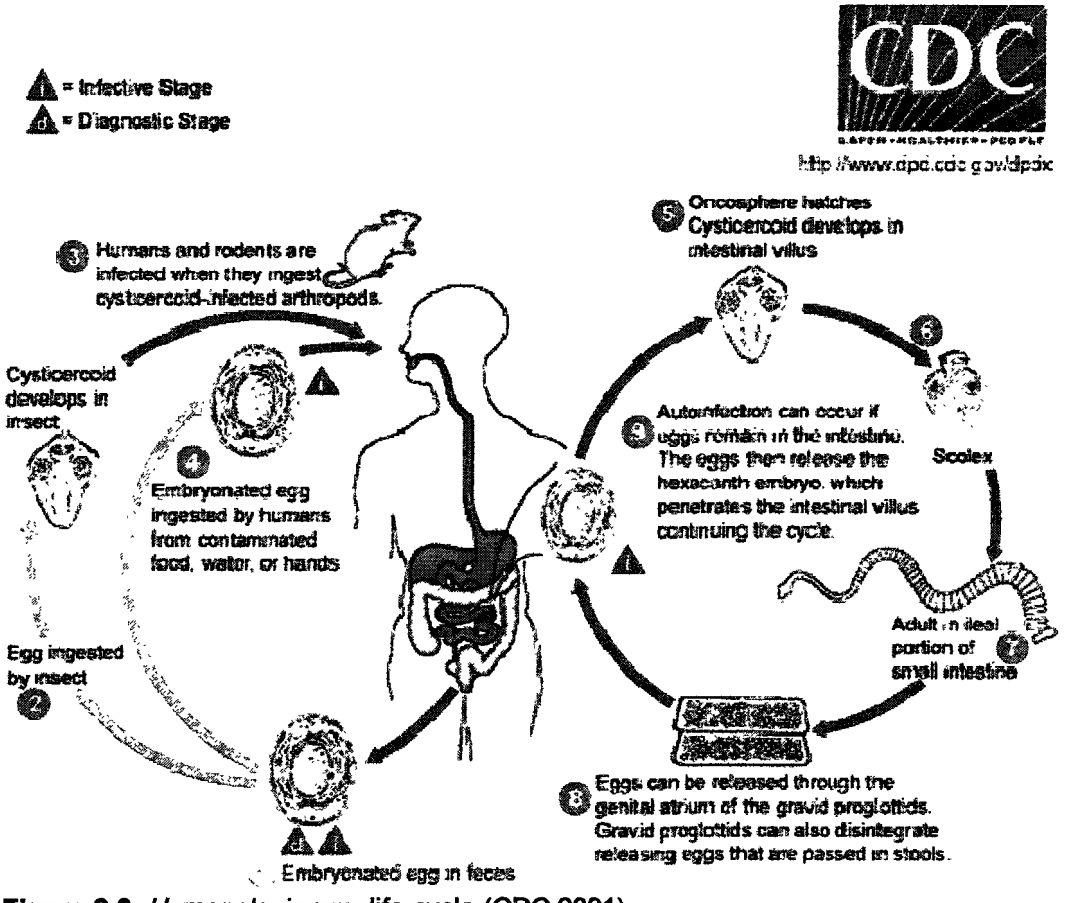

Figure 2:3: *Hymenolepis* spp. life-cycle (CDC 2001).

2.6.3 Phylum: Platyhelminthes
Class: Trematoda
Order: Digenea
Species: *Nanophyetus* (or *Troglotrema*) *salmincola*

Salmon poisoning, caused by the small fluke *Nanophyetus salmincola*, is a condition that chiefly affects canids. It is a zoonotic disease primarily acquired from salmonids and known to infect a wide variety of piscivorous mammals and birds (Bennington and Pratt 1960; Schmidt and Roberts 1977:310). Salmon poisoning has been recorded in dogs and other piscivorus canids along the Pacific Northwest Coast since the mid-19th century (Eastburn et al. 1987; Harrell and Deardorff 1990). The trematode itself can be parasitized by the rickettsial species *Neorickettsia helminthoeca* (Eastburn et al. 1987; Schmidt and Roberts 1977:309). This rickettsia is potentially fatal to canids and has earned the parasite its common name, though it has demonstrated little effect on humans and other species. Eggs shed with the host's faeces must enter a water source to develop into a 1st stage miracidia, that must in turn penetrate a freshwater periwinkle snail, *Oxytrema silicula* (Bennington and Pratt 1960).

Once developed into a 2nd stage cercarae, they emerge from the snail back into the water and penetrate the skin of salmonid species. Larvae that encyst within the flesh and organs of the fish are infective and

can be transmitted through the consumption of raw or undercooked salmon (Bennington and Pratt 1960), or from oral contact with contaminated hands or utensils after processing (Harrell and Deardorff 1990). The parasite matures sexually in the small intestine of the definitive host. Golden-brown, ovoid and operculated eggs are similar to *Diphyllobothrium* in appearance. *Nanophyetus* can be distinguished by a prominent abopercular knob and average in size from 64-97 µm x 35-55 µm (Bennington and Pratt 1960; Eastburn et al. 1987; Foreyt 2001).

Conditions for effective transmission to humans necessarily include a contaminated fresh water source, the presence of the intermediary host species (*Oxytrema silicula* and Salmonidae), specific means of food preparation and the disposal of contaminated faecal waste near a fresh water source. As humans are accidental hosts, the presence of the parasite in archaeological assemblages is a good indication of the presence of dogs in the community as well.

2.6.4 Phylum: Nemahelminthes
Class: Nematoda
Order: Ascaridae
Species: *Ascaris lumbricoides*

Ascaris lumbricoides, the giant human roundworm, is a cosmopolitan, soil-transmitted species currently estimated to infect over one billion people worldwide (Cox 2002; Crompton 1999; de Silva et al.

2003; Hotez et al. 2003). Adult worms of both sexes range in size from 15 to 35 cm, living and reproducing in the jejunum of the small intestine. Fertilized eggs are evacuated from the human host in faeces (Cox 2002). Warm, moist, and shaded soil conditions allow the eggs to embryonate over the course of two weeks to several months, temperature dependent (Horne 1985; Hotez et al. 2003). Infective eggs have the adaptive capacity to withstand adverse environmental conditions outside of a host for considerable amounts of time (upwards of 6 years) (Christenson 1974; Horne 1985; Larsen and Roepstorff 1999; Marsden 1982:345). Dry, sun-exposed conditions are the most detrimental to egg survival (Gaasenbeek and Borgsteed 1998; Larsen and Roepstorff 1999; Wagner and Polley 1999). Once infective, eggs may contaminate anything that soil has come into contact with, from dirty fingers, unwashed vegetables to contact with animals such as dogs, which can carry the sticky eggs on their fur. Transmission is alimentary via oral contamination of the embryonated eggs. Children between five and nine years of age are particularly susceptible to infection, primarily due to relaxed hygiene habits (Hotez et al. 2003; Vecchiato 1997). After 10-12 weeks of maturation, female worms can produce from 200 000 up to 2 million eggs within a 24 hour period (Halton 2004:387; Hotez et al. 2003; Noble and Noble 1982; Sinniah 1982). Chitinous eggs shells are thick, mammilated, and golden brown in

colour (Christenson 1974; Wharton 1980). The size of the egg, from unembryonated to fully embryonated stages, can range from 45-95 µm x 35-50 µm (Meyer and Olsen 1980; WHO 1991). These qualities increase the potential for transmission and broaden the geographic range of this particular species. Epidemiological factors that may promote infection include warm, moist, and shaded environmental conditions, compromised sanitation or hygiene and frequent contact with contaminated soil.

Ascaris lumbricoides is closely related to a porcine parasite, *Ascaris suum* (Hotez et al. 2003; Larsen and Roepstorff 1999; Wagner and Polley 1999). The eggs of both species are morphologically indistinct, and there is considerable debate concerning the evolutionary history of ascarid speciation (Loreille and Bouchet 2003). However, pigs were not introduced into the Americas until European contact, therefore the ascarid eggs found in this study are considered to be *Ascaris lumbricoides*, the human-specific roundworm.

Humans can harbour low numbers of worms with little to no obvious effect. However, heavy burden can interfere with nutrition, cause gastrointestinal upset, intestinal obstruction, stunt growth or contribute to general morbidity (Markell et al. 1999:9; Smith et al. 2001; Stephenson 1980). It is typically considered a pathogen of urban societies, as it is

considered a measure of hygienic conditions and host population density (Hotez et al. 2003).

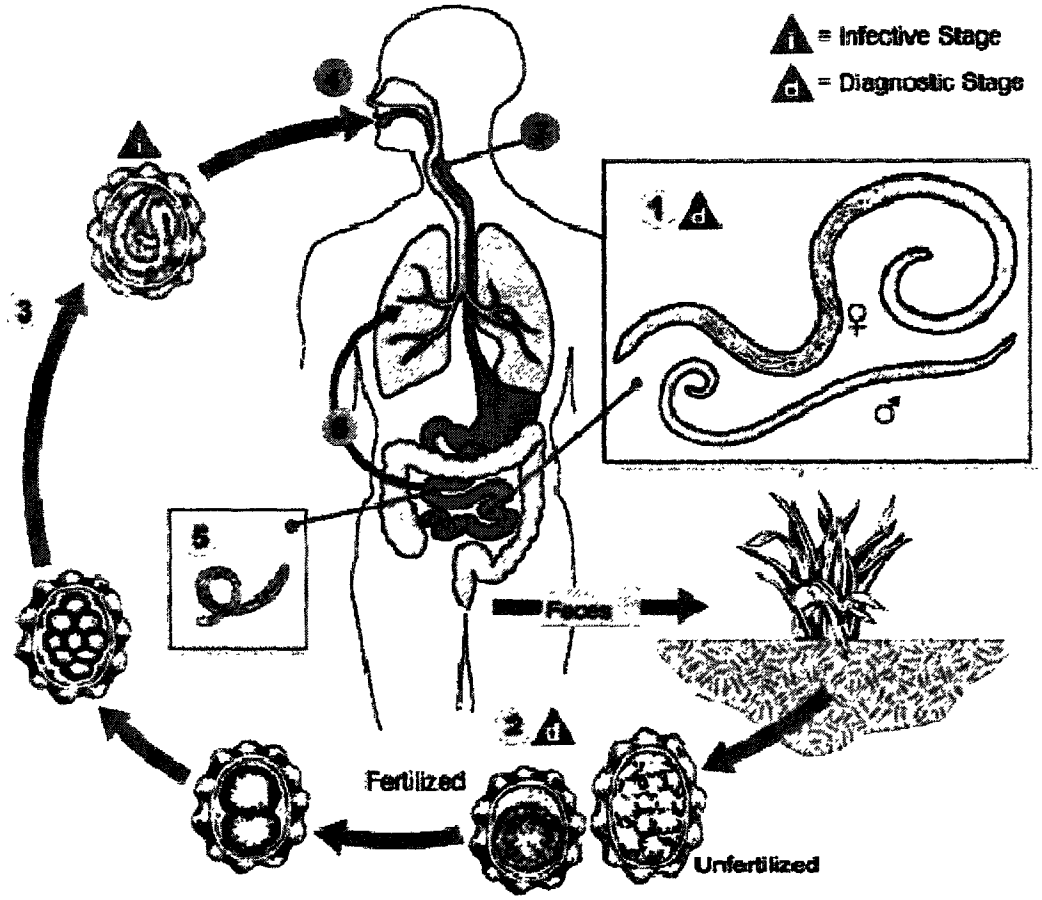

Figure 2.4: *Ascaris lumbricoides* life-cycle (CDC 2001).

Cohen and Crane-Kramer (2003:84) predict that chronic infections such as those derived from ascarid worms are likely to have infected early hunting and gathering populations. Larval ascarids have been documented in faecal samples of modern Alaskan Eskimo (Rausch et al. 1967), though they have not yet been documented prehistorically in the

region. The earliest evidence for *Ascaris* in the Americas dates to 2620-1740 cal. BC in Los Gavilance, Peru (Patrucco et al. 1983). The earliest North American evidence is from Upper Salts Cave, Kentucky (Fry 1985), appearing ~1125 BC, 1000 years later than the evidence in Peru. To date, *Ascaris* from the pre-Contact period has been identified in the Huarmey Valley in Peru; Gentio Cave, Brazil; Upper Salts Cave, Kentucky; Big Bone Cave, Tennessee; Elden Pueblo, Arizona; and Adak Island, Alaska (see Gonçalves et al. 2003 for a current review).

2.6.5 *Parasite Summary*

Gastrointestinal (GI) helminths are simple organisms with complex life cycles. They are currently estimated to infect over a quarter of the world's population (Koski and Scott 2001). Their evolutionary development has accompanied that of the humans they have parasitized, adapting to new niches and stresses as their hosts have (Baum and Bar-Gal 2003; Ewald 2003; Zimmer 2001). Although hunter-gatherers are presumed to have suffered primarily from zoonotic infections, the oldest human parasite evidence recovered to date is the human-specific *Ascaris lumbricoides*, the giant human roundworm. It has been linked to human coprolites as much as 30,000 years old in France (Bouchet et al. 1996). Historically, *A. lumbricoides* has been mentioned in some of the earliest written medical texts, such as *The Yellow Emperor's Classic of Internal*

Medicine from China, dated ca. 2700 B.C. and the *Ebers Papyrus* of Egypt, dating to ca. 1550 B.C. (Cox 2002; Maggeneti 1981), demonstrating that humans have been familiar with this parasite for a very long time. With minor worm burden, helminth infection may be asymptomatic, but intense cases or complications due to polyparasitism (infection with more than one parasite), malnutrition or stress can have serious health consequences including anaemia, stunted growth, impaired cognitive function and even death (Horton 2003; Nelson 1972). All parasites recovered in this study were gastrointestinal helminth species. Although the cycles through which they were transmitted differ, all excreted their eggs in the faeces of their definitive hosts. Therefore, it can be assumed that all evidence of parasites recovered from archaeological sediment have derived from an initial faecal source.

Chapter 3:
ARCHAEOLOGICAL CONTEXT

3.1 The Pacific Northwest Coast

The Northwest Coast of North America is a narrow geographic corridor extending along the Pacific Ocean from southeast Alaska to northern California (Ames and Maschner 1999:16; Drucker 1955:1). The hunting-fishing-gathering populations that inhabited this region shared a similar affluent and distinguishing cultural pattern. The topographic landscape is divided north and south by the Gulf of Georgia, at roughly 49°parallel, near the current international Canadian/US Border. Topography to the north is more rugged than that to the south, characterized by deep fjords, rocky cliffs, islands and meandering island passages (Ames and Maschner 1999:16). The climate is wet and temperate, conditions accommodating to the growth of the coniferous rainforest, dominated by cedar and fir (Pojar et al. 1991). The Canadian Coastal Range mountain landscape is tectonically active, interspersed with a multitude of water drainage systems (Barrie and Conway 2002). These rivers and streams are spawning habitat to five species of Pacific salmon, *Oncoryhynchus* spp. (*O. gorbuscha* – pink salmon, *O. keta* –

chum salmon, *O. kisutch* – coho salmon, *O. nerka*, sockeye salmon, and *O. tshawytscha* – chinook salmon), an anadromous[2] resource of dietary and economic importance to the populations living on the coast (Suttles 1990:24). As European explorers did not reach the Northwest until late in the 18th century, the colonial period has been comparatively short, and colonization has been slow to alter the geographic landscape in this region as dramatically as it has in much of North America (Kelley and Williamson 1996).

The central portion of the Northwest Coast is bounded within the province of British Columbia, and encompasses the region surrounding the ancient village of Namu, currently recognized as the oldest continuously occupied human habitation site in Canada, with a chronicled history extending over 10 000 years (Carlson 1996). Situated at the confluence of Fitz Hugh Sound and Burke Channel, the region encompasses sites on the lower half of Hunter Island, King Island and the mainland coast, within the traditional territory of the Heiltsuk First Nation (Figure 3.1). Archaeological evidence documents the presence of humans at Namu, located at the mouth of the Namu River, by at least 9600-8650 cal. BC (Cannon 2000a; Carlson 1996), during a period of isostatic

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[2]Anadromous species are those that migrate to sea, but spawn in fresh water.

rebound and coastal innundation that followed deglaciation of the Cordilleran ice sheet at the end of the last glacial maximum (Barrie and Conway 2002; Lambeck and Chappell 2001). Heiltsuk oral tradition substantiates their ancestry in the region prior to the onset of the great flood (Boas 1932:2).

Over the course of its settlement history, the region has experienced dramatic changes in sea-level, as well as substantial storm and tectonic activity (Barrie and Conway 2002). It is situated within the Coastal Western Hemlock biogeoclimatic zone, the rainiest climatic region in British Columbia (Pojar et al. 1991:96). Annual precipitation averages 228-400 cm (Coupland 1998; Pomeroy 1980:7). Summers in the zone are characteristically cool and winters mild, owing to the warm offshore Japanese Current. The coldest mean annual temperature averages 0.2°C (Pojar et al. 1991:96).

Ethnographic and historic evidence characterize the cultures of the Northwest as "complex" hunter-fisher-gatherers, expressing a distinctive artistic style, hierarchical ranking, and elaborate redistribution system, such as the potlatch (Drucker 1955; Marshall 1998; Testart 1982). Populations were semi-sedentary, densely aggregated, and specialized in harvesting their preferred resources, most significantly fish. Access to resources was controlled by a system of social ranking (Donald 1997).

Pre-contact population for the entire Northwest Coast has been estimated between 200,000 and 1 million (Ames and Maschner 1999:53; Cybulski in press; 1994), with upwards of 80,000 residing in British Columbia alone (Cybulski 1994).

Full-time marine and riverine adaptation is evident from the earliest periods of coastal occupation. A broad variety of subsistence resources including marine and freshwater fish, invertebrates and mammals, birds and bird eggs, terrestrial herbivores, and an assortment of flora such as roots, seaweed, wood, bark, and berries have been documented ethnographically for use by coastal populations (Ellis and Swan 1981; Folan 1984; Lepofsky and Lyons 2003:1365). Archaeological findings substantiate these claims with abundant faunal evidence from a variety of fish species, particularly salmon, halibut, and herring, shellfish and other invertebrates, sea mammals such as pinnipeds, cetaceans, and sea otters, waterfowl, and terrestrial mammals such as deer, bear, and mountain goat (Cannon 1991; Coupland 1998; Driver 1993; Fladmark 1975; Mitchell and Donald 1988). Isotopic studies of archaeological human and dog bone collagen confirm that the diet of early coastal inhabitants was rich in marine protein (Cannon et al. 1999; Chisholm et al. 1983; Lazenby and McCormack 1985; Schulting 1994).

Settlement history along the Northwest Coast is based on a system of habitation sites that vary in their degree of permanence and site use. Site types have been differentiated into three general categories based on the magnitude of sedentism: aggregate village (usually winter occupation), village or broad-activity base camp and short-term resource acquisition camp (Cannon 2002; Lepofsky and Lyons 2003; Mitchell 1983; Mitchell and Donald 1988). The basic social and economic unit was the household or 'corporate group' (Hayden and Cannon 1982; Mitchell and Donald 1988:313). Each village was comprised of several households that would temporarily disband to smaller camps to acquire resources (Harkin 1997:7; Mitchell and Donald 1988:309). This stable system of settlement and site use was maintained in the Namu region for thousands of years, punctuated at times by brief periods of settlement growth and site diversification. New villages and a diversity of new specific-acquisition sites expanded in the region ca. 500 BC (Cannon 2000a; 2002). Based on site size, seasonality, and the density and variety of fish remains, Cannon (2002:318) identified a total of 6 site types in use along the central coast after 500 BC: winter villages, spring/summer villages, base camps, specific-purpose camps, small multi-purpose camps and rocky islet camps.

Shell middens are the most common type of archaeological feature found along the coasts, rivers, and shorelines of the North Pacific. Middens are heaps of cultural refuse, frequently very large in size and conspicuously composed of accumulated shellfish debris (Ambrose 1967; Trigger 1986; Waselkov 1987). Shell is durable and resistant to decay, but middens also encompass an array of cultural rubbish such as bone, fire-cracked rock, and manufactured artifacts (Hobler 1990). Results from this project confirm faecal wastes were also disposed in shell middens. As shell decomposes, it leaches carbonate, an alkali salt, that neutralizes the naturally acidic soil of the coniferous littermat, promoting the preservation of other midden components such as bone (Claassen 1998; Matteson 1960:119). The complex stratigraphy of shell middens can be accumulated rapidly over the course of hundreds of years, or slowly over thousands, through intermittent patterns of site use and abandonment (Stein et al. 2003). The restricted living space at most coastal sites ensured that waste, for the most part, stayed where it was initially deposited (Kelm 1998:43), accumulating into deposits that, in some instances, exceed 4 metres in depth.

All samples in this project were drawn from auger samples derived from shell middens. Middens on the Northwest Coast should not be considered autonomous site features. The availability of flat, habitable

land was limited by the rugged coastal terrain, interspersed with rocky outcrops, drainage systems, swamps and trees. Beaches were ideal habitation sites, as minimal effort was required to clear the ground (Jones 1914:53). Burials were at times interred within, and dwellings built upon, the foundations of shell middens (Hobler 1990:300). The aerated, course-grained shell matrix likely aided water drainage in the perpetually wet environment. As a result of these cumulative patterns of utilization, independent house or activity features are not readily discernable in midden stratigraphy.

Core and auger sampling of midden sediments have allowed for the investigation of generalized trends without having to resort to expensive, destructive, and labour intensive excavation strategies (Casteel 1976; Hoffman 1993; Stein 1986; Whittaker and Stein 1992). Such methods have been increasingly used on the coast to determine patterns in faunal deposition over time (Cannon 2000b; Coupland 1993; Ham 1976), taphonomic and site formation processes of midden sediments (Stein 1992; Whittaker and Stein 1992), settlement type and local/regional settlement distribution (Cannon 1996; 1997; 2000b). Samples for this study were derived from a core and auger survey conducted by Cannon (1996; 1997; 2000a; 2000b) in 1996-1997, to assess the variability in fish resources at sites within the Namu region.

Cannon's analysis confirmed the validity of the sampling method at Namu by finding analogous results in the standardized abundance of fish remains from auger samples compared with those from full-scale site excavation (see Cannon 2000b). However, auger sampling renders it impossible to differentiate site features below the surface of a midden exposure. Comparing patterns of evidence between culturally constructed site features over time can therefore be limited.

3.2 Complexity, Disease and Health on the Northwest Coast

The cultures of the Pacific Northwest Coast are often portrayed as a paragon of "complex" or affluent hunter-gatherers (Lightfoot 1993; Pomeroy 1980; Suttles 1968; Testart 1982), embodying many characteristics typically associated with agrarian societies (Matson 1992:367). There has been a preoccupation in coastal studies to discover the evolutionary mechanism or series of mechanisms that initiated the development of "complexity" in the region. The assumption in such studies is that there is an linear and progressive threshold at which a culture becomes complex, and subsequently a point at which Northwest Coast culture of the ancient past became recognizable as the culture of the more recent past and ethnographic present (Sanger 1983:186). Complex hunter-gatherers are distinguished by sedentism or reduced

mobility, permanent dwellings, large population size and density, a sophisticated division of labour, social ranking, refined technology, territoriality and/or competition for resources and the intensive utilization of reliably exploitable foods (Ames 1991; Maschner 1991; Matson 1992; Pomeroy 1980; Yesner 1980). Seasonal variation in specialized food acquisition strategies, analogous to the abundant harvests of cultivated plant foods, has also been considered a characteristic of complex hunter-gatherers (Testart 1982).

The first archaeological evidence for many of these mechanisms, such as increased population, plank house construction, and storage are widely recognized along the coast ca. 6000-4000 BP (Ames 1981:793; 1994; Ames and Maschner 1999; MacDonald and Inglis 1980-81:42; Lightfoot 1993; Moss 1993). However, there is no set time when these criteria culminated together in the same places, and no period through which all of these distinguishing features remained consistent. Maschner (1999) presents evidence from Alaska, for instance, that suggests settlement permanence was in constant flux throughout the history of coastal occupation. Other archaeological evidence also establishes that some of these mechanisms predate 6000 years. Those who believe preservation and storage technologies were a relatively late innovation (i.e. Ames and Maschner 1999; Matson and Coupland 1995) have been

challenged in recent years. Increasing zooarchaeological evidence of intensive salmon utilization, which was a seasonal occupation for which storage may be necessarily inferred, is now associated with some of the earliest dated sites along the coast (Butler and O'Connor 2004; Cannon 1996; Matson 1983). In the early 1970's, Fladmark (1975) proposed that intensive salmon harvesting began as soon as river systems and spawning habitats had stabilised after deglaciation, though he purported this only occurred over the last 5000 years. Carlson (1998) recognized intensive salmon harvest dating older than 6000 years at a minimum of 7 sites along the BC coast, including Namu. Cannon (1991; 2001; 2002) reports that evidence of intensive salmon harvesting at Namu is apparent in the earliest levels of preserved faunal debris, ca. 5000-4000 BC.

Although the populations of the Northwest Coast responded to changing environmental, climatic, and social conditions throughout their occupation, evidence does not support the supposition that this was a linear progression. The hunting-fishing-gathering cultures of the Northwest Coast are distinguished by a unique set of cultural features, mediated by distinct local ecology, and demonstrating the range of variability that can be expected in hunting and gathering populations of the past. Many of these distinguishing features, in turn, had the potential to sculpt the health and disease profile of those living on the coast.

3.2.1 *Sedentism and Mobility*

Ethnohistorically, villages were permanent amalgamations of several households, populated in some instances with upwards of 500 individuals (Suttles 1968:56). They were comprised of several plank-house structures that were occupied by several families (Suttles 1968). Sedentism on the Northwest Coast pertains to both 1) behavioural sedentism, characterized by the duration of physical habitation, and 2) emotional and/or economic attachment to place, also referred to as social sedentism (Ames and Maschner 1999:54; Johnson and Earle 1987; Testart 1982). It should not be viewed as an irreversible event, distinct from mobility, but rather as a continuum between extremes (Soffer1989) involving multiple dimensions of movement (Kelly 1992).

Behavioural sedentism is characterized by reduced spacial mobility (Rafferty 1985; Soffer 1989), and was demonstrated by year-round habitation at the same location, by at least a portion of a collective social group (Ames and Maschner 1999:154). Villages were typically aggregated into permanent settlements over the winter months (Harkin 1997:7; Mitchell 1983). Sedentary lifestyles may benefit individual health, providing an opportunity to care for the ill and extend life expectancy (Cohen 1989). However, the dense and recurrent nature of behavioural sedentism would also promote the accumulation of waste and subsequent

soil and water contamination. Such conditions would amplify the potential for the development and exchange of soil-borne and water-borne pathogenic organisms (Cohen 1989). *Ascaris lumbricoides* (human roundworm) and *Ancylostoma duodenale/Necator americanus* (hookworm), for example, are soil-borne parasites that can be sustained in the environment under appropriate conditions for months or even years (CDC 2001). Dogs shared these living conditions with humans, contributing to the pathogenic load and risking exposure to the same sedentary cycle of infection. Children were weaned into these environments, increasing their risk of exposure to both food/water-borne and soil-borne pathogens during their vulnerable developmental years.

However, sedentism of place does not require sedentism of persons (Ingold 1987:176), and there was considerable movement of individuals and socially sedentary groups between different locations. This social, or organizational, form of sedentism is secured in property rights (Soffer 1989) and social relationships. In this sense, entire sedentary villages could be dismantled and relocated (Ames et al. 1992; Ames and Maschner 1999:154; Harkin 1997:7). The seasonal nature of site occupation and mobility of individuals may have limited any long-term exposure to infectious agents and restricted their ability to circulate within a population. Alternately, residential mobility may promote the efficient

exchange of pathogens between populations. Mobility due to trade, warfare, seasonal round, marriage or group congregation would have brought people into frequent contact with one another, facilitating the exchange of pathogenic organisms. Trade in goods themselves, such as dried fish or dogs, may also have widely dissipated pathogens throughout a region.

3.2.2 *Population Density*

The populations of the Northwest Coast achieved population densities the likes of which are uncharacteristic of traditional concepts of hunting and gathering societies. This achievement is primarily attributed to the reliability and abundance of resources and the reduced mobility strategies that were utilized to exploit them (Ames and Maschner 1999:53; Soffer 1989). Population estimates are commonly calculated from house and hearth features, though unfortunately these are rarely uncovered at coastal sites (Ames et al. 1992). Instead, increased rates of midden deposition or an accumulation and diversification of site types have also been used to infer population growth (Erlandson and Moss 1999). There appears to have been intermittent periods during Northwest Coast history during which population expanded. Human specific pathogens are sensitive to increases in population size or density, as they rely on a

human population base large enough to sustain them, independent of intermediary hosts or routes of transmission.

3.2.3 *Intensive Utilization of Resources*

An abundance of zooarchaeological evidence from coastal sites attest that marine resources were variable and abundant, though generally available in seasonal cycles (i.e. Balkwill and Cybulski 1992; Cannon 1991; Driver 1993; Ham 1982; Matson 1992; Pomeroy 1980; Stewart and Stewart 2001). The abundance of salmon remains relative to any other exploited species, including other fish, birds or mammals, is considered an indication that the ethnographic importance of this ubiquitous resource extended throughout the history of coastal occupation (Cannon 1991; Carlson 1996). Therefore, food-borne pathogens or zoonotic diseases derived from fish or game were a likely health risk.

Considering the dietary emphasis on salmonids, human populations risked infection with two species of parasite in particular, *Anisakis simplex* and *Diphyllobothrium latum*, both known to infest salmonids in the Pacific Northwest (Butt et al. 2004). Severe infections with *Diphyllobothrium latum* could lead to vitamin B_{12} deficiency resulting in pernicious anaemia (Goodman and Salt 1990), a condition that could manifest skeletally. Anaemia occurs in modern-day populations in approximately 2% of worm carriers (Bylund 1982:221). Tapeworm

infection has been documented in Eskimo populations in Alaska in association with the consumption of raw or smoked salmon, though there was no evidence that the infection progressed to anaemia (Hilliard 1960; Rausch et al. 1967).

3.2.4 *Seasonality*

Resource seasonality was an influential factor in settlement patterns along the coast. The reliable and predictable availability of resources such as salmon, herring (*Clupea harengus pallasi*), eulachon (*Thaleichthys pacificus*), marine mammals, and shellfish is considered incentive for sedentary settlement choices and the development of territoriality. Mass harvesting led to innovations in technology such as fish traps/weirs (Carlson 1998:27; Erlandson and Moss 1999; Erlandson et al. 1998; Pomeroy 1980) and was maximized by the development of preservation and storage technologies.

Some resources were harvested during periods of optimal availability. Salmon, for instance, was harvested *en masse* from rivers in late spring, late summer or early fall, during spawning season (Ford 1989; Pomeroy 1980:47). Eulachon (also known as olachen, ooligan or candle-fish), another anadromous species, were harvested from rivers during late spring (Kuhnlein et al. 1996), while herring were caught just offshore during the spring spawning season (Cannon 1991; Pomeroy 1980:46).

Terrestrial game such as deer (*Odocoileus hemionus*) and mountain goat (*Oreamnos americanus*) were hunted over the winter months (Harkin 1997: 7), whereas seal pups (*Phoca vitulina*) were available during the spring (Cannon 1991).

Other seasonal choices may have been made due to pathogen avoidance strategies. Shellfish, specifically bivalves such as clams and mussels, were frequently – though not exclusively – harvested during the winter. The Haida, for instance, only collected shellfish during the winter, as they believed they were infested with "worms" over the summer months that could prove to be fatal if consumed (Dawson, 1880: 112B). As there are no bivalve "worms" that could negatively affect human health known to this region, it is possible this practice was in avoidance of red-tide and associated toxins such as paralytic shellfish poisoning. Red-tide can result from toxic algae blooms that occur during months when coastal waters are warmest (Moss 1993:644; Muddie et al. 2002). Shellfish act as filters, concentrating toxin levels in their flesh, a condition with potentially fatal consequences for the consumer (Steffian and Simon 1996:576). Geological studies document the presence of red-tide-causing dinoflagellate cysts as much as 7000 years old in sediment cores from the southern coast of Vancouver Island in British Columbia (Mudie et al. 2002).

3.2.5 *Technology*

The seasonal variability and abundance of resources such as salmon, herring and eulachon encouraged mass harvesting and the utilization of a storage based economy (Ames and Maschner 1999; Suttles 1990). Drying, rendering and fermenting were methods of food preservation that were employed ethnographically. Fat-rich foods such as eulachon or dogfish were rendered for their grease, which was used as a condiment or preservative with dried foods such as fish or berries (Dawson 1880: 112B; Elis and Swan 1981; Kuhnlein et al. 1996; Turner 2000). Lean foods such as shellfish and some species of salmon were smoked or sun-dried to preserve the stores throughout the lean winter months. These forms of processing do not involve cooking or heating, allowing larvae of parasites such as *Diphyllobothrium spp.* (fish tapeworm) to remain viable (Beldsoe and Oria 2001:S-1100). Other foods, such as herring spawn and salmon roe or heads, were buried and left to ferment, producing a choice delicacy (Hoffman et al. 2000), which has occasionally been associated with health ailments. The Haida of the Queen Charlotte Islands, for instance, believed a small "worm" could infest fermenting salmon roe, fatally poisoning the consumer (Dawson 1880:111B). While it is possible for a "worm", likely a larval pathogen or maggot, to be observed in such preparations, the probable cause of such maladies was

botulism toxin (Dolman 1974; Schaffer et al. 1990). Health Canada (2002) reports that 1-3 cases of botulism were reported each year from 1996-2002 in British Columbia as a result of traditional salmon roe fermentation, in some cases with fatal consequences.

Zoonotic pathogens such as *Diphyllobothrium* spp. or *Nanophyetus salmincola* had the potential to infest resources that were seasonally available in abundance and subsequently stored for extended use. Thus, exposure to such pathogens was not restricted to the season in which they were harvested, but could be extended for months or several years after storage. Storage may in turn have attracted human commensals such as mice, which can be intermediary hosts of tapeworm such as *Hymenolepis* spp. Technology that allowed for mass harvesting, processing, and subsequent storage would also effectively increase the risk of parasite infection.

3.2.6 *Northwest Coast Health and Disease Summary*

Sedentism/mobility, population density, intensive utilization of seasonal food resources, and technological innovations in food procurement and processing are cultural factors characteristic of coastal lifestyles that could change or influence the risk of pathogenic infection among these hunter-fisher-gatherers. There is no distinct threshold at which all of these factors emerged at all locations in the region, and

considerable evidence to suggest many were already in place with the earliest settlers. Environmentally, the habitat at each site was damp and temperate, with confined access to freshwater resources, rendering them susceptible to contamination. The cultural and environmental context of the region was adequate to acquire and sustain pathogenic organisms, such as intestinal parasites.

3.3 Coastal Skeletal Anaemia

Smallpox, measles, malaria, whooping cough, typhus, typhoid and influenza are pathogens that were introduced to the Northwest Coast after European contact in the 18th century (Ames and Maschner 1999:54; Codere 1950). Relatively less is known about the disease profile of the pre-contact inhabitants of the region, in part due to a general assumption that, as hunter-gatherers, populations were likely to have been relatively free of disease. Detailed health records were not kept of the Kwakiutl until after the 1837 smallpox outbreak, and subsequent records had a tendency to focus on severe infectious (and introduced) outbreaks rather than day to day and endemic health matters (Codere 1950:51). What little that is known has been derived from studies of skeletal material summarized by Cybulski (in press; 1990), the majority of which is only representative of the last 5500 years, though some examined skeletons

are as much as 10 000 years old (Cybulski in press). Evidence is limited, and the only burial collection that has been studied from the central coast region was uncovered at Namu (Curtin 1984; Cybulski 1990).

There are graded degrees of iron deficiency, but only the most severe form, iron deficiency anaemia, is believed to interfere with the development of the maturing skeleton. Anaemia is characterized by low red blood-cell counts and/or diminished haemoglobin concentrations (Garn 1992). When children are afflicted with iron deficiency anaemia, skeletal growth is disrupted. Enlargement of the bone marrow cavities and decreased cortical bone thickness resulting from anaemia are believed to be the primary cause of the characteristic pitting in the orbital sockets called *cribra orbitalia* and 'spongy' porosity on the parietals of the skull vault, known as *porotic hyperostosis* (Stuart-Macadam 1985; 1992; Stuart-Macadam and Kent 1992). It is important to realize the skeletal manifestations are a reflection of *childhood* morbidity, and are likely to manifest after a child has been weaned onto solid foods and water. The lesions persist and are maintained as the skeleton matures, but may be remodelled over time, obscuring evidence of the condition in older skeletons. Anaemia may afflict older individuals, and chronic anaemia may prevent the effective remodelling of bone lesions, but these skeletal manifestations do not develop in a mature skeleton.

Some researchers have demonstrated that cribra orbitalia and porotic hyperostosis may not, in fact, be related to iron deficiency anaemia. Histological evidence of anaemia does not always corroborate the gross-morphological diagnosis, and researchers suggest other inflammatory conditions may cause the characteristic porosity (Shultz 2001; Wapler et al. 2004). However, given the cultural and environmental conditions discussed above, as well as the strong dietary reliance on fish known to carry parasites that can cause anaemia, the most likely aetiology of the skeletal condition on the coast is acquired iron deficiency anaemia.

Cribra orbitalia and porotic hyperostosis are frequent conditions among archaeological burial populations in both North and South America (i.e. Curtin 1984; Cybulski in press; 1994; 1992; 1977; Dale 1994; Hart 1998; Stuart-Macadam and Kent 1992; Walker 1986; Wright and Chew 1998; Ubelaker 1992). Evidence from the Pacific Coast of the Americas demonstrates a pre-contact incidence of skeletal anaemic indicators comparable to that of fully agricultural archaeological sites in Central America (Table 3.1 and 3.2). Cybulski (1977; 1990; 1994) and Dale (1994) have suggested that decreased sanitation, and thus increased pathogen exposure resulting from population growth and aggregation, may account for the skeletal anaemia found in British Columbia

populations. Keenlyside proposes the same aetiology for cribra orbitalia and porotic hyperostosis in Alaskan Eskimo and Aleut skeletons (1998:61). Although the skeletal manifestations are common throughout the Northwest Coast, there are regional variations in frequency. The condition appears more common in skeletal populations from the Strait of Georgia on the south coast than among burials at Prince Rupert Harbour to the north (Cybulski in press).

Cribra orbitalia/Porotic hyperostosis
British Columbia Coastal Sites

Site	*Date Range*	*# of observable individuals*	*% with cribra*	*Source*
Blue Jackets Creek	ca. 2000 BC	21	28.6	Cybulski 1990
Prince Rupert Harbour	1500 BC - AD 500	157	6.4	Cybulski 1990
Namu	ca. 4000 BC - AD 1000	25	8.0	Curtin 1984
Strait of Georgia	1500 BC - AD 500	58	31.0	Cybulski 1990
Greenville	AD 500 - contact era	38	21.1	Cybulski 1992
Historic Kwakiutl	contact era	174	9.8	Cybulski 1990

Table 3.1: The frequency of skeletal anaemic indicators in Northwest Coast burial populations.

Cribra orbitalia/Porotic hyperostosis
Selected Agrarian Central American Sites

Site	*Time Period*	*# of observable individuals*	*% with cribra*	*Source*
Cuello	Preclassic Maya 1200 BC - AD 100	57	5.2	Saul and Saul, 1997
Chichen Itzá	Classic Maya AD 400 - 800	35	65.7	Hooton, 1940
Lamanai	Post Classic Maya AD 900 - 1500	53	9.0	White, Wright and Pendergast, 1994
Lamanai	Historic Maya AD 1670	100	17.0	White, Wright and Pendergast, 1994
Oaxaca	Non-intensive 1400 - 500 BC	56	16.0	Hodges, 1987
Oaxaca	Intensive 500 BC - AD 1400	150	21.3	Hodges, 1987

Table 3.2: The frequency of skeletal anaemic indicators in a few selected agrarian Central American populations.

As maritime foods are rich sources of iron and other micronutrients, skeletal anaemia has frequently been attributed to pathogen burden (Cybulski 1977; Stuart-Macadam 1992; Stuart Macadam and Kent 1992; Ubelaker 1992; Walker 1986). Marine and terrestrial animals such as fish, shellfish, waterfowl and marine mammals are rich sources of heme iron, the most bioavailable and digestible form of iron (Hawkins 1983:121). Therefore, dietary iron would have been liberally available to hunter-fisher-gatherers, and dietary deficiency is not considered a sufficient explanation for the skeletal evidence. Intestinal helminths can interfere with iron absorption and metabolism. They may also exacerbate

nutritional inadequacies and impact the health of an individual, promoting susceptibility to conditions such as anaemia. Current medical studies correlate the development or exacerbation of iron deficiency anaemia with the infection of one or more intestinal parasites (Crompton 2000; de Silva et al. 2003; Horton 2003). *Ascaris lumbricoides*, for example, competes with its host for vitamin A, and infection may result in a substantial loss of this nutrient (Koski and Scott 2001). Vitamin A promotes the absorption of non-heme iron from plant food sources (Lynch 1997), therefore a deficiency in vitamin A due to ascariasis can interfere with the absorption and metabolism of iron. Likewise, fish tapeworm (*Diphyllobothrium latum*) competes for vitamin B_{12} with the host. Vitamin B_{12}, along with iron, is essential for red blood cell development and maintenance (von Bonsdorff 1977:99). Some intestinal parasites such as hookworm (*Ancylostoma duodenale/ Necator americanus*) directly consume red blood cells from the host, leading to blood loss and iron deficiency (Albonico et al. 1998).

Infants and juveniles, who are more exposed to oral/faecal contamination, are also more vulnerable to parasitic infection and anaemia (Cook 1990). Late weaning may likewise cause anaemia, and children on the Northwest Coast may not have been weaned until 2-3 years of age (Cybulski 1977). But circumstantial evidence suggests cultural knowledge may have correlated the ingestion of salmon at an

early age with ill-health. Based on an age-specific discrepancy in carbon isotope signatures recognized in skeletons 4500 years old or less, Lazenby and McCormack (1985) suggest children at inland sites consumed more terrestrial protein than adults. They attribute this pattern to cultural choice and the intentional avoidance of vitamin D toxicity, which they demonstrate could occur if growing children consumed too much salmon. Whether strategies of avoidance were developed to evade parasites or hypervitaminosis D, isotopic studies corroborate that coastal societies were likely aware of at least some of the risks associated with their dietary choices.

3.3.1 *Coastal Anaemia Summary*

Although information about the health of pre-contact populations on the Northwest Coast is limited, there is just cause to expect foodborne and waterborne pathogens, in particular, were a risk to these hunter-fisher-gatherer populations. As intestinal parasite eggs have been demonstrated to preserve archaeologically, and skeletal evidence exists to imply parasitic infection, this study focussed on recovering evidence of intestinal parasites from shell middens. These were the samples that were available, and the locations that were most likely to include faecal wastes.

3.4 Context of the Archaeological Sample

In total, 15 sites were tested for parasite evidence (Cannon 2000a; 2000b). All sites were located within a 20 km radius of the central village site at Namu (ElSx-1). All dates, site type designation, and background information are derived from Cannon's 1996-1997 core and auger survey (1996; 1997; 2000a; 2000b; 2002) unless otherwise noted. All dates are 2 sigma calibrated ranges.

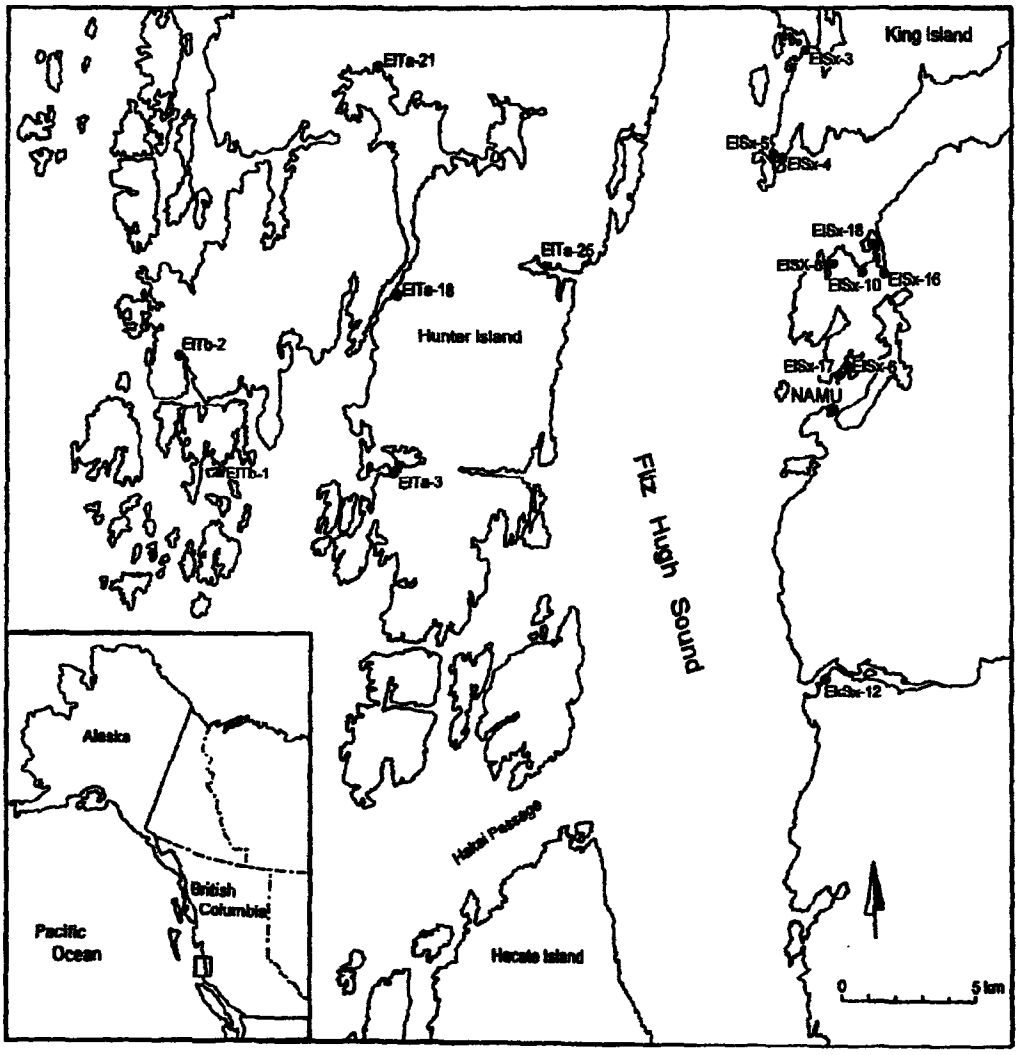


Figure 3.1: Sites tested along the central coast of British Columbia, Canada (from Cannon 2000a).

EkSx-12 Koeye River
Site Type: Winter village
Initial Date: cal. 255 BC - AD 30 Terminal Date: European contact

This site, located on the south side of the Koeye River, was a winter aggregate village with ample site area and an abundance of level, habitable living space. The midden is concentrated along the edge of the river, which is slow moving, draining Koeye Lake located to the east. Historically, it was one of the most productive pink salmon streams on the central coast. A long, sandy beach stretches out to Fitz Hugh Sound, though no intertidal resources are available from this location.

ElSx-1 Namu
Site Type: Winter village
Initial Date: cal. 9600-8650 BC Terminal Date: European contact

Namu may have initially been a base camp, with the first significant accumulation of shell and the development of the village occurring 5280-4720 cal. BC. From this time it was a village site, utilized primarily during the winter but with evidence of year-round occupation. The site is located at the top of a steep embankment on the north side of the Namu River, which drains Namu Lake into Fitz Hugh Sound. Ancient DNA documents the presence of pink (*Oncorhynchus gorbuscha*), coho (*O. kisutch*), chum (*O. keta*), and sockeye (*O. nerka*) salmon at the site as early as 7000 years BP (Yang et al. 2004). A fish trap for harvesting such salmon is located at the mouth of the river. The habitable space surrounding the site

is abundant and level. Structures at the site would have faced southwest, towards the sea, and midden rubbish was deposited towards the front of the site.

ElSx-3 Kisameet Bay, King Island
Site Type: Winter village
Initial Date: cal. 940-770 BC Terminal Date: European contact

This winter village is located on the southern end of King Island on the south side of the Kisameet River, facing west toward Kisameet Bay and the open Fisher Channel. Kisameet Lake is located east of the site. Living space was constrained, and sites ElSx-4 and ElSx-5 were within walking distance or short transport by water. An intertidal fish trap branches from the side of the river and the midden extends into the intertidal zone. Today, salmon berries grow well on old midden sites such as this one.

ElSx-4 Windsor Cove, King Island
Site Type: Small multi-purpose camp
Initial Date: cal. 890-670 BC Terminal Date: cal. AD 1435-1685

This site is situated close to ElSx-5 on the southern tip of King Island at the confluence of the Burke and Fisher Channels. Initial occupation post-dates that at ElSx-5, but it is contemporaneous with the village at ElSx-3. The midden at this small camp site is constrained by rock outcrops, a steep slope and a wide, narrow beach, providing limited living area. A very small stream marks the western boundary of the site.

Salmon and other fish remains are not abundant. The site encompasses a high terrace that offers a good lookout over Burke Channel and Fitz Hugh Sound.

ElSx-5 Windsor Cove, King Island
Site Type: Base camp
Initial Date: cal. 4780-4510 BC Terminal Date: cal. AD 1470-1700

This base camp is larger and older than the adjacent site at ElSx-4 to the east, and also faces south into Windsor Cove from the southern tip of King Island. The site is located on a terrace at the top of a high, steep slope. A stream cuts through the eastern portion of the site, providing fresh water. Like ElSx-4, salmon remains are present at this site, though they were not likely caught at this location. Barnacle is the most common component of the shell midden.

ElSx-8 Fougner Bay
Site Type: Specific-purpose camp
Initial Date: cal. AD 140-430 BC Terminal Date: cal. AD 1660-1950

This small, sheltered camp site on Fougner Bay appears to have been a specialized shellfish acquisition site. The midden contains a diversity of shellfish, but is patchy with no evidence of even short-term residence. The long tidal flats expose fish traps and ample space for shellfish harvesting. Fish remains, however, are rare and no salmon were recovered.

ElSx-10 Fougner Bay
Site Type: Base camp
Initial Date: cal. 4315-3960 BC Terminal Date: cal. AD 1655-1950

This base camp, located off Burke Channel on Fougner Bay, has a landscape and occupational history similar to that of Namu located to the south. Topographically, the site is elevated and flat, sloping at the back where a small stream constrains a swamp. The midden builds outwards, with the deepest deposits located at the front of the site. In spite of a lack of sandy beach or clam beds, there is considerable shellfish accumulation in the midden, suggesting these resources were acquired elsewhere. A variety of fish remains were recovered from the site, including salmon and herring.

ElSx-16 Fougner Bay
Site Type: Small multi-purpose camp
Initial Date: cal. AD 660-940 BC Terminal Date: cal. AD 1670-1950

Just to the east of ElSx-10, around a bend, is a narrow site with a shallow, rocky beach. To the north of the site, a narrow passage runs through Fougner Bay out to the Burke Channel. A small, fresh-water stream crosses the site. Flat space was limited compared to ElSx-10. Herring was the most common fish represented at the site, indicating predominantly spring utilization, though there was some evidence of salmon recovered as well.

ElSx-17 Sunday Island, Namu Harbour
Site Type: Rocky islet camp
Initial Date: cal. AD 990-1165 (only one date is associated with this site)

The site is a comprised of a minor patch of midden located on a very small island in Namu harbour. It is unlikely that it served as even a short term residence. Traces of salmon and shellfish were noted at the site.

ElSx-18 Fougner Bay
Site Type: Base camp
Initial Date: cal. 1575-1310 BC Terminal Date: cal. AD 1710-1950

Located within view of ElSx-10 across the bay, this site is slightly elevated but constrained by rock. A stream used to flow behind the site around a large, rock-face, but was re-routed historically due to logging practices. A variety of shellfish and fish were recovered from this base camp, of which salmon and herring were the most abundant.

ElTa-3 Watt Bay, Hunter Island
Site Type: Specific-purpose camp
Initial Date: cal. AD 1160-1300 Terminal Date: cal. AD 1660-1950

This small camp represents a specialized fishing trap on the southern end of Hunter Island near Watt Creek. The midden is located on an elevated terrace. Some shell and a variety of fish remains were recovered, though none were abundant. Salmon, anchovy and herring were the most common fish species identified.

ElTa-18 Kildidt Inlet
Site Type: Small multipurpose camp
Dates: cal. 9605-9250 BC Terminal Date: cal. AD 1220-1460

This small site is located on Hunter Island, up a sheltered inlet near Kildidt Creek. After Namu, with which it is contemporaneous, it is the oldest site in this regional survey. The midden, which is located on a high terrace, produced little evidence of shell or vertebrate faunal preservation throughout most of the deposits, though salmon was recovered from relatively recent shell midden accumulations. A small stream is located to the south, providing a local source for fresh water.

ElTa-25 Kiltik Cove, Hunter Island
Site Type: Specific-purpose camp
Initial Date: cal. 2420-2025 BC Terminal Date: cal. AD 1655-1950

Salmon, herring and anchovy are present in the faunal assemblage, but shellfish are the most common component of the midden at this site. The location on the east side of Hunter Island, facing south into Kiltik cove, is sheltered from west-prevailing storms. Large clam flats extend from the front of the site, cut by a river on the west side that empties into the cove.

ElTb-1 Hurricane Island
Site Type: Summer village
Initial Date: cal. 805-410 BC Terminal Date: European contact

This densely inhabited summer village site is located on the southern side of Hurricane Island, separated from Hunter Island to the

north by Spitfire Channel. The occupation area was very small, constrained by water, rocky outcrops and swampland. A large beach lines the cove at the front of the site, providing a variety of shellfish. An assortment of fish species were recovered from the midden, with some such as herring and salmon in great abundance. Although there is a bog at the back of the site, there is no obvious fresh-water source available at this location.

ElTb-2 Spitfire Channel, Hunter Island
Site Type: Specific-purpose camp
Initial Date: cal. AD 20-245 Terminal Date: cal. AD 1255-1445

This site represents a very small, general-purpose campsite, located on the southern end of Hunter Island on Spitfire Channel, near Steward Creek. Although fish remains were the most diverse of any site, the abundance was limited and salmon was a minor component. A small stream, with a fish-trap, marks the northernmost border of the site. The midden is located on a small terrace, slightly elevated from the surrounding, grassy flood-plain.

Chapter 4:
METHODS

4.1 Precedent for Methods

Since the 1960's, there have been several published papers that detail different methods for isolating parasite eggs from a range of archaeological contexts (i.e. Bouchette et al. 1999; Callen 1967; Callen and Cameron 1960; Fry 1977; 1985; Faulkner et al. 2000; Jones 1990; Jones and Hutchinson 1991; Pike 1968; Reinhard et al. 1986; Warnock and Reinhard 1992). None, however, have dealt specifically with shell midden deposits. Given the temperate climate of the Northwest region of North America, the open nature of the sites, the high level of water activity in the coastal rainforest, the economy of the populations that lived there (hunter-fisher-gatherers), and the rarity of discrete faecal deposits recovered from such contexts, there was a presumption that shell middens were unlikely to contain preserved evidence of intestinal parasites. In 1999, Bouchette and colleagues published evidence of eggs recovered from historic Aleutian woodworking middens, decisively demonstrating that parasite evidence could survive in the temperate climate of the Northwest. But it was still unclear which method of

processing would be most appropriate for isolating parasite evidence, considering the microenvironmental and cultural contexts that are particular to shell middens. It was therefore necessary to test several processing techniques, in order to elucidate which method would be most successfully applied to the archived midden samples available for analysis.

The methods utilized in archaeoparasite studies are largely dependent upon the nature of the sample being analysed. Coprolites are, by far, the most commonly mined sources of archaeoparasite evidence, and subsequently most published methods have concentrated on processing this particular medium. Dry, desiccated material such as coprolites or mummified remains require rehydration prior to examination, in order to soften the binding matrix and reconstitute the shape of the eggs into diagnostically recognizable forms. Alternatively, wet samples characteristic of latrine soils or temperate climates may be examined without rehydration, as long as samples remain moist. There has been a considerable amount of experimentation in concentration techniques designed to optimize parasite recovery, including acidization, flotation and/or sedimentation. This project tested 3 different methods for processing soil samples before settling on a modification of one that was

first pioneered by Canadian researchers Callen and Cameron in 1960 for use with coprolite material.

4.1.1 *Sample Processing*

Modern medical and veterinary parasitologists have refined protocol for extracting eggs from faeces and soil. But methods for isolating fresh eggs from modern faecal or soil samples have not always been successful for the recovery of ancient artifacts. Eggs are susceptible to a wide range of taphonomic changes, including fossilization, drying, flattening, shrinkage, cracking, and degradation. Mechanical processes such as trampling, digging, digestion, freezing, and thawing may also result in fragmentation or decomposition (Reinhard et al. 1986). These conditions change the characteristics of the eggs, making them less susceptible to modern processing techniques. Therefore, archaeological studies have had to develop methods more conducive to recovering fragile, damaged or degraded evidence.

Archaeoparasitological studies in the UK have examined the rare coprolite or faecal concretion, but soil samples from refuse pits and the living floors of features such as roadways or buildings are the most commonly excavated sources for parasite evidence (Jones 1982; 1987; Jones et al. 1988). The temperate climate and frequently waterlogged conditions of these sites often preserve eggs with their shape and

morphology intact. Therefore, soil samples undergo minimal processing prior to analysis. Aggregated specimens, such as faecal concretions, are bound together with calcium phosphate (identified by x-ray diffraction in Jones 1987:184), the chief mineral component of coprolites. A dilute mixture of hydrochloric acid or sodium pyrophosphate ($Na_4O_7P_2$) has been used to dissolve or soften the calcium aggregate and loosen the eggs from the soil (Jones 1990; Jones and Hutchinson 1991). Moist soil samples are simply disaggregated in water, screened, and the suspension is examined as a wet-mount under a microscope (Jones 1986; 1988). This is similar to a direct faecal smear, utilized in medical parasitology to establish the presence of parasites in fresh samples, which microscopically examines a smear of faeces suspended in a drop of saline solution (Foreyt 2001:7; Markell et al. 1999:432; WHO 1980). As the midden samples in this study were originally derived from moist conditions, this was the first processing method attempted in this study. But an examination of samples drawn from two separate augers (ElSx-10, auger A10 and ElTb-1, auger B26) yielded no positive results.

Most studies of fresh samples are designed to measure the intensity of parasite eggs as a means of evaluating the severity of clinical infection in an individual by sampling faeces, or the prevalence of an infection within a population by sampling soil (Hall and Holland 2000).

However, studies that are only interested in establishing presence or incidence utilize concentration techniques that are designed to recover as many eggs as possible from a sample. Concentration is a particularly useful method for research that is interested in recovering rare species or establishing the relative incidence of parasite infection from dilute faecal deposits, such as soil samples. Therefore, concentration techniques lend themselves well to the research goals of ancient parasite studies, which are interested in recovering evidence of as many preserved parasites as possible from ancient or diluted materials.

The three most common methods utilized to concentrate eggs are sieving, flotation and sedimentation. Sieving concentrates faecal sediment by filtering off any material larger than 150 µm, the upper size range of modern medically relevant parasite eggs (McSorely 2000). In fresh samples, some species' eggs may be recovered by heavy liquid flotation in a salt or sugar solution with a specific gravity higher than that of the eggs (Ajala and Asaolu 1995; David and Lindquist 1982). The specific gravity of most veterinary or medically important parasite eggs ranges between 1.0 -1.3 (David and Lindquist 1982). Callen (1967:262) reported that efforts to float parasite eggs from coprolites with a salt solution yielded negative results, which he attributed at the time to the abundance of plant detritus that he considered likely to have obstructed any parasite

evidence. Dittmar and Steyn (2004) however, have been more successful floating eggs from Iron Age coprolites. For certain species, dense and heavy eggs are isolated more readily through sedimentation techniques such as centrifugation. Some techniques utilize both methods, with the intention to recover a range of different species (i.e. Fry 1977; Bouchette et al. 1999; 2001). Reinhard and colleagues (1986:224, 231; Warnock and Reinhard 1992) have found that archaeological parasite eggs are exposed to diagenic changes that can affect buoyancy, frequently rendering them unresponsive to chemical flotation or more susceptible to collapse due to the osmotic pressure of flotation liquids. Thus, they suggest ancient eggs are best concentrated with simple size/density sedimentation techniques such as centrifugation (Bouchet et al. 1999; 2003:50; Reinhard et al. 1986).

Acidization is a general technique developed from palynological studies that investigate soil commonly derived from core or auger samples. In order to readily isolate floral remains such as pollen, spores or phytoliths from soil, background detritus or 'noise' such as wood, macerated organic debris, minerals or carbonates are removed from the sample by various acid treatments. This technique has been used in archaeological studies that have combined interests in palynological and archaeoparasitological remains (Reinhard et al. 1986; Warnock and

Reinhard 1992). Parasites that have survived a human (or other organism's) digestive tract are more likely to survive processes that simulate digestion, such as acidization. Thus, such treatment can also serve to eliminate less robust species, such as soil nematodes, that could otherwise cause confusion with identification. Such caustic methods are destructive, however, and limit the variety of information that can be gained from microanalytical techniques. Furthermore, the effect of acid treatment on fossilized or ancient parasites is not fully understood, and the possibility remains that such treatment could destroy already fragile or decomposing archaeological evidence (Coil et al. 2003). The second processing method applied to midden samples in this study was a modification of Warnock and Reinhard's technique (1992), and involved acidization in dilute hydrochloric acid (HCl) to remove excess carbonates, followed by flotation with sodium nitrate ($NaNO_3$, specific gravity 2.26 g/ml) and sedimentation by centrifuge. This method also achieved no positive results in 3 samples drawn from augers A21, A22 and A23 at ElSx-1.

4.1.2 *Parasite Identification*

Identification is based on a number of morphological characteristics that include size, shape, surface structures, stage of development, colour and distinguishing features such as opercula or

hooks (Brooke and Melvin 1989; Reinhard, 1992; WHO 1980). Helminth egg shells are composed primarily of one or a combination of two compounds: chitin – a polymer, and/or sclerotin – a protein (Christenson 1974; Smyth 1969; Wharton 1980). Both are stable and highly resistant to decay in a variety of environments, though preservation of the embryonic organism is not as common. This can make identification of ancient remains more difficult, as some diagnostic features, such as hooks, are characteristics of the embryo and not the egg shell. Species differentiation, therefore, is not always possible (Reinhard et al. 1986:228). Technological advances such as aDNA processing have become an ancillary method for confirming species diagnoses based on morphological characteristics, though they provide little information about the synchronic or diachronic distribution of archaeoparasite species. Methods that can quickly and efficiently compare the relative frequency of archaeological remains are still essential to epidemiological and comparative studies.

In order to recognize morphological characteristics, it is first necessary to reconstitute the natural shape of the egg as much as possible. Such features are usually maintained in samples that have remained wet, but dry samples require a method of reconstitution. Callen and Cameron (1960) pioneered such a method using a weak solution

(0.5% weight per volume) of trisodium phosphate or TSP (Na_3PO_4). Sodium ions replace calcium ions in solution, softening carbonate concretions such as coprolites or faecal aggregates and swelling the chitinous or sclerotinous shell of the eggs, reconstituting their morphological shape. Reconstituted eggs can appear damaged or cracked, and may have experienced shrinkage due to initial drying, but morphological characteristics are usually preserved adequately for diagnostic purposes (Reinhard et al. 1986). Today, rehydration of dried or desiccated samples with 0.5% TSP solution is standard practice in most archaeoparasite studies (Bouchet et al. 2003; Fry 1985; Gonçalves et al. 2003; Horne 1985; Reinhard et al. 1986; Wilke and Hall 1975).

The final processing experiment in this study utilized the rehydration method as outlined by Callen and Cameron (1960). Fry (1985:140) later refined the method and clearly outlined standard processing techniques for small samples, which were followed in this study. Results of this rehydration method were successful (Bathurst 2005), and subsequently applied to all samples reported in this research.

4.1.3 *Sampling*

The midden deposits available for analysis had been archived from a prior research study. They comprised the residual component of samples derived from a core and auger survey of shell midden sites

conducted by Cannon (1996; 1997; 2000a; 2000b) on the central Northwest Coast. The original aim of Cannon's survey was to investigate inter-site fish variability by comparing the relative frequency of fish bones over time and between different site locations. Matrix that had been washed from screened auger samples was dried and curated for potential future use. The auger excavates material 7 cm in diameter by 15 cm deep on average, yielding ~300 g of bulked, unwashed material per sample. Each sample could therefore represent a depositional time interval of several months to hundreds or thousands of years. Washing the auger samples served to homogenize the sediment and any weathered faecal components (McSorley 2000; Swift and Bignell 2001:20). This process aids in avoiding the probability of sampling a single faecal or dumping episode, assuring all samples drawn from a single auger deposit are equally representative of the same general time interval, thus eliminating the potential for temporal bias. Sub-samples for microscopic analysis were drawn randomly from this representative midden matrix.

Sample size was based on the rate of success demonstrated in other archaeoparasite and palynological studies and mediated by the amount of archived soil available for analysis, the time available for examination and the methods of quantification deemed appropriate for relative comparison (see below). Coil et al. (2003:997) argue there is no

"general rule" to guide how much soil is appropriate for testing, and consider that such decisions are dictated by the quality of the sediment being tested, the density of preserved micro-artifacts, and the goals of the researcher. Fry used a sample "the size of a pea" [probably 1 g or less] for isolating eggs from coprolite samples (Fry 1985:14). Likewise, Pike (1968) processed "small quantities" of cesspit soil. Warnock and Reinhard (1992:262) recommended processing as much as 33 millilitres (roughly 33 grams) of latrine soil for both palynological and parasitological extraction. From excavated latrine pits, Han and colleagues (2003) analysed 10 g samples, while Faulkner et al. (2000) used 8 grams. Reinhard and colleagues (1986; Reinhard and Bryant 1992:265; Santor et al. 2003) have utilized as little as 5 grams of coprolite material. Horne has used anywhere from 1 gram of latrine sediment (Horne and Tuck 1996) to 3 grams of desiccated faecal material recovered from mummies and burials (Horne 2002). Ultimately, 1 gram of sediment was considered adequate for comparative analysis in this study.

4.1.4 *Quantification*

Modern quantification methods are designed to estimate the intensity of infection or the amount of adult helminths responsible for producing the number of eggs recovered in a faecal sample (Hall and Holland 2000; Lee et al. 1972; Markell et al. 199:452; Muller 2001:260). A

myriad of conditions can influence the number of eggs retrieved from a sample, such as age, size or species of host and/or helminth, the consistency and/or amount of faeces produced, the season or even time of day at which the faeces were deposited (Sinniah 1982). Therefore, measures of intensity or estimated worm burden are not practical for soil studies, as the number of faecal episodes, individuals parasitized, and the amount of time that contributed to a soil sample are impossible to control, especially in antiquated samples. However, the quantification of incidence, or the number of eggs estimated per gram of soil (EPG), can serve as a means of comparing the relative distribution of eggs across space and time. Results may also be compared between both modern and archaeological studies, as EPG transforms egg counts into a standardized measure.

The introduction of a fixed number of exotic reference spores to a sample can serve as a means of quantifying the number of eggs per gram (EPG) of sediment, by calculating the ratio of recovered eggs to the known number of introduced spores. This is a common method utilized in palynological studies (Coil et al., 2003; Wood et al. 1996; Pearsal 2000:304), and has been applied by Warnock and Reinhard (1992) for sampling latrine soil. Such methods usually require larger quantities of

soil than were considered efficient for this project, so spore ratio quantification was not utilized in this study.

Norman Stoll developed a method for quantifying the EPG in diluted sediment that is still one of the most commonly used methods in modern medical helminthology (Lee et al. 1972; Markell et al. 1999:452). Jones has applied Stoll's method to soil studies from the UK as a means of estimating the intensity of faecal contamination at archaeological sites (1985). The amount of soil required for quantitative analysis is minimal. The Stoll technique is a standardized method for calculating the number of parasite eggs recovered per gram of sediment in fresh samples (Lee et al. 1972; Markell et al. 1999:452; Muller 2001:261). One gram of homogenized sediment was considered sufficient for the reliable replication of comparative results in this study. Based on Stoll's calculations, the EPG (eggs per gram) is estimated by multiplying the number of eggs counted in 1/100 of a measure of sediment by 100. The formula based on 1 gram of soil was calculated as follows:

1) 1 gram of sediment per auger sample is placed in a 15 ml centrifuge tube and topped off with 0.5% TSP solution to 15 ml.
2) 10 slides of 0.015 ml of sediment solution are examined, totalling 0.15 ml of examined sediment per sample.
3) 0.15 ml is 1/100 of 15 ml, so the number of eggs in 0.15 ml is multiplied by 100 to estimate the total number of eggs in the original gram of sediment (EPG).

For each 15 ml test tube, a total of 0.15 ml of sediment was scanned for eggs (10 slides of 0.015 aliquots of sediment each). The sum total of eggs recovered in 0.15 ml, multiplied by 100, equaled the estimated number of eggs per gram of sediment (EPG). It should be noted that this estimate is calculated from sediment less than 2 mm in size. Geologically, this is the largest size range of soil texture, with anything larger than 2 mm being classified as gravel (Saxton 1986). The EPG provided a relative estimate of abundance by which to compare the faecal contamination of soil between time periods and across sites.

4.2 Processing Protocol

Several different processing methods were attempted, including direct smear (as with moist samples – after Jones 1990), acidization (as with combined pollen and parasite samples – after Warnock and Reinhard 1992) and flotation (also after Warnock and Reinhard 1992). None of these were as successful as the TSP rehydration and simple sedimentation process, which was consequently adopted for all samples in this study (Table 4.1).

Method	Nature of Soil	TSP	Acid	Float	Sediment	Disaggregate
Jones	wet					●
Warnock and Reinhard 1992	dry	●	●	●	●	●
Callen and Cameron 1960; Fry 1985	dry	●			●	●

Table 4.1: Attempted methods of matrix processing. Callen and Cameron's method was the most successful method for isolating parasite eggs from midden matrix.

A multi-scalar sampling strategy provided an opportunity for several layers of comparative analysis. On a regional scale, 15 different sites were tested, demonstrating a range of use, from permanent residence to short-term resource acquisition camps (Cannon 2000b) (Table 4.2). This range offered the opportunity for inter-site comparisons of site use, activity, and ecological conditions. In sum, 120 individual auger samples were drawn from 25 different auger locations, providing an opportunity for comparison within and between sites, and intra-site comparisons of midden deposition patterns and activity areas. Contiguous samples were drawn throughout the depth of the midden, providing a vertical profile that could allow for the investigation of temporal patterning. One gram of matrix was tested per auger sample, totalling 120 grams of analysed midden sediment.

The samples examined in this study were obtained from an auger survey of 15 shell midden sites within the Namu region of the central

coast of British Columbia, Canada. Auger samples were bagged as they were collected in ~7-15 cm vertical intervals, and returned to McMaster University for processing. Once in the lab, each auger sample was washed through 2 mm mesh screen, homogenizing each sample. The sediment that passed through the 2 mm screen was recovered, dried, and bagged separately for archival purposes.

Rehydration of the <2 mm dried sediment followed the methods outlined by Callen and Cameron (1960) and detailed in Fry (1985). One gram of homogenized sediment was randomly drawn from each auger sample and weighed on an Acculab VI-350 scale, then placed into a 15 ml centrifuge tube. The tube was topped off to 15 ml with a 0.5% aqueous solution of Trisodium Phosphate (Na_3PO_4). Each tube was shaken to disaggregate the soil and left to soak in the TSP solution for a minimum of 48-72 hours (Callen and Cameron 1960) before being processed for examination under the microscope.

After soaking, the 15 ml tubes were centrifuged for 10 minutes at 3500 rpm, in a Becton Dickinson/Clay Adams Compact II centrifuge, in order to sediment any preserved eggs. Each examined sample was drawn by graduated pipette from the top (lightest) layer of sediment, and a 0.015 ml aliquot of the solution was placed onto a microslide (dimensions 25x75x1 mm). A drop of glycerin was smeared into the sample in order to

keep it hydrated and to aid in preservation. The sample was then covered with a micro cover-slide (dimensions 22x30 mm) and scanned by light microscopy as a wet mount at x100 and x200 magnification under a Nikon Eclipse E600 compound microscope. Artifacts were compared with photographic, archaeological and modern reference samples for identification purposes.

Positive samples were photographed at both x200 (20x Plan Flourite lens) and x400 (40x Plan Apochromat lens) with a Nikon DXM1200 digital mounted camera, utilizing ACT-1 digital imaging software, version 2.12. Photo cropping and measurement was performed on Simple PCI software version 3.2.1 (Compix, Inc. Imaging Systems), which had been calibrated with a standard stage micrometer. Positive wet-mounted slides were preserved with a layer of nail polish to seal the outside edges of the cover glass. The quantification of recovered eggs was based on a modification of the Stoll counting technique, as outlined above.

4.3 Samples Processed: By Site

Site Type	*Borden #*	*Site*	*Initial Date Range cal. BC*	*Terminal Date Range cal. BC*	*Auger locations*	*# Samples tested*
Residential winter/ year-round village	ElSx-1	Namu	9600-8650 BC	contact	A	26
					J	2
Residential winter village	ElSx-3	Kisameet Bay, King Island	770-50 BC	contact	C	12
					F	5
Residential winter village	EkSx-12	Koeye River	225-BC - AD 30	AD 1520-1865	B	1
					C	6
					D	7
Residential summer village	ElTb-1	Hurricane Island	805-410 BC	contact	B	10
Residential base	ElSx-10	Fougner Bay	4315-3960 BC	AD 1655-1950	A	11
					B	1
Residential base	ElSx-18	Fougner Bay	1575-1310 BC	AD 1710-1950	A	3
Residential base	ElSx-5	Windsor Cove, King Island	4780-4510 BC	AD 1470-1700	A	8
Specific-purpose camp	ElTa-25	Kiltik Cove, Hunter Island	2420-2025 BC	AD 1655-1950	B	2
					C	4
					core	3

Site Type	*Borden #*	*Site*	*Initial Date Range cal. BC*	*Terminal Date Range cal. BC*	*Auger locations*	*# Samples tested*
Specific-purpose camp	ElSx-8	Fougner Bay	AD 140-430	AD 1660-1950	A	2
Specific-purpose camp	ElTa-3	Watt Bay, Hunter Island	AD 1160-1300	AD 1660-1950	A	2
Multi-purpose camp	ElTa-18	Kildidt Inlet	9605-9250 BC	AD 1590-1950	A	2
					B	1
Multi-purpose camp	ElSx-4	Windsor Cove, King Island	890-670 BC	AD 1435-1685	A	1
					B	1
Multi-purpose camp	ElSx-16	Fougner Bay	AD 660-940	AD 1670-1950	A	2
					B	1
Rocky islet camp	ElSx-17	Sunday Island, Namu Harbour	AD 890-1165	no evidence	A	2
Multi-purpose camp	ElTb-2	Spitfire Channel, Hunter Island	AD 20-254	AD 1255-1445	A	5
				Total # of Auger Samples Tested	**25**	**120**

Table 4.2: Processed sites. All dates include the 2σ ^{14}C calibrated range in calendar years (from Cannon 2003).

Chapter 5:
RESULTS & ANALYSIS

5.1 Control Measures

The recovery of preserved intestinal parasite eggs from shell midden soil required a novel procedure, and several control measures were implemented in order to account for discrepancies that could be related to deposition or taphonomic changes unique to shell midden deposits. Depositional factors affecting matrix composition can alter the accumulation and preservation of parasite eggs. Taphonomic conditions such as chemical or mechanical weathering and age may also affect the quality of preserved evidence. Finally, familiarity with the variety of evidence that would be encountered during microscopic analysis was necessary, in order to differentiate which artifacts represented intestinal parasites and which did not.

5.1.1 *Depositional Environment*

The depositional environment at each site was considered a potential limiting factor in parasite egg preservation. In order to compare relative differences in egg recovery between sites or stratigraphic depth, several methods were employed to control for depositional bias, including

acidization, stratigraphic sampling and comparative associations with other auger components.

An acidization test was devised, in consultation with Cannon (personal communication), in order to determine if there were a relationship between the number of eggs recovered and the amount of organic or carbonate material in a sample. The analysis was conducted by McDonald (2005) as part of an ongoing study. A soil profile was constructed for ElTb-1 (Auger B) by removing the organic and carbonate matrices by acid treatment. Auger B at ElTb-1 was selected for this experiment, as there were obvious stratigraphic differences in midden composition, but parasite evidence had been consistently recovered at this location throughout the depth of the deposit. The soil profile compared levels that produced parasite eggs with those that did not. An independent

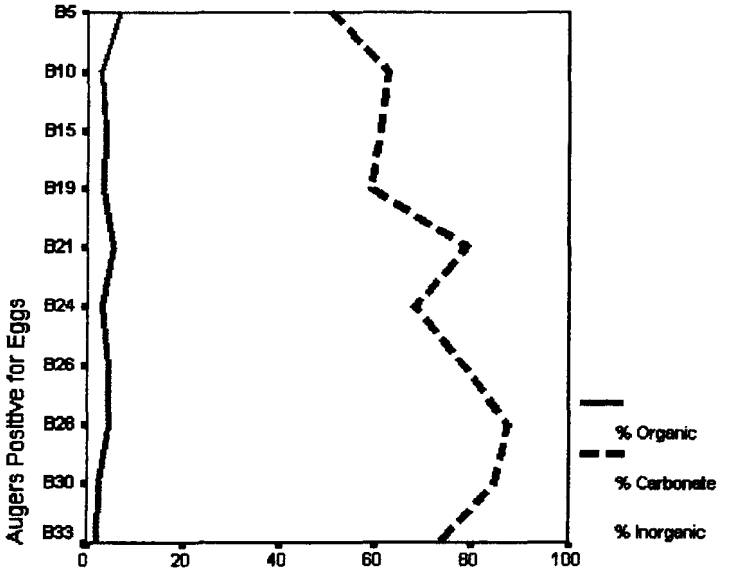


Figure 5.1: Matrix profile from ElTb-1 calculated by acid reduction.

measure of 5 g of dry, <2 mm soil matrix from each auger sample was used to measure organic content. Dilute hydrochloric acid (10%) was added to dissolve carbonates from the matrix. Acid was slowly added to the matrix until the reaction had ceased. Samples were rinsed and dried before being weighed. This was followed by a treatment of nitric acid (70%), which was used to dissolve organic material. After dissolution, samples were once again rinsed, dried and weighed. The differences between the original weight of the sample (5 grams) and the values obtained after each acid reduction were used to calculate the percentage of organic, carbonate and inorganic components in the soil profile. The auger samples from which parasite eggs were recovered were compared to the organic, carbonate and inorganic components (Figure 5.1). Results indicate there was no consistent relationship between the preservation of eggs and the composition of sediment in which they were recovered.

In order to eliminate sample bias, auger samples were tested consecutively throughout the stratigraphic profile at ElSx-1 (Auger A), and at random intervals from the top to the bottom of augers at ElSx-3 (Auger C), ElSx-5 (Auger A), ElSx-10 (Auger A), ElTb-1 (Auger B) and ElTb-2 (Auger A) (see Appendix I). The concentration of eggs did not decline nor increase with distance from the surface. This is an indication that eggs were not leached through the soil with rainwater or runoff, nor was there

any pooling of leached eggs at the level of groundwater or bedrock. Rather, eggs were recovered in isolated deposits throughout the stratigraphic profile, frequently being found together in clumps. Multiple intra-site auger locations were tested at ElSx-3 (Augers C and F); ElSx-4 (A and B); ElSx-10 (A and B); ElSx-16 (A and B); EkSx-12 (B, C and D); ElTa-18 (A and B); and ElTa-25 (B, C and Core 2) (see Table 4.2, p. 110). Results were consistent across sites; if eggs were found in one auger location, they were equally likely to be discovered at a different location on the same site.

In order to determine if there were a relationship in the recovery of parasite eggs and the amount of fish remains that had been deposited in the midden, the relative number of eggs recovered in 1 ml of soil (the equivalent of 1 gram) at ElTb-1 (A) and ElSx-10 (A) were compared with the density of fish bones, standardized as the number/litre of matrix >2mm in diameter from the same auger samples (Figures 5.2 and 5.3). The Pearson's product-moment correlation was r =.21 at ElTb-1, indicating a weak correlation between variables in relation to the correlation coefficient calculated from ElSx-10, which was r =.83. The correlation between these variables was not consistent between sites, therefore no obvious relationship could be drawn between fish processing and parasite egg deposition (Tables 5.1 and 5.2).

Qualitative associations were noted in the microscopic examination of midden sediment. Due to the time commitment necessary for quantifying microscopic artifacts, no attempt was made to systematically count other types of microscopic evidence (i.e. pollen, phytoliths, etc.). However, any associations parasite eggs may have had with common soil components such as fungal spores, marine shell, macerated organic debris, wood, or charcoal were noted. There was no consistent relationship observed between parasite eggs and other artifacts, though eggs were *not* found in matrices that were entirely bereft of any organic or carbonate artifacts. This could indicate that either 1) eggs were only deposited with cultural debris or 2) carbon and organic compounds help to preserve chitinous egg shells.

Table 5.1: Correlation of fish to parasite eggs from auger B at ElTb-1.

Level	# of Fish/litre	# of Eggs/ml
B5	247.06	0
B10	268.00	1200
B15	248.19	200
B19	143.86	0
B21	68.35	100
B24	404.92	1000
B26	112.12	1200
B28	13.33	300
B30	50.00	100
B33	25.00	200

Two-tailed Pearson's product-moment correlation (n=10) r =.21.

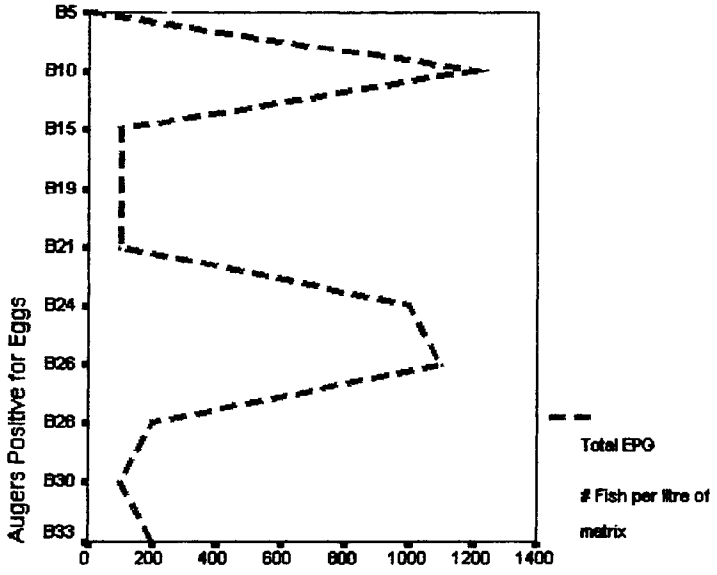


Figure 5.2: Relationship of parasite eggs to fish remains at ElTb-1 (auger B).

Table 5.2: Correlation of fish to parasite eggs from auger A at EISx-10.

Level	# of Fish/litre	# of Eggs/ml
A4	58.33	0
A6	80.00	0
A8	126.67	100
A10	285.71	200
A11	40.00	200
A12	108.57	600
A13	271.43	100
A14	240.00	0
A16	120.00	200
A19	22.86	200
A22	30.00	100

Two-tailed Pearson's product-moment correlation (n=11) $r = .83$.

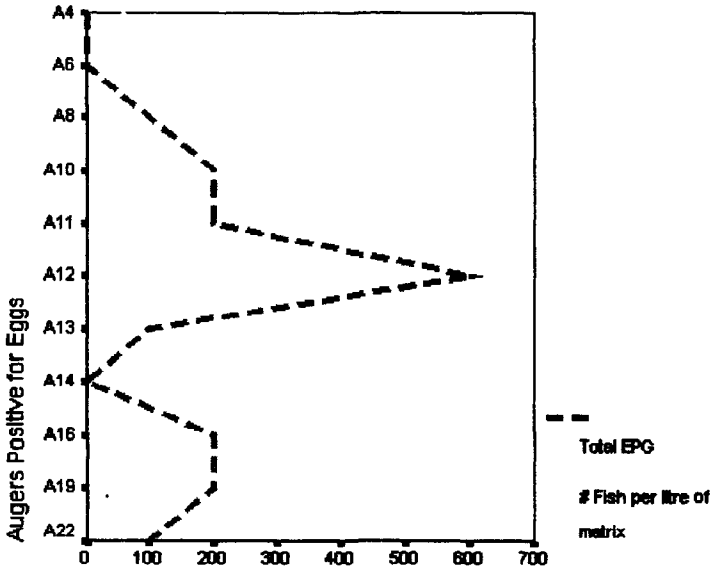


Figure 5.3: Relationship of parasite eggs to fish remains at EISx-10 (auger A).

5.1.2 *Taphonomic Conditions*

Taphonomic or diagenic factors related to the decomposition of midden sediments and/or parasite eggs were also considered potential sources of bias. Differences in soil conditions or cultural modifications may have favoured or discouraged egg preservation. Efforts to control for these factors included measuring matrix pH and testing for the affects of dog coprophagia, or digestion.

The protocol for testing the matrix pH was developed as follows. The pH of each sample was recorded in order to determine if soil alkalinity or acidity had an effect on egg preservation. A separate measure of 0.20 g of homogenized sediment was weighed into a small dish. To this, 0.30 ml of distilled water was added and the sample was stirred into suspension. The pH was measured with a Quikchek pocket metre soil probe, model 106. The metre was rinsed and re-calibrated to neutral (7) after each sample was read. The results indicate eggs were preserved in soil pH from 7.2 to 8.3. Normal faecal pH averages between 7.0-7.5 (Fry 1985:128). The measured range is more on the alkaline side of neutral (7), likely due to the dissolution of carbonates from marine shell (calcium carbonate, $CACO_3$), which can buffer the naturally acidic decomposition of coniferous rainforest litter and subsurface granite bedrock. There was no evidence of a relationship between soil pH and

egg recovery. This finding is in keeping with Reinhard et al. (1986), who report finding no significant difference in pH and egg count in latrine soils. It also provides an additional measure of confidence in the matrix profiling discussed above, in which no relationship was noted between egg recovery and the deposition of carbonates.

Dog remains are common elements of Northwest Coast faunal assemblages, indicating this domesticated species was present throughout the occupational history of the region (Bathurst 2000; Cannon 1991; Conover 1978:85; Crockford 1997:4; Cybulski 1992:63). At ElSx-1 (Namu), dog remains have been recovered from the earliest faunal assemblages dating to 7000 BP (Cannon 1991; Conover 1978). Dogs are efficient scavengers, and coprophagia is a commonplace habit, as canids are capable of deriving nutrients from faeces that have already passed through another animal's digestive tract (Morris and Rogers 1989; Simoons 1991). Therefore, dogs must also be considered a potential source of taphonomic alteration. Modern medical studies have implicated dogs as mechanical vectors of human roundworm *(Ascaris lumbricoides)* (i.e. Traub et al. 2002). The durable eggs of *Ascaris* have been demonstrated to survive the stool-consuming habits of dogs, and be redeposited in wholly viable condition. However, it was not known if other parasite eggs, such as those from *Diphyllobothrium*, would also be as

likely to survive the canine digestive system. An experiment was conducted in order to test this prospect.

Two samples from sites rich in *Diphyllobothrium* eggs were selected to test the resilience of genera other than *Ascaris* to simulated dog digestion: ElTb-1 (B24); ElTb-2 (A6). Two grams of screened soil were measured from each auger sample, and split through a sample splitter. One gram of sediment was placed in a centrifuge tube and left to soak in TSP without any further processing. The other was treated with dilute hydrochloric acid (pH 1) to simulate dog digestion, left for 24 hours, rinsed and dried before TSP was added for rehydration. A blind test of both samples was then conducted, following the protocol established for this study. The results were identical for each sample; there was no reduction in the number of *Diphyllobothrium* eggs recovered in the acid-treated simulation (Table 5.3). Therefore, it was concluded that dog coprophagia would have had no significant effect on the preservation of parasite eggs of any species.

Site	Auger Sample	# Eggs Recovered	
		Control	Digested
ElTb-1	B24	2	2
ElTb-2	A6	0	0

Table 5.3: Dog digestion simulation: the affects of digestion on *Diphyllobothrium spp.* egg preservation.

5.1.3 *Confidence: Identification*

Finally, it was important to have confidence in my ability to differentiate between parasite remains and other microscopic soil artifacts. In order to confidently identify parasite eggs, it was first necessary to be familiar with soil components that can be confused with eggs. Pollen, phytoliths, plant fibre, foraminifera, hyphae, spores, fungus, resin, wood and other amorphous organic materials are collectively known as palynofacies in geological studies (Batten 1996; Wood et al. 1996). These, along with bone and shell, inorganic components such as sand and minerals or inert and optically dense matter such as charcoal, constitute the bulk proportion of a microscopic soil assemblage. These components were not quantified in this study, but there was a visible difference in the distribution of these artifacts within and between sites (Figure 5.4 matrix photos). This superfluous detritus can cause considerable confusion in isolating and identifying parasite elements, however it also provides valuable data for palaeoenvironmental reconstruction. It is therefore necessary in archaeoparasitological analysis either to remove this excess material from a sample by sieve or acid treatment, or become familiar with the differential artifacts that will be encountered under the microscope. As an exploritory project, I felt it prudent to familiarize myself with as much of the microassemblage as

possible, so no efforts were taken to remove excess material less than 2 mm in size.

Identification of parasite eggs were based on both photographic and existing reference specimens. Sources included high quality images available from parasite atlases (i.e. CDC 2001; Foreyt 2001), a reference slide of archaeological *Ascaris* spp. and *Trichuris* spp. (whipworm) derived from a Medieval occupation level of York, England (courtesy of Andrew Jones, Bradford, UK) and modern reference slides of *Ascaris lumbricoides*, *Schistosoma sp.* (schistosomiasis) and *Ancylostoma duodenale/Necator americanus* (hookworm) (courtesy of Rose McQueen, Regional Parasitology Laboratory, St. Joseph's Hospital, Hamilton, ON). Egg dimensions were measured in order to confirm homogeneity of genus/species. Length and width measurements were recorded and compared to the range of modern egg sizes and normal distribution curves. Previous studies have demonstrated that rehydration with TSP does not affect egg size (Callen 1967:262), though some have suggested mounting media such as glycerine, which was used in this study, *can* cause shell shrinkage (Hall et al. 1983:91).

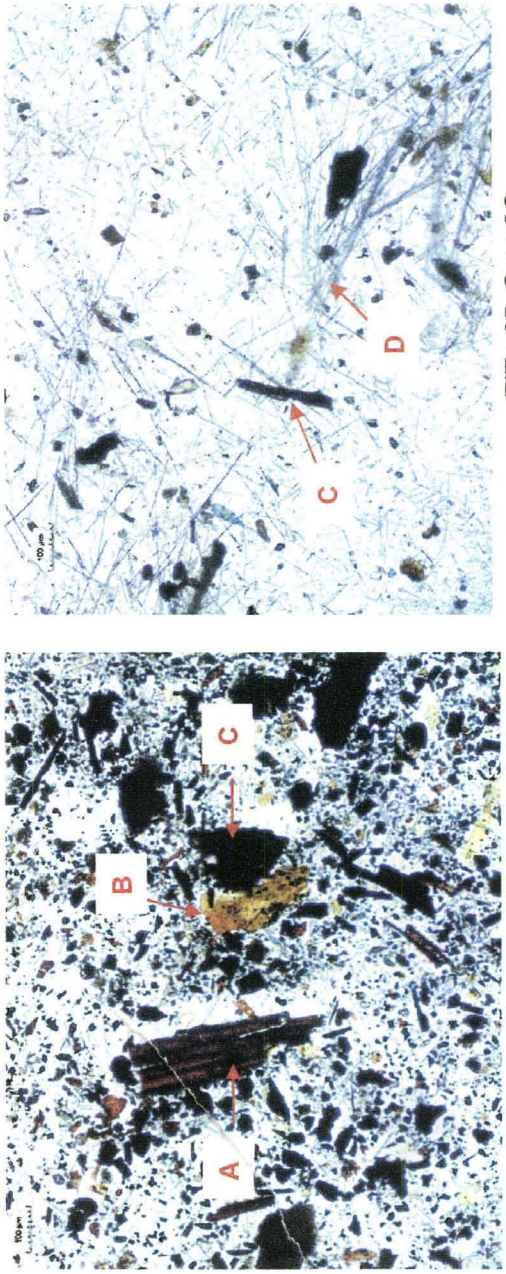


Figure 5.4: Selected examples of microscopic midden matrix. A) wood fragment; B) bone fragment; C) charcoal; D) shell (mussel).

5.1.4 *Control Measures: Summary*

Efforts were made to control for three potential sources of error or bias that could affect the preservation or identification of parasite eggs: deposition, taphonomy and identification. The eggs recovered in this study were well preserved, and display no obvious association with the organic, carbonate, faunal or other microscopic components of the midden matrix. Thick chitinous and/or sclerotinous egg shells, characteristic of the parasite genera recovered, are resistant to decay in both acidic and alkaline soils (Wharton 1980:454). Nor were there any more parasite eggs recovered in matrices rich in fish remains or organic components such as spores, pollen or wood. Dog coprophagia does not appear to be related to egg preservation. Finally, confidence in egg identification was based on the development of a familiar knowledge with a variety of soil artifacts and reference comparisons. Parasite eggs, therefore, have been found to be randomly deposited throughout the midden profile, with an equal possibility of being recovered at any level and any location at those sites that were tested.

5.2 Analysis

Of the three techniques tested to isolate parasite eggs from midden soil, the method that was most successful was that originally introduced

by Callen and Cameron in 1960 and refined by Fry (1977). Jones's method (i.e. 1990; 1987) involved the least amount of preparation and is designed for use with wet soil. It is likely the best method to use for samples that have retained their moisture, and thus it is more appropriate for use with fresh or frozen samples. Although the auger samples in this study were wet when obtained, they were dried after they were processed for archive purposes. Warnock and Reinhard's (1992) methods were designed for the optimal recovery of microscopic artifacts, utilizing acid to concentrate samples, and flotation to recover eggs. This method was also considered unsuitable for processing midden samples. It is doubtful that acid treatment reduced the number of eggs recovered in any significant way, as the dog digestion control experiment used similar acid reduction methods and chitin is naturally resistant to chemical degradation (Wharton 1980:455). However, flotation of the samples was not successful. The best processing method for shell midden matrix therefore involved the reconstitution of dried eggs in a mild phosphate solution (0.5% TSP), followed by the simple sedimentation of the samples by centrifuge.

For each gram of sediment sampled, 10 slides of 0.015 g aliquots of sediment were examined (total = 0.15 g/sample). As the total amount of sediment analyzed from each auger only amounted to about one-seventh

of a gram, the results are presumed to represent the most robust parasite genera preserved within the midden matrix. Processing larger quantities of matrix might have resulted in the discovery of rarer and more fragile species, however.

In order to establish the presence/absence of parasite eggs, it was necessary to examine a minimum number of 3 slides per sample. In 80% of cases, eggs were discovered on one of the first three slides examined (Figure 5.5). These results are in keeping with modern testing frequencies that also employ sedimentation techniques (Markell et al. 1999:435), and are a measure of the success of this concentration method for use with archaeological soils.

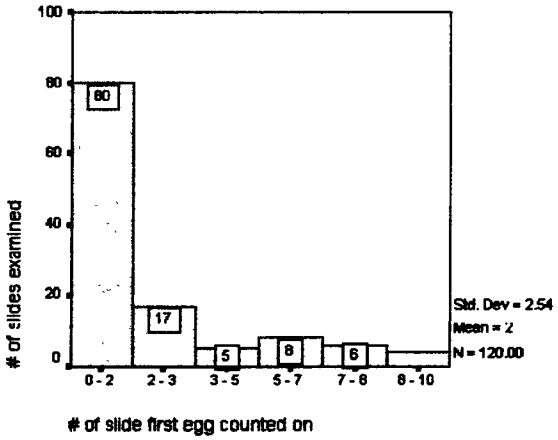


Figure 5.5: Recovery of parasite eggs in archaeological midden matrix by successive examinations.

Two variables were quantified in this study: the number of eggs and the number of parasite genera. Efforts to control for the effects of taphonomy and deposition confirmed no relationship between the amount of fish and/or shellfish deposited in the midden and the number of parasite eggs recovered. Nor was there any correlation between eggs and the alkali, carbonate, organic or inorganic composition of the midden matrix. Therefore, comparisons with independent variables of time and space were considered valid. The following will first discuss general patterns in the parasite findings. This will be followed by the detailed results from each site. Temporal and spatial patterns in the number of eggs quantified and species richness will then be considered.

Borden #	*Auger location*	*Samples tested*	*Diphyllo EPG*	*Ascaris EPG*	*Nano EPG*	*Cyclo EPG*	*Total EPG*
EkSx-12	B	1	0	0	0	0	700
	C	6	0	400	0	0	
	D	7	0	300	0	0	
ElSx-1	A	26	200	4600	0	200	5000
	J	2	0	0	0	0	
ElSx-3	C	12	400	100	0	0	1300
	F	5	700	0	100	0	
ElSx-4	A	1	1900	0	0	0	3300
	B	1	1300	0	100	0	
ElSx-5	A	8	700	300	0	200	1200
ElSx-8	A	2	0	0	0	0	0
ElSx-10	A	11	400	1100	100	100	1700
	B	1	0	0	0	0	
ElSx-16	A	2	200	0	0	0	1100
	B	1	900	0	0	0	
ElSx-17	A	2	0	0	0	0	0
ElSx-18	A	3	300	100	0	200	600
ElTa-3	A	2	0	0	0	0	0
ElTa-18	A	2	0	0	0	0	0
	B	1	0	0	0	0	
ElTa-25	B	2	900	100	0	0	1900
	C	4	900	0	0	0	
	core	3	0	0	0	0	
ElTb-1	B	10	3300	600	100	300	4300
ElTb-2	A	5	6500	100	0	0	6600
	Total	**120**	**18600**	**7700**	**400**	**1000**	**27700**

Table 5.4: Site by Site Findings. Egg counts were multiplied by 100 to determine EPG (eggs per gram of matrix).

5.3 Findings

On a regional scale, parasite eggs were successfully recovered from 11 of the 15 sites investigated (73.3%) (Tables 5.4 and 5.5). Seventeen of the 25 auger locations at these sites were positive for parasite evidence (68%). In total, 120 grams of sediment were rehydrated and tested, representing 120 separate auger samples of which 54 (45%) were positive for parasite eggs. A grand total of 1200 individual slides were examined and recorded. Four taxonomic orders of intestinal parasites were recovered: Pseudophyllidea *(Diphyllobothrium spp.)*, Digenea (*Nanophyetus salmincola*), Ascaridae *(Ascaris lumbricoides*), and Cyclophyllidea.

	# Tested	# Positive	% Positive
Total Sites	15	11	73.3
Total Auger Locations	25	17	68.0
Total Grams	120	54	45.0

Table 5.5: Summary of all positive findings.

5.3.1 *Diphyllobothrium*

The identification of *Diphyllobothrium* spp. was based on size, shape, colour and distinguishing features. Eggs were golden brown in colour, ovoid in shape and smooth in texture (Figure 5.6). The median length was 56.6 µm, while the mean was 57.1 µm and the median width

was 38.0 µm with a mean of 38.5 µm (N = 159) (Table 5.6). Their size distribution is consistent with a normal curve, suggesting all eggs likely represent one genus if not one species of *Diphyllobothrium* (Figure 5.8). A characteristic opercular cap had slipped off most specimens, and some eggs displayed an abopercular knob (Figure 5.7). While an abopercular knob is a clear diagnostic feature of *Diphyllobothrium* eggs, they are not always evident.

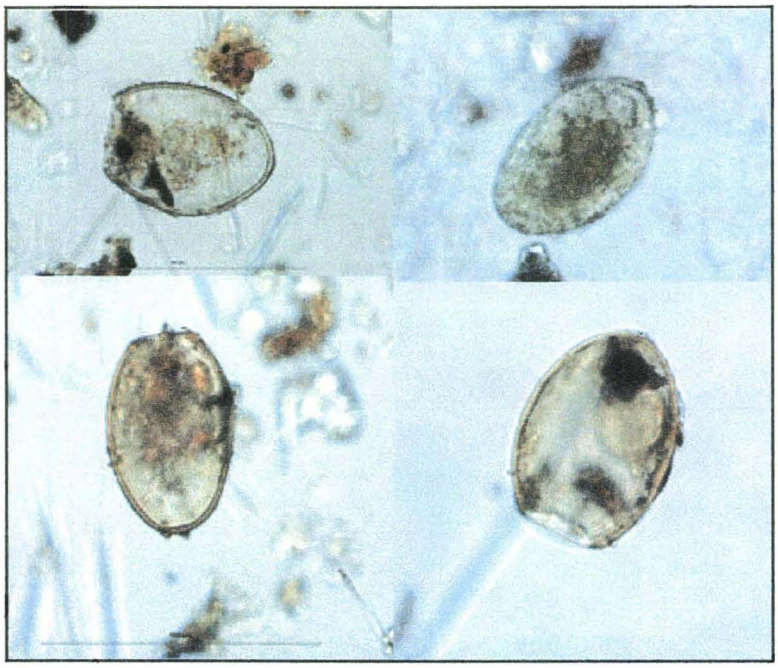


Figure 5.6: Examples of the range of variability in recovered *Diphyllobothrium* spp. eggs. Unembryonated egg top right (x400).

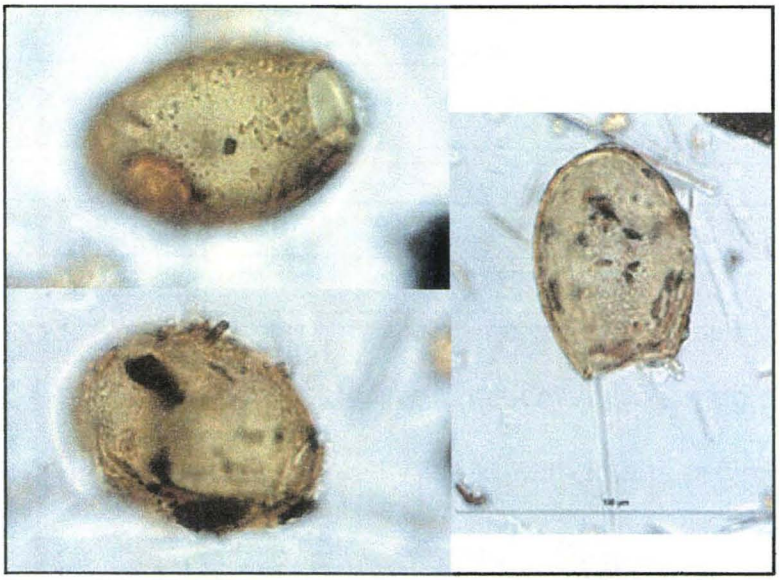


Figure 5.7: *Diphyllobothrium* spp. without operculum (top left) and with operculum (bottom left). Abopercular knob visible on right (x400).

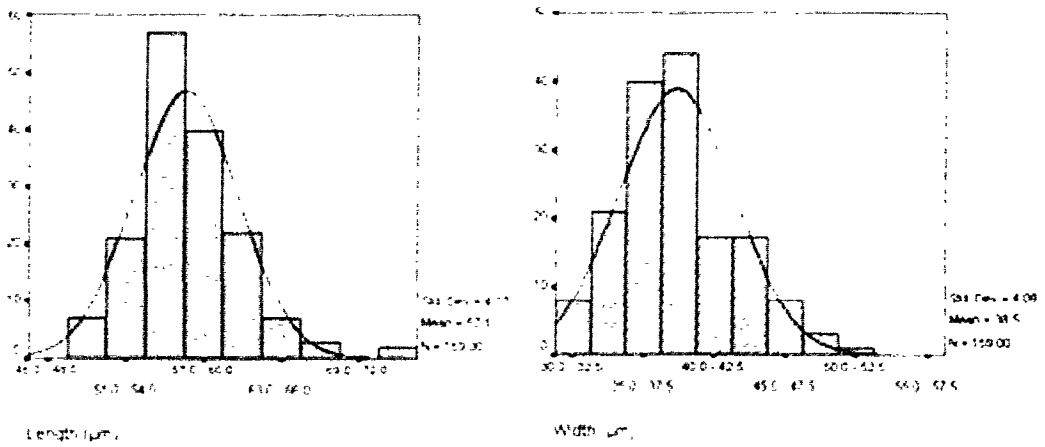


Figure 5.8: Range of *Diphyllobothrium* spp. egg length and width.

	Length µm	Width µm
Mean	57.1	38.5
Median	56.6	38.0
Standard Deviation	4.07	4.08

Table 5.6: *Diphyllobothrium* dimensions (N = 159).

	Length µm	Width µm	Source
D. latum	55 - 76	41 - 56	Bylund 1982; Meyer and Olsen 1980; Noble and Noble 1982
D. ursi	55 - 67	39 -46	Hilliard 1960
D. dendriticum	51 - 62	36 - 45	Rausch and Hilliard 1970
D. pacificum	40 - 60	35 - 40	Baer 1969

Table 5.7: Modern range of egg dimensions of different *Diphyllobothrium* species.

The genus *Diphyllobothrium* includes several species, differentiated by the definitive and/or intermediary host(s), the ecological conditions necessary for development, and the morphological characteristics of the adult worm (Anderen and Halvorsen 1978; Bylund 1982; Ching 1984;

Curtis and Bylund 1991; Dick et al. 2001; Holiday et al. 2003; Rausch and Hilliard 1970). Currently only one species, *D. latum*, is known to cause serious morbidity in infected humans (Dick et al. 2001; von Bonsdorff 1977). As there is considerable overlap in the size and morphological characteristics of the eggs between species (Table 5.7), it was not possible to confidently identify *Diphyllobothrium* beyond the genus level.

A raw total of 186 *Diphyllobothrium* spp. eggs (18 600 EPG) were recovered from 10 of the 15 sites tested (67%) (Table 5.8). The sites with the most evidence of fish tapeworm were ElTb-2 (6500 EPG) and ElTb-1 (3400 EPG). There was no evidence of *Diphyllobothrium* recovered from ElSx-8, ElSx-17, ElTa-3, ElTa-18 and EkSx-12. The oldest eggs were recovered from ElSx-5, (A11), at a depth of 147-163 cm. A sample of shell from the corresponding level of the adjacent core (Core 1) was submitted for AMS ^{14}C (see Cannon 2000a and 2000b for details on this methodology), and returned with a 2 sigma calibrated range of 3700-3490 BC (Beta-189447).

Diphyllobothrium	**# Tested**	**# Positive**	**% Positive**
Sites Tested	15	10	66.6
Augers Locations Tested	25	14	56.0

Table 5.8: Summary of positive *Diphyllobothrium spp.* findings.

5.3.2 *Ascaris*

The identification of *Ascaris* eggs was based on the presence of a thick, mammilated exterior coat, round to ovoid shape, golden brown colour and grey or black internal mass (Brooke and Melvin 1989) (Figure 5.9). A raw count of 77 *Ascaris* eggs (7700 EPG) was recovered from 9 of the 15 sites tested (60%) (Table 5.9). The median length of recovered eggs was 41.5 μm, while the mean was 43.5 μm, and the median width was 37.5 μm, while the mean was 38.9 μm (N = 67) (Table 5.10; Figure 5.10). The higher mean of both measurements reflects a slight positive skew to the distribution, with a larger number of small eggs being recovered and measured. There is considerable range to be expected in *Ascaris* egg dimensions (Brooke and Melvin 1989:13; Meyer and Olsen 1980; WHO 1991) (Table 5.11). It is likely that the smaller-size distribution reflects that the majority of eggs recovered had been preserved in a fertile (infective) stage of development.

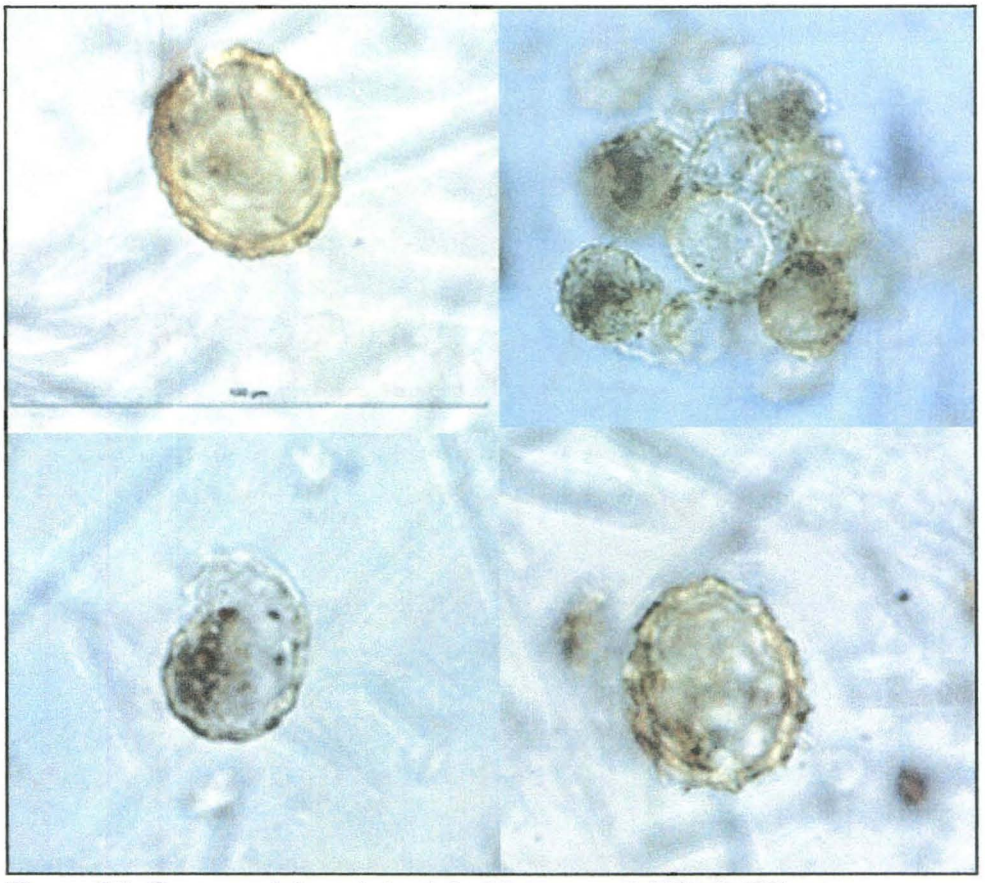


Figure 5.9: Recovered *Ascaris lumbricoides* egg variability (x400).

Ascaris	# Tested	# Positive	% Positive
Sites Tested	15	9	60.0
Augers Samples Tested	25	10	40.0

Table 5.9: Summary of positive *Ascaris* findings.

The eggs recovered in this study are considered to represent the species *A. lumbricoides*, or giant human roundworm. *Ascaris lumbricoides* eggs are indistinguishable from those of *A. suum*, a closely related porcine parasite. However, pigs were first introduced to the Americas by Europeans, and most if not all of the *Ascaris* evidence recovered pre-dates European contact with this region of the coast in the late 18th century.

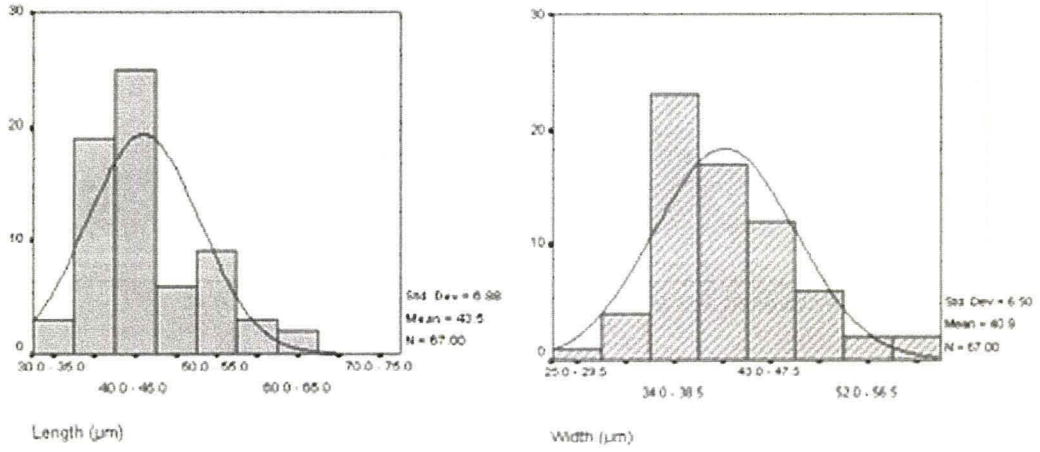


Figure 5.10: Range of *Ascaris* egg length and width.

	Length µm	Width µm
Mean	43.5	38.9
Median	41.5	37.5
Standard Deviation	6.88	6.49

Table 5.10: Ascaris egg dimensions (N = 67).

	Length µm	Width µm	Source
A. lumbricoides Fertilized	45 - 70	35 - 45	Brooke and Melvin 1989:13; WHO 1991
A. lumbricoides Unfertilized	85 - 95	35 - 45	Brooke and Melvin 1989:13; WHO 1991

Table 5.11: Range of modern *Ascaris* egg dimensions.

The site at which the most *Ascaris* eggs were recovered was ElSx-1 (4600 EPG), followed distantly by ElSx-10 (1100 EPG). There was no evidence of *Ascaris* at ElSx-4, ElSx-8, ElSx-16, ElSx-17, ElTa-3, or ElTa-18. Some of the oldest eggs were recovered from ElSx-1 (Namu) in a deposit 183-196 cm below the surface, ^{14}C dated between 3300-1850 cal BC (Carlson 1996). However an *Ascaris* egg was also recovered from a deposit 289-306 cm below the surface at ElSx-5 (auger A). While there is no date associated with this level, the base (365 cm) of the closest corresponding core (1) was securely dated to a comparable 4775-4510 cal. BC (Cannon1997).

5.3.3 *Nanophyetus*

A raw count of four eggs was identified as *Nanophyetus salmincola*. Morphological characteristics were similar to *Diphyllobothrium spp.*, however *Nanophyetus* was differentiated by the prominence of the abopercular knob (Figure 5.11). Unfortunately, the sample size was small (N = 4), and therefore not likely representative. The mean length was 77.4 µm with a median of 71.1 µm, and the mean width was 56.9 µm with a median of 49.8 µm, demonstrating considerable range (Table 5.12). Modern *Nanophyetus* eggs average 70-97 µm x 40-55 µm (Bennington and Pratt 1960; Foreyt 2001:30; Eastburn et al. 1987). Considering the morphological and dimensional similarities of *Diphyllobothrium* spp. eggs, some overlap in identification is likely to have occurred, though *Nanophyetus* does not appear to be as common as *Diphyllobothrium*.

Nanophyetus eggs were identified from 4 of the 15 sites examined (27%): ElSx-3, ElSx-4, ElSx-10 and ElTb-1. *Nanophyetus* was recovered at ElSx-10 (Auger A) at a depth of 278-298 cm. The oldest deposits at ElSx-10 have been dated between 4315-3960 BC. A radiocarbon sample from the base of the midden deposits in a nearby core at a depth of 300 cm yielded a date of 2465-2150 cal. BC (Cannon 1997; 2003). This date is likely close to that of the recovered *Nanophyetus* egg. A sample from one metre higher (196-202 cm) in the same core yielded a date of 1870-1610

cal BC (Beta – 189449). Therefore the oldest Nanophyetus evidence recovered in the region is older than 1610 BC but does not predate 2465 BC.

Nanophyetus	**# Tested**	**# Positive**	**% Positive**
Sites Tested	15	4	26.6
Augers Locations Tested	25	5	20.0

Table 5.12: Summary of positive *Nanophyetus* findings.

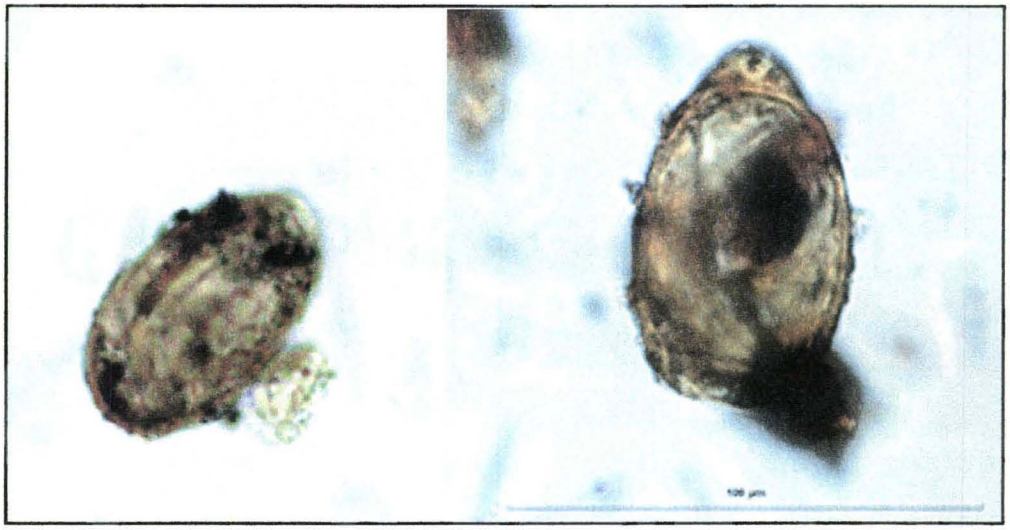


Figure 5.11: Variation in recovered *Nanophyetus* eggs (x400).

5.3.4 *Cyclophyllidea*

A raw total of 10 Cyclophyllidea eggs were identified from 5 of the 15 sites (33%): ElSx-1, ElSx-5, ElSx-10, ElSx-18, and ElTb-1 (Figure 5.12). Confident identification based on morphological characteristics is not possible beyond the family level. A lack of preserved diagnostic features such as embryonic hooks made identification even more difficult. Distinguishing morphological characteristics included a round shape and gold to colourless shell that, on occasion, exhibited radial striations in the outer membrane. The mean length and width of the recovered eggs averaged 37.8 x 35.4 µm (N = 10), though the small sample size should be noted (Table 5.13). Modern dimensions for species in the order of Cyclophyllidea range from 30 µm up to 80 µm, species dependent (Brooke and Melvin 1989:14; Foreyt 2001:32; WHO 1980) (Table 5.12).

	Length µm	Width µm
Mean	37.8	35.4
Median	38.7	36.2
Standard Deviation	5.6	6.4

Table 5.13: Recovered Cyclophyllid egg dimensions.

Given the small size range of recovered eggs, *Hymenolepis diminuta* can be eliminated as a potential contributor to the Cyclophyllidea parasite assemblage (Table 5.14). The Hymenolepidae species that is within the size range of recovered eggs, *H. nana*, may infect humans

and/or rodents without the aid of an intermediary host. The Taeniid species, *Taenia multiceps*, *T. pisiformis*, *Echinococcus granulosus*, *E. multilocularis* prefer dogs as definitive hosts, but may accidentally infect humans (Foreyt 2001). *T. multiceps*, *E. granulosus* and *E. multilocularis* utilize wild ruminants as intermediary hosts, while *T. pisiformis* larvae infect rabbits. The Dilepididae species, *D. caninum*, also prefers dogs as a definitive host, though humans can be accidentally infected. *Dipylidium caninum* eggs are deposited within a "packet" that can contain up to 20 eggs. No evidence was found of a "packet", and the Cyclophyllid eggs were not recovered in clusters, therefore *D. caninum* is also considered an unlikely diagnosis.

	Size µm	Source
**Taenia multiceps*	38 - 50	Foreyt 2001; WHO 1980
**T. pisiformis*	32 - 38	Foreyt 2001
**Echinococcus granulosus*	30 - 35	Carmello 1996; Foreyt 2001
**E. multilocularis*	30 - 40	Carmello 1996
**Hymenolepis nana*	30 - 47	Carmello 1996; CDC 2001
H. diminuta	70 - 80	Carmello 1996; WHO 1980
Dipylidium caninum	25 - 40	Foreyt 2001; WHO 1980

Table 5.14: Modern range of egg dimensions of different Cyclophyllidea species. (*) denotes the most likely Cyclophyllidea genera.

The oldest Cyclophyllidea evidence was recovered from the same deposit as the oldest *Diphyllobothrium* at EISx-5 (see above), therefore establishing its presence ca. 3700-3490 cal. BC (Beta-189447).

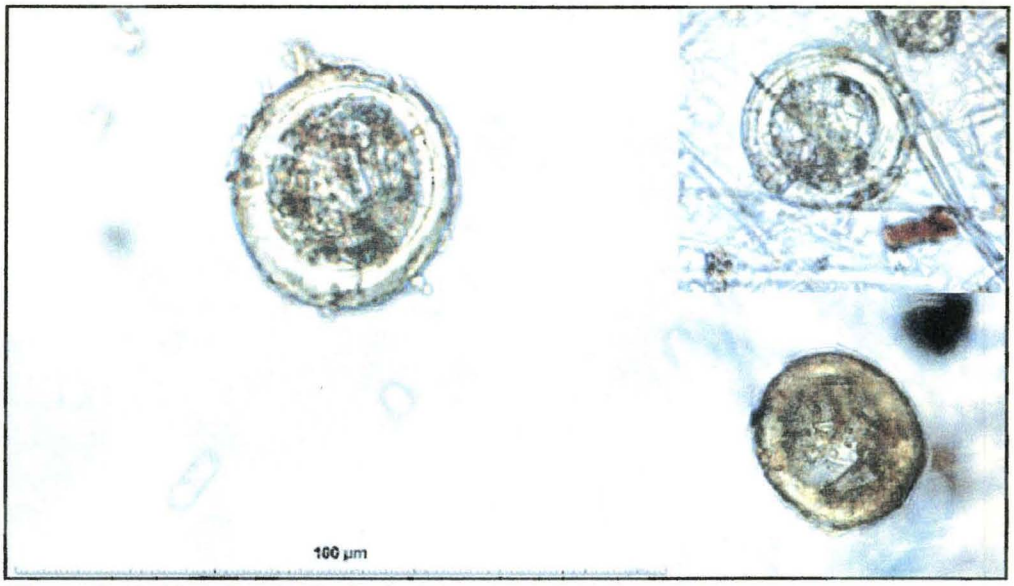


Figure 5.12: Variation in Cyclophyllidea eggs (x400).

5.4 Individual Site Findings

5.4.1 *EkSx-12 Koeye River winter village*

The Koeye River village is one of only two sites at which distinct house features were present and deliberately tested (Figure 5.13). Three auger locations were examined (augers B, C and D), from which *Ascaris* was the only recovered genera (700 EPG). The microscopic matrix appeared rich in shell, sand, and charcoal, with little organic component (Figure 5.4). One sample tested from auger B, located inside a surface house depression (House 4), yielded negative results. Six samples were tested from auger C, located in the vicinity of a surface depression pit also located in House 4. A sum total of 4 (400 EPG) *Ascaris* eggs were recovered from two samples, ranging in depth from 55-132 cm below surface. Seven samples were tested from auger D, located just outside the estimated perimeter of House 5, where a total of 3 (300 EPG) *Ascaris* eggs were recovered from intermittent depths: 56-80 cm, 138-153 cm and 242-250 cm.

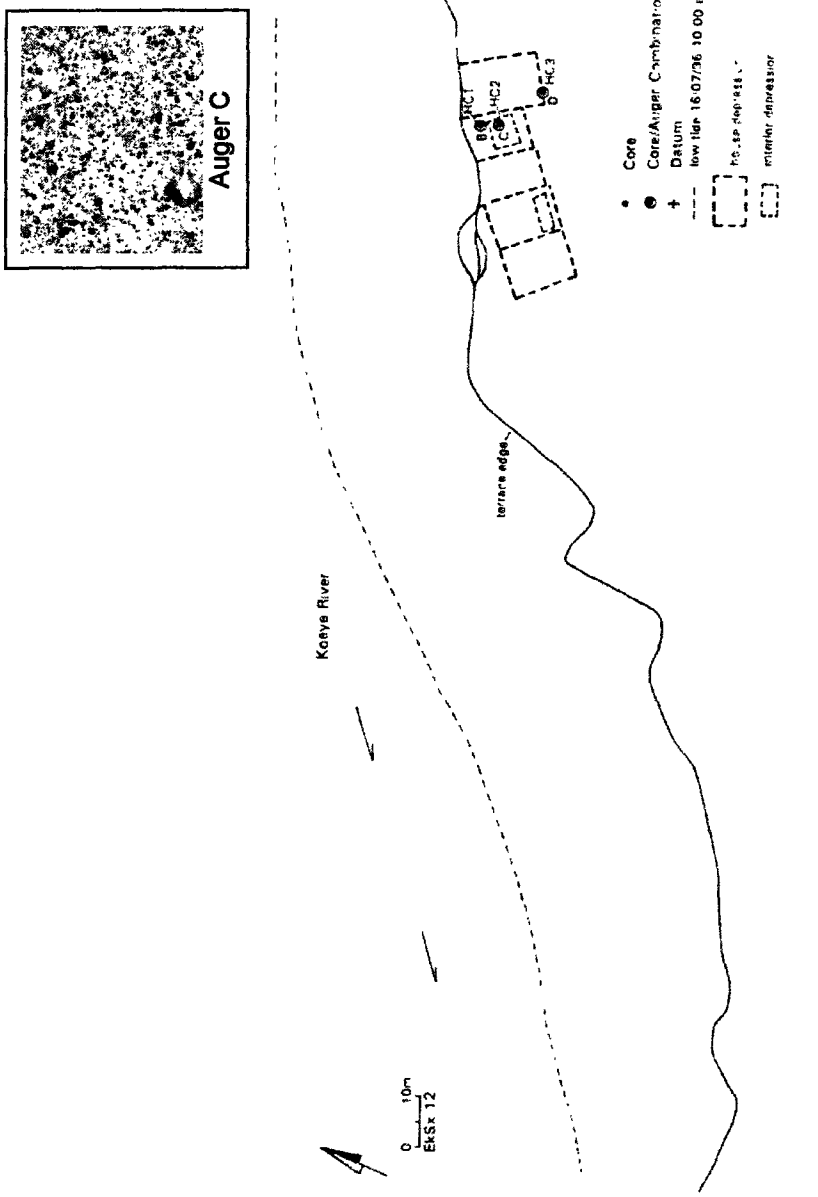


Figure 5.13: EkSx-12
Koeye River

5.4.2 *ElSx-1 Namu year-round village*

Two auger locations (A, J) were tested at ElSx-1 (Figure 5.14). Only one location (A) produced positive evidence of three parasite taxa: *Diphyllobothrium*, *Ascaris* and Cyclophyllidea. A total of 26 samples were analysed from auger A. Only 2 samples were analysed from auger J, both culturally sterile of shell or faunal debris, and composed primarily of beach sand. The microscopic matrix from auger A appeared rich in shell and silicates (sand), with inclusions of organic evidence such as spores, wood and macerated vegetation (Figure 5.4).

A total of 26 contiguous samples, extending the depth of the shell midden, were tested at location A. *Ascaris* was the only genus recovered in abundance (4600 EPG), and was frequently discovered clustered in "clumps". *Diphyllobothrium* was also identified at Namu, though only 2 eggs were recovered (200 EPG), both preserved in an unembryonated stage of development. Two (200 EPG) Cyclophyllidea eggs were also identified. All eggs were recovered between a depth of 123 and 196 cm below surface. One auger (A10), located 162-171 cm DBS, yielded evidence of three parasite taxa: *Diphyllobothrium* 100 EPG; *Ascaris* 4200 EPG; Cyclophyllidea 100 EPG. This depth also represented the single richest deposit of *Ascaris* eggs (n = 42) from any of the 15 sites tested,

many of them clustered. The strata from which these augers were drawn has been dated 4780-3490 cal. BC (Cannon 2002; Carlson 1996).

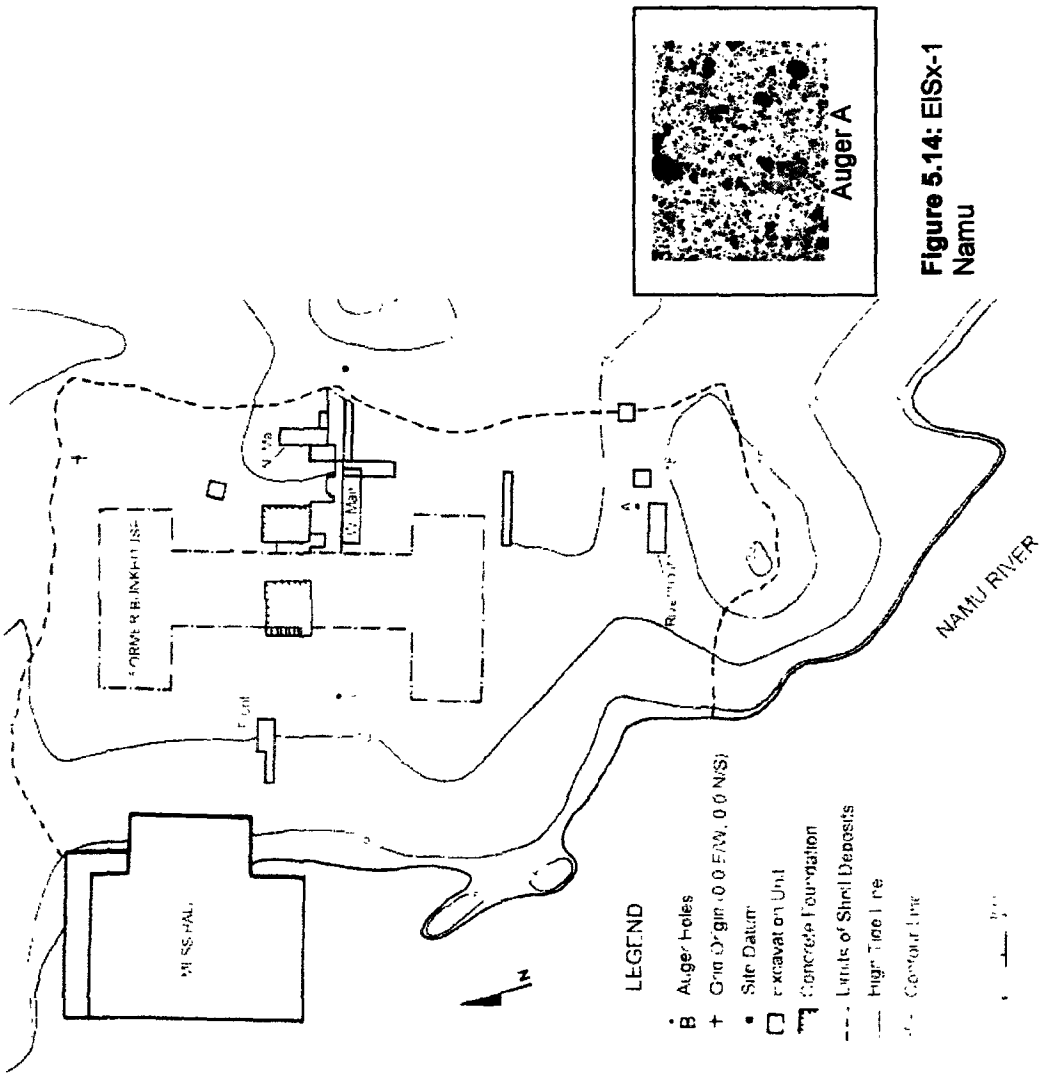


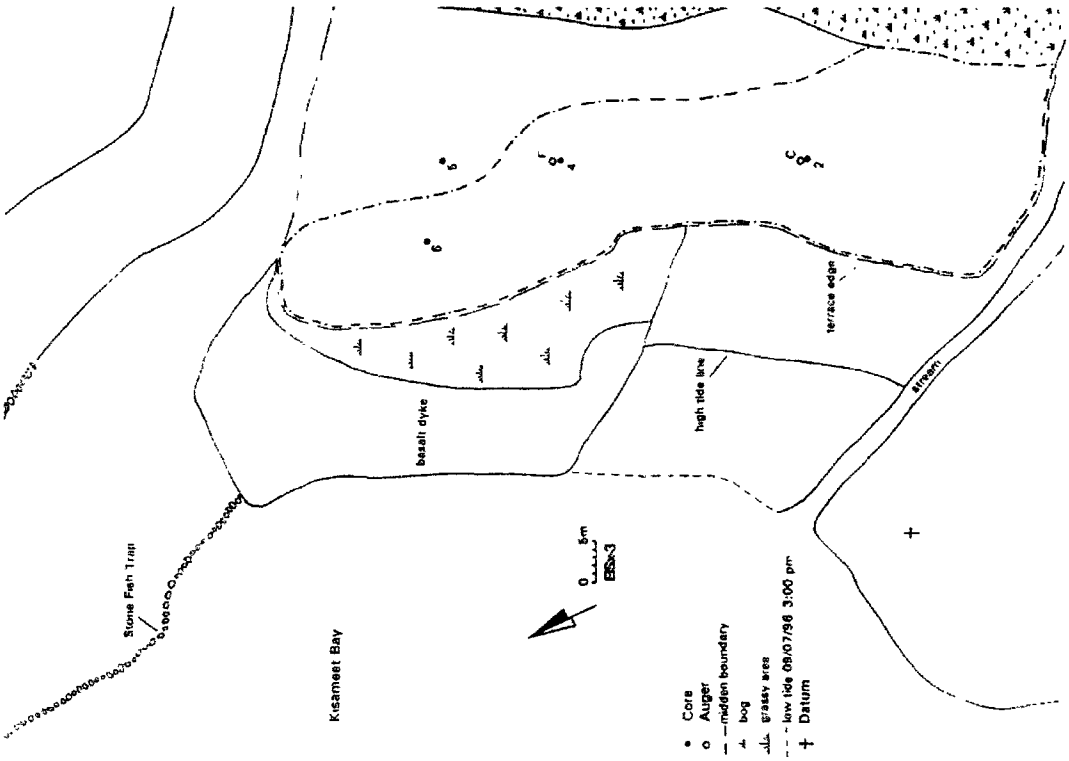
Figure 5.14: ElSx-1 Namu

5.4.3 *ElSx-3 Kisameet Bay winter village, King Island*

Two auger locations (C, F) were tested at the Kisameet Bay winter village (Figure 5.15), both yielding parasite evidence. Three genera of parasites were identified at this village site, a finding similar to that at Namu, which is the closest identified village south of King Island. Unlike Namu, *Diphyllobothrium* was the most abundant genus represented at the site (1100 EPG). One egg each of *Ascaris* and *Nanophyetus* was also recovered. No Cyclophyllidea eggs were identified from these deposits. Twelve samples were analysed from auger C. The microscopic assemblage was rich in shell but also contained evidence of charcoal, wood and other organics (Figure 5.15: auger C). Two of the 12 samples were positive for *Diphyllobothrium* (400 EPG) and one for *Ascaris* (100 EPG). All eggs were recovered between 176-247 cm DBS.

Five samples were analysed from auger F, located closer to the river, where midden accumulation was thinner and the microscopic matrix appeared leaner in shell and richer in charcoal, burnt resin, silicates and bone (Figure 5.15: auger F). Two of the 5 samples were positive for *Diphyllobothrium* (700 EPG) and one for *Nanophyetus* (100 EPG). At this auger location, all eggs were recovered between 118-169 cm DBS. Marine shell from core 2, corresponding to a depth of 346-354 cm at

auger C, yielded an AMS date of 940-770 cal. BC (Beta – 189447), providing a basal date range for this deposit.



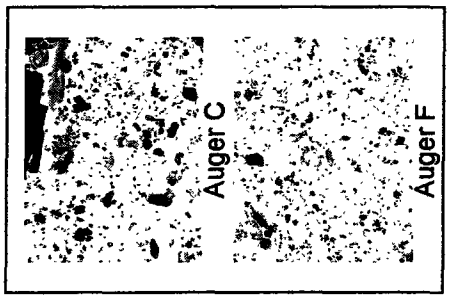


Figure 5.15: EISx-3
Kisameet Bay

5.4.4 *ElSx-4 Windsor Cove multi-purpose camp, King Island*

Two auger sample locations (A and B) were tested at Windsor Cove, both on the low terrace located approximately two metres apart (Figure 5.17). Only one sample was tested from each auger location, but two genera were recovered from the site: *Diphyllobothrium* (3200 EPG) and *Nanophyetus* (100 EPG). *Diphyllobothrium* was the only parasite recovered from auger location A (1900 EPG), while both *Diphyllobothrium* (1300 EPG) and *Nanophyetus* (100 EPG) were recovered from auger location B. The microscopic matrix from both augers was rich in shell, macerated organic debris, fungal spores, wood and charcoal (Figure 5.4; Figure 5.16).

Figure 5.16: Fern spore x200.

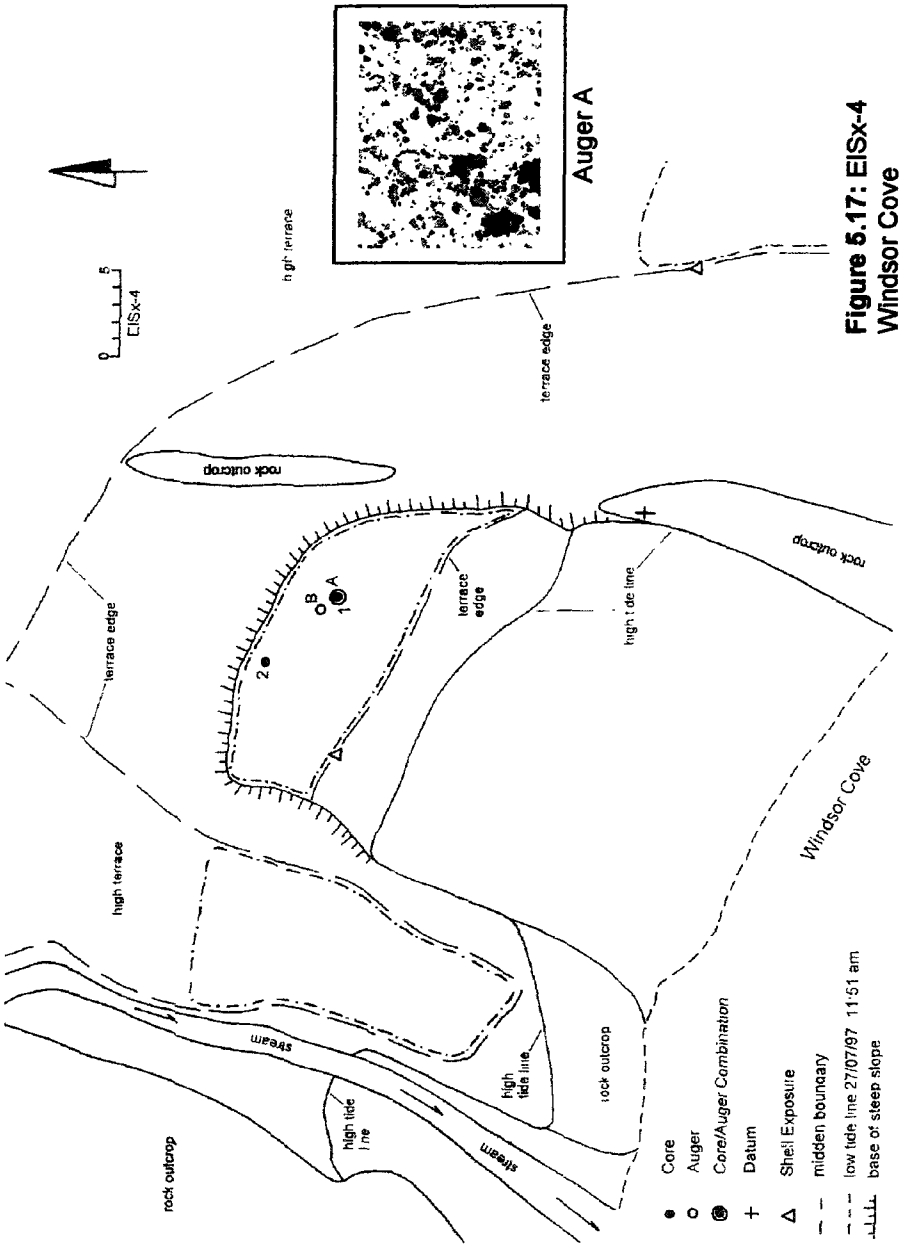


Figure 5.17: EISx-4 Windsor Cove

5.4.5 *ElSx-5 Windsor Cove base camp, King Island*

The base camp at ElSx-5 is located a short distance from the multi-purpose camp at ElSx-4 to the east and the winter village at ElSx-3 to the north-east. Only one auger location (A) was tested, located close to the bog at the north end of the site (Figure 5.19). Shell was the most visually common component of the microscopic assemblage, though samples also contained macerated organics, fish scales, silica as well as wood and charcoal. Microscopic debris from the deepest auger sample (A21 – 320-341 cm DBS) included mussel shell and chitinous foraminiferal linings (n=7) (Figure 5.18).

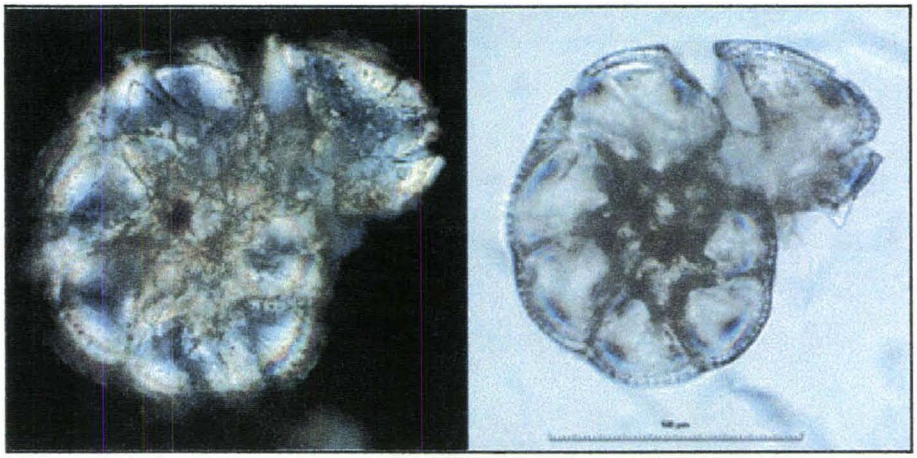


Figure 5.18: Polarized (left) and bright-field (right) foraminiferal lining x400.

A total of 3 genera were recovered from 8 analysed samples: *Diphyllobothrium* (700 EPG), *Ascaris* (300 EPG) and Cyclophyllidea (200 EPG). The oldest evidence of *Diphyllobothrium* and Cyclophyllidea recovered from this project were found 147-163 cm DBS (auger A11). A sample of marine shell from core 1, that corresponded to a depth of 159-163 cm DBS at auger A, yielded an AMS date of 3700-3490 cal. BC (Beta – 189448). The estimated oldest *Ascaris* eggs were also recovered at this site. The oldest sample was derived from auger A19, at a depth of 289-306 DBS, over a metre deeper than the *Diphyllobothrium* and Cyclophyllidea eggs. The corresponding core (1) yields a basal date of 4775-4510 cal. BC (Cannon 1997) at 365 cm, a full 60 cm below the *Ascaris* find. Therefore, the age range of the oldest *Ascaris* egg can be estimated between 4775 -3490 BC.

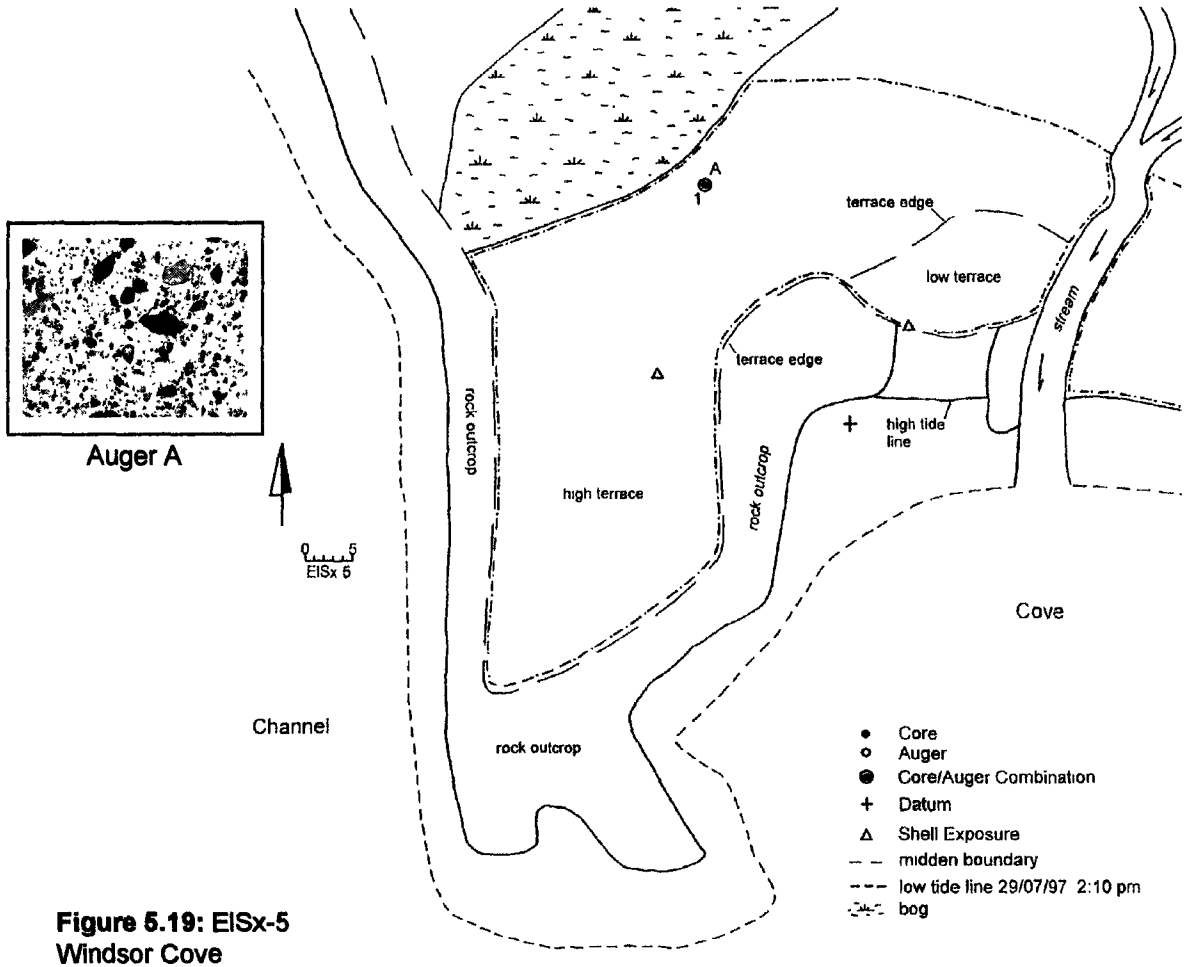


Figure 5.19: ElSx-5
Windsor Cove

5.4.6 *ElSx-8 Fougner Bay specific purpose camp*

Two samples were examined from one auger (A), located close to the terrace edge in a narrow strip of patchy midden at this site on Fougner Bay (Figure 5.20). There is no evidence to suggest even short-term residence at this site. The microscopic matrix was chiefly shell and sand (Figure 5.4). Neither sample demonstrated positive results.

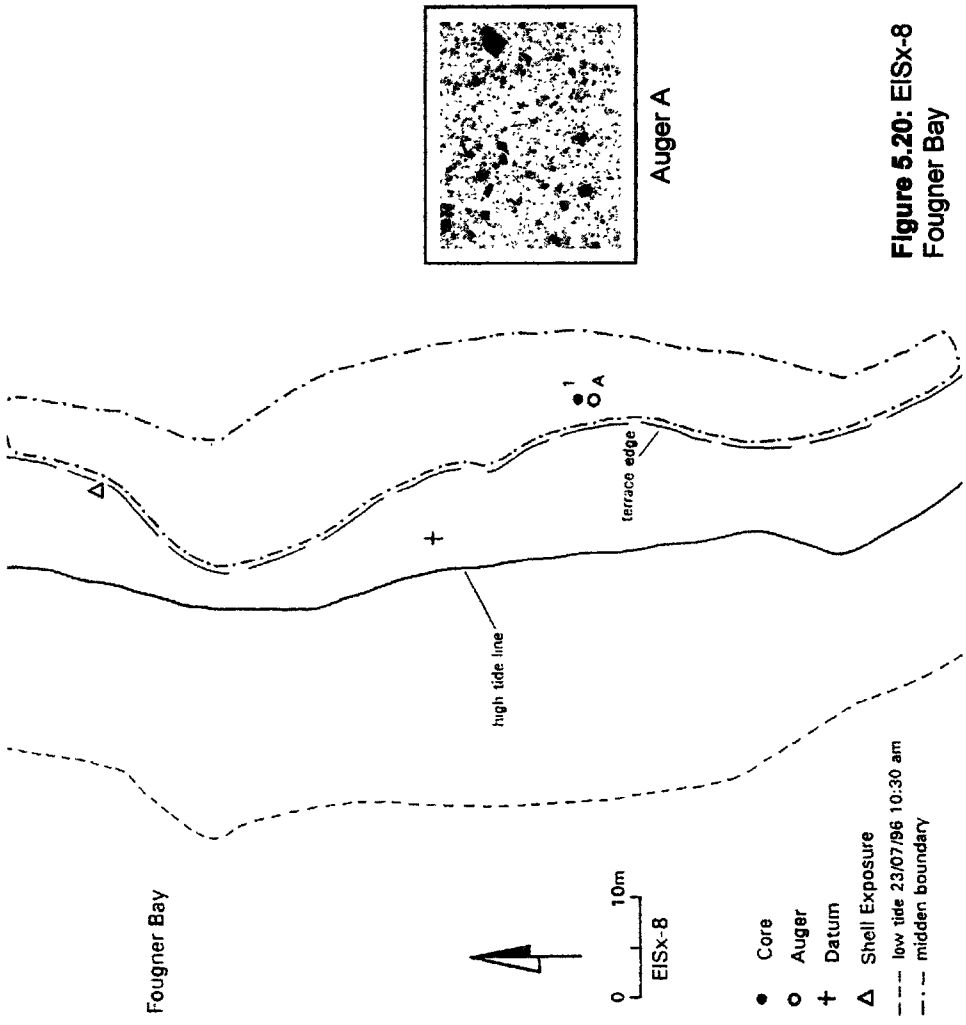


Figure 5.20: ElSx-8 Fougner Bay

5.4.7 *ElSx-10 Fougner Bay base camp*

Two locations (A and B) were tested at ElSx-10, although only one (A) produced positive results. Eleven samples were analysed from auger A, and 1 from auger B. Auger A was located at the front of the midden, representing a deeper section than auger B, located at the western margin of the site (Figure 5.21). The microscopic matrix from A was predominantly shell, but also included macerated organic debris, wood and charcoal (Figure 5.4). The matrix from auger B consisted of mostly charcoal, resin and sand, with little evidence of shell. A single foraminiferal lining was recovered from auger A8 (126-135 cm DBS). All four genera identified in this project were recovered at this base camp. *Ascaris* (1100 EPG) was the most abundant genera, followed by *Diphyllobothrium* (400 EPG) and one egg each of *Nanophyetus* and Cyclophyllidea. Eggs were recovered throughout the auger column, starting from 126 cm and extending the depth of the deposit to 340 cm DBS.

An *Ascaris* egg was recovered in the lowest level of midden deposit (A22 – 332-340 cm DBS), dated to 2465-2150 cal BC (Cannon 1997; 2003). The deepest evidence of *Diphyllobothrium* and Cyclophyllidea at this site was recovered from A12, at a depth of 190-202 cm DBS. An AMS radiocarbon date of cal BC 1870-1610 (Beta – 189449) was derived from

marine shell recovered from core 1, at a depth corresponding to 196-202 cm DBS at auger A. It is likely that the oldest *Nanophyetus* evidence from the region was also recovered from this site. Although there is no precise date to associate with the find, one *Nanophyetus* egg was recovered from A19 at 278-298 cm DBS, a section of auger that was therefore deposited between 2465 cal BC (A22) and 1610 cal BC (A12).

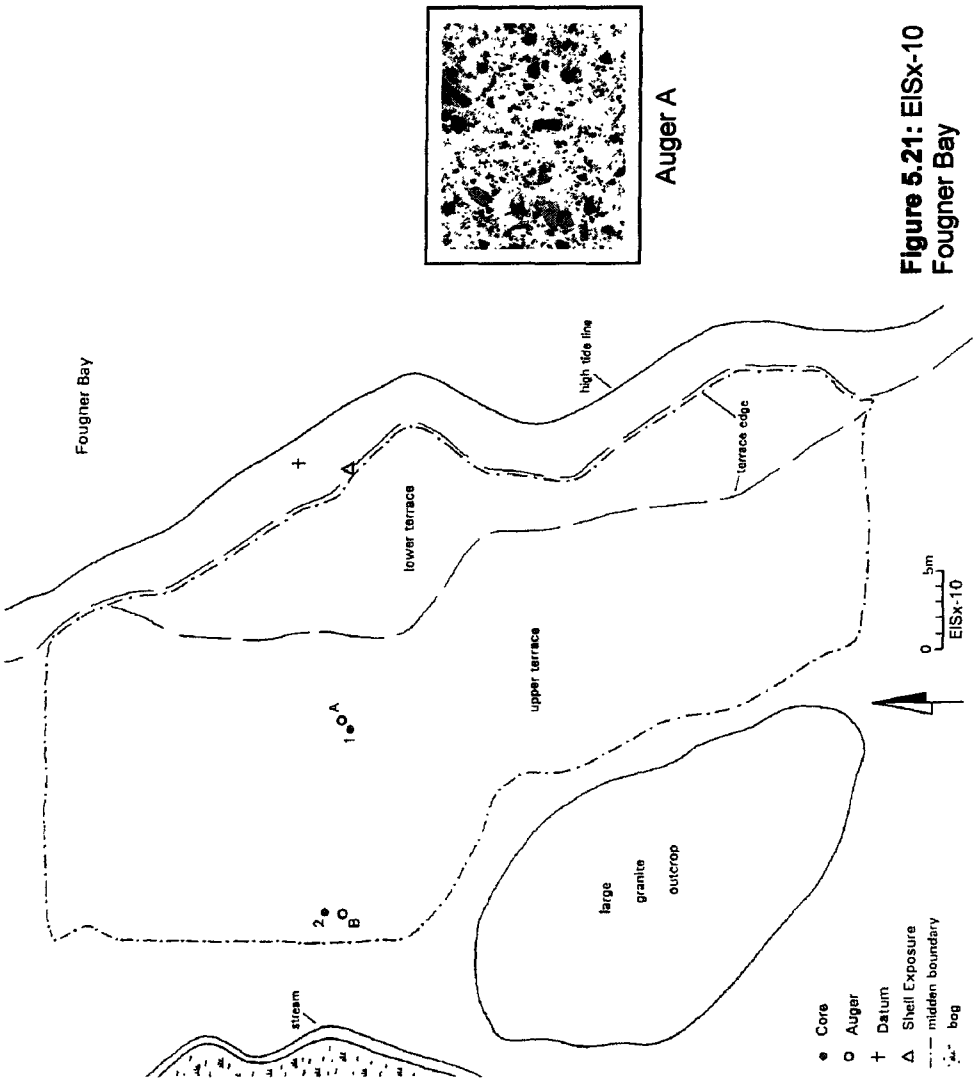


Figure 5.21: EISx-10 Fougner Bay

5.4.8 *ElSx-16 Fougner Bay multi-purpose camp*

Three samples from two auger locations (A and B) were examined at this multi-purpose camp located on Fougner Bay (Figure 5.23). Both auger samples were drawn from a narrow strip of midden. Organic components such as wood (Figure 5.22) and spores, as well as shell and charcoal, were common in the microscopic assemblage (Figure 5.4). *Diphyllobothrium* was the only genera recovered (EPG 1100), and evidence was derived from both auger locations at a depth of approximately 1 to 1.5 metres.

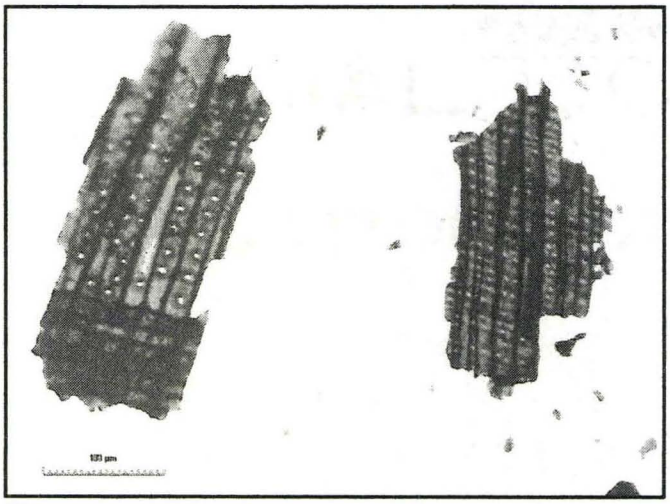


Figure 5.22: Wood fragments x200.

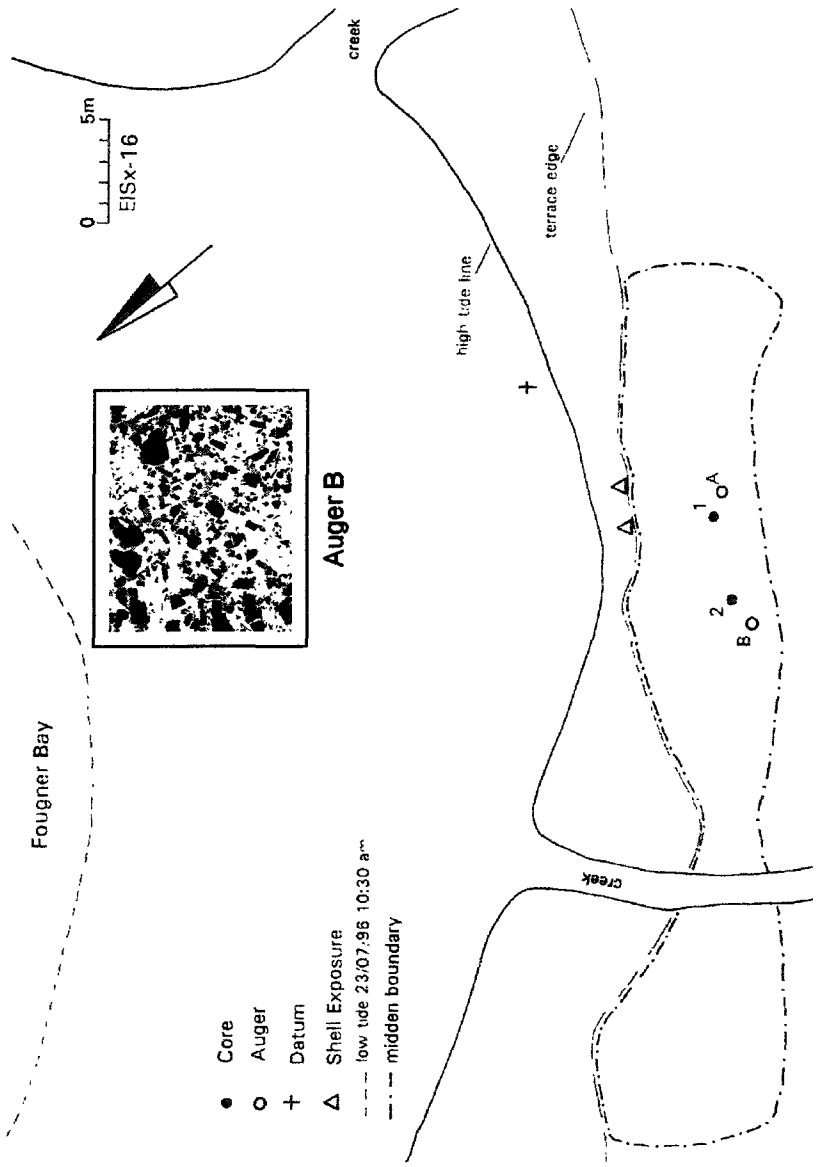


Figure 5.23: ElSx-16 Fougner Bay

5.4.9 *ElSx-17 Sunday Island camp, Namu Harbour*

Two samples were examined from auger A at this small, rocky island site in Namu harbour, located a short distance from the village site of ElSx-1 (Figure 5.24). Minimal midden evidence available at this location suggests site use was limited (Cannon 2000b). Even short-term residence was not likely at this location due to the constricted size. The microscopic matrix contained sand, wood and charcoal, but no evidence of shell (Figure 5.4). Neither sample produced parasite eggs.

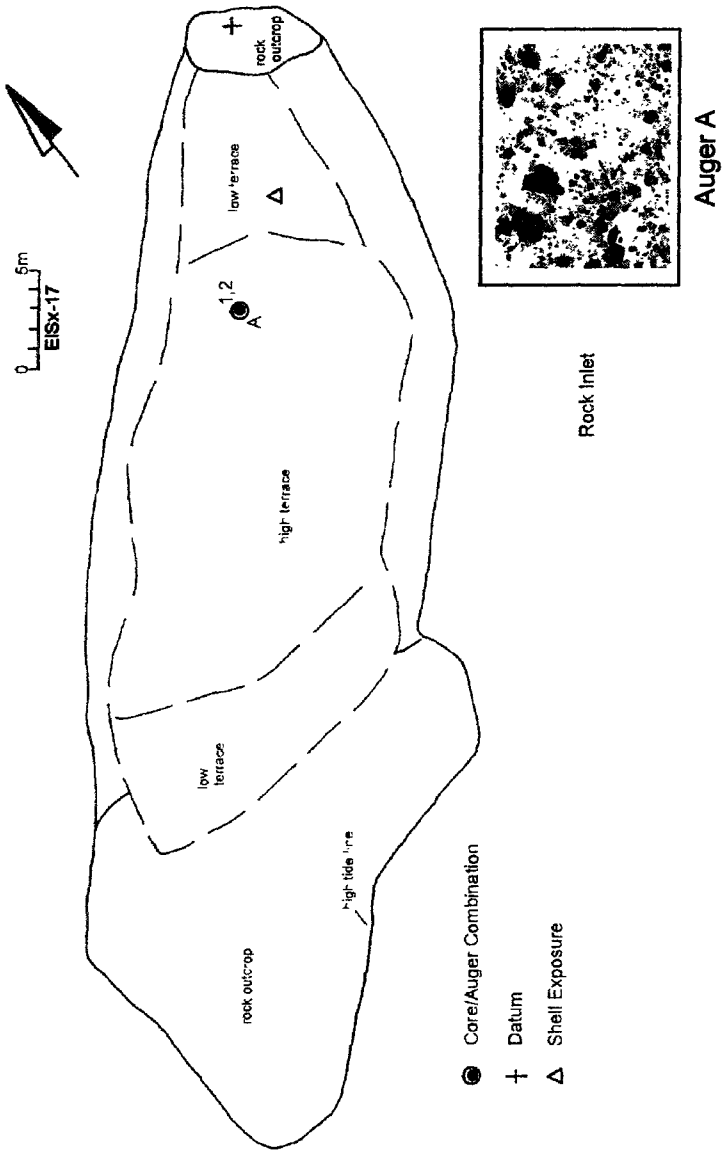


Figure 5.24: EISx-17
Sunday Island, Namu Harbour

5.4.10 *ElSx-18 Fougner Bay base camp*

Three samples were examined from one auger location (A) at this base camp located at the southern end of Fougner Bay (Figure 5.26). A total of 3 genera were recovered from the samples: *Diphyllobothrium* (EPG 300), *Ascaris* (EPG 100) and Cyclophyllidea (EPG 200). The midden deposits at auger A, in the front portion of the site, were thicker than those at the back of the site. The microscopic assemblage included a broad selection of shell, charcoal, fish scales (Figure 5.25) and organic debris, including hemlock pollen (Figure 5.4). Eggs were recovered at depths 108-120 cm DBS, 173-193 cm DBS and 250-264 cm DBS.

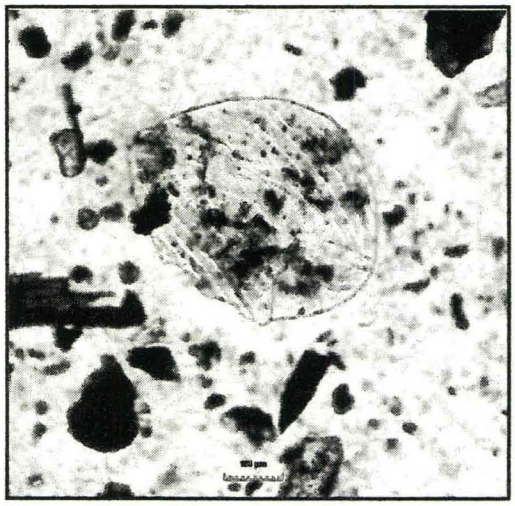


Figure 5.25: Fish scale x100.

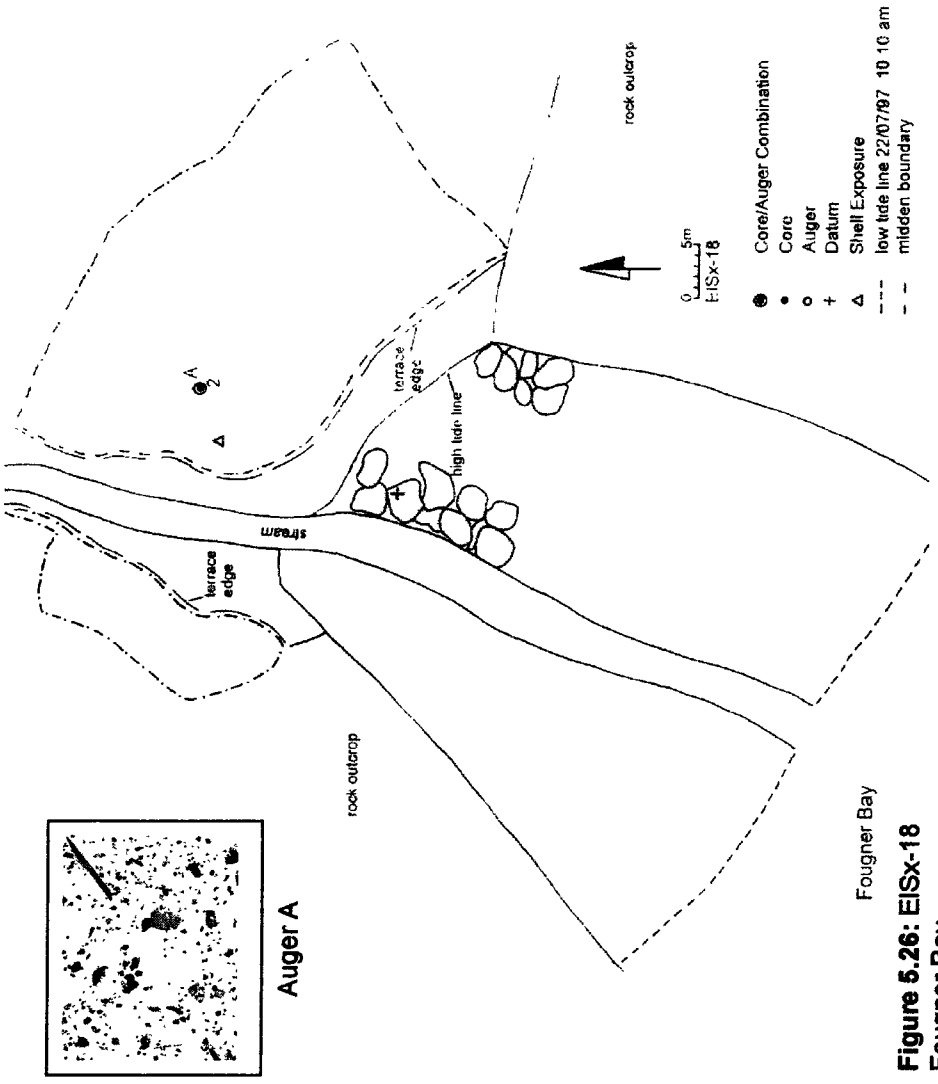


Figure 5.26: ElSx-18 Fougner Bay

5.4.11 *ElTa-3 Watt Bay specific purpose camp, Hunter Island*

Evidence of a fish trap at this site is an indication of the use of this location. Two samples were drawn from one auger (A) on the terrace of this small midden (Figure 5.28). Shell was not a common component of the microscopic assemblage, though wood, spores, pollen and other organic debris were noted (Figure 5.4; Figure 5.27). There was no evidence of parasites in either sample examined.

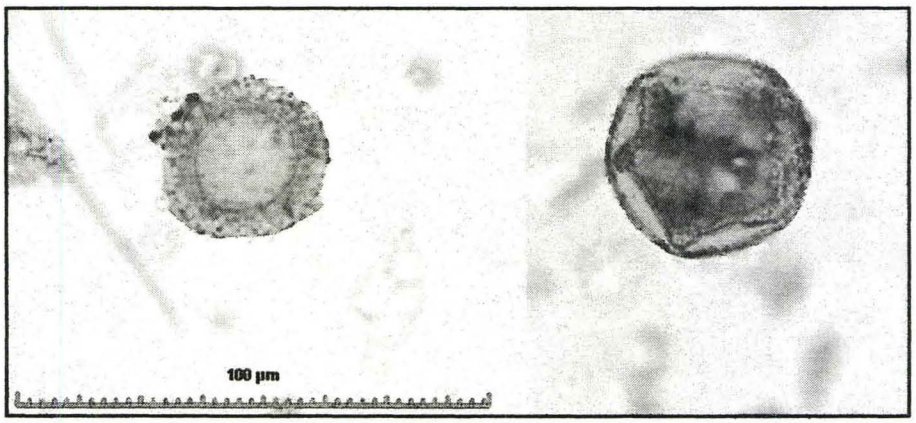


Figure 5.27: Examples of pollen. Hemlock (left) and alder (right) x400.

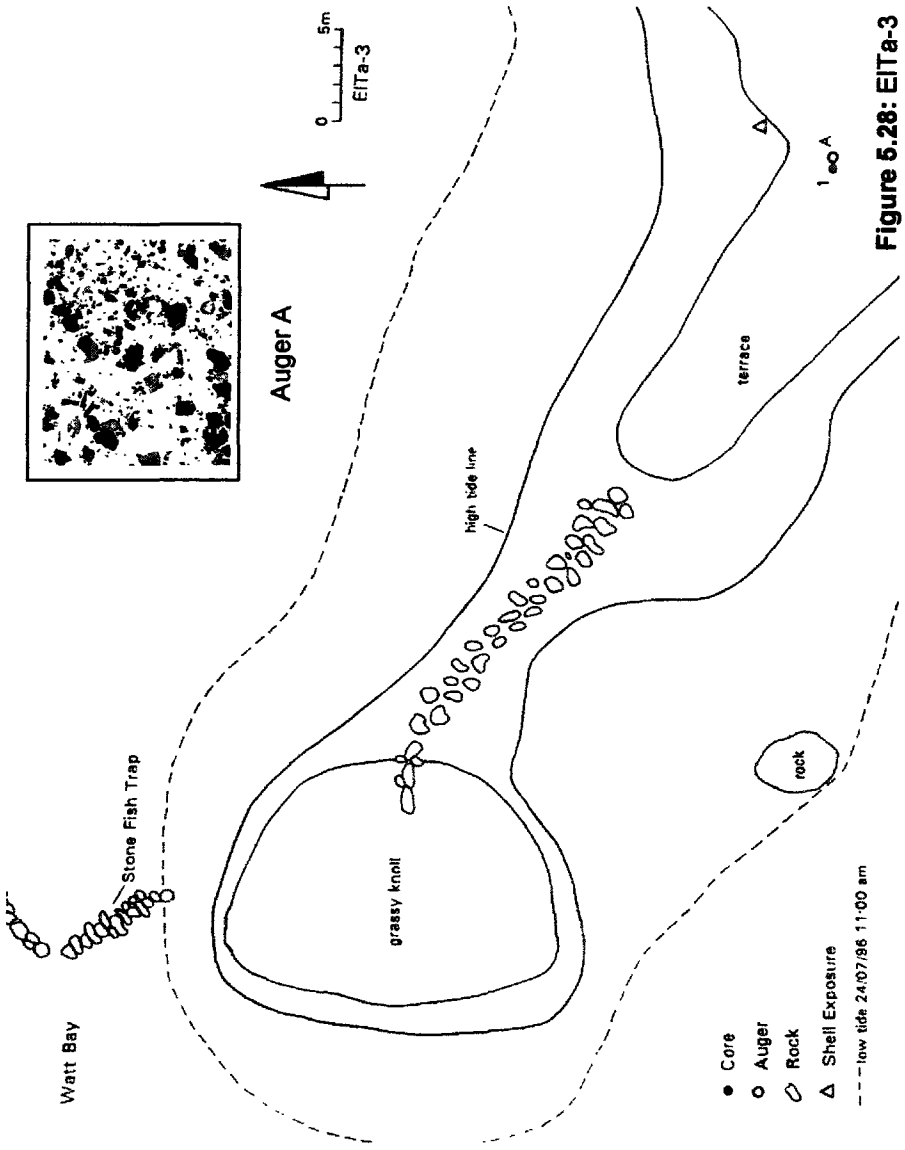


Figure 5.28: ElTa-3 Watt Bay

5.4.12 *ElTa-18 Kildidt Inlet multi-purpose camp*

This small camp is one of the oldest sites examined in this study (9370-9050 cal. BC) (Cannon 2002). Three samples were taken from two different augers (A and B) (Figure 5.29). Auger A was the only location with preserved shell and fauna. The matrix appeared culturally sterile at the microscopic level, displaying little evidence of shell or organic debris and no evidence of charcoal (Figure 5.4). No parasite eggs were recovered from this site.

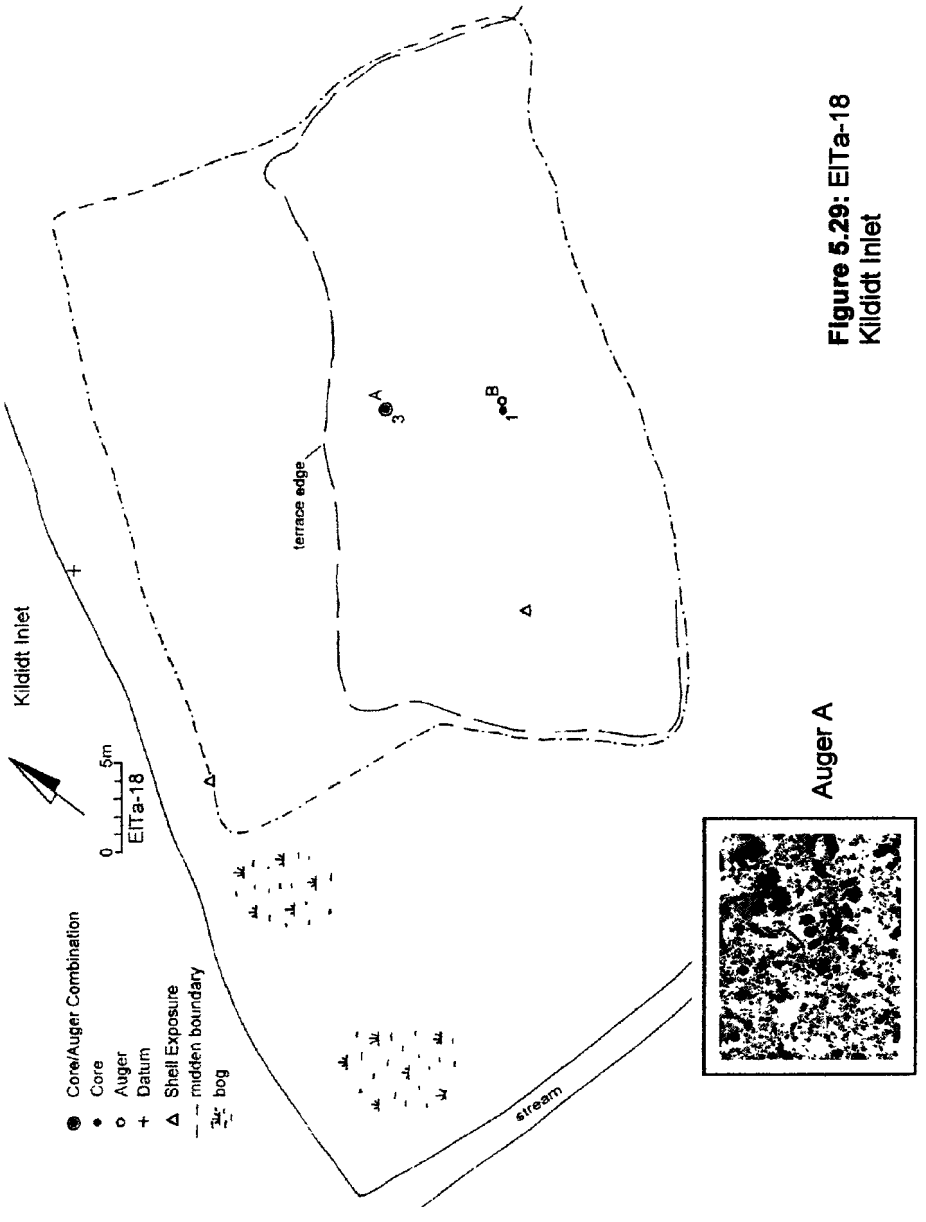


Figure 5.29: EITa-18
Kildidt Inlet

5.4.13 *ElTa-25 Kiltik Cove specific purpose camp, Hunter Island*

Two auger locations (B and C) and one core (#2 – located close to auger B) were sampled at this shellfish harvesting camp located on the east side of Hunter Island, facing Fitz Hugh Sound (Figure 5.30). Both auger locations produced positive results, although the core sample that was also tested did not. Auger B was located close to the outer perimeter of a contemporary cabin, and the microscopic matrix was rich in organics, comprising less shell than seen in auger C (Figure 5.30: auger C). Two samples tested from auger B yielded evidence of both *Diphyllobothrium* (EPG 900) and *Ascaris* (EPG 100) from a depth between 128 and 185 cm below surface. An AMS date of marine shell from core 2, corresponding to 183-190 DBS at auger B, provided a date of cal AD 210-440 (Beta 189446). Auger C was located at the back of the midden, and was comprised predominantly of shell. Three samples were drawn from auger C, but only one sample (auger C13, 115-130 cm DBS) produced evidence of one genera: *Diphyllobothrium* (EPG 400).

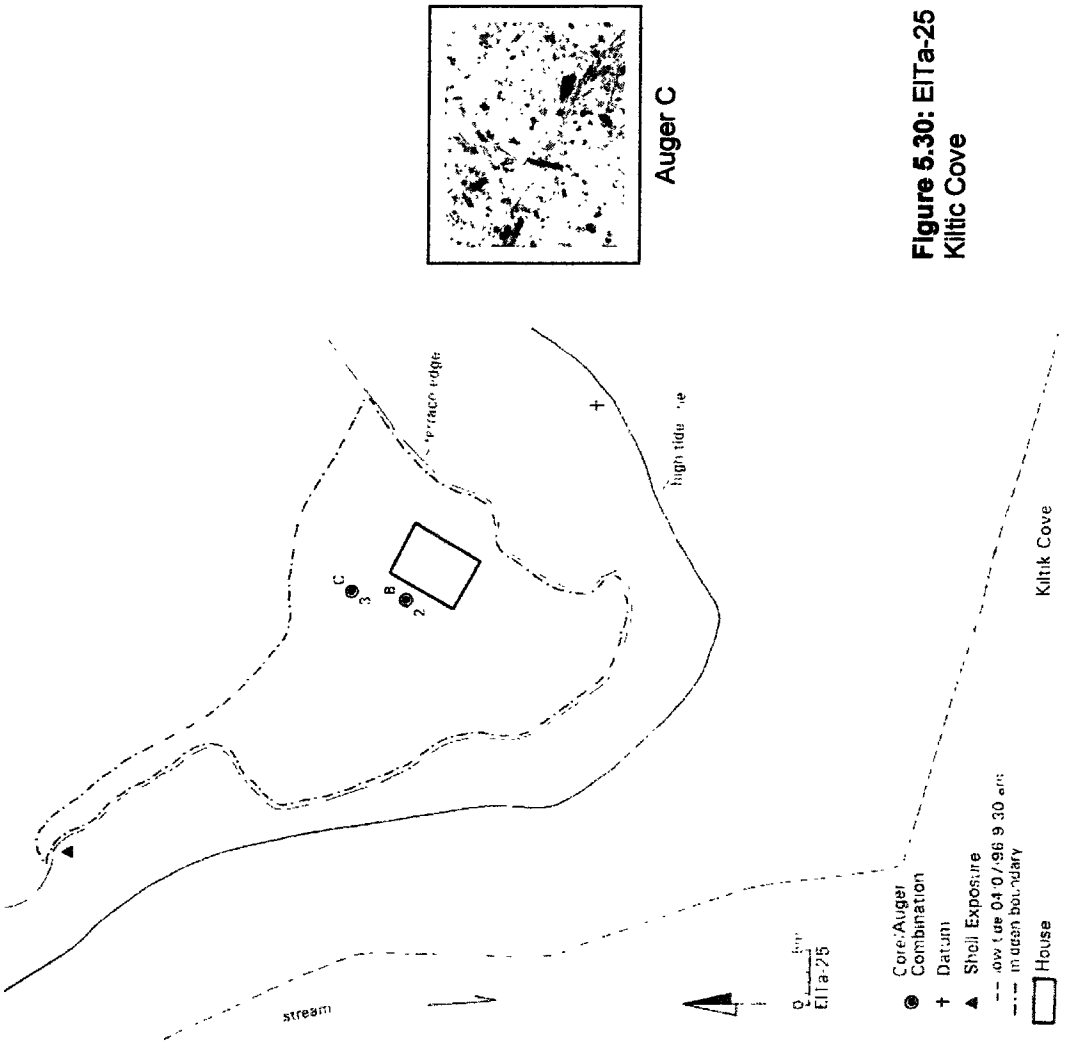


Figure 5.30: ElTa-25 Kiltic Cove

5.4.14 *ElTb-1 Hurricane Island summer village*

Ten auger samples were examined from only one location (B) at this summer village site. Auger B was located within the estimated boundaries of a collapsed plank house, close to a bog that marks the periphery of the midden at the back of the site (Figure 5.32). Living space at this location was constrained by natural features including swamp, rock outcrops and water. The microscopic matrix was rich in shell, phytoliths (Figure 5.31), wood and charcoal (Figure 5.4). All four genera were recovered, extending the depth of the midden from 171 to 454 cm DBS. Deposits examined from B26 (358-396 DBS) were the most dense in quantifiable evidence and richest in species diversity: *Diphyllobothrium* (EPG 1000), *Ascaris* (EPG 100) and *Nanophyetus* (EPG 100).

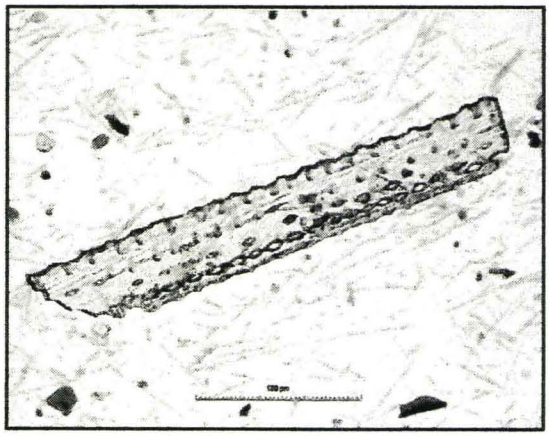


Figure 5.31: Phytolith x400.

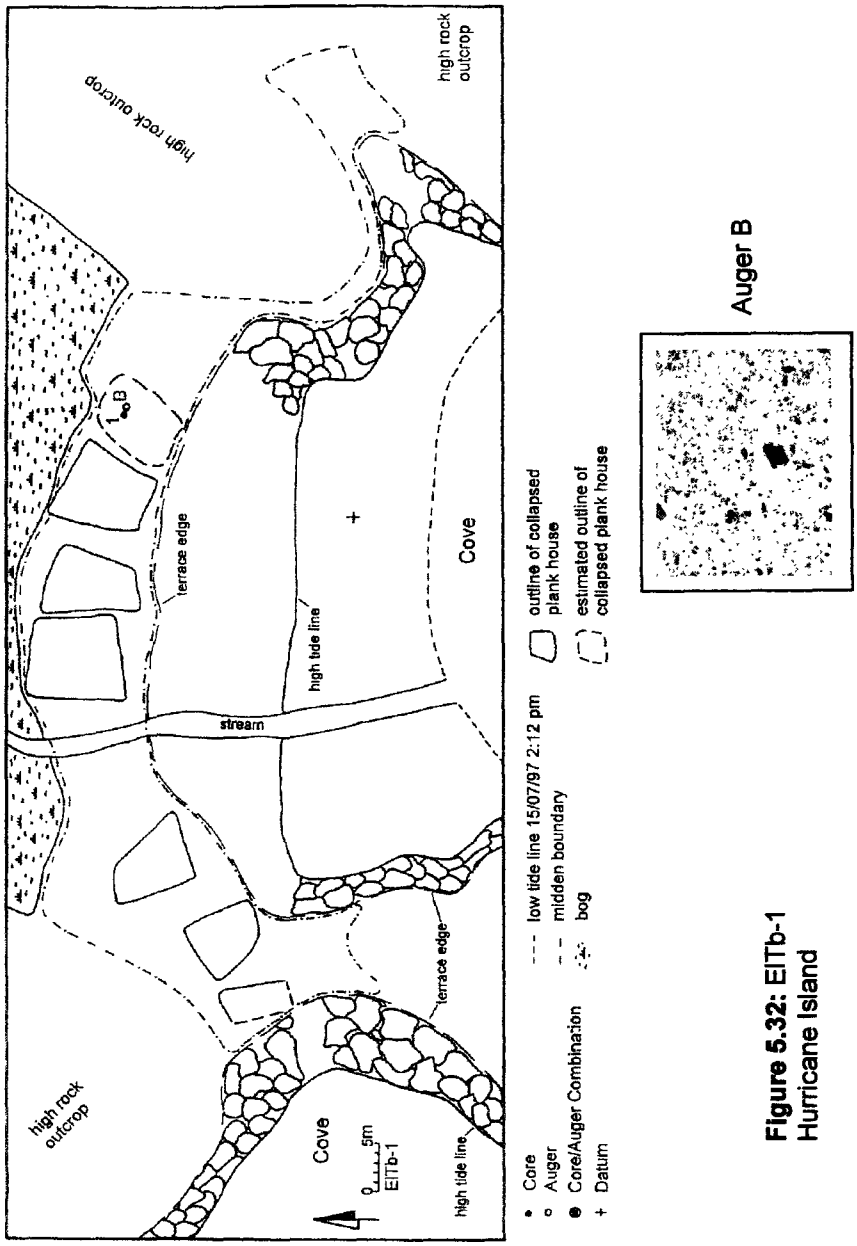


Figure 5.32: EITb-1
Hurricane Island

5.4.15 *ElTb-2 Spitfire Channel specific-purpose camp, Hunter Island*

Only one auger location (A) was sampled at this small campsite (Figure 5.34). Microscopic debris was diverse, including spores, pollen, wood, phytoliths, charcoal and shell (Figure 5.4). One slide contained evidence of an arthropod, possibly from the order Phthiraptera (sucking lice), though identification is inconclusive (Figure 5.33). Two genera, *Diphyllobothrium* (EPG 6500) and *Ascaris* (EPG 100), were recovered from five samples examined from the site. The single, richest deposit of *Diphyllobothrium* recovered in this project (EPG 6400) was obtained from auger A6 at a depth of 85-95 cm DBS.

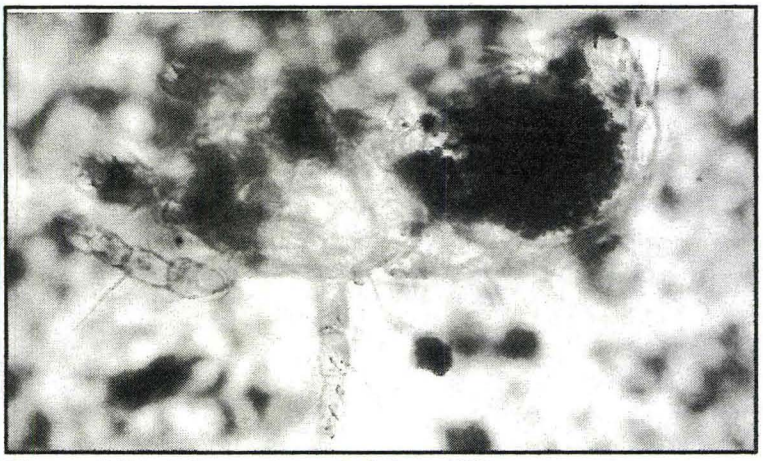


Figure 5.33: Arthropod exoskeleton x400.

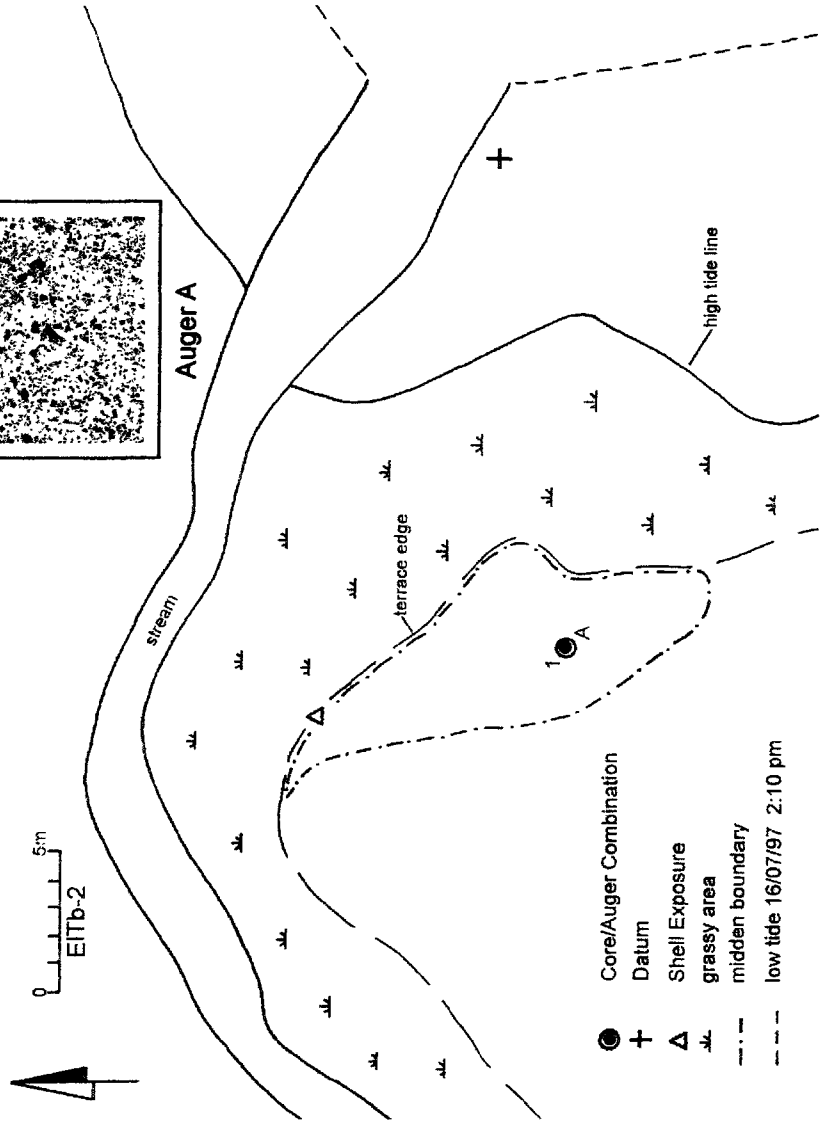


Figure 5.34: ElTb-2
Spitfire Channel

5.5 Temporal Patterns

Site	*Auger*	*Depth Range of Parasite Finds*	*Closest Estimated Date Range of Positive Finds (Calibrated Calendar Years)*
ElTa-25	B	128-185 cm DBS	AD 210-440 - contact (surface)
	C	94-130 cm DBS	
ElTb-2	A	85-130 cm DBS	AD 20 - AD 1450
EkSx-12	C	55-132 cm DBS	250 BC - contact (surface)
	D	56-250 cm DBS	
ElSx-16	A	85-142 cm DBS	650 BC - contact (surface)
	B	80-92 cm DBS	
ElTb-1	B	171-454 cm DBS	800 BC - contact (surface)
ElSx-4	A	133-152 cm DBS	900 BC - AD 1700
	B	158-172 cm DBS	
ElSx-3	C	176-247 cm DBS	940 BC - contact (surface)
	F	118-169 cm DBS	
ElSx-18	A	108-264 cm DBS	1600 BC - contact (surface)
ElSx-10	A	126-340 cm DBS	2465-1610 BC
ElSx-1	A	123-196 cm DBS	3300-1850 BC
ElSx-5	A	147-341 cm DBS	4775 BC - AD 1700

Table 5.15: Depth range and closest estimated age range of positive finds.

Parasite	*Site*	*Auger*	*Depth*	*Date Range of Oldest Finds*
Ascaris	ElSx-5	A19	289-306 cm DBS	4775-3490 cal. BC
Diphyllobothrium	ElSx-5	A11	147-163 cm DBS	3700-3490 cal. BC
Cyclophyllidea	ElSx-5	A11	147-163 cm DBS	3700-3490 cal. BC
Nanophyetus	ElSx-10	A19	278-298 cm DBS	2465-1610 cal. BC

Table 5.16: Oldest estimated date range of recovered parasite taxa.

Namu (ElSx-1) is the only site that has been comprehensively dated throughout the stratigraphic profile (Carlson 1996). Initial and terminal dates are available for all sites, but funding limitations curb more precise dating strategies. Four additional dates were obtained for this project in order to establish a more specific time frame for significant deposition events; expressly for establishing the oldest dates associated with *Diphyllobothrium*, the most abundant parasite genus recovered in this study (Table 5.15).

The oldest evidence for 3 of the 4 parasite genera originated from the base camp site at ElSx-5, where all but *Nanophyetus* were recovered. The oldest salvaged parasite egg was identified as *Ascaris*, with an estimated date range from 4775-3490 cal. BC (Table 5.16). However, the oldest *abundant* evidence of *Ascaris* was recovered from ElSx-1, with an estimated date range from 3300-1850 cal. BC (Carlson 1996). This date range of *Ascaris* from ElSx-5 predates the oldest *Ascaris* evidence recovered in the Americas to date, discovered in Peru and dated 2620-1740 cal. BC (Patrucco et al. 1983).

Diphyllobothrium and Cyclophyllidean eggs were recovered from the same level at ElSx-5, over a metre above the *Ascaris* evidence and dated by AMS to 3700-3490 cal BC. The oldest dated *Diphyllobothrium* spp. evidence in the Americas to date has been recovered from Chile,

ranging from 4110-1950 BC (Ferreira et al. 1984). The oldest North American *Diphyllobothrium* spp. find dates to 300 BC-AD 200 (McClary 1972). As it was not possible to identify the Cyclophyllidea findings beyond taxonomic order, comparative findings are difficult to determine. To date, the oldest unidentifiable cestode findings have been reported by Fry (1977) from the desert southwest of North America.

The oldest evidence of *Nanophyetus* was also recovered from a base camp, located at ElSx-10, estimated to date between 2465-1610 BC. This is the first reported archaeological finding of *Nanophyetus* in the literature, so there is no comparative evidence with which to compare these results.

Eggs were encountered randomly throughout the strata at each site; there was no indication that eggs were pooled recently at the surface of a deposit nor were they leached to the bottom of the midden. Evidence was often found in "clusters" or clumps, an occurrence noted most frequently with the nematode eggs of *Ascaris*. These findings are in opposition to Reinhard and colleagues (1986), who suggest parasite eggs have a tendency to percolate through the soil. The specific components of the shell midden deposit may account for such patterns. Layers of midden used as living floors or walkways may have compacted the matrix, trapping percolated particles at the levels of compressed strata (Kelso et

al. 2000). Alternatively, large, flat objects such as rocks or open clam shells may also prevent percolation by trapping smaller particles (Kelso et al. 2000; Stein et al. 2003: 312). However, McSorley (2000) notes that nematode eggs, specifically, are usually unevenly distributed horizontally in ecological studies, often being recovered in clumps. This is attributed to the sticky, mammilated shell of nematode eggs, which promotes cluster bonding.

Parasite finds ranged in depth from 55 cm DBS to as low as 454 cm DBS. The prevalence of parasite eggs does not appear to increase over time, as the most abundant finds are randomly distributed in any given profile. In most cases, those sites utilized by larger groups for longer durations (residential sites) demonstrate greater species diversity (ElSx-1, ElSx-5, ElSx-10, ElSx-18, ElTb-1).

5.6 Spatial Patterns

5.6.1 *Settlement Types*

The classification of site types, as defined by Cannon (2000a; 2000b; 2002) was amalgamated into two functional categories of settlement, differentiated by the degree of site permanence, the density of the population utilizing the site, and the intensity of site use (Table 5.17). Summer and winter aggregation villages along with base camps were

considered to represent intensely utilized residential sites. These sites are characterised by a moderate to large size midden, a diversity of fish remains and a variety of site activities (Cannon 2002). It is assumed that a greater number of people utilized these sites, accumulating larger quantities of diversified forms of waste in a more sedentary pattern of site residence. Limited-term camp sites, in contrast, are generally smaller in size and focussed on a smaller range of resources (Cannon 2002). Camps would have been inhabited for shorter periods of time most frequently during the warmer months of the year, when conditions were favourable to travel and targeted resources were in season. There is less diversity in the range of activities recognized in the archaeological record at these sites. Limited site activity suggest such sites were used seasonally by small groups of people, functioning specifically for target resource acquisition on a short-term basis.

This classification system for site activity is imprecise, and diminishes some of the discriminating attributes that Cannon (2000a; 2000b; 2002) originally used to evaluate variation in the fishing economy between sites within the Namu region. However, it is sensitive enough to allow for comparison between variables relevant to parasite epidemiology, specifically site permanence and population density, either of which could have an impact on the parasite assemblage.

Borden #	*Site Type*	*Auger location*	*Samples tested*	*# +*	*# –*	*% Positive*
EkSx-12	Residential	B	1	0	1	0
		C	6	2	4	0.33
		D	7	3	4	0.43
ElSx-1	Residential	A	26	5	21	0.19
		J	2	0	2	0
ElSx-3	Residential	C	12	3	9	0.25
		F	5	2	3	0.40
ElSx-5	Residential	A	8	5	3	0.62
ElSx-10	Residential	A	11	8	3	0.73
		B	1	0	1	0
ElSx-18	Residential	A	3	3	0	1.00
ElTb-1	Residential	B	10	8	2	0.80
Residential Total		12	92	39	53	0.42
ElSx-4	Camp	A	1	1	0	1.00
		B	1	1	0	1.00
ElSx-8	Camp	A	2	0	2	0
ElSx-16	Camp	A	2	2	0	1.00
		B	1	1	0	1.00
ElSx-17	Camp	A	2	0	2	0
ElTa-3	Camp	A	2	0	2	0
ElTa-18	Camp	A	2	0	2	0
		B	1	0	1	0
ElTa-25	Camp	B	2	2	0	1.00
		C	4	2	2	0.50
		core	3	0	3	0
ElTb-2	Camp	A	5	2	3	0.40
Camp Total		13	28	11	17	0.39

Table 5.17: Distribution of positive and negative finds at different site types.

	Samples positive for Parasites	Samples negative for Parasites	
Camp Sites	11	17	28
Residential Sites	39	53	92
Total samples tested	50	70	120
$\chi^2 = 0.085$, $df = 1$, $p \leq 1$			

Table 5.18: Distribution of positive and negative findings plotted by site type.

In order to justify comparisons between these site types, it was necessary to confirm that the number of parasites recovered was simply not a function of the number of samples that were investigated. A chi square analysis of independent samples found no significant difference in the distribution of positive finds between residential and camp sites ($\chi^2 = 0.085$, $df = 1$, $p \leq 1$) (Table 5.18). Therefore, there was an equal probability of finding parasite eggs at either site type, in spite of the fact that more samples were investigated from residential sites.

	Samples positive for *Ascaris*	Samples negative for *Ascaris*	
Camp	2	26	28
Residential Sites	27	65	92
Total samples tested	29	91	120
Fisher's Exact 2-tailed Test $p = 0.0214$			

Table 5.19: Distribution of positive and negative *Ascaris* finds, plotted by site type.

	Samples positive for *Diphyllobothrium*	Samples negative for *Diphyllobothrium*	
Camp	11	17	28
Residential Sites	19	73	92
Total samples tested	30	90	120
$\chi^2 = 3.97$, $df = 1$, $p \leq 0.05$			

Table 5.20: Distribution of positive and negative *Diphyllobothrium* finds, plotted by site type.

Ascaris finds were significantly more common at residential sites (Fisher's Exact 2-tailed Test $p = 0.0214$) (Table 5.19). Likewise, 92% (12 /13) of samples positive for *Nanophyetus* and/or Cyclophyllidea were also recovered at residential sites. Conversely, evidence of *Diphyllobothrium* was recovered significantly more often at camp sites ($\chi^2 = 3.97$, $df = 1$, $p \leq 0.05$) (Table 5.20). It can be inferred, therefore, that a greater diversity of parasite species was found at residential sites, where activity was more intense, population densities greater and longer periods of time were spent in one location (Figure 5.35).

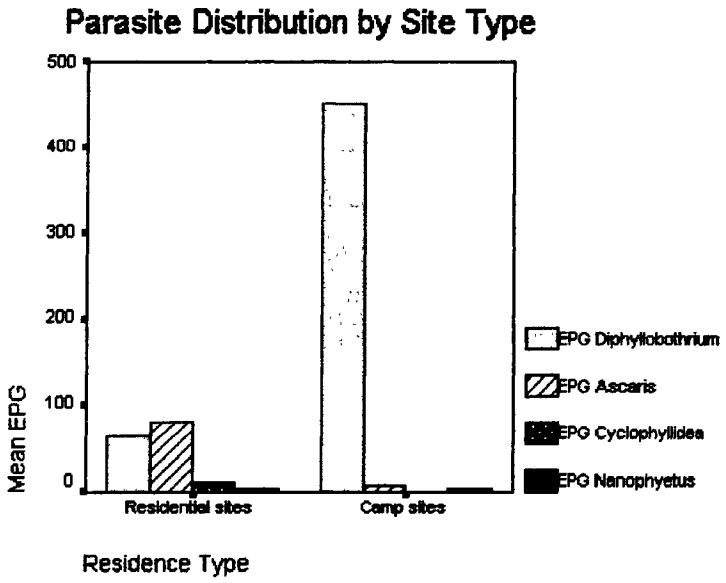


Figure 5.35: Distribution of parasites eggs by site type.

5.6.2 *Intra and inter-site comparisons*

As results of the analysis at each individual site indicates, diversity is inherent in the ecological, social and historical circumstances unique to each site. Only two sites, EkSx-12 and ElTb-1, provided auger samples that could be clearly associated with surface house features. Although it should be acknowledged that the sub-surface predated the surface features by centuries at EkSx-12, samples positive for parasite eggs were collected beneath an interior house depression in House 4 and below the location of the exterior wall of House 5. *Ascaris* (EPG 700) was the only genus recovered at the site.

As a soil-borne pathogen, the morphological characteristics of *Ascaris* eggs enhance efficient mechanical dissemination. The sticky, mammilated shell adheres readily to soil particles, vegetation, hair/fur, clothing, tools or fingers (O'Lorcain and Holland 2000:52). Therefore, it is able to spread from the primary point of faecal deposition, and as an archaeological artifact, it is frequently found where trampling and foot traffic were common (Jones 1982b; 1985). Jones has also found evidence of *Ascaris* along the exterior walls of houses and other structural features, a factor he attributes to the impetuous defecation habits of children (1987). Studies of refuse deposition patterns have demonstrated a tendency for large-sized casual or non-useful debris to be removed from

main living areas to secondary refuse deposits such as middens, or alongside structural walls, whereas smaller debris may accumulate under permanent items (i.e. beds), along inside walls or in the corners of dwellings (Hayden and Cannon 1983; Needham and Sørensen 1988; Schiffer 1976; Smith 2003:174). Children, or those suffering from ailments such as diarrhea, may have contributed to the contamination level of dwelling floors (Swanton 1905:139). Any *Ascaris* eggs trampled into a dwelling on soiled feet may have been accumulated within interior house features as primary refuse or swept up with larger household debris and deposited as secondary refuse within the midden, along the outside wall of the dwelling or into the hearth. The number of eggs recovered from this site is negligible. However, if the location of the house features remained consistent over time, then the distribution of *Ascaris* eggs within an area that is later in proximity to an internal house pit and along the exterior of a house wall may be demonstrative of secondary refuse deposition. Such a deposition pattern might therefore be an indication of intense site use (Schiffer 1976). Although this explanation may account for the presence of *Ascaris* at EkSx-12, it is more difficult to account for the absence of other parasites. EkSx-12 is the only residential site that exhibits less than 3 parasite genera.

As only one auger location was tested at the summer village at ElTb-1, there was no basis for comparing intra-site features. However, ElTb-1 is comparable to EkSx-12, as both are village sites with distinguishable and tested house features. The only auger examined from ElTb-1 was located within the estimated boundaries of a collapsed plank house, which produced evidence of all four genera of parasites. In stark contrast to EkSx-12, only one *Ascaris* egg (EPG 100) was recovered from ElTb-1, whereas *Diphyllobothrium* was the most numerous genera discovered (EPG 3300). Therefore, due to the complex nature of midden development which involves both refuse deposition and habitation (see Archaeological Context chapter), it cannot be presumed that all village house features will display the same patterns of evidence that were recognized at EkSx-12.

Constrained living space may limit refuse deposition patterns and influence the number and diversity of parasite genera recovered. The village sites at EkSx-12 (area = 2500 m^2), and ElSx-1 (8100 m^2), where relatively few *Diphyllobothrium* eggs were recovered, differ from the village sites at ElTb-1 (1110 m^2), and ElSx-3 (1630 m^2) in the amount of unconstrained living space available to the inhabitants at each location. *Diphyllobothrium* was abundant at ElTb-1 (EPG 3300) and ElSx-3 (EPG1200). *Ascaris* was also present with an EPG 600 and EPG 100,

respectively. However, an EPG of 400 *Diphyllobothrium* eggs and the second largest quantity of recovered *Ascaris* eggs (EPG 1100) after ElSx-1 was retrieved from the base camp at ElSx-10, a profile more in keeping with that at ElSx-1 and EkSx-12. But the living space at this site was also the smallest of any residential site (840 m^2). So if constrained living space was a factor influencing the number and location of *Diphyllobothrium* deposited at a site, then the smallest residential site (ElSx-10) should yield the most *Diphyllobothrium* evidence, which it does not. Therefore, while a compelling explanation, living space alone cannot account for the patterns in parasite distribution.

The evidence at ElTb-1 represents the second largest *Diphyllobothrium* assemblage recovered in this study after ElTb-2 (EPG 6500), a short term summer camp. Based on the seasonal indicators of the faunal assemblage derived from the auger samples at ElTb-1, Cannon (2000a; 2000b) believed this village was also predominantly occupied during the spring/summer resource-harvesting season. However, summer residence is not a simple explanation for the observed deposition patterns. Although ElTb-1 may be a spring/summer village, all other village sites (EkSx-12, ElSx-1, ElSx-3) were occupied over the winter season and all but EkSx-12 demonstrated evidence of 3 or more parasite genera. The distribution of the taxon, however, may have some relation to

seasonal patterns, as most *Diphyllobothrium* finds were recovered from camp sites, presumably inhabited briefly during warmer months.

The density of *Diphyllobothrium* eggs (EPG 6500) at ElTb-2 is another unexpected finding. The diversity of fish species represented in the faunal assemblage is broad, and salmon, from which *Diphyllobothrium* is presumed to have been acquired, is a relatively minor component (Cannon 2000b). This location was not likely used to harvest spawning salmon, therefore it is unlikely that the numerous fish tapeworm eggs recovered at ElTb-2 were a result of consuming salmon at this site. Consequently, eggs deposited at this location would lack access to an intermediary host (salmon), necessary for the completion of the parasite's life-cycle. The process of infection is likely to have taken place at a location better adapted to this life-cycle. As *Diphyllobothrium* is a long-lived parasite, capable of residing in a human intestine for up to 30 years, tapeworm eggs may have been excreted into the environment wherever the infected individual defecated. *Diphyllobothrium* eggs were also found at camps ElSx-4, ElSx-16, and ElTa-25 in densities over 500 eggs per gram. The evidence in these cases can be attributed to human mobility, as eggs are most likely to have been excreted by those who were infected at remote locations.

The village site to the north of EkSx-12 is Namu (ElSx-1). Like EkSx-12, *Ascaris* was the most common parasite recovered at this site. Unlike EkSx-12, two other genera were also recovered, *Diphyllobothrium* and Cyclophyllidea, though evidence was minimal. The samples at ElSx-1 were not taken from a defined surface house feature as they were at EkSx-12. The minimal evidence of *Diphyllobothrium* (EPG 200) in comparison to that discovered at other village sites such as ElTb-1 (EPG 3300) and ElSx-3 (EPG 1100) is enigmatic, as an individual harbouring *Diphyllobothrium* would excrete eggs wherever they defecated. A supplementary post hoc analysis at Namu, designed to appraise the presence or absence of *Diphyllobothrium* at other locations around the expansive village site, investigated soil from an additional 12 different locations (see Appendix III). Although *Ascaris* and Cyclophyllidea eggs were discovered, only 1 *Diphyllobothrium* egg was identified. This too, like the other 2 *Diphyllobothrium* eggs recovered at Namu, was in an unembryonated stage of development. Furthermore, a supplementary survey of the midden matrix from a village site at ElTb-10 on McNaughton Island, off Hunter Island on the outer coast (see Appendix III), also demonstrated the presence of *Diphyllobothrium,* the oldest recovered from a level dated 810-410 cal. BC (Pomeroy 1980). Therefore, the sparsity of *Diphyllobothrium* findings at Namu, especially in consideration of the large

number of samples examined from this site (38 in total), appears to have been a genuine anomaly.

Both ElSx-1 and EkSx-12 are located on the mainland coast, and both were large sites with abundant site area and unconstrained, flat living space. Both villages had access to a salmon-spawning river and lake system (Namu and Koeye Rivers, respectively). However, Namu was considerably elevated above the river, where wastes from the midden would not wash into the river. Even if individuals infected with *Diphyllobothrium* from a remote source were to visit or take up post-marital residence at these sites, the ecology of these locations may not have been conducive to the life-cycle of the parasite, and proliferation of this genus could not be elevated to archaeologically visible levels.

5.7 Analysis Summary

The history of parasitism on the coast is long and varied. The earliest evidence suggest parasites had been encountered by at least 6000 years ago. *Ascaris lumbricoides*, a human-specific, soil-borne parasite represents the oldest parasite finding, recovered from a intensively utilized base camp. *Diphyllobothrium* was the most abundant genera recovered. The random distribution of evidence suggests

variability in the temporal distribution of parasites, with no evidence to indicate parasite burden increased over time.

Differences in the number of parasites and parasite taxa recovered within and between sites demonstrates the complexity of site formation processes and the variability inherent at each unique site. A significant pattern was revealed in the spacial distribution of evidence indicating an association between the diversity of parasite genera and the intensity of site use. Residential sites (villages and base camps), where site use was more sedentary and populations larger and more dense, were more likely to exhibit a richer variety of taxa than specific-use campsites. This finding is analogous to the patterns in fish remains that were recovered from the same sites (Cannon 2000a; 2000b). The taxa most common at residential sites were *Ascaris*, *Nanophyetus* and Cyclophyllidea. Although *Diphyllobothrium* were present in significant numbers at some village sites, they were more frequently recovered from camps. Differences in the distribution of evidence may be attributed to a number of factors, including seasonality, mobility, living space, site features and local ecology.

Chapter 6:
DISCUSSION

6.1 Relevance of Parasite Evidence

Four genera of intestinal parasite eggs, some as much as 6000 years old, were successfully recovered from the shell midden matrix at 11 different sites along the temperate coastline of the Pacific Northwest. Although taphonomic processes are expected to have influenced the quantity and quality of the evidence that was recovered, attempts were made to control for processes relating to deposition and diagenesis. The homogenized midden samples that were analysed were likely to contain the weathered components of both formed and loose stools from an assortment of healthy and morbid individuals, accumulated over time, thus providing a standardized parasite profile of the contributing population at each site. All of the recovered genera have prolonged periods of infectiveness and are thus persistent pathogens, capable of being maintained within an ecosystem for long periods of time or among different host species. All but one of the recovered genera are transmissible zoonotic pathogens, conceivably indigenous to North America. The exception is *Ascaris lumbricoides*, a human-specific,

infectious pathogen that likely accompanied human migrants onto the continent. In order to assess the consequences of parasite burden for the populations of the coast, it is necessary to consider the biological, environmental, and cultural interrelationships that contributed to their fluorescence and archaeological visibility.

The relevance of the data recovered in this project is pertinent to archaeological studies on four thematic scales: Hunter-gatherer health; Pre-contact North-America; Pacific Northwest hunter-fisher-gatherers; and Local site variability.

6.2 Relevance to Hunter-Gatherer Health

The hunting and gathering mode of production did not isolate humans from the pathogens in their environment. As predicted by several researchers (i.e. Armelagos et al. 1996; Cohen 1989:33; Cohen and Crane-Kramer 2003; Froment 2001; Huss-Ashmore 1992; Nelson 1972; Thompson 2001; Waguespack 2002), the majority of parasite genera recovered were zoonotic species that do not require humans to complete their life cycle. *Diphyllobothrium* spp., *Nanophyetus salmincola* and Cyclophyllidea are food-borne parasites, transmitted through ingestion of contaminated fish or animal flesh. They are capable of being maintained within the environment independent of a human host. Bear, wolf, otter,

raccoon, fox, seagulls, and other carnivores/piscivores that have been documented as indigenous to the region in palaeontological and zooarchaeological collections, are also susceptible to infection by these particular foodborne pathogens. However, the cultural nature of the shell midden deposits, in association with the quantity of evidence that survived taphonomic processes and methodological processing, attests to their probable anthropogenic source.

Finding evidence of pathogenic organisms at settlements inhabited by hunter-fisher-gatherers corroborates those hypotheses that predicted environmentally persistent pathogens were a health risk to human populations prior to the advent of agriculture. *Ascaris lumbricoides* was the only human-specific parasite recovered in this study. Comparative studies of modern hunter-gatherers, such as that by Dunn (1968), presumed human-specific pathogens such as *A. lumbricoides* would require a population large and immobile enough to sustain them on humans alone. However, newer perspectives in evolutionary epidemiology recognize that some pathogens, such as those that do not require direct horizontal (i.e. person to person) transmission, can still develop a propensity for host specificity – in this case, people – if they can be sustained in the environment long enough to survive intermittent human contact. Since the life-cycle of *A. lumbricoides* requires a period of

embryonation in moist, warm, and dark soil, the eggs of *Ascaris* are capable of withstanding a considerable amount of environmental exposure. Thus, eggs can be maintained within the soil in a viable state for months or even years, awaiting the intermittent opportunity to infect a human host. An increase in the host population and a prolongation in the period of exposure would effectively result in an increase in the pathogen, both within the host population as well as in the environment. Settlement conditions on the central coast were populous and dense enough to produce archaeologically visible levels of *Ascaris* at coastal settlements by 4775-3490 cal. BC.

But where did this species come from? Today, *Ascaris lumbricoides* has a global distribution, and appears to have been present in the Old World and New Worlds contemporaneously, thousands of years prior to European expansion (Gonçalves et al. 2003). Some of the oldest archaeological parasite evidence that has been recovered has been identified as *A. lumbricoides* (Bouchet et al. 1996). As it is human-specific, it is reliant on human mobility for this global distribution pattern. The origins of this parasite and the antiquity of its presence in the New World have been cause for considerable debate (Kliks 1990; Loreille and Bouchet 2003).

Some researchers follow the epidemiologic transition model, and propose *A. lumbricoides* originated from a closely related porcine parasite, *Ascaris suum* (Kliks 1990). The close contact humans subsequently had with pigs after their domestication hypothetically provided the opportunity for this parasite to jump species, along with another now exclusively human parasite, *Trichuris trichiura*. Recently, other researchers have proposed the opposite scenario, implicating *humans* as the ancestral host species from which *pigs* eventually acquired these pathogens (Dark 2004; Loreille and Bouchet 2003). In some cases, it has been suggested our relationship with *Ascaris* extends the length of our species' history, and is conceivably a relic of our primate ancestry (Loreille and Bouchet 2003).

The presence of *Ascaris lumbricoides* in the New World is also considered proof of its ancient association with humans. Pigs are not indigenous to the Americas, so *A. lumbricoides* could not have independently evolved from *A. suum* on these continents. The only other explanation for its presence in the Americas prior to European contact is to presume it travelled there with its human hosts. Stewart's (1960) cold filter hypothesis proposed that the harsh and frigid conditions of Beringia, through which initial New World populations were believed to have migrated, were too harsh to sustain many pathogens, providing an

evolutionary bottleneck that resulted in a 'healthier' New World population. However, such hypotheses did not recognize alternate routes of entry into the New World, along the coast and through climatic conditions less harsh than originally imagined (Mandryk et al. 2001). Furthermore, they fail to acknowledge that humans themselves are not adapted to surviving exposure to such conditions without shelter. They would have made use of dwellings, in which the soil would be warm, moist, and dark; these are the conditions appropriate for the maintenance and dissemination of *Ascaris* eggs. Veterinary experiments in Saskatchewan have demonstrated that *Ascaris suum* eggs remain viable in sheltered barn conditions even over the winter, when the only source of warmth is pig body-heat (Wagner and Polley 1999). Humans also wear clothing, to which sticky *Ascaris* eggs would readily adhere and intermittently shed (O'Lorcain and Holland 2000:52). And they brought with them one domesticated species – the dog – which has also been demonstrated to be an effective mechanical vector of *Ascaris* eggs, both externally and internally, as they are able to consume and defecate viable eggs in their faeces (Traub et al. 2002; 2005:45).

Therefore, evidence in this debate is currently weighted towards the hypothesis that *Ascaris lumbricoides* is a human specific parasite of great antiquity. As such, it was maintained and endured by hunting and

gathering populations. Its presence in the New World, for which the oldest evidence (ca. 6000 years) has been documented in this project, is further testament that this species first migrated with humans onto the continent thousands of years before the advent of agriculture.

Although evidence of *Ascaris* has been recovered from other North American archaeological sites (i.e. Bouchet et al. 2001; Faulkner 1991; Faulkner et al. 1989; Patrucco et al. 1983; Reinhard et al. 1987), it is not a commonly salvaged species in comparison to other regions of the world. *Ascaris* is a standard find at European sites, where it is usually found in association with *Trichuris trichiura* (whipworm) (Dark 2004; Jones 1990; 1979) and attributed to urban living conditions. Modern epidemiological studies have also noted a positive association between the two species (Smith et al. 2001). However, no evidence of *Trichuris* was discovered in this study, though it has been recovered more frequently than *Ascaris* has from other pre-contact sites in both South and North America (Gonçalves et al. 2003; Reinhard et al. 1987).

To date, the majority of anthropological and epidemiological studies interested in the antiquity of human health have underestimated the diversity of hunting and gathering populations, and thus have restricted their focus, narrowly concentrating on the consequences of agricultural production. A better understanding of human health and

disease history will come from those that recognize the antiquity of human cultural variability and complexity, and the concomitant epidemiological consequences of such nonuniformity. The "just so" story of an evolutionary agricultural transition is no longer a sufficient explanation for the diseases we have experienced and developed throughout our history.

6.3 Relevance to Pre-contact North America

The relevance of *Ascaris lumbricoides* to hunter-gatherer studies and, more specifically, North American studies, has already been discussed. It is my contention that this species was introduced to the Americas with the earliest hunter-gatherer migrations onto the continent.

The significance of *Diphyllobothrium* spp. to North American archaeology is twofold. The oldest *Diphyllobothrium* eggs recovered by this project date between 3700-3490 cal. BC, establishing it as the oldest evidence of this genera yet recovered in North America. Secondly, these findings extend the known range of pre-contact *Diphyllobothrium* spp. to the Central Pacific Coast of Canada. Bouchet and colleagues (2001) documented *Diphyllobothrium* spp. eggs in association with a pre-contact child burial from the Aleutian Islands of Alaska, dated ca. 840 $\pm^{40}$ BP. Dickson and colleagues (2004) recovered *Diphyllobothrium* spp. eggs from the intestines of Kwäday Dän Ts'ìnchí, a young man who had been

mummified in the ice of Northern British Columbia ca. AD 1400-1490. McClary (1972) recovered pre-contact (ca. 300 BC - AD 200) evidence of what he identified as *Diphyllobothrium* spp. eggs in a coprolite from the Schultz site in the Saginow Valley, Michigan, though the species that deposited the coprolite could not be conclusively ascertained. The recovery of *Diphyllobothrium* spp. in this study extends the documented temporal range of this parasite earlier into the pre-contact era, and its geographic range from Michigan and the Aleutian Islands of Alaska, southwards to at least the Central Pacific Coast of Canada. Considering this geographic pattern of distribution, it is expected that evidence of *Diphyllobothrium* extends further south along the Pacific Coast to South America, where ample archaeological evidence of the species *Diphyllobothrium pacificum* has been recovered from coastal sites (Callen and Cameron 1960; Gonçalves et al. 2003; Holiday et al. 2003; Reinhard and Urban 2003).

The archaeological recovery of *Nanophyetus salmincola*, predominantly a dog parasite that dates to between 2455-1610 cal. BC, is the first documented evidence of its kind in archaeoparasitology literature. As such, it adds to a growing list of parasite genera indigenous to New World sites. Due to the complicated life-cycle of *N. salmincola*, which involves two intermediary hosts, a fresh-water snail and a fish, this

parasite may also serve as an ecological biomarker, as the distribution of the parasite is limited to the environmental distribution of the 2nd intermediary host (a freshwater snail).

Dogs may also have been a factor in the presence of Cyclophyllidea eggs in the recovered parasite assemblage. Identification to genus or species level was not possible based on the preserved morphological characteristics of the recovered eggs. Based on site ecology, the geographic range of potential intermediary or definitive hosts, and the size range of the recovered eggs, *Echinococcus* and *Taenia* are the most likely genera to be represented, although larger eggs may alternately represent *Hymenolepis*. Archaeologically, Hymenolepidae and Taenidae have been reported from pre-Columbian sites in the Americas (Fry 1977:39; Reinhard 1990:149; Reinhard et al. 1987), though Gonçalves et al. (2003:110) ruled out the possibility that *Taenia* was present in the New World based on the assumption it is a parasite solely associated with domesticated cattle and swine.

Eggs of the Taeniid family (includes *Taenia* and *Echinococcus*) have been identified in coprolites from several sites in the desert southwest (Fry 1977; Reinhard 1990). Reinhard (1990) considers dogs the likely source of this parasite in the samples he investigated, while Fry

(1977) attributes the source of the coprolites in his investigation to humans.

The *Taenia* species have traditionally been associated with a synanthropic life-cycle, circulating between human and/or dog definitive hosts and domesticated intermediary hosts of cattle (*T. saginata*) and swine (*T. solium*). Based on this premise, the possibility of finding this species in the Americas prior to the European introduction of these food domesticates has not been considered credible (Gonçalves et al. 2003). Yet, too little is known about the evolutionary history of *Taenia* infection to make this presumption. New phylogenetic evidence suggests hominids were the ancestral host of these species, not cattle or swine (Hoberg 2002; Hoberg et al. 2000). If the human relationship with *Taenia* is older than agricultural and domestication practices, then it is possible this genera was present in the Americas prior to the introduction of European agricultural products. However, there are no known species of *Taenia* endemic to South America (Hoberg 2002:860) and modern medical studies find Taeniid infections to be sporadic in tribal populations of that continent as well (Salzano 1990:205). On the basis of this information, *Taenia* may be considered an unlikely, though not an implausible, contributor to the parasite assemblage recovered in this project.

The only evidence of *Echinococcus* that has been recognized archaeologically has been in the form of calcified hydatic cysts recovered from the abdominal cavities of human burials (Ortner and Putschar 1981:232; Williams 1985). As humans are accidental intermediary hosts of *Echinocuccus* spp., the parasite does not complete its life-cycle in the human gut and eggs are not excreted in human faeces. The resulting indirect life-cycle leads, instead, to the development of cysts in humans infected with the parasite, effectively rendering humans as potential intermediary hosts. Dogs and other canines act as definitive hosts, in which sexual reproduction occurs and eggs are excreted with faeces. Evidence of *Echinococcus* spp. eggs, then, would be an indication that dog faeces contributed to the midden matrix, though the epidemiological significance of this parasite to humans should not be disregarded on this basis.

As hydatid cysts have been recovered in pre-contact North America (Williams 1985), it is conceivable that dogs migrated into the Americas already infested with *Echinococcus*, which they in turn transmitted to their human companions and introduced into a new food web. Alternately, *Echinococcus* can be maintained within the environment in a sylvatic life-cycle, and there is no reason to expect that North American evidence of *Echinococcus* spp. would necessarily represent an

introduced species. Today, *Echinococcosis* spp. are considered endemic among Native populations of Alberta, Yukon, and the Northwest Territories (Fortuine 1989: 61; Lantis 1981:89; Meltzer et al. 1956), where its maintenance is attributed to a life-cycle involving dogs and terrestrial herbivores such as caribou, moose, and deer. Therefore, *Echinococcus* spp. is considered a likely contributor to the Cyclophyllidean parasite assemblage recovered in this project.

Hymenolepis nana is a zoonotic parasite, for which humans, mice or rats may serve as definitive hosts. Common rats, however, were only introduced to the Americas after European contact. Flour and grain beetles may act as intermediary hosts, but they are not necessary, as eggs are immediately infective upon excretion from the definitive host. Pre-contact archaeological evidence of *Hymenolepis* spp. eggs have been recovered from Brazil (Gonçalves et al. 2003:112), the desert southwest (Reinhard et al. 1987) and from Michigan (McClary 1972). *Hymenolepis nana* is therefore considered a potential contributor to the Cyclophyllidean egg assemblage from the Northwest Coast. Although the size of *Hymenolepis* spp. eggs are generally larger than the archaeological artifacts recovered in this project, there is the possibility that drying or processing the samples may have altered (shrunk) the original size of the eggs. Findings from Brazil date this genus to as much

as 4000 years old, though the oldest Cyclophyllidea eggs recovered in this project predate these findings by over 1000 years: 5650-5440 cal. BP.

The four genera of parasites recovered add to the catalogue of archaeological parasites documented in the Americas and expand on their known geographic range. This project documents the first evidence of pre-contact era parasites to be recovered from archaeological settlements in Canada. The absence of parasite evidence retrieved from Canadian archaeological sites to date can be better attributed to a lack of exploration for this evidence than to preservational bias.

6.4 Relevance to Pacific Northwest Coast Hunter-Fisher-Gatherers

The recovery of parasite eggs, in some instances thousands of years old, demonstrates that shell-midden matrices and temperate environments are conducive to chitin preservation, the substance that comprises the outer layer of most parasite eggshells. The oldest parasite evidence (*Ascaris*) is roughly 6000 years old and corresponds to a region-wide phenomenon of bulk shell midden accumulation that also occurred at this time (Cannon 1991:67; Erlandson and Moss 1999). A noted increase in the number of faunal remains recovered from midden sites during this period is attributed to the neutralizing properties of calcium carbonate, derived from the erosion of shell, which act to preserve bone collagen and

apatite. While it is tempting to relate the preservation of parasite eggs to the same phenomenon, the evidence does not entirely support this proposition. Parasite eggs are more impervious to acidic environments than other forms of biological evidence (Pietrock and Marcogliese 2003:294; Wharton 1980:454). The chemical structure of the outer layers of parasite egg shells, as long as they remain intact, are able to withstand digestive acids and the harsh conditions of open environmental exposure (Jacobs 1974:186-187; Smyth 1969:119; Wharton 1980:455). Experimental and case studies have demonstrated that *Ascaris*, for instance, can withstand being digested by dogs (Traub et al. 2002; 2005), chickens, pigs (Olsen et al. 2001), houseflies (Dipeolu 1982), even earthworms (Kraglund et al. 1998; Larsen and Roepstorff 1999:217) and still remain viable and infective. Therefore, taphonomic conditions can be ruled out, and it is reasonable to consider that the appearance of parasite eggs in archaeological deposits after 6000 BP alternately represents a change in the density of parasite eggs deposited in the local environment.

Parasite recovery, however, is not consistent through midden strata. Eggs were frequently recovered in intermittent stratigraphic 'pockets', suggesting that the temporal patterns in the density of egg deposition after 6000 BP were variable. This variability is most likely attributed to fluctuating changes in population density and site use over

time. As there were only four sites in this project with occupation levels that pre-dated 6000 BP (ElSx-1, ElSx-5, ElSx-10 and ElTa-18), there was little opportunity to examine deposits older than 6000 years. Therefore, a lack of any parasite eggs exceeding 6000 years old may be a function of the variable nature of their occurrence and/or the small number of early samples examined. There was no evidence to suggest that parasite density, once established at archaeologically visible levels, increased over time or culminated at the point of European contact.

6.4.1 *Relevance of parasite evidence to skeletal anaemia*

Although there is local variation, a general pattern of pathological evidence for iron deficiency anaemia has been frequently noted on human skeletons from the Northwest Coast. Evidence of *Diphyllobothrium,* and to a lesser degree *A. lumbricoides*, both of which are frequently found at the same site, could help explain this pattern. In severe cases, *Diphyllobothrium latum* (giant fish tapeworm) is capable of causing pernicious anaemia. Anaemia acquired in adulthood would not affect the mature skeleton, but if severe anaemia is acquired during childhood, it may be expressed skeletally as cribra orbitalia or porotic hyperostosis. Severe fish tapeworm infection in a young person could result from a regular and prolonged diet of infected salmon. While not capable of causing iron deficiency anaemia on its own, *Ascaris lumbricoides* can

exacerbate poor health in immunocompromised or nutritionally deficient children, and thus contribute to conditions that could lead to a skeletal expression of iron deficiency anaemia.

Modern biomedical literature has debated the antiquity of *Diphyllobothrium latum* in the Americas. Several researchers (i.e. Lantis 1981; Peuzzi and Boucher-Rodoni 2001; Torres et al. 2004; von Bonsdorff 1977:61) have proposed that *Diphyllobothrium latum*, the species that is pathogenic to humans, was introduced to the continent with eastern European immigrants, who brought it with them from regions such as western Finland, Switzerland, Romania, Denmark and Northern Italy, where it was historically endemic (von Bonsdorff 1977:57). Others, such as Bajkov (1933 cited in Dick et al. 2001:65), argue that *D. latum* was endemic in the Lake Winnipeg region of Manitoba prior to European contact, and that Native populations were well acquainted with the infection, recognizing it as a common intrusion in the faeces of the dogs that they kept. The antiquity, regularity and range of the findings in this study suggest *Diphyllobothrium* spp. were endemic to the Northwest Coast of Canada thousands of years prior to European contact. Unfortunately, it was not possible to demonstrate conclusively that the recovered eggs represent *Diphyllobothrium latum*, based on the

morphological characteristics of the eggs alone. However, there is circumstantial evidence that supports this inference.

Species of *Diphyllobothrium* are taxonomically differentiated on the basis of the morphological characteristics of the larvae or adult worm, the preferred intermediary or host species, the location where larvae develop within an intermediary fish species and the environmental conditions required for embryonation (Rausch and Hilliard 1978). Although some researchers have demonstrated correlations between egg size and species (Andersen and Halvorsen 1978; Reinhard and Urban 2003), others have convincingly argued there is too much variability for reliable identification based on the morphological characteristics of the egg shells alone (Andersen and Halvorsen 1978; Bathurst 2005; Bylund 1982; Ching 1984; Holiday et al. 2003; Rausch and Hilliard 1970).

Three species of *Diphyllobothrium* of relevance to humans have been recurrently documented in ecological or medical studies along the Pacific Northwest Coast: *D. latum*, *D. dendriticum* and *D. ursi* (Ching 1984). The preferred definitive hosts of *D. dendriticum* are seagulls (Bylund 1982; Curtis and Bylund 1991; Torres et al. 1998; Wright and Curtis 2000). While this species has also been associated with human diphyllobothriasis infection (Bylund 1982), it is shorter-lived than *D. latum*, surviving only ~ 7 months in the human gut (Rausch and Hilliard 1970;

Torres et al. 2004). This shorter lifespan limits its capability to chronically interfere with vitamin B_{12} absorption, and is thus not associated with the more severe affliction of pernicious anaemia.

Diphyllobothrium ursi is a parasite of bears, though humans can serve as accidental definitive hosts. It has been implicated in at least one modern case of diphyllobothriasis infection due to the consumption of fish liver pâté (Margolis et al. 1973), though it is also not an aetiological source of pernicious anaemia.

Both *D. dendriticum* and *D. ursi* larvae can encyst within the viscera of fish, and are transmitted via the consumption of organs. There is no evidence that *D. latum* larvae encyst, rather they simply embed within the flesh of fish without developing a protective cyst (von Bonsdorff 1977). Fish encysted with *Diphyllobothrium* larvae can appear emaciated and the viscera may become difficult to remove (Ross et al. 1989:36). The Inuit are intuitive of the inferior quality of such fish, and will feed these less desirable quarry to their dogs (Ross et al. 1989).

Diphyllobothrium dendriticum and *D. ursi* may have been more of a risk for dogs, which were likely to feed or scavenge on viscera as a by-product of fish processing. Ethnographic evidence collected from Alaska and the Yukon document that dogs were also fed "stink fish" (raw, fermented fish), "salmon guts and eggs" as well as dried salmon heads

and backbones, over the winter months (Lantis 1980:17). Similar evidence from comparable "complex" riverine hunter-fisher-gatherers in Kamchatka, Russia, who also mass-harvested salmon resources, demonstrate that dogs were commonly fed the "heads and spines" or "bone" remnants of salmon processing (Shnirelman 1994:174). However, once a fish expires, larvae will migrate from the organs through the flesh. For this reason, the Inuit are careful to remove the viscera and organs as quickly as possible before fish are left to dry (Ross et al. 1989). Some researchers have proposed the Inuit practice of cutting fish into thin slices is also a measure of parasite avoidance (Fortuine 1989:61). *Diphyllobothrium dendriticum* and *D. ursi*, therefore, cannot be ruled out as contributing species to the *Diphyllobothrium* assemblage recovered in this project.

However, of the three species documented on the Pacific Coast, *Diphyllobothrium latum* is the only species that prefers humans as definitive hosts, propagating most successfully within this species (von Bonsdorff 1977:10). Dogs may serve as accidental hosts, though the parasite life-cycle is shortened considerably (to a maximum of 2 years) and the eggs they pass are less fertile than those shed by humans (von Bonsdorff 1977:11; Wolfgang 1954). It is also the only species capable of causing serious morbidity and pernicious anaemia in humans. Larvae

embed within the flesh of the intermediary host, making *D. latum* a greater pathogenic risk to human salmon consumers. Larvae can also remain viable in dried or smoked stores (Beldsoe and Oria 2001; Butt et al. 2004; Torres et al. 2004; von Bonsdorff 1977), extending the infectious period beyond the season in which salmon were likely to be consumed fresh and mass harvested.

Like other *Diphyllobothrium* species, with the exception of *D. pacificum*, *D. latum* requires fresh water for eggs to embryonate and hatch. Anadromous salmonids hatch and spend the earliest part of their life-cycle in fresh-water, returning to spawn and die when they reach maturity. They are the most common intermediary host species of *D. latum* along the Pacific Coast (Beldsoe and Oria 2001; Butt et al. 2004; Dick et al. 2001; Ruttenber et al. 1984). As demonstrated, salmonids were an economically important delayed return resource, harvested in bulk during spawning season, and stored for later use. It was a commonly consumed food-source, either fresh or preserved, throughout the year.

Therefore, considering the temperate climate, freshwater ecosystem, year-round and concentrated access to salmon, along with modern medical evidence of *D. latum* infection associated with salmon consumption on the Northwest Coast, and skeletal evidence of iron deficiency anaemia in coastal burial populations, it is therefore argued

that at least some of the cestode eggs recovered in this project are likely to represent the human pathogenic species, *Diphyllobothrium latum*.

6.4.2 *The significance of dogs*

The only known domesticate that accompanied humans into the Americas was the dog. Thus, the antiquity of dogs in North America reflects that of humans (Schwartz 1997). Dog bones have been recovered from the earliest levels of faunal preservation at Namu, ca. 7000 BP (Cannon 1991), an indication that dogs and humans have shared an ecological niche, living conditions, and a food source throughout the history of coastal occupation. Ethnographic evidence from Kwakiutl narratives reflect the care that was given to some dogs, noting that 'good' dogs slept indoors and were intentionally fed (Boas 1935:119-122). Their epidemiological significance in the emergence, maintenance and dissemination of disease, therefore, should not be overlooked.

Although dog parasites have occasionally been noted when found at archaeological sites, they are not usually the focus of interest or recovery, considered most frequently as an intrusion to cultural assemblages or as a potential cause of misdiagnosis (Fry 1985; Horne 1985; Jones 1990). The epidemiological and ecological significance of dog-related parasites has yet to be fully appreciated by archaeologists.

The Cyclophyllidean genus, *Echinococcus*, serves as an example of the importance of dog parasites to epidemiological reconstruction. Archaeologically, the presence of *Echinococcus* spp. cysts found among human remains has frequently been considered a surrogate indicator of agricultural practices (Gonçalves et al. 2003; Ortner and Putschar 1981:232). This interpretation comes from the modern association of *Echinococcus* species such as *E. granulosis* (dog tapeworm) with domestic ruminants such as cattle and sheep, that frequently serve as intermediary hosts (Meltzer et al. 1956). However, the sylvatic life-cycle of such parasites is still poorly understood (Traub et al. 2005:44), and it is likely that the parasite was maintained within North American wildlife ecosystems between such intermediary hosts as wild goats, moose, caribou and/or deer, and definitive hosts such as wolves, coyotes or fox without the necessary presence of domesticated ruminants (Lantis 1981:88). Ethnographic evidence suggests Northwest Coast dogs were valued for their hunting capabilities, including tracking species such as deer and goat (Cummins 2002:283; Schwartz 1997:35), therefore there is reason to speculate there was regular contact between these species. Hydatid cyst disease, attributed to *Echinococcus* infections, has been documented among First Nations and Eskimo populations in Alaska and the subarctic, a finding attributed to the presence of dogs in these

populations (Fortuine 1989:61-62; Lantis 1980:2, 17). Archaeologically, cysts have been recovered from human burials in North Dakota and the Aleutians (reviewed in Reinhard 1992), though neither of these contexts were associated with agriculture.

Today, *Echinococcus* is a common parasite of domestic and semi-domestic dogs in developing countries. However, studies in the distribution of the parasite have found a higher prevalence in dogs from nomadic and semi-nomadic communities over dogs from more sedentary settlements, including those with access to urban abattoirs and the viscera of domestic animals (Traub et al. 2005:44). The implication of these findings is that the sylvatic life-cycle of the parasite may, in fact, be more important to the dissemination of the parasite than the domestic life-cycle. The authors of this study suggest these findings may be due to the tendency to hunt older animals that have subsequently accumulated more parasites, as opposed to domestic animals, which are more likely to be culled at a young age.

The archaeological significance of this genus, along with *Taenia* discussed earlier, need not be considered obligatory confirmation of agricultural practices. Nor should it be presumed that these Taeniid genera only reached the Americas through European expansion and the subsequent introduction of their domestic ruminants. Its significance

should not be neglected in hunting and gathering populations. The potential presence of *Taenia* at Northwest Coast archaeological sites was not only a health risk and likely indication that dogs were present in the community, but may also serve as cultural and ecological evidence of hunting practices and resource choice.

Evidence of the trematode *Nanophyetus* recovered in this project also serves to demonstrate the value of dog parasites in archaeological interpretation. Although *Nanophyetus salmincola* carries a rickettsia species, (*Neorickettsia helminthoeca*) that is fatal specifically in canines, there is little documented evidence of a severe adverse effect on humans (Beldsoe and Oria 2001; Eastburn et al. 1987). Human infection is relatively uncommon and due to accidental infection (Harrell and Deardorff 1990), therefore health risk was minimal. Like *Diphyllobothrium*, salmonids are the most successful second intermediary hosts of *Nanophyetus* (Harrell and Deardorff 1990). Larvae typically encyst within the kidneys and muscles of the fish, elements likely to have been fed to or scavenged by dogs (Eastburn et al. 1987). Coastal wolves have been observed consuming only the heads of salmon, a strategy that some researchers attribute to the adaptive avoidance of parasites such as *Nanophyetus salmincola* (Darimont et al. 2003:352). Humans may act as alternative hosts, excreting unembryonated eggs in their faeces (Beldsoe

and Oria 2001; Schmidt and Roberts 1977:310), so the presence of eggs in human cultural deposits may be attributed to humans or dogs.

As a companion species sharing food, living space, and a local ecology, Northwest Coast dogs were exposed to the same epidemiological conditions as human populations. Today, dogs are considered a significant source of human zoonotic infections, such as *Echinococcus*, particularly among children, pregnant women and immunocompromised individuals (Robertson et al. 2000). They can act as alternative or reservoir hosts for species such as *Diphyllobothrium* spp. (Hull 1963:437; Torres et al. 1998; 2004) or mechanical vectors of *Ascaris lumbricoides* (Traub et al. 2002; 2005), contributing to site contamination or parasite dissemination. As archaeological evidence, canine parasites are relevant indicators of disease risk and environmental conditions on the Northwest Coast, and their cultural significance should be valued as highly as human parasite evidence.

6.5 Relevance to Local Sites: Palaeoepidemiology and Pathoecology

As the samples in this project constituted homogenized midden matrix, the population of a community/site was the lowest level of analysis that could be isolated. The significance of the temporal and spatial distribution of parasite evidence on the Northwest Coast is best

demonstrated at this local community level. This is also the level at which diversity is most apparent, and thus interpretations are most varied. In experimental studies with *Ascaris suum* and *Trichuris suis*, Larsen and Roepstorff (1999) intentionally implanted parasite eggs in experimental plots in order to study their development and survival properties. They discovered that only a fraction of the eggs that were implanted were recovered after just 30-50 weeks. Therefore, in uncontrolled archaeological conditions of significantly greater time depth, it must be assumed that the eggs recovered in this project represent only a fraction of those that were initially deposited.

There are multiple biological, environmental, and culture factors that can affect parasite population dynamics, what Martinson and colleagues (2003) refer to as *pathoecology*, that in turn influence the archaeological recovery of parasite evidence over time or between different sites. The factors influencing these changes are likely to have been dynamic, and to have differed based on each site's unique ecology, population, and culture history. Epidemiologists study the interwoven factors that shape the dynamics, distribution and determinants of disease in populations. Palaeoepidemiology extends this interest to past populations (Martin and Goodman 2002; Mendonça de Souza et al. 2003) to demonstrate how disease transformed human health, culture, and

ecology. Some of the epidemiological factors influencing the diversity in the distribution of parasite evidence that will be discussed in the following section include differences in host (including intermediary host) population size/density, resource base, degree of mobility/sedentism, living space, site use, technology, intergroup and interspecies contact, ecology, preservation as well as changes in all these variables over time (Cohen 2000; Dobson and Carper 1992; Dunn 1968; Kent 1992; Noble and Noble 1982; Petney 2001; Thompson 2001).

6.5.1 *Health*

It should be acknowledged that health is a subjective cultural concept and conclusions about the health of the populations that experienced parasite infection cannot be made from an emic perspective. Although the presence of parasite eggs implies infection, and infection by Western biomedical standards implies ill health or disease, worm accommodation is not always considered a morbid affliction. In many instances, minor parasite burden in a well-nourished individual is not likely to have caused morbidity, so there would be no obvious reason to associate its presence with malaise. It is impossible to know how people on the coast thought or felt about intestinal parasites, but we can assume they were aware of their existence. Intestinal helminths, or *macro-* parasites, are large enough to be seen with the naked eye. Whether

consumers were conscious of the larvae or cysts embedded in the food they ate or not, they must have taken notice of the proglottids (tapeworm segments) or worms they or their dogs would periodically excrete.

There is no mention of parasites in the rich ethnographic literature of the Northwest Coast, and barely any mention of defecation habits at all, but analogy regarding their attitudes towards the parasites they harbour, can be drawn from other cultures around the world. The Pichátaro of Mexico, for example, recognize two different types of intestinal worms, *solitaria* (tapeworm) and *lombrices* (stomach worms) (Young and Garro1994). The names alone show an indigenous knowledge of parasite life-cycles. Tapeworms, such as *Diphyllobothrium* or *Taenia*, can become large, and humans are frequently only parasitized with one at a time. *Ascaris lumbricoides* (human roundworm), on the other hand, can be amassed in the gut in numbers so great that they can sometimes lead to impaction. The Pichátaro believe everyone has a solitaria, which is considered essential for "calling the appetite" and maintaining the body's strength (Young and Garro1994:55). In fact, the *lack* of a solitaria is considered a dangerous condition, as it could cause one to loose their appetite entirely.

Rural Dominican populations in the West Indies believe every human body is born with a "worm bag", an organ specifically for housing

worms, situated just above the stomach (Quinlan et al. 2002). The worm bag is empty when a child is born, but it is believed to be filled by inadvertently ingesting 'invisible' worm eggs from soiled hands, food or objects. Therefore, without visual validation of the existence of parasite eggs, Dominican populations understand that worms can be transmitted through contaminated soil (i.e. as *Ascaris lumbricoides* is), objects, or water. It is believed that humans and worms share a symbiotic and primarily beneficial relationship, but too many worms can create an internal imbalance resulting in a detrimental effect on the system.

Anthropologist Edward Green (1999) has noted similar cultural conceptions of the benefit or even the necessity of an internal worm or "snake" among Africans along the eastern and southern coast countries of Mozambique, Swaziland and South Africa. Like the Pichátaro, there is a distinction made between a singular 'snake' or 'worm' and multiple 'snakes' or 'worms'. These worms are associated with bodily functions, such as appetite, strength or even menses or childbirth. But there is also, in some cases, a distinction between health-promoting and protective worms and those that cause illness, weaken the body or "eat"/"suck up" a person's blood (Green 19999:95). This distinction seems related primarily to a concept of physiological balance, whereby too many worms can be

detrimental to an individual, but too few are considered dangerous to one's health as well.

The Sidama of Ethiopia share similar beliefs about worms and internal 'balance' (Vecchiato 1997:254). Worms are considered necessary for proper digestion, and any symptoms affiliated with poor digestion such as nausea, cramping or diarrhea, are considered a sign that the worm is dissatisfied or has rejected the ingested food. Among the Sidama, when a person is gravely ill it is believed that their worm (or *hamasho*) migrates to their mouth in search of food, an event that is considered a fatal omen as it frequently accompanies death (Vacchiato 1997:255). Therefore, the loss of too many worms at any point in one's life is considered dangerous or 'unhealthy'.

Even biomedical studies have demonstrated that there are health benefits to worm burden. *Ascaris lumbricoides*, for instance, stimulates the production of IgE antibody in those with chronic parasite infections, thus effectively decreasing allergic and asthmatic reactions to environmental stimuli (Bundy et al. 2000; Gore and Custovic 2004; O'Lorcain and Holland 2000:55; Yazdanbakhsh et al. 2002). Other studies have shown that infection with worms that prefer other host species (i.e. *Trichuris summ*) reduces the symptoms of Crohn's (inflammatory bowel) disease (Bundy et al. 2000:274; Gore and Custovic 2004). Studies in fish biology

have also demonstrated that cestode infection can actually increase fish size (Arnott et al. 2000), a symptom with enticing economic benefits for the angler, if not a competitive advantage for the fish.

6.5.2 *Nanophyetus*

Macroparasite infections are typically persistent or chronic in nature, with the capacity to be maintained within a host for years or even decades. While the parasites recovered in this project may contribute to or exacerbate morbidity, they were more likely to have had an indirect, rather than a direct association with an individual's death. There are some exceptions. For instance, *Nanophyetus salmincola*, the vector of the rickettsia *Neorickettsia helminthocea*, can be acute and fatal for canid species. Infection in humans, known colloquially as "salmon flu", may cause mild morbidity and symptoms such as diarrhea, abdominal discomfort, and fatigue, but is not known to have had any long-term deleterious consequences. No evidence of this infection would be apparent on human skeletal remains. Although *N. salmincola* is known to veterinarians along the Northwest Coast as an aetiological cause of abrupt death in modern dogs that consume raw salmon, the history of the parasite in the region is as yet unknown.

Nanophyetus egg morphology is similar to that of *Diphyllobothrium*. Some overlap in identification may have occurred, but the number of eggs

with clear and definitive characteristics of *Nanophyetus* were few (n=4). Most eggs were recovered from residential sites (EISx-3, EISx-10, EITb-1) that were inhabited by larger populations of both humans and dogs for longer durations of time, allowing for the accumulation of faecal wastes from both species. It was also found at one camp, EISx-4. But even at the residential sites, the density of *N. salmincola* was minimal, with only one egg found at each location. Therefore, *Nanophyetus* does not appear to have been a consistent or significant risk to humans or their dogs at the sites tested in this region.

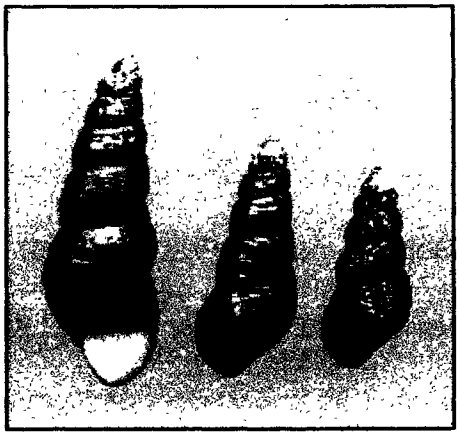


Figure 6.1: Size range of freshwater snail, *Juga pliciferea* (from Kohl 2000).

As an archaeological artifact, *N. salmincola* is a valuable ecological indicator. While trematodes such as *Nanophyetus* can be indiscriminating in their choice of definitive host, they are more particular about the species in which the 1st stage larvae (the cercariae) develops (Georgi 1974:147). Therefore, the distribution of the species is limited to the geographic range of the first intermediary host, the freshwater snail *Juga plicifera* (synonym *Oxytrema silicula*) (Figure 6.1), found attached to rocks or debris in deep sections at the bottom of freshwater streams along the

North American Pacific Coast (Barlough et al. 1998; Bennington and Pratt 1960; Eastburn et al. 1987; Schmidt and Roberts 1977:311). What is more, cercariae will only be shed by snails larger than 2.5 cm in length (Bennington and Pratt 1960:94), suggesting this parasite requires a healthy and stable snail population in order to thrive. As freshwater snails were of no known economic importance to humans, the significance of *Juga* spp. in archaeological assemblages may have been disregarded. *Nanophyetus salmincola* is pathogenic to fish, and could be detrimental to the health of salmon stocks and deleterious to their appearance, triggering avoidance strategies (Bennington and Pratt 1960:95). Thus a proliferation of the parasite within the local ecosystem could negatively affect the economy of the humans that relied on salmon resources.

6.5.3 *Cyclophyllidea*

Some Cyclophyllidean species would be capable of causing chronic infection and severe morbidity. Although it was not possible to ascertain microscopically which genera were represented by the Cyclophyllidea findings, it was determined that the Taeniid (tapeworm) genera *Taenia* and/or *Echinococcus* or the Hymenolepididae genera *Hymenolepis* (dwarf tapeworm), were the most likely possibilities. *Hymenolepis* symptoms can cause abdominal pain or diarrhea, but in most cases infection would likely go undetected. Cyclophyllidea eggs

were only recovered from residential sites. The storage of foods at residential sites for consumption over winter may have drawn commensals such as mice or rodents into more frequent human contact, increasing the pool of potential hosts and providing more opportunity for transmission between species.

Recent medical evidence has suggested *Taenia,* like *Diphyllobothrium*, may also cause vitamin B_{12} deficiency, leading to pernicious anaemia (Vuylsteke et al 2004). Both *Taenia* and *Echinococcus* can produce cysticercosis (cysts) in humans, the majority of which are asymptomatic, but on occasion can rupture and lead to fatality (Lantis 1980; 1981). No evidence of calcified cysts have been noted from human burials on the coast, though such evidence is not a common archaeological find from any location. Such negative evidence may be attributed either to the naivety of the excavator in discerning calcified material among other shell midden debris or diagenic processes which can restrict their preservation.

Animals from which the Taeniid genera *Taenia* or *Echinococcus* were most likely to have been transmitted – wild goats and deer – were primarily hunted during the fall and winter months, when residential sites were most frequently occupied (Harkin 1997:7). All 10 of the Cyclophyllidea eggs recovered were found at residential sites: ElSx-1,

ElSx-5, ElSx-10, ElSx-18 and ElTb-1. The presence of dogs at coastal sites may have significantly contributed to the distribution of these parasites, as they can act as definitive hosts of Taeniid species. Large dog populations, or the tethering of dogs at residential sites, would lead to an accumulation of dog faeces, increasing the amount of Cyclophyllidea eggs deposited at such locations (Lantis 1980). This parasite appears in the archaeological assemblages of this region at the same time *Diphyllobothrium* does, 3700-3490 cal. BC.

The relatively low frequency (n=10) but consistent presence of Cyclophyllidean eggs relative to *Diphyllobothrium* or *Ascaris* finds suggests this parasite was of minor but continuous significance to coastal occupants. Due to an inability to differentiate taxa, several Cyclophyllidea species may be represented in the recovered assemblage, each with different life-cycles, modes of transmission, and virulence.

Hymenolepid genera would have been of minor health significance, but the practice of storage may have increased the density of the parasite in the local ecosystem. Alternatively, terrestrial hunting practices would have had a minor impact on the life-cycle of Taeniid genera. As humans are not definitive hosts, worms do not mature within human hosts nor are eggs shed in human faeces. Therefore, larger human populations or greater predation pressure on parasitized herbivores would not result in

more Taeniid parasites. An increase in the population of definitive hosts, however, may serve to increase the amount of Taeniid eggs excreted into the environment. Thus, an increase in dog population or density is likely to have amplified the regularity with which Taeniid eggs were deposited at a site, resulting in a greater likelihood of archaeological recovery. But embryonated eggs must be consumed by intermediate hosts, either terrestrial herbivores or humans, in order to develop into infective cysts. Deer and/or goat were not likely to have increased their grazing around human settlements, so an increased density of eggs at human settlements would have little opportunity to infect a definitive host population. Although humans may serve as intermediary hosts, dogs were not likely to gain regular access to human flesh for consumption, thus the life-cycle of Taeniid eggs would not be completed. Any increase in the density of eggs deposited at a site is not likely to have had an impact on the circulation of Taeniid genera in the ecosystem. Thus, the human impact on the natural life-cycle of this parasite would be minimal.

6.5.4 *Ascaris*

The health consequences of ascariasis were potentially significant, depending on the severity of infection. Mild cases involving only a few worms in relatively healthy individuals, can be asymptomatic. Today, *A. lumbricoides* is one of the world's most common intestinal parasites, and

many of those infected are not likely to even be aware of it. However, in situations where health is compromised or nutritional resources are inadequate, *A. lumbricoides* infection can become quite serious, leading to gastrointestinal upset, stunted growth, impaired cognitive capacity, intestinal obstructions, lowered immunity, fat, protein and vitamin A malabsorption or even death (O'Lorcain and Holland 2000; Stephenson 1980). It is particularly common in children, in whom there is an increased risk of severe infection and fatality (Carneiro et al. 2002; Stephenson 1980).

Ascaris is the oldest parasite genera recovered in this project, dating to 4775-3490 cal. BC, preceding other initial parasite finds by as much as 2000 years. As argued, it likely accompanied the earliest human occupants into the region, an inference supported by the antiquity of the finds. It is an environmentally persistent pathogen, surviving in the soil for months or even years, and is likely to have plagued humans for millennia, but increased sedentism and population density would have provided more opportunity for infection. *Ascaris* eggs were significantly more common at residential sites and were recovered at every residential site tested. Conditions at such sites would constitute close living arrangements in aggregated housing, circumstances that have been demonstrated to lead to easier dissemination in modern populations (May

and Anderson 1983; O'Lorcain and Holland 2000). Abundant archaeological evidence of plank housing first appears on the coast ca. 2000 BC (Ames and Maschner 1999:93). Accumulated faecal waste and extended contact with such debris would increase the density of parasite evidence in the local environment. The close proximity of housing to waste disposal, as is necessary at coastal sites, is also conducive to the mechanical dissemination of helminth larvae by trampling, dogs, and even common houseflies (Vecchiato 1997:250), in which *A. lumbricoides* larvae can remain viable in the vomitus for up to 8 hours (Dipeolu 1982).

Individual *Ascaris* worms only survive about two years in the human gut (O'Lorcain and Holland 2000:54), but infection can be maintained indefinitely if exposure to viable eggs is habitual and consistent. Infected individuals would have carried *Ascaris* with them to resource acquisition camp sites, where fewer people would contribute to the accumulation of faecal waste, but the parasite would be deposited, nevertheless. Thus, there was the potential for camps ElTa-25 and ElTb-2, the only two camps where *Ascaris* eggs were found, to assist in the dissemination of the parasite throughout the region, if such sites were used contemporaneously by different family groups from different residential locations. Most transmission, however, was likely to occur and

be maintained at residential sites, where larger numbers of people resided in densely compacted living conditions.

Abiotic factors associated with midden deposition and taphonomic processes may provide another explanation for the higher density of *Ascaris* eggs recovered at residential sites. *Ascaris* is a soil-borne pathogen, and modern veterinary studies interested in the viability of *Ascaris suum* eggs in barnyard conditions have demonstrated that eggs survive better in situations where faeces are rapidly deposited in moist and shady conditions, as opposed to those where they are more slowly accumulated and left exposed to sun and dessication (Gaasenbeek and Borgsteede 1998; Larsen and Roepstorff 1999). Faeces that are rapidly buried remain moist and experience less temperature extremes that can ultimately be detrimental to egg preservation (Larsen and Roepstorff 1999:217). They are also less susceptible to dissemination by wind transport or runoff from rain or melting snow (Patz et al. 2000), keeping them within the midden where they were deposited and increasing their likelihood of archaeological recovery.

Aggregated populations at residential sites would accumulate waste rapidly over the duration of habitation, which was most common during the winter months when fresh resources were scarce. *Ascaris* egg development and infectivity slows down in colder temperatures (Wagner

and Polley 1999), though eggs can also accumulate over the winter months and develop all at once when conditions warm up in April or May (Larsen and Roepstorff 1999:218; Wagner and Polley 1999). At short-duration camp sites, faecal wastes would accumulate at a slower rate and would be left exposed for longer periods of time. Such sites were also more likely to be used during summer months, when multiple resources were available and transportation was easier. Thus, eggs would be exposed to warmer, sunnier conditions, which are detrimental to *Ascaris* egg preservation (Gaasenbeek and Borgsteede 1998; Larsen and Roepstorff 1999).

6.5.5 *Diphyllobothrium*

Diphyllobothriasis appears to have been a common infection, as evidence of this parasite was recovered in high densities at most of the sites tested. Given the dietary importance of salmon, the preferred second intermediary host of *Diphyllobothrium* larvae, this is not an unexpected finding. Diphyllobothriasis has the potential to be a chronic infection, maintained for decades in an individual's intestine. Circumstantial evidence of skeletal anaemic infection, common to many burial populations along the coast, supports the likelihood that coastal inhabitants were at risk to severe cases of fish tapeworm infection and subsequent pernicious anaemia.

However, *Diphyllobothrium* eggs were not recovered from all sites tested in this survey. The two mainland sites from which little or no evidence was recovered are particularly notable: ElSx-1 and EkSx-12. Both are village aggregation sites, with large salmon streams, and ample archaeological evidence of intensive salmon utilization. The entire depth of the Namu Rivermouth Trench was tested, 26 consecutive auger samples in total to a depth of 3.5 meters, but only 2 *Diphyllobothrium* eggs were recovered, both preserved in an unembryonated state. In order to control for sampling error, an additional 12 separate locations were tested across the Namu site (Appendix III). Only one additional *Diphyllobothrium* egg was identified, also preserved in an unembryonated state. Several *Ascaris* (n=5) and Cyclophyllidean eggs (n=3) were also recovered from various locations across this site, so deposition conditions were conducive to parasite egg preservation. If deposition and taphonomic processes are controlled for, what then, can account for the lack of *Diphyllobothrium* eggs recovered from Namu and Koeye River?

The ecological circumstances at ElSx-1 may have been unfavourable for the fish tapeworm life-cycle. Parasite species such as *Diphyllobothrium* have been used as biological tags to identify the origin of fish stocks (Bailey 1984; MacKenzie and Abaunza 1998; Mosquera et al. 2000). This method is based on the premise that parasites can be

sensitive to very specific environmental conditions, and fish will only become infected at a location where that parasite is endemic in the ecosystem (Dzikowski et al. 2003; MacKenzie and Abaunza 1998). *Diphyllobothrium* are a suitable tag, as their complex life-cycle requires very specific environmental conditions in order to thrive at an endemic level. These conditions are not present at all salmon-spawning locations. Once excreted by the definitive host (i.e. humans), the first stage of the parasite's life-cycle requires embryonation in fresh water. Ideal conditions require shallow, litoral environments with light exposure and minimal movement, along with the presence of both first intermediary (copepod) and second intermediary (fish) host species (Bylund 1982:222). A change in any of these factors due to anthropogenic or natural forces can result in a suspension of the parasite's life-cycle. It appears the conditions at Namu were never appropriate for the maintenance of *Diphyllobothrium* in the local ecosystem, from initial habitation onwards, regardless of anthropogenic impact on the environment.

The village at Namu was located on a terrace, steeply elevated from the river. Therefore, excrement deposited in the midden was prevented from entering and contaminating the river. The Namu River is deep, so any eggs entering the watercourse may not have had enough light exposure to hatch. The flow empties directly into Fitz Hugh Sound, a

wide, exposed channel that opens to the Pacific Ocean. Anthropogenic contamination is less significant in open water than it is in confined estuaries and sheltered bays due to the dilution of contaminants (GESAMP 1991). Fluctuations in water level due to tidal processes may also have left eggs vulnerable to exposure and dessication (Pietrock and Marcogliese 2003). The presence/absence of the first intermediary species, copepods, cannot be verified archaeologically, though it is likely they were present in the ecosystem. Regardless, if human excreta contaminated with eggs had minimal contact with the river, then salmonids that hatched and spawned in the Namu River would be exposed to less tapeworm infection. If the Namu residents primarily consumed fish from uncontaminated sources, they would harbour less *Diphyllobothrium* infection and excrete fewer eggs. A low incidence of skeletal anaemia in the Namu burial population, in relation to other coastal sites, is consistent with these negative findings.

The site at EkSx-12 was only slightly elevated and the midden was located along the river. However, the Koeye River is deep and faster flowing, conditions that are also non-conducive to the viability of *Diphyllobothrium* eggs. Therefore, a lack of appropriate environmental conditions to maintain *Diphyllobothrium* would result in less infection of

the fish resources, and thus less human infection with the parasite at this site as well.

Yet the distance from the Namu or Koeye River villages to the other sites tested in the project is minimal, in some cases less than 5 km. Considering the chronic nature of diphyllobothriasis, humans infected with the parasite could excrete eggs for decades, once infected. Wherever they defecated, *Diphyllobothrium* eggs could be deposited. Considering cultural factors that are likely to have brought contemporary populations into contact with one another, such as trade, intermarriage, kinship, and even conflict (Harkin 1997), it is unreasonable to expect that those infected with fish tapeworm from other *Diphyllobothrium*-infected village sites such as ElTb-1 or ElSx-3 did not reside, intermarry, visit or defecate at ElSx-1 or EkSx-12. However, the matrix samples analysed in this study were homogenised samples representative of the site's population over considerable periods of time. Individual, isolated infections are expected to have contributed to the midden matrix, though such samples would be diluted.

Diphyllobothrium eggs are not transmitted directly by soil and require water and sunlight for embryonation (Bylund 1982; von Bonsdorff 1977). Those *Diphyllobothrium* eggs that entered the midden were not likely to contribute significantly to the pathoecology of the parasite in the

local ecosystem, as they represent eggs that were fixed in place and did not make it to a water source to complete the first stage of their developmental cycle. Some eggs would be removed from the midden in water runoff from rain or melting snow and transported to larger water-courses (Larsen and Roepstorff 1999). Likewise,
midden debris deposited within tidal range, a very deliberate practice, could be swept to sea every 24 hours (Jones 1914:57), taking recently deposited eggs with it. But the excreta deposited in the midden was likely only a portion of that produced by a site's population. Although faecal waste was clearly deposited in shell middens, it was not likely the sole repository of such wastes. Swamps, rivers, small bodies of water, and tidal flats were also used as defecation sites (Boas 1928:23, 57; Jones 1914; Swanton 1905:217). The parasite eggs recovered in this project should be considered but a proxy of the level of diphyllobothriasis infection present in the resident population.

Although they were recovered at all site types, *Diphyllobothrium* eggs were significantly more common at camp sites. The taphonomic conditions that are hypothesized to have preserved *Ascaris* eggs at residential sites may not have been as optimal for the preservation of *Diphyllobothrium* eggs. There are no comparative studies on the factors that influence *Diphyllobothrium* egg preservation in soil, as there are for

Ascaris eggs. But *Ascaris* eggs require soil and shaded conditions to embryonate and become infective. *Diphyllobothrium* eggs, conversely, require sunlight for embryonation, and thus the structure of their egg shells are able to withstand sun exposure. *Diphyllobothrium* eggs deposited in moist but sunny conditions may have preserved better than *Ascaris* eggs deposited in the same conditions.

Cultural avoidance strategies may also account for this spatial pattern of parasite distribution. Ethnographic evidence documents that the Kwakiutl had an expansive pharmacopoeia of herbal medicines (Codere 1950:58). Plants available on the coast such as berries and fern root have natural vermifuge properties. Strawberries, blueberries, and cloudberries (synonym – baked-apple berries *Rubus chamaemorus*) have been demonstrated to be effective in driving out tapeworms (von Bonsdorff 1977:84). In the bogs of north Finland, where *Diphyllobothrium latum* is endemic, seasonal berry pickers are said to leave "heaps of broad tapeworm deposited with excrements ... on the bogs" (von Bonsdorff 1977:84). Berries such as salmon-berries, strawberries, raspberries, currents, blueberries, and crab-apples were harvested on the Northwest Coast seasonally over the summer months (Dawson 1880:114; Folan 1984; Pomeroy 1980:47), when short-term and specific resource acquisition camps are most likely to have been utilized. Although they

were dried or preserved in grease, it can be assumed that many were enjoyed fresh, in peak quality. Thus, the seasonal consumption of resources such as berries could result in the inadvertent expulsion of *Diphyllobothrium*, accounting for the higher densities of fish tapeworm eggs at camp sites. While the vermifuge qualities of fresh berries have been noted to be effective for tapeworm expulsion, there is no reference to their effectiveness with other types of internal parasites.

The most effective vermifuge available to the coastal inhabitants, however, was the root of the male fern (*Dryopteris filix mas* – of the Dryopteridaceae or wood fern family) (Amici 2001; von Bonsdorff 1977:84). Male fern rhizomes have been recognized for millennia as an effective treatment for tapeworm infection in other regions of the world. Pliny the Elder expounded on the anthelminthic virtues of this species in Rome in the first century AD (Amici 2001:5). Male fern is a common vascular plant indigenous to the Northwest Coast that prefers rocky crevices and moist, alluvial forests (Douglas et al. 1991:129; Zika 1989). It was available through the summer and collected and dried in October

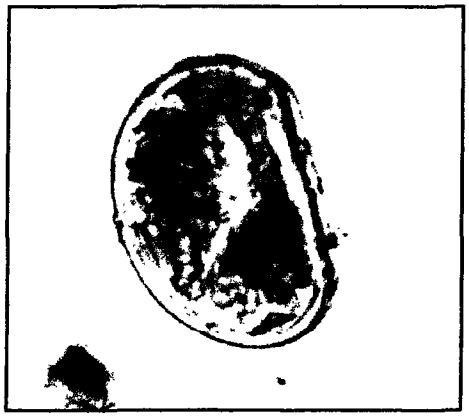


Figure 6.2: Dryopteridaceae (wood fern) pollen from ElTb-1.

(Pomeroy 1980:47), extending the use of the potential vermifuge throughout the winter months. Evidence of Dryopteridaceae pollen was observed in the microscopic samples analysed in this project (Figure 6.2).

The active ingredients in male fern are a group of acylphloroglucinol compounds, a natural derivative of which is desaspidin, which is still used to dispel tapeworm such as *Diphyllobothrium latum* in eastern European countries (i.e. Kvist 1963; Palva et al. 1965) under the marketed name of Rosapin™ (von Bonsdorff 1977:85). Desaspidin paralyses the scolex (head) of the tapeworm, the mechanism by which they "hook" or suction to the human intestine, forcing it to release (von Bonsdorff 1977:84). This treatment is not effective on other forms of parasites, such as nematodes (i.e. *Ascaris*), as they do not require a hooking mechanism to attach to the intestine. Thus, the coastal populations had at their disposal several means by which to treat helminthic infections, particularly on a seasonal basis. This combination of ecological and cultural factors may account for the high density of *Diphyllobothrium* spp. at camp sites in relation to other parasite genera.

The risk of diphyllobothriasis infection is also correlated with the size of the intermediary host (fish) and the frequency with which it had ingested infective larvae (Vickery and Poulin 1998). Faecal contamination of fresh water sources would lead to increases in phosphorous and

nitrogen, the food-source of zooplankton. This supplementary food base would sustain increases in aquatic herbivores, such as copepods and fresh-water snails, the intermediary hosts for both *Diphyllobothrium* and *Nanophyetus salmincola*, respectively. Freshwater copepods are a primary food source for salmon fry and other small fish. *Diphyllobothrium* larvae may also survive through successive paratenic hosts, weathering consumption up the food chain, infecting planktivorous and carnivorous species alike. The longer fish lived and ate in these environments, the more time they would have to accumulate parasites. Thus larger, older fish are inclined to harbour more *Diphyllobothrium* spp. (Ching 1984; Torres et al. 1998; 2004). Targeting older fish, therefore, would increase the risk of diphyllobothriasis infection. Storage would also elevate the risk of exposure by extending the period of susceptibility.

Salmon Species	*Freshwater residence*	*Age at maturity*	*Spawning Period*
Sockeye (*O. nerka*)	1-2 years	3-7 years (average 3-4)	spring and summer
Chinook (*O. tshawytscha*)	0.5-2+ years	3-7 years (average 5-7)	spring and fall
Coho (*O. kisutch*)	1 year	2-4 years (average 3)	fall
Chum (*O. keta*)	1-3 months	2-7 years (average 3-4)	fall
Pink (*O. gorbuscha*)	1-3 weeks	2 years	fall

Table 6.1: Life-cycles of Pacific salmon species (modified from Ruckelshaus et al. 2002:668).

Species of salmon differ in the length of time they spend in fresh-water ecosystems (Table 6.1). Pink salmon (*O. gorbuscha*), for instance, a lean species commonly dried for storage, spends the least amount of time in fresh water, migrating out to sea just 2-3 weeks after hatching, and returning to spawn at 2 years of age (Ruckelshaus et al. 2002:668). Pink fry and smolt would only have access to freshwater copepods for a very short period of time. Chum salmon (*O. keta*), another lean species, spend 1-3 months in freshwater before migrating out to sea, returning to spawn at 2-7 years of age (typically 3-4 years) (Ruckelshaus et al. 2002), so their exposure time to infected copepods is also limited. Others such as sockeye (*O. kisutch*) or chinook (*O. tshawytscha*) spend more time in freshwater systems after hatching (1-2 years) and return to spawn at 3-7 years of age (Ruckelshaus et al. 2002). Coho (*O. kisutch*) is intermediate between these extremes, spending about a year in fresh water before migration, and returning after 2-4 years at sea (typically 3) (Ruckelshaus et al. 2002).

Sockeye and chinook are oilier species, and the rich quality of the flesh is highly prized. Due to the length of time they spend in fresh water, they are more likely to be infested with parasites such as *Diphyllobothrium* spp. or *N. salmincola*. All species of salmon were likely preserved to some degree, extending the period of time humans and dogs were exposed to

any harboured parasites, though oilier species were more vulnerable to spoilage. Patterns in the utilization of different salmon species may have influenced the amount of diphyllobothriasis infection a particular community was exposed to, thus accounting for some of the variability in the recovery of archaeological parasite eggs. Sockeye, chinook and coho may have harboured more *Diphyllobothrium* spp. than pink or chum. But the intestinal contents of a preserved human mummy found in northern British Columbia contained the scales of chum salmon along with *Diphyllobothrium* spp. eggs (Dickson et al. 2004). Testing this hypothesis will be possible with technological advances in PCR extraction of DNA from archaeological salmon remains, allowing for the precise identification of salmon species. Preliminary research along this line of enquiry has begun along the central coast at Namu (Yang et al. 2004), where chum, sockeye, coho, and pink salmon have been identified from archaeological salmon vertebrae. Unfortunately, there was little evidence of *Diphyllobothrium* recovered from Namu with which to correlate these findings. But the majority of salmon bones tested from Namu also represent those species that spend the least amount of time in fresh water, and are subsequently least likely to harbour *Diphyllobothrium* larvae: pink (45.1%) and chum (23.4%) (Cannon and Yang In press). Sockeye (25.2%), coho (4.5%) and chinook (0.9%), species that spend

the most amount of time in fresh water, represent the remaining portion of the salmon faunal assemblage.

6.6 Discussion Summary

From a biomedical perspective, the four genera of parasites recovered do not indicate that there was a diverse or significant health risk to residents of the Northwest Coast. Most of the genera recovered in this project were of zoonotic origin, a finding in keeping with many researchers' predictions of hunting and gathering economies. Humans are not a required host in their reproductive life cycle. As the sampling methods in this study were aimed at recovering robust evidence, it is possible that analysing larger soil samples from a greater diversity of intra and inter-site locations might have uncovered a greater breadth of species. However, it can be assumed that those genera that were recovered are a reflection of the most abundant and common parasites that could have infected humans in each ecosystem.

Discussing patterns of parasite diversity in relation to the geographic distribution of hunter-gatherers, Dobzhansky (in Dunn 1968:226) states that "Where [the] diversity of inhabitants is great, the environment is rich in adaptive opportunities." By analogy, where dietary diversity is great, there is a risk of encountering a greater variety of food-

borne pathogens. Thus, there was greater richness in the parasite genera recovered from residential sites that were frequently revisited, where habitation periods were extended and a variety of stored and fresh foods would have contributed to the diet over the leaner winter season. The most common and regularly exploited resource in the region was fish, particularly salmon. Two of the four recovered genera also required salmon as intermediary hosts (*Diphyllobothrium* and *Nanophyetus*).

Unlike the other three genera recovered, the life-cycle of Cyclophyllidean parasites does not appear to have been affected by any anthropogenic modification of the local ecosystem. Human behaviour was not likely to have increased the number of Cyclophyllidea eggs circulating among terrestrial herbivores, though the accumulation of faecal waste characteristic of residential sites did increase the archaeological visibility of the eggs.

Unlike Cyclophyllidea, anthropogenic factors do appear to have contributed significantly to the density of *Diphyllobothrium* spp. in the ecosystem at the local level. If abiotic and biotic conditions at a site were adequate to maintain the *Diphyllobothrium* life-cycle, then cultural practices such as a dietary reliance on salmon, mass harvesting, and cold-smoked or dried storage could amplify the risk of exposure to infective larvae. Greater numbers of infected humans and/or dogs could

result in more eggs entering the ecosystem. Thus, more contaminated eggs would infect greater numbers of fish, perpetuating the cycle of infection, and elevating the number of eggs that would preserve archaeologically.

Like *Diphyllobothrium*, *Nanophyetus salmincola* was acquired by the consumption of uncooked, smoked or dried salmon. Therefore, many of the same anthropogenic factors that increased the density of fish tapeworm should have led to an increase in *N. salmincola* as well. Fish infected with the parasite are morbidly affected and appear sick, so transmission may have been mediated by selective avoidance. As the number of *N. salmincola* eggs were nominal, the significance of this parasite to the human populations on the coast is considered to have been minimal.

Roundworm was the only human-specific parasite recovered, and the only parasite that was transmitted directly to humans from faecal-oral contamination of the soil. Human modification of the environment likely increased the opportunities for the transmission of this parasite as well. Elevated levels of soil contamination and shared dwellings at residential sites would increase the probability of transmission from the soil to other humans. The significant lack of *A. lumbricoides* evidence at camp sites of short occupational duration may have more to do with taphonomic

conditions than human behaviour. Minimal amounts of waste would be left exposed for longer periods of time at camp sites, conditions detrimental to the preservation of *Ascaris* eggs.

The consequence of parasite burden to the coastal hunter-fisher-gatherers of the Northwest was twofold; parasites impacted human health and that of the ecosystem in which they lived. Whether the impact was negative or not cannot be deduced from the recovered evidence. The parasite evidence recovered in this project demonstrates that hunting and gathering populations did have experience with disease pathogens that, in some instances, had the potential to cause great harm to some individuals. Parasites such as *Diphyllobothrium* spp., *Nanophyetus salmincola* and likely Cyclophyllidea as well, were presumptively indigenous pathogens inadvertently encountered by the humans that settled along the coast. Others, such as *Ascaris lumbricoides*, were introduced into the ecosystem by their human hosts. In some instances anthropogenic change as a consequence of population density, resource choice, reduced mobility, and waste accumulation provided the opportunity for parasites such as *Diphyllobothrium* and *A. lumbricoides* to flourish. By contrast, human agency appears to have had little impact on *N. salmincola* and Cyclophyllidea species. The parasite evidence recovered in this project is testament to the distinct cultural, biological,

and environmental history of coastal cultures prior to European contact, and is representative of the diversity of the human disease experience.

Chapter 7:
CONCLUSION

7.1 Significance of Parasites as Archaeological Evidence

This research project was initiated as a means of broadening what is known of human health in pre-agrarian, hunting and gathering populations. It developed into a project with significant findings at four scales of inquiry: Hunter-gatherer health, New World diseases, Pacific Northwest Coast culture history, and Local site palaeoecology and community epidemiology. The results document some of the oldest pathogens to have been present in North America prior to the advent of agriculture or the importation of a suite of new infectious diseases after European contact. At the smallest scale of inquiry, it has also demonstrated the complex and unique history of human populations at the local level, as a testament to cultural variability.

7.1.1 *Contribution to hunter-gatherer Health*

Empirical studies of hunter-gatherer health are severely under-represented in the archaeological and/or bioarchaeological literature. This has resulted in a deeply entrenched, pan-disciplinary presumption that hunter-gatherers, particularly those of the ancient past, believed to

represent humanity's 'natural state', were relatively disease-free. Those diseases that hunter-gatherers are hypothesized to have been at risk to, zoonotic and persistent infections, are considered benign or insignificant. To an extent, this project validated such hypotheses, demonstrating that the intestinal parasites experienced by the coastal fisher-foragers of the ancient BC Coast constituted both zoonotic and persistent pathogens. However, the presumption that such diseases had a superficial impact on human culture or history is erroneous.

Today, zoonotic pathogens are recognized in biomedicine to be among the leading and most unpredictable sources of emerging infectious diseases, and are considered a substantial and previously underappreciated threat to human health (Ambroise-Thomas 2000; Slifko et al. 2000; Thompson 2001). Likewise, evolutionary biologists and parasitologists recognize that parasites have been an active force shaping evolutionary history (Zimmer 2000). Bell (1982), for instance, has even proposed that the initiation and persistence of sexual reproduction, which results in genetically recombined offspring, was a biological strategy for parasite avoidance. Beyond health implications, we have yet to fully consider what role parasites and other infectious diseases played in shaping the current human genome, behavioural patterns, local ecologies or cultural history. It is time to shift the search for the antiquity

and evolutionary relevance of human disease away from a focus on the advent of agriculture.

7.1.2 *Expansion of New World diseases*

Of the four taxa recovered, only one, *Ascaris lumbricoides*, is likely to have been introduced to the Americas with human migrants. To further substantiate this point, the eggs of *A. lumbricoides* are the oldest parasite evidence recovered in this project. This also represents the oldest documented evidence of this species on either the North or South American continents. The antiquity of the finding contributes to the debate concerning the evolutionary history of *Ascaris* spp., suggesting it originated as a human-specific parasite that was later passed along from humans to domesticated pigs, and not vice versa.

The recovered *Diphyllobothrium* spp. eggs are the oldest evidence of diphyllobothriasis in North America to date. As they are likely to represent a species other than the salt-water exclusive *D. pacificum* that has been documented in South America, it is probable that eggs represent the oldest fresh-water *Diphyllobothrium* species yet to be documented in the New World. Should this evidence prove to be *D. latum*, this project will offer an example of how the extended time depth of archaeological studies can contribute to modern medical or veterinary parasitology, where the antiquity of this species in the Americas is

currently debated solely on the predicted evolutionary mutation sequences of phylogenic traits.

Nanophyetus salmincola can be added to the growing global list of archaeologically recovered parasite species, as it is the first identification of this species from ancient contexts. Finally, although the significance of the Cyclophyllidea eggs is difficult to interpret without knowing which genera are represented, they, along with all the other taxa recovered, are the first pre-contact evidence of intestinal parasites to be documented from archaeological settlements in Canada.

7.1.3 *Northwest Coast culture history*

Of the four parasite taxa recovered, three are likely indigenous to Northwest Coast ecosystems: *Nanophyetus salmincola*, *Diphyllobothrium* spp. and Cyclophyllidea. Based on the quantity of eggs, two of the recovered taxa, *Diphyllobothrium* spp. and *A. lumbricoides*, appear to be particularly responsive to anthropogenic pressures. The consistency with which parasite eggs were found over time and between different site types is testament to long-term patterns in the continuity of site use, the exploitation of specific resources, and the preparation methods of those resources for consumption.

Parasite eggs are empirical evidence of infection. Their retrieval from homogenized midden matrix suggests they presented considerable

risk to the populations that utilized the eleven sites on which they were recovered. Although the presence of a pathogen is a necessary condition for disease, it alone is not sufficient to cause disease. Therefore, the recovery of parasite eggs from cultural deposits cannot confirm that disease was experienced by coastal populations, it can only imply the possibility of its existence. Skeletal evidence from the Northwest Coast supports the inference that parasite burden contributed to instances of skeletal anaemia found to be relatively common in coastal burial populations.

7.1.4 *Local site palaeoecology and community epidemiology*

As an archaeological line of evidence, parasites were used in this project to infer disease, mobility patterns, site use, patterns of waste disposal, food choice, methods of food preparation, and risk avoidance strategies. Reduced human mobility, site re-use, and population density are likely to have been the most influential factors in parasite accumulation and dissemination at the local level. The accumulation of shell middens provides visible evidence for all three of these determinants at coastal sites. Population growth may also have increased the number of eggs distributed in the environment, but it is not a determining factor. Currently, there is no evidence to support a definitive association between

human population (host) growth and parasite recovery on the central coast of British Columbia.

Reduced human mobility and site re-use influenced parasite life-cycles by increasing the opportunities for transmission. All of the taxa recovered are faecal-borne parasites, and thus their recovery in this project is evidence of environmental faecal contamination. Both human and dog faeces accumulated in the soil and fresh-water ecosystems, providing increased opportunity for the transmission of soil and water-borne pathogens within and between these species. For the soil-borne parasite, *A. lumbricoides*, this provided a direct opportunity for transmission between human hosts. Although water-borne transmission was also likely, the complicated nature of *Diphyllobothrium* spp. and *N. salmincola* life-cycles, both of which require two intermediary hosts and specific abiotic conditions, the opportunity to proliferate was mediated by the local milieu. A break in the chain of infection at any juncture due to environmental or cultural factors would result in a either a lack of, or decrease in, these parasites within the ecosystem (Noble and Noble 1982; Timmreck 2002:12; Wolfgang 1954).

There was a significant difference in the richness of taxa recovered from residential sites in comparison to camp sites. Yet there were also significant differences in the distribution of different parasite taxa between

site types. The human-specific nematode, *A. lumbricoides*, was more frequently recovered from residential sites. Such evidence is in keeping with the epidemiology of the parasite, which is best transmitted in dense, sedentary living conditions where soil is prone to contamination. Whereas the foodborne *Diphyllobothrium* spp., which was most likely *acquired* at residential sites where faunal evidence suggests the most salmon was also consumed, was more frequently recovered from small camp sites. Therefore, while large archaeological sites such as residential villages and base camps may be more representative of the suite of pathogens humans were exposed to in a particular ecosystem, they are not necessarily the place where the most parasite evidence will be recovered.

On a regional scale, patterns in the recovered parasite assemblage correlate with the intensity of settlement and site use. But at the local level, historical, environmental, and cultural particularities resulted in a pathogen profile unique to each site.

7.2 Methods

In total, 1200 slides were examined from 15 different sites in the Namu (ElSx-1) region of the central British Columbia coast. A total of 277 eggs (EPG 27,700) were recovered, representing 4 intestinal parasite taxa. This project has demonstrated that parasite eggs can be recovered

from hunter-gatherer contexts even in temperate regions, at sites that lack discrete evidence of faecal deposits (i.e. coprolites, latrines or burials). Although cultural and preservation conditions will vary at archaeological sites throughout the Americas, based on the success of this project, there is every reason to expect such evidence would be recoverable from a broad range of North American pre- and post-agrarian sites as well.

As this was an exploratory study, a "gentle" soil processing protocol was utilized (Coil et al. 2003:999) that minimized the elimination of excess soil components. This method produced a great deal of superfluous material to sort through while scanning microslides. Although it provided additional evidence of the cultural (i.e. charcoal, shell) and ecological (i.e. pollen, wood, foraminferal linings) conditions at each site, future analysis that is strictly interested in the recovery of parasite eggs should utilize more refined screening methods and/or acid treatment to remove excess carbonate, silicate, and organic material. Sieving off material larger than 200 μm should retain artifacts in the size range (~25-170 μm) of most medically-important helminth eggs (Brooke and Melvin 1984:26).

As greater species diversity was recovered at residential locations, a more robust sampling strategy at such sites should be considered. The sampling methodology used in this study was designed to recover the

most robust parasite species in quantities large enough to be comparable between different site types. A sampling strategy that examines more soil from a greater variety of site locations, though mediated by financial and time constraints, would increase the likelihood of finding rarer species, broadening the spectrum of recovered pathogens.

7.3 Future Directions

As the recovery of macroscopic parasite eggs is evidence of faecal contamination, it stands to reason that other faecal pathogens were also present, but undetected, at these sites. Protozoan parasites such as giardia or *Entamoeba* may also have proliferated within such contexts. Current genetic modelling predicts that human-specific bacteria, *Salmonella typhi* (typhoid fever), may be from 15,000 to 150,000 years old (Kidgell et al 2002). Shigella, another human-specific bacteria, transmitted by faecal-oral contamination, is estimated to be as much as 35,000-270,000 years old (Pupo et al. 2000) The small size of these pathogens makes them difficult to isolate and identify. Therefore, future research should consider the utilization of refined light microscopy methods such as higher magnification, immunofluorescence, staining or DNA extraction to identify the presence of other pathogens. Medical immonoassay techniques, designed to identify immune-system antigens in

faeces, have recently been successful in isolating evidence of amoebiasis (*Entamoeba histolytica*) from human coprolites (Gonçalves et al. 2004). This method poses a promising new direction for the study of protozoan parasites in archaeological material.

Anthropogenic climate change is currently recognized as having a significant impact on the development and transmission of infectious diseases in both marine and terrestrial ecosystems (Harvell et al. 2002). It stands to reason climate change would have had a similar impact in the past. The broad temporal scale of archaeological studies provides an opportunity for evaluating climatic impact and long-term anthropogenic change, as well as a baseline with which to compare current studies. Butt and colleagues (2004) suggest parasitoses are common in marine ecosystems, and that all marine animals are likely to be parasitized to some degree. Marine parasites might therefore be a promising new line of evidence to pursue zooarchaeological, palaoecological or human health research questions.

This research was not conditioned by the best evidence for parasite recovery, but by the best evidence *available* for such analyses. It has been an exercise in coping with archaeological reality, and dealing with evidence that has already been excavated and even processed, in reference to someone else's research interests. I believe the future of

archaeological study will involve increasingly finer scales of analysis such as these, in an effort to obtain more information from our limited cultural resources.

7.4 Summary

Initially, archaeologists were restricted to reconstructing the past based on limited macroscopic evidence of stone, bone, metal or shell. Over the decades, technological advances have allowed us to broaden our categories of recoverable evidence by, ironically, narrowing our visual scale of focus from the macroscopic to the microscopic. While this expands the questions we can ask about the past, it complicates our answers. This survey of microscopic evidence from coastal shell middens has demonstrated that the earliest hunting and gathering populations of Pacific North America lived neither in an affluent paradise free from affliction, nor on the brink of a brutish and diseased existence. The significance of archaeological parasite evidence is not as a dramatic harbinger of ill health or as proof of pestilence, but rather as a sculptor of biological, environmental, and cultural diversity. Parasites were but one of a constellation of influences interwoven into the life experiences of the oldest inhabitants of the Northwest Coast of North America.

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APPENDIX
I

Raw Data

Appendix I
Raw Data: Auger Samples

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
1	EkSx-12	B12	151-168 DBS	0	0	0	8.1
2	EkSx-12	C5	55-76 DBS	0	100	0	6.9
3	EkSx-12	C9	114-132 DBS	0	300	0	7.7
4	EkSx-12	C11	143 -156 DBS	0	0	0	7.4
5	EkSx-12	C13	168-171 DBS	0	0	0	7.8
6	EkSx-12	C14	171-179 DBS	0	0	0	7.6
7	EkSx-12	C15	179-192 DBS	0	0	0	8.0
8	EkSx-12	D3	56-80 DBS	0	100	0	7.3
9	EkSx-12	D4	80-97 DBS	0	0	0	7.2
10	EkSx-12	D8	138-153 DBS	0	100	0	6.9
11	EkSx-12	D9	153-163 DBS	0	0	0	7.6
12	EkSx-12	D11	173-184 DBS	0	0	0	7.5
13	EkSx-12	D14	202-212 DBS	0	0	0	7.3
14	EkSx-12	D18	242-250 DBS	0	100	0	7.5
15	ElSx-1	A1	54-74 DBS	0	0	0	7.9

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
16	ElSx-1	A2	74-86 DBS	0	0	0	7.9
17	ElSx-1	A3	86-99 DBS	0	0	0	8.2
18	ElSx-1	A4	99-109 DBS	0	0	0	8.2
19	ElSx-1	A5	109-125 DBS	0	0	0	8.0
20	ElSx-1	A6	123-137 DBS	0	100	0	8.0
21	ElSx-1	A7	137-143 DBS	0	0	0	8.2
22	ElSx-1	A8	143-150 DBS	0	100	100	8.0
23	ElSx-1	A9	150-162 DBS	100	0	0	8.2
24	ElSx-1	A10	162-171 DBS	100	4200	100	8.2
25	ElSx-1	A11	171-183 DBS	0	100	0	8.2
26	ElSx-1	A12	183-196 DBS	0	100	0	8.2
27	ElSx-1	A13	196-210 DBS	0	0	0	8.2
28	ElSx-1	A14	210-221 DBS	0	0	0	8.2
29	ElSx-1	A15	221-236 DBS	0	0	0	8.2
30	ElSx-1	A16	236-244 DBS	0	0	0	8.1
31	ElSx-1	A17	244-254 DBS	0	0	0	8.2
32	ElSx-1	A18	254-267 DBS	0	0	0	8.2

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
33	ElSx-1	A19	267-284 DBS	0	0	0	7.9
34	ElSx-1	A20	284-302 DBS	0	0	0	8.0
35	ElSx-1	A21	302-311 DBS	0	0	0	8.0
36	ElSx-1	A22	311-328 DBS	0	0	0	8.0
37	ElSx-1	A23	328-343 DBS	0	0	0	8.1
38	ElSx-1	A24	343-351 DBS	0	0	0	7.9
39	ElSx-1	A25	351-357 DBS	0	0	0	7.9
40	ElSx-1	A26	357-359 DBS	0	0	0	8.1
41	ElSx-1	J32	500-510 DBS	0	0	0	8.0
42	ElSx-1	J32[2]	500-510 DBS	0	0	0	8.0
43	ElSx-3	C4	63-81 DBS	0	0	0	7.9
44	ElSx-3	C7	105-120 DBS	0	0	0	8.0
45	ElSx-3	C8	120-144 DBS	0	0	0	7.9
46	ElSx-3	C9	144-147 DBS	0	0	0	8.0
47	ElSx-3	C10	157-176 DBS	0	0	0	8.0
48	ElSx-3	C11	176-192 DBS	300	0	0	7.5
49	ElSx-3	C13	202-213 DBS	0	0	0	8.1

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
50	ElSx-3	C14	213-230 DBS	0	0	0	8.3
51	ElSx-3	C15	230-229 DBS	100	0	0	8.3
52	ElSx-3	C17	242-247 DBS	0	100	0	8.1
53	ElSx-3	C19	250-256 DBS	0	0	0	7.8
54	ElSx-3	C21	259-272 DBS	0	0	0	7.9
55	ElSx-3	F7	118-147 DBS	600	0	100	x
56	ElSx-3	F10	167-169 DBS	100	0	0	7.2
57	ElSx-3	F13	199-210 DBS	0	0	0	7.8
58	ElSx-3	F17	224-230 DBS	0	0	0	7.8
59	ElSx-3	F20	252-258 DBS	0	0	0	7.9
60	ElSx-4	A6	133-152 DBS	1900	0	0	7.6
61	ElSx-4	B8	158-172 DBS	1300	0	100	7.7
62	ElSx-5	A9	120-131 DBS	100	0	100	8.2
63	ElSx-5	A11	147-163 DBS	600	0	100	7.8
64	ElSx-5	A13	189-202 DBS	0	0	0	7.8
65	ElSx-5	A15	222-242 DBS	0	100	0	7.3
66	ElSx-5	A16	242-258 DBS	0	100	0	7.8

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
67	ElSx-5	A17	258-268 DBS	0	0	0	7.8
68	ElSx-5	A19	289-306 DBS	0	100	0	7.8
69	ElSx-5	A21*	320-341 DBS	0	0	0	7.9
70	ElSx-8	A5	87-99 DBS	0	0	0	7.2
71	ElSx-8	A8	122-134 DBS	0	0	0	8.0
72	ElSx-10	A4	94-105 DBS	0	0	0	7.9
73	ElSx-10	A6	107-116 DBS	0	0	0	7.9
74	ElSx-10	A8	126-135 DBS	0	100	0	8.1
75	ElSx-10	A10[2]	157-170 DBS	0	200	0	8.2
76	ElSx-10	A11	170-190 DBS	200	0	0	7.9
77	ElSx-10	A12	190-202 DBS	200	300	100	8.1
78	ElSx-10	A13	202-207 DBS	0	100	0	7.4
79	ElSx-10	A14	207-227 DBS	0	0	0	7.8
80	ElSx-10	A16	230-246 DBS	0	200	0	8.0
81	ElSx-10	A19	278-298 DBS	0	100	100	8.2
82	ElSx-10	A22	332-340 DBS	0	100	0	8.1
83	ElSx-10	B5	104-117 DBS	0	0	0	7.8

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
84	ElSx-16	A5	85-114 DBS	100	0	0	7.6
85	ElSx-16	A8	129-142 DBS	100	0	0	8.1
86	ElSx-16	B4	80-92 DBS	900	0	0	7.5
87	ElSx-17	A2	71-84 DBS	0	0	0	7.3
88	ElSx-17	A3	84-91 DBS	0	0	0	7.2
89	ElSx-18	A6	108-120 DBS	100	0	0	8.3
90	ElSx-18	A10	173-193 DBS	100	0	200	8.2
91	ElSx-18	A15	250-264 DBS	100	100	0	8.3
92	ElTa-3	A5	84-95 DBS	0	0	0	7.9
93	ElTa-3	A7	102-115 DBS	0	0	0	7.5
94	ElTa-18	A3	59-76 DBS	0	0	0	7.5
95	ElTa-18	A6	109-130 DBS	0	0	0	7.1
96	ElTa-18	B9	158-169 DBS	0	0	0	7.5
97	ElTa-25	B-7	128-164 DBS	200	0	0	8.1
98	ElTa-25	B-8	164-185 DBS	700	100	0	x
99	ElTa-25	C11	94-105 DBS	500	0	0	7.7
100	ElTa-25	C13	115-130 DBS	400	0	0	7.8

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
101	ElTa-25	C16	149-156 DBS	0	0	0	7.7
102	ElTa-25	C22	200-213 DBS	0	0	0	7.4
103	ElTa-25	Core 2A	235 DBS	0	0	0	7.7
104	ElTa-25	Core 2B	207-227 DBS	0	0	0	x
105	ElTa-25	Core 2C	12-13 cm from top of core	0	0	0	x
106	ElTb-1	B5	94-106 DBS	0	0	0	x
107	ElTb-1	B10	171-184 DBS	1100	100	0	x
108	ElTb-1	B15	225-238 DBS	100	0	100	7.4
109	ElTb-1	B19	269-280 DBS	0	0	0	7.7
110	ElTb-1	B21	292-303 DBS	100	0	0	7.2
111	ElTb-1	B24	321-337 DBS	800	100	100	7.4
112	ElTb-1	B26	358-374 DBS	1000	100	100	7.4
113	ElTb-1	B28	386-396 DBS	200	0	100	7.5
114	ElTb-1	B30	406-414 DBS	0	100	0	7.8
115	ElTb-1	B33	433-454 DBS	0	200	0	8.0
116	ElTb-2	A3	40-58 DBS	0	0	0	6.9
117	ElTb-2	A5	75-85 DBS	0	0	0	8.0

No.	Site	Auger	Level	EPG Diph.	EPG Ascar.	EPG Other	pH
118	ElTb-2	A6	85-96 DBS	6400	100	0	7.4
119	ElTb-2	A7	97-115 DBS	0	0	0	7.3
120	ElTb-2	A9	124-130 DBS	100	0	0	7.4
TOTAL				18600	7700	1400	

APPENDIX II

Presence/Absence of Taxa

Appendix II
Presence/Absence

Type	*Borden #*	*Site*	*Augers tested*	*Positive* #	*Positive* %	*Diphyllo* +	*Diphyllo* –	*Ascaris* +	*Ascaris* –	*Other* +	*Other* –
Winter village	EkSx-12	Koeye River	14	5	.36	0	14	5	9	0	14
Year-round village	ElSx-1	Namu	28	5	.18	2	26	5	23	2	26
Winter village	ElSx-3	Kisameet Bay, King Island	17	5	.29	4	13	1	16	1	16
Summer village	ElTb-1	Hurricane Island	10	8	.80	6	4	5	5	4	6
Base camp	ElSx-5	Windsor Cove, King Island	8	5	.62	2	6	3	5	2	6
Base camp	ElSx-10	Fougner Bay	12	8	.67	2	10	7	5	2	10
Base camp	ElSx-18	Fougner Bay	3	3	1	3	0	1	2	1	2
Specific-purpose camp	ElSx-8	Fougner Bay	2	0	0	0	2	0	2	0	2
Specific-purpose camp	ElTa-3	Watt Bay, Hunter Island	2	0	0	0	2	0	2	0	2
Specific-purpose camp	ElTa-25	Kiltik Cove, Hunter Island	9	4	.44	4	5	1	8	0	9
Specific-purpose camp	ElTb-2	Spitfire Channel, Hunter Island	5	2	.40	2	3	1	4	0	5

Type	*Borden #*	*Site*	*Augers tested*	*Positive* #	*Positive* %	*Diphyllo* +	*Diphyllo* –	*Ascaris* +	*Ascaris* –	*Other* +	*Other* –
Multi-purpose camp	ElSx-4	Windsor Cove, King Isl.	2	2	1	2	0	0	2	1	1
Multi-purpose camp	ElSx-16	Fougner Bay	3	3	1	3	0	0	3	0	3
Multi-purpose camp	ElTa-18	Kildidt Inlet	3	0	0	0	3	0	3	0	3
Rocky islet camp	ElSx-17	Sunday Isl., Namu Harbour	2	0	0	0	2	0	2	0	2
		Total # of Augers Tested	**120**	50	.42	30	90	29	91	13	107

APPENDIX
III

Raw Data
Additional Namu (ElSx-1) Auger Samples

Appendix III
Raw Data:
Extra Namu (ElSx-1) Auger Samples

No.	Strata	South/North	West/East	Level	Period	Diph.	Ascar.	Other
1	7	28-30 S	2-4 E	120-125 DBS	2000 cal. BP - contact	0	0	0
2	5E	26-28 S	2-4 E	150-160 DBS	4000-2000 cal. BP	0	0	0
3	5D	32-34 S	6-8 W	150-160 DBS	4000-2000 cal. BP	1	1	0
4	Burial 3	unknown	unknown	unknown	ca. 5000 - 1000 BP	0	2	3
5	5C	26-28 S	2-4 E	230-240 DBS	5000-4000 cal. BP	0	0	0
6	5B	32-34 S	2-4 W	120-130 DBS	5000-4000 cal. BP	0	2	0
7	4A	32-34 S	2-4 W	170-180 DBS	7000-6000 cal. BP	0	0	0
8	4	32-34 S	8-10 W	230-240 DBS	6000-5000 cal BP	0	0	0
9	4	32-34 S	2-4 W	150-160 DBS	6000-5000 cal BP	0	0	0
10	3	32-34 S	6-8 W	130 DBS	6000-5000 cal. BP	0	0	0
11	2B	23-33 S	2-4 E	130-140 DBS	7000-6000 cal. BP	0	0	0
12	2B	32-33 S	0-2 E	106-115 DBS	7000-6000 cal. BP	0	0	0
					TOTAL	1	5	3