Shell Microband Analysis as a tool in New Zealand Archaeology

Danielle Trilford

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New Zealand

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Abstract

Recent improvements in animal biology and microscopy now allow for finer-grained analyses of microstructures in archaeofaunal specimens than previously possible. Novel new applications of microscopy methods applied to in the intertidal New Zealand cockle (*Austrovenus stutchburyi*) species demonstrate a strong link between microbands and tidal and lunar cycles. The application of the technique has significant implications for high-precision seasonal and absolute dating in New Zealand archaeology. Applying the technique to a short-lived archaeological midden deposit from Wairau Bar demonstrates the time-of-death in archaeological samples can be calculated with much higher-precision than tools which are currently available in the temporal-dating suite. The method holds significant potential for sclerochronological, Bayseian applications in radiocarbon dating, and palaeoclimate analyses.
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Chapter 1

Time and palaeoseasonality problems in New Zealand archaeology

Time is a central concept in archaeology, but in New Zealand there are certain issues and problems that make time a particularly difficult concept to deal with. Firstly, New Zealand was colonised by humans 500 years ago, which means it has the shortest chronology of human occupation anywhere in the world (Higham et al., 1999). Secondly, New Zealand Māori society underwent enormous transformations over this relatively short time span (Golson, 1959, Green, 1975, Simmons, 1969). Therefore understanding these very rapid changes requires a much finer degree of precision than would be expected in many other places.

Thirdly, radiocarbon dating poses some specific problems in New Zealand (Shawcross, 1969). In a short-chronology setting it is difficult to reduce radiocarbon error ranges to the level of precision required to understand the timing of major events. There are several approaches to radiocarbon dating which have increased the accuracy of dates, such as correct species selection in samples, inbuilt age analysis, marine upwelling calculations, and application of the calibration to the terrestrial “wiggle” (Bronk-Ramsey et al., 2004, Hogg et al., 2003, McFadgen et al., 1994). Attempts to do this were triggered by Anderson’s (1991) “chronometric hygiene” approach and have certainly tightened standards, but have not entirely solved the precision/scale issue. Fourthly, because New Zealand remained isolated from outside cultural influences following colonisation, there are no opportunities to draw on external chronological sequences to cross-check or constrain New Zealand age estimates. Fifthly, there are no artefact classes in New Zealand that support any kind of high to medium-precision seriation analysis. This was identified early-on in New Zealand archaeology by Jack Golson (Golson, 1955) who called this phenomenon “typological unresponsiveness” (See also Bain, 1985, Harsant, 1987, Hjarno, 1967).
Overall, dating the short-but-eventful human history of New Zealand has created challenges for archaeologists. This thesis approaches the problem of time in New Zealand by presenting a refined dating method enabling archaeologists to examine time through a cyclical framework. Specifically, this thesis develops a methodology for high-precision seasonality analysis. The method developed in this study builds directly on existing seasonality approaches but is guided by new developments in the biology of seasonality and uses innovative new microscopy techniques.

While seasonality studies are traditionally concerned with understanding the timing or periodic nature of economic activities, the methods developed here also provide a tool to improve the quality of conventional (e.g. calendar) studies of time. For example, high-precision seasonality data can provide Bayesian priors, support the development of sclerochronology, and isolate data for the study of event duration and temporal relativity. These approaches do not form part of the current study, but will be reviewed in Chapter 6.

The thesis will isolate microstructural time-controlled phenomena in Austrovenus stutchburyi using Scanning Electron Microscopy Composite Backscatter Detection imagery (BSE) and Electron Dispersive X-ray Spectroscopy (EDS). This methodology will be used to gain precise measures of growth behaviours to gain fine-grained seasonality estimates. These results will be applied to the examination of a discrete discard event on a fourteenth century New Zealand site.

**A history of time analysis in New Zealand archaeology**

Because of the problems with time measurement in New Zealand archaeology listed above, New Zealand archaeologists seem to focus more on issues of chronology than that of other prehistoric archaeologies. This thesis will show how key questions about New Zealand’s past can be more effectively addressed by adopting non-linear time approaches – such as ‘duration’ and ‘temporal relativity’. Before discussing the idea of non-linear scales this chapter will review time-measurement in New Zealand archaeology, with particular emphasis on the role and influence of radiocarbon dating.
Before the rise of radiocarbon dating in the 1960s, the chronology of New Zealand’s prehistory was usually examined by way of oral whakapapa and traditions. Initially, this was done by matching historical events to known genealogies – an event could thus be said to have occurred in the time of a particular known ancestor. This approach was later refined by adopting the ‘genealogical method’ which matched genealogical time to an absolute time scale by assigning a given number of years for each generation (Roberton, 1956, Smith, 1915).

With the advent of radiocarbon dating, archaeologists were able to directly date objects and phenomena to calendar time. Therefore this method took over as the primary tool for chronological reckoning for the next five decades. While radiocarbon methodologies were well received in archaeological analysis internationally, attempting to advance New Zealand’s short prehistory requires higher resolution that the technique currently offers. Standard errors in the analyses could be as much as 80-100 years which is equivalent to 15% of the country’s prehistory (McFadgen, 1982) (Figure 1). Addressing the issue of temporal resolution saw tools and criteria introduced to improve the accuracy of dates. In an attempt to address the poor temporal resolution, archaeologists began to introduce strict criteria, such as the exclusive dating of short-lived species, to radiocarbon dating. These prompted serious reconsideration of older radiocarbon dates which contributed to the archaeological understanding of key events of New Zealand prehistory because they were not of sufficient quality under the new criteria. As these new methods came on-line, they prompted a serious reconsideration of when most of the analysed of the chronology of key events in New Zealand prehistory (Anderson, 1991, Bronk-Ramsey et al., 2004).
Figure 1. Diagram showing the relative error in radiocarbon dates when results from an overseas sample is plotted to the prehistoric time-span (left) (occupying a relatively small portion) and the same radiocarbon error range is applied to the New Zealand prehistoric time span (occupying a relatively large portion) (right).

A handful of physical markers left from New Zealand’s past act as reference points from which key events may be measured against in relative terms. Such reference points include the presence of Kaharoa Tephra in a stratigraphic profile (Hogg et al., 2003, Lowe et al., 1998), the presence in sites of extinct fauna such as moa, (Aves: Dinornithiformes) and a wide range of forest and marine birds (Anderson, 1989b, Holdaway and Jacomb, 2000). These markers equip archaeologists with the tools to gain impressions of the relative order of events by acting as reference points – but they are coarse-grained markers and radiocarbon dating cannot make them much more fine-grained.

One of the most significant changes in the way archaeologists think about New Zealand prehistory over the last 50 years has been in terms of the length of our prehistory. Smith’s influential (1915) model created a 1000 year prehistory that was later questioned by Simmons (1967), but still retained enough appeal to contribute to Davidson’s (1984) “orthodox” model of prehistory. Kirch (1986) proposed an East Polynesian colonisation model which opened up the possibility of landfall occurring in New Zealand even earlier than 1000 years ago. Sutton
(1987) took up the challenge proposing human landfall in New Zealand as early as 200 A.D. This earlier human settlement appeared to have left no archaeological remains and could only be traced through palynological evidence. This model also insinuates the settlers ignored the big-game moa and seal access for centuries if material culture was in fact absent. Sutton’s (1987) proposition for the span of New Zealand prehistory asserts human landfall using an absence of evidence which is often hard to refute, however the strict demands for the model to hold truth are extremely unlikely. A critical alternative known as the “short chronology” model was proposed by Anderson (1991) which hypothesised that human history in New Zealand spanned no more than ~800 years (from 1100 A.D.). The short chronology model was based on dates from samples using a strict criteria regarding sample selection which involved wood species standards, multiple sample requirements, inbuilt age restrictions. This “short chronology” model provided a new impetus for the investigation of colonising events in New Zealand (for example: Higham et al., 1999, Hogg et al., 2003, Jacomb et al., 2014). The shorter time-span also required new models to explain changes in social organisation and settlement patterns, as well as explanations as to what factors were driving continuity and change over time (Anderson and Smith, 1996, Walter et al., 2006). Even with a shorter chronology and stricter criteria for radiocarbon dating, radiocarbon techniques usually do not provide the resolution New Zealand archaeologists require to meaningfully examine the timing of events.

**Exploiting time theory to improve the New Zealand scale issue**

**Time theory – linear and non-linear**

Abstract versions of time theory are hard to test with archaeometric techniques (Bailey, 1983, McGlade, 1999). However there are some basic concepts in time theory which can be applied to thinking about New Zealand’s prehistory (Bailey, 1983). This thesis distinguishes two simple classes of time. The first is linear time, which operates under the basic past-present structure and which is measured in absolute calendar years (Bailey, 1983, Barnes, 1971, McGlade, 1999). The second is non-linear time, which is limited in this thesis to cyclical, repetitive frames which can be used to understand events (Figure 2) (Bailey, 1983). The
following section explains how concepts of linear and non-linear times are useful for thinking about New Zealand archaeology.

![Diagram of unidirectional and cyclic paths of linear and non-linear time]

Figure 2. Diagrams of the unidirectional and cyclic paths of linear and non-linear time

**Linear time**

Linear time is unidirectional (Barnes, 1971). There are two categories of linear time which assist archaeological investigations in this thesis, the first is complete time and the second is constrained time. Below is a summary of the theory of each with a discussion of their application to New Zealand archaeology.

**Complete time**

Complete time places all events on an absolute time scale. Complete time operates in calendar years, and presents events in a long-term “big-picture” perspective. The “complete time” framework addresses questions of time by ordering events along a single axis, and is used to order multiple events relative to one another (Carlstein et al., 1978).

Complete time has been influential in the way archaeologists have thought about New Zealand prehistory; events such as human landfall, moa extinction, fur seal extinction, pā construction, arrival of whalers, and signing of The Treaty of Waitangi can all be all plotted as points or lines along a single axis (Figure 3). The limitation of dating methods used to place the events on the complete time axis prevent a strong understanding of the details of overlap between events, or of the tempo of culture change. This means New Zealand archaeology
cannot sufficiently address questions of event duration and relativity while working on a complete time axis and relying on radiocarbon methods.

Figure 3. Diagrammatic example of how complete linear time orders New Zealand’s human past. Dates are based on (Higham et al., 1999, Holdaway and Jacomb, 2000, Schmidt, 1996)

**Constrained time**

Constrained time is a concept which helps understand the duration of an event, but does not operate on a prescribed calendar time scale like complete time. Rather, constrained time is measured in independent years (or some other temporal measure) to understand how long a single event lasted (Figure 4). Constrained time data are created by isolating an event and examining the internal linear time structure within it. It is conceptually similar to complete time by having a unidirectional path, but it is different because it focuses strictly on the internal linear time-span of the event. Unlike complete time, constrained time is not used to examine the relationship between events – it solely serves to aid understanding how long a single event lasted.

Figure 4. Diagrammatic representation of the difference between constrained and complete time.

The duration of events in archaeological sites can be examined using constrained time theory, but due to New Zealand’s short prehistory, conducting constrained time analysis is best applied using non-linear dating techniques. Constrained time is most obviously relevant when dealing with short-lived events – such as an adze cache or a human burial event. These types of events act as a snapshot of human history, where the constrained time-depth is
undoubtedly short (or conceptually instantaneous). In fact, instantaneous events have
duration of zero time so are not, technically, amenable to more comprehensive chronological
investigation.

**Non-linear time**

Any form of time which does not have a unidirectional time scale is non-linear (McGlade,
1999). This thesis restricts consideration of non-linear time to repetitive events driven by solar
and lunar cycles - specifically, tidal and seasonal cycles. Non-linear cycles accumulate to create
larger cycles and these oscillations repeat to create linear time (Barnes, 1971, McGlade, 1999).
For example, minutes repeat to form hours, hours repeat to form days, days repeat to form
weeks etc. Each of these repetitions can be projected on a linear axis and it is this relationship
between linear and non-linear time that provides a key for resolving dating problems in New
Zealand’s short prehistory.

New Zealand archaeology commonly examines non-linear time through the lens of
seasonality. Seasonality is recurring human behaviour organised around seasons. It differs to
other repetitive events because is it driven by the lunar and solar cycles rather than cultural
pulses are found in the remains of some animals, such as shellfish, found in archaeological
sites.

**Potentials for time analysis - the relationship between seasonal and
constrained time**

The fact that seasonal data can be converted to linear time data has important implications for
the challenges of dating New Zealand’s prehistory. This thesis acknowledges the need to order
basic chronological events, but will show there are three other time structures which can
substantially contribute to constructing prehistoric culture-change models. The first structure
for time examination is seasonality, which is how humans operate around cyclical
environmental patterns of their ecological niche (Binford, 2001). The second structure is
duration of events, which can be identified by understanding seasonal structure within the
event. The same seasonal structure of events can also inform the third time paradigm; temporal relativity both within a site (intrasite) and also across landscapes (intersite).

Cyclical data used to understand seasonality regimes is also the same data used to examine duration and temporal relativity, so it is conceptually efficient to consider seasonality as stage-one in the analysis of duration and temporal relativity. Seasonality appears to have had a strong role in early New Zealand prehistory which benefits time analysis because there are strong seasonal pulses which are not found in tropical Pacific assemblages. The significance of seasonality, duration and temporal relativity of events in relation to New Zealand’s prehistory are discussed below:

**The role of seasonality in early New Zealand prehistory**

Early New Zealand settlers’ diet was characterised by a protein base and supplemented with sea foods and a range of wild and domesticated carbohydrate foods (Anderson, 1989b, Davidson, 1984, Leach, 1968, Smith, 1985). The availability of meat appears to have fluctuated seasonally. The specific timing of hunting and gathering in both the calendar sense, and more precisely, in a seasonal sense, is still poorly understood. Such information is important because it provides evidence of human interaction with adaptation to the environment and relates to human agency; the choices people exercised as hunters and land-users.

New Zealand’s settlers were accustomed to subsistence practices suited to tropical East Polynesia (Barber, 2004b, Davidson, 1984, McGlone et al., 1994). This is marked by horticultural activities in both dry areas and wetlands, supplemented with hunting, animal husbandry and fishing (Walter, 1996). Horticultural productivity in Tropical Polynesia is barely affected by seasons, and this year-round access to horticulture determined the basic structure of subsistence and settlement patterns. Once settlers began exploiting New Zealand’s subtropical climes and found year-round production to be impracticable, cycles of resource scheduling were inevitable.

The key factor that off-set the limited horticultural potential was undoubtedly the greater biomass of terrestrial and marine faunas (Anderson, 1983, Anderson, 1989a, Holdaway and
Jacomb, 2000, Smith, 2005). Varied regional resource access appears to have determined the intensity of hunting and gathering for New Zealand’s settlers (Anderson, 1989b, Oskam et al., 2012). It is likely that subsistence adaptation included the adoption of opportunistic or systematic hunting, as well as an increased reliance on wild-foods (Leach, 1968) in an economy that was regionally variable but included horticulture where possible (Walter et al., 2006).

Anderson (1983) noted that seasonality in the early New Zealand population, probably extended beyond food procurement strategies to seasonal stone collecting and working, clothes making, wood collecting, and shelter maintenance. Finer aspects of this interpretation have since been questioned (Smith, 1985); nevertheless there is little doubt that the adoption of cyclical behavioural strategies was an essential component of the New Zealand adaptation.

Seasonal human behaviours are normally repetitive, and generate a cyclic pulse which should be archaeologically visible. If these pulses can be identified this provides access to another temporal scale which can be used to examine cultural change. More immediately, the ability to identify cyclical activities provides a tool for the examination of duration and temporal relativity of events.

**Duration of events**

The difference between early and late lifeways in New Zealand prehistory is very distinct. However, the nature of change is incredibly indistinct - the flow and rate of change over time has not been successfully addressed. Seasonal studies contribute to identifying the duration of events – for example by analysing how many seasons are present in a set of stratigraphic observations. The study of duration contributes to an understanding of prehistory in a range of ways. Firstly, an understanding of duration of occupation is necessary in order to examine patterns of mobility which is itself a critical factor in understanding the colonisation process (Kinaston et al., 2013, Walter et al., 2010). Secondly, there is a relationship between duration of occupation, site complexity and site function. In other words, some of the problems involved in understanding the diversity of early site types, may be resolved if duration of
occupation can be established. The patterns and drives to the difference between early and late prehistoric culture in New Zealand will be better understood if duration of events is more clearly understood.

Temporal relativity

Temporal relativity deals with the temporal relationship between archaeological observations or events. Data sets that reflect seasonal differences, like shell or bone, often contain highly discrete markers of environmental events (such as storms, spawning events, floods etc.). These can act as reference points to examine relationships between separate samples in a manner similar to that used in dendrochronology. Relativity is rarely examined in New Zealand archaeology because of the coarse-grained dating methods available to us.

Current problems in New Zealand archaeology that could be addressed if we had control over temporal relativity include understanding the timing and nature of decline in long distance trade (Sheppard, 2004). Similarly, the shift from Duff type 2A to 2B adzes (Best, 1977, Duff, 1977) could have included an overlap between the two types, a transitional adze form, or a period of time where neither were being used. Broad-spectrum foraging in New Zealand prehistory is probably closely related to megafaunal collapse (Anderson, 1983, Nagaoka, 2002), but was this a sudden change which occurred in less than a couple of years; did it happen at the same rate nationwide; and what was the rate of foraging intensification? There are many ways that archaeologists can draw on concepts of temporal relativity to address questions of prehistory (e.g. Bailey, 1983, McGlade, 1999). Two particular ways of thinking about temporal relativity that are useful in New Zealand archaeology are discussed below. These are contemporaneity and repetitiveness.

Contemporaneity

Contemporaneity is the temporal synchrony of two or more events. Each event may be of very different duration, but it is the area of temporal overlap that is the focus of archaeological attention in studies of contemporaneity. There are a wide range of potential research
problems for which some control over the question of contemporaneity would be useful. For example in New Zealand, the rise of pā in relation to resource competition could have occurred simultaneously. Alternatively it is possible that pā may have emerged following the resource competition such that pā developed as a way of exercising control over landscapes (McGlone et al., 1994, Phillips and Campbell, 2004).

**Repetitive events**

Seasonality is a type of repetitive event that is strictly bound to lunar and solar patterns. Some repetitive events occur because of cultural stimuli. Examples of non-seasonal repetitive events would include rituals surrounding human birthing and burials. To some extent many human events repeat – but not on a regular predictable cycle. This work is solely concerned with seasonal based events.

**Palaeoseasonality**

This thesis is a study of seasonality. Seasonality is important in New Zealand archaeology for two main reasons:

1. It informs the understanding of human behaviour in prehistoric society, such as resource scheduling, mobility, and settlement patterns.
2. It provides a useful first step in fine grained studies of time. For example, understanding seasonal patterning in archaeological deposits provides a tool for studying duration and temporal relativity.

Palaeoseasonality studies in New Zealand have been carried out in varying ways; the most promising is the use of the New Zealand cockle, *Austrovenus stutchburyi* (Coutts, 1970, Sheppard, 1985). Previous attempts to use *A. stutchburyi* in New Zealand archaeology have had problems and there seems to be a general view expressed amongst archaeologists that it is of limited value. However, in the past decade there have been a number of international studies analysing timing-of-death in closely related species. These suggest that the problem New Zealand archaeology encountered was related to scale – earlier studies were limited to
low magnification thin-section microscopy which could only identify growth markers at a very gross scale. A detailed survey of palaeoseasonality is contained in Chapter 2. Below is a review of the changing state of the science over the past decades that have allowed this thesis to progress.

Internationally the archaeological application of bivalve death estimations faced the same difficulties as New Zealand – the coupling of a substandard understanding in biological growth factors and low resolution and magnification (for example: Claassen, 1983, Custer and Doms, 1990, Evans, 1972, Ham and Irving, 1975, Keen, 1979, Monks and Johnston, 1993). Advances in microscopy, image software, and biological growth analyses now enable the accuracy of seasonality analysis is to be tested and applied to reach time-of-death estimations down to the nearest high-tide in some scenarios (for example: Andrus, 2011, Burchell et al., 2013, Hallmann et al., 2009, Schöne et al., 2005).

The New Zealand cockle (Austrovenus stutchburyi) is an intertidal, estuarine bivalve which has seasonal growth mechanisms (McKinnon, 1996). A. stutchburyi is one of the most commonly found shell-species in midden (Coutts and Higham, 1971, Larcombe, 1971, Marsden, 2004, McKinnon, 1996). The season of death is represented in the fabric of the shell in transverse section. Discovery of these growth patterns prompted some unique and detailed archaeological investigations in New Zealand to estimate the season of death in shell midden (for example: Coutts, 1970, Coutts and Higham, 1971, Higham, 1990, Rowland, 1977, Samson, 1995). There are complications with the previous studies, all of which are underpinned by poor resolution in imagery and limited understanding in physiological growth factors of A. stutchburyi. This thesis uses the concepts crafted by these original studies but applies them with advanced microscopy methods guided by well-developed bivalve physiological growth literature to revise the method’s validity and application to New Zealand archaeology.

**Aims**

The goal of this study is to use live collected cockles (A. stutchburyi) to develop a reliable, high resolution method to determine the time of death within the annual cycle. The method will be
applied to archaeological specimens from a fourteenth century midden deposit to determine the season of deposition. The specific aims are as follows:

1. To use Backscatter Electron (BSE) imagery to identify the strength of the relationship between tidal and microband periodicity subsequent to the final macro-increment in the *A. stutchburyi* microstructure. This information will provide a means to measure the number of tidal events between the last winter and the death of the shell.

2. To use Backscatter Electron (BSE) imagery to establish any correlation between spring and neap tides and microband width in the microstructure of the *A. stutchburyi*. This will provide information on the moon phase at the time of shell death.

3. To test whether Electron Dispersive X-ray Spectroscopy (EDS) linear mapping in the *A. stutchburyi* can identify fluctuations in trace element distributions across an annual cycle resulting from seasonal thermodynamic processes. This could provide further information on season of death.

The results from the live collection will be used to analyse archaeological specimens from a midden deposit at the fourteenth century Wairau bar site (Higham *et al.*, 1999, Jacomb *et al.*, 2014). The aims for archaeological analysis are:

1. To identify time of death of a sample of cockles within the annual cycle.

2. To determine whether the cockles were collected over a short period or whether they represent a series of collection events.

**Thesis structure**

This thesis investigates a palaeoseasonality technique and applies it to an archaeological midden assemblage from Wairau Bar. Chapter 2 reviews the ways palaeoseasonality has been applied in New Zealand archaeology and the part it has played to the understanding of resource use, duration of occupation, and settlement patterns. This is followed by an overview of the study site, Wairau Bar, and the midden deposit which the *A. stutchburyi* archaeological sample is derived from. Chapter 3 starts with a discussion of the growth patterns of the *A. stutchburyi*, and the anatomical expression of environmental and temporal events in the
species. It then moves into a discussion of the control and archaeological assemblages. It then presents the methods used to extract the microband data using a range of scanning electron microscopic techniques. Chapter 4 presents the results from the analysis of the control collection from Wairau Estuary, the data from this section contributes to the model of expected sub-annual growth patterns for _A. stutchburyi_ samples from the region. Chapter 5 presents the results from the analysis of the specimens from the archaeological midden deposit at Wairau Bar. The results are used to calculate the time of death of the shellfish which then provides data needed to determine scenarios of collection events represented in the deposit. The results of Chapter 4 and 5 are discussed in Chapter 6. This final chapter considers what the results say about the time depth and temporal relativity of shellfishing evident in the archaeological deposit. Chapter 6 discusses the scenarios of shellfishing in light of other temporal data known about the deposit to construct a more contextualised understanding of the feature. Chapter 6 also evaluates the efficacy and future role of the method as a tool for fine-grained 'time studies' in New Zealand archaeology.
Chapter 2

Palaeoseasonality and Wairau Bar

Palaeoseasonality studies often contribute to the understanding of prehistoric settlement types, human mobility patterns, and subsistence strategies. These topics are central themes in New Zealand archaeology which means that palaeoseasonality plays a significant role in the way in which archaeologists study and reconstruct prehistory. It is especially important in understanding annual resource schedules of New Zealanders because of the strongly variable resource access - both regionally and seasonally. Such diversity could have greatly impacted upon the way in which humans colonised and moved within landscapes.

Wairau Bar is an archaeological site in the South Island of New Zealand occupied by people recently arrived from the tropical Pacific. One of the first adaptations to New Zealand conditions would have been related to the seasonal conditions of the New Zealand environment. This research draws on Wairau Bar data to develop the seasonality methods and as a case study in seasonal exploitation behaviour.

Palaeoseasonality

The study of palaeoseasonality in archaeology uses various forms of evidence. The most dominant form is derived from the analysis of fauna from food refuse deposits. The ways palaeoseasonality has been explored in New Zealand are described in this section. The scope narrows to those most relevant to this thesis which used growth patterns in *A. stutchburyi* to identify seasons of death.

Previous palaeoseasonal studies in New Zealand

Palaeoseasonal studies can isolate specific dimensions of the archaeological record, such as faunal presence or absence, and physiological investigations into seasonally variable species in midden (Monks, 1981) (Figure 5). Other studies address palaeoseasonal questions by
incorporating a variety of data sets, such as settlement patterns, artefact functions, and population sizes to derive conclusions (Monks, 1981) (Figure 6).

![Diagram showing forms of direct seasonal evidence found in the archaeological record as determined by Monks (1981).](image1)

![Diagram showing forms of indirect seasonal evidence found in the archaeological record as determined by Monks (1981).](image2)

**Integration of indirect evidence**

The integration of indirect evidence is an approach that can be used to examine palaeoseasonality in New Zealand. Northland’s Tauroa Point was examined to show that seasonality was a core element to the economic base of the 14th century settlements (Allen, 2006). Seasonality was explored by integrating evidence of site size, neighbouring site complexity, faunal analysis, and radiocarbon dates (Allen, 2006). Further south a prehistoric settlement at Bay of Plenty’s Kohika Bay underwent microfossil analysis of pollen, phytoliths, and diatoms; the analysis showed that occupation occurred at least during mid-summer (Horrocks et al., 2003). Radiocarbon dates, taxonomic ratios, growth analysis of shellfish, and neighbouring site complexity were factors used to interpret the seasonality and economic systems at Pleasant River Mouth (Smith, 1999). Palaeoseasonality studies in New Zealand do not always deal with wide spread evidence, and often the seasonal factor is hinted at in finer
economic understandings, such as stratigraphic profiling in middens and environmental conditions (Campbell et al., 2003, Jacomb, 2009).

The integration of indirect evidence in palaeoseasonality studies has been critiqued as being susceptible to bias. Data which may not suit the model can be ignored or rejected on the basis that it is relatively insignificant. Therefore, palaeoseasonal studies which integrate varieties of evidence to make conclusions can lack objectivity – a common issue in any analysis which considers several bodies of data. While some models are stronger than others when using this method, the overall absence of criteria and classification for how evidence is applied in New Zealand prehistoric studies means there are irregularities and inconsistencies in the way evidence is considered. There is often little theory or classifications defining what factors matter, or the prioritisation of these. However, this thesis sees the value in this method if treated as a secondary body of data which is considered after a specialised analysis of direct palaeoseasonal evidence (Figure 5).

**Settlement types defined by economics - inferences for palaeoseasonality**

Palaeoseasonal studies have also been conducted by defining site types and social stratification. Groube (1965) created an economic-driven settlement typology for New Zealand that allowed for palaeoseasonal analyses. The analytical structure for site interpretation was a three-layered model, beginning with analysis of domestic evidence (such as cooking, eating, and storage), followed by an analysis of how communal units fit within the domestic evidence to create “hamlets”, and then examining the bonds these hamlets and communal units displayed both economically and socially (Groube, 1965). This model later inspired many other major studies of New Zealand prehistoric economics. The Wairarapa Research Programme (Leach and Leach, 1979b) was influenced by Groube’s (1965) approach. It concluded that seasonal group cohesion was represented in the archaeological data set from that region (Leach and Leach, 1979a). Groube’s (1965) site-type-model was also the basis for the “Southern Hunters Project”, which concluded that after big-game faunal depletion human
settlement was dispersed and less sedentary in many parts of southern New Zealand (Anderson, 1982).

The economic correlates of settlement patterns, like most processual models for prehistory, can be critiqued as environmentally deterministic. The model proposed by Groube (1965) assumes resource access underpinned the connections between communities, and does not provide an analytical tool to examine any socio-political connections shared. Groube’s hypothesised connection regarding the management of economic resources to be political is based on ethnography, meaning the applicability to earlier contexts is questionable, although he has acknowledged that the connection between enviro-economics and socio-politics is an ongoing struggle for archaeologists (Phillips and Campbell, 2004:88). Groube’s (1965) model provides a strong platform to examine culture change from outside stimuli, however it does not provide a means to examine culture change internally – like those occurring due to socio-politics. Even so, Groube’s (1965) model has enabled many informative analyses into settlement patterns of New Zealand prehistory, and these also create data regarding the sub-annual access to resources which means that palaeoseasonal information is created.

**Foraging theory**

Foraging theories calculate food availability and foraging techniques based on the breadth of food types and ecological niches that are represented in middens. These types of food collection strategies have large conceptual overlaps with seasonal resource use. Middens from Shag River Mouth were examined for foraging efficiency, patch choice, and diet breadth predictions (Nagaoka, 2002). Results suggested that the decline in regional resource availability caused food collection methods to eventually become, “more mobile, dispersed, and probably seasonal” (Nagaoka, 2002:38). Foraging efficiency was also a model applied to certain periods of occupation at sites on Harataonga Beach to suggest that there was recurrent seasonal site use in response to economic needs (Allen, 2011).

Similar to critiques that Groube’s (1965) settlement patterns faced, the processual assumption involving environmental determinism means there are similar flaws in foraging theories.
Foraging theories are often based on relative data, by measuring the change in resource access across space or time. The temporal clarity needed for foraging theories in New Zealand archaeology are therefore problematic, because the lack of time-resolution means the best usual division is binary by providing an “early” and “late” version of how people collected foods. Also similar to Groube’s model, the lack of socio-political consideration in foraging theories means any evidence of food trading between community units, or geopolitical land and resource management is disregarded and creates a bias. Additional flaws within the application of foraging theory involve oversimplified concepts for the mobility of hunter units, the assumption that hunters consistently returned to a base community, universal types of group banding, and presumed community agreements on what “mobility” involves when gathering – the realities of residential foraging mobility, socio-politically driven mobility, and other reasons for resource variety, add layers of complexity to foraging models (Kelly, 1992, Lupo, 2007). While these critiques hold truth, the role resource access held in prehistoric communities is not discredited and foraging theories continue to be a way archaeologists can investigate palaeoseasonality.

**Faunal proportions**

Of the few palaeoseasonality studies that have been conducted on early prehistoric New Zealand sites, most address questions of subsistence-economics and focus on placing sites within a temporal framework of annual resource cycles (Butts, 1977, Coutts and Jurisich, 1972, Higham, 1976, Leach, 1979, Leach and Davidson, 1977, Nagaoka, 2002) One common way this has been done is by recording the presence and absence of migratory and seasonally variable species in midden. This approach was used to examine yearly economic systems at Ruapuke Island (Coutts and Jurisich, 1972). It is also seen in Palliser Bay’s Washpool midden site which shows a year round occupation of the site (Leach, 1979). Foveaux Strait’s prehistoric economy was used to interpret mobility, and faunal data was used to propose that small mobile groups were dispersed, and coalesced in the harsher winter months (Higham, 1976).
There are issues with some of the assumptions underlying this method, due to the ethnographic evidence of meat drying in Māori communities which changes the timing of consumption and deposition of food remains (Anderson, 1982, 2000, Higham, 1976). Similarly, the transport of prey flesh also skews the interpretation of seasons seen in a food refuse deposit. Moreover, archaeological absence of data does not strictly define total absence on site. While these problems still have value, studies which have used faunal proportions to examine palaeoseasonality have supported the overall understanding of early New Zealand economic patterns.

**Micro and macrostructures of molluscs**

Certain shellfish species deposit shell material variably depending on seasons, and this seasonal variation can be analysed to estimate the season a shellfish died. Analysing shellfish growth structures to estimate the season of death has been a part of some archaeological projects in New Zealand (Coutts 1970, 1971, Coutts and Higham, 1974, Higham, 1990, 1996, Samson, 1995, Till 1984, Till and Blattner 1985). Shellfish material from the 14th century camp at Shag River Mouth was subject to seasonal analysis to understand resource scheduling and economics (Higham, 1996, Higham and Horn, 2000). Through oxygen isotopes and the analysis of physiological markers, the seasons of site use and reuse was identified to ground conclusions regarding economically driven human mobility and resource use. Shellfish from middens in the Coromandel’s early period sites on Tairua Point found palaeoseasonal evidence, and these results were supplemented by the presence and absence of seasonally abundant species (Rowland, 1977). Discussion of settlement types are explored in Rowland’s (1977) study, and are aligned to propose very brief seasonal occupation, with a strong annually cyclic economic-resource system. Over the 1970s and 1980s archaeologists explored the more basic forms of seasonal growth evidence which guided the more specific growth analyses that done through the 1990s (Coutts, 1970, 1971, Coutts and Higham, 1974, Higham, 1990, 1996, McFadgen, 1984, Samson, 1995, Rowland, 1977, Till 1984, Till and Blattner 1985). Using these pioneering studies two more recent research projects by Higham (1990) and then
Samson (1995) made detailed technical improvements on the most promising sample-type of all, the growth processes in *A. stutchburyi*.

**Palaeoseasonality using Austrovenus stutchburyi growth**

The seasonal growth patterning in *A. stutchburyi* and their archaeological implications are explained in Chapter 3, this section provides a description of the main work in New Zealand that used *A. stutchburyi* to explore palaeoseasonality in archaeological analyses. It explains the how each project analysed seasonal growth, the palaeoseasonal and methodological conclusions drawn, the obstacles and issues each found, and how this thesis aims to mitigate these.

**Initial investigations**

In the 1960s the discovery of seasonally variable banding phenomena in bivalve species triggered archaeologist Peter Coutts and research associates to investigate whether *A. stutchburyi* also deposited a seasonally variant shell matrix (Berry and Barker, 1968, Coutts, 1970, Coutts and Higham, 1971, House and Farrow, 1968, Panella and MacClintock, 1968, Runcorn, 1968). Investigations were conducted over two main phases, the first phase of work established types and possible triggers to basic growth phenomena in live collected *A. stutchburyi* samples (Coutts, 1970). The second phase investigated growth in more detail and applied the conclusions and methods to archaeological samples from southern New Zealand sites Wakapatu and Tiwai Point (Coutts, 1974, Coutts and Higham, 1971). Monthly collected live *A. stutchburyi* samples were sectioned along the transverse plane and examined under low-resolution microscopy to prove the winter phase of growth deposited a deep dark notch, and finer microbands were visible between each winter notch. Additional to the pilot banding analysis, Coutts also explored seasonal shell growth by measuring distances from one winter notch to the next to establish any metric relationship between an annual growth cycle and shell growth distance (Figure 7). Shell matrix between each winter notch was considered a single year and the relative annual distances were normalised under the equation $\Delta E(i, m)/E(i, i- 1)$ to deduce the season of death based on the rates of growth from previous years. Coutts
and Higham’s (1971) results suggested Tiwai Point was occupied early to mid-summer, while Wakapatu was occupied over autumn. The method’s archaeological application set a platform for further work to investigate palaeoseasonality through shellfish samples in New Zealand archaeological sites (McFadgen and Sheppard, 1984, Rowland, 1977, Till, 1984), and alongside the expanding physiobiological and fisheries research into the A. *stutchburyi*, archaeological methods and requirements were refined by two research theses in the 1990s.

Figure 7. Geometric diagram of a cross section through an *Austrovenus stutchburyi* specimen illustrating the dimensions used by Coutts to explore the metric relationship between shell growth and an annual cycle. (Coutts, 1971:269).

**Refined investigations and archaeological application**

Shell growth patterns in the *A. stutchburyi* were investigated by Higham (1990) and Samson (1995) to explore the validity of the technique developed in earlier decades. The authors refined Coutts’ method and applied the improved techniques to archaeological samples as a means to explore palaeoseasonality in New Zealand archaeological sites.

Higham’s (1990) research worked to test the method proposed by Coutts by assessing the seasonal growth results to the results of stable oxygen isotopic variation (\(^{16}\)O and \(^{18}\)O) in the New Zealand Blue Mussel (*Mytilus edulis*). Stable isotope analysis in marine shell is a well-accepted and reliable method for thermodynamic predictions, meaning the isotopic results were reliably compared to the calculated *A. stutchburyi* growth indices. The results suggested
the analysis of growth indices to predict season of death was a generally reliable technique when applied to shells where growth rates were active and not yet senile (Higham, 1990:109-110).

Testing the method with low resolution microscopy found it was difficult to differentiate winter bands from bands resulting from periods of arrested growth. Additionally, smaller shell specimens may have had skewed results considering measuring tools may have introduced inaccuracies to the level of precision needed. Higham (1990) noted that during testing of the method winter was well under-represented in the samples, this is probably due to the varying growth rates not equally distributing across shell matrix in a year (as already discovered in other studies by: Samson, 1995, Schöne, 2008, Schöne and Gillikin, 2013). Most importantly, the growth indices technique applied to the archaeological sample were not tested with a control collection, so Higham (1990) notes the seasonal growth results alone must but accepted with caution. Nonetheless, the reliability of stable isotope results meant the growth indices were able to be tested and compared with confidence. This confirms the reliability of the method for use in New Zealand archaeology. The application of Higham’s method to archaeological samples provided results which gave important insight into the early period subsistence patterns in southern New Zealand and aided the development of the an important settlement and mobility model known as the “transient settlement” of prehistoric New Zealand (Anderson and Smith, 1996).

Following Higham’s study, Samson (1995) researched the same general concept of growth indices analysis as Coutts (1970, 1974, 1971) and Higham (1990) to explore palaeoseasonality in A. stutchburyi. Samson (1995) examined palaeoseasonality using a method proposed in American studies which differs from the aforementioned methods by creating the growth index profiles differently (Custer and Doms, 1990, Samson, 1995). The technique calculated the season of death by grouping monthly growth index values and then analysing the groups as percentage frequency histograms to get an impression of the month of death. Samson (1995) created a robust control collection spread over many nearby sites and invested over 3000 hours to create 3384 thin sections for photomicrography and analysis. Results from the
archaeological collection suggested Pleasant River Mouth was occupied during most seasons in the earlier period of occupation but in later centuries was occupied more sporadically. Samson attributes this to dwindling resources which caused a type of broad spectrum foraging to develop.

Similar to Higham’s (1990) research, limitations of palaeoseasonality investigations at Pleasant River Mouth were underpinned by low image resolution and limited physiobiological knowledge. Other limitations included the inability to differentiate a growth interruption from a winter band, measuring tools which introduce inaccuracies considering the level of precision needed, and the margins of error in this approach was three months (which is effectively the span of an entire season). Samson mitigated some of these errors by integrating palaeoseasonal findings from other archaeological results such as taphonomy, faunal proportions, and presence and absence of certain species, such as Barracouta (*Thrysites atun*) and juvenile fur seal (*Arctocephalus forsteri*), to aid the palaeoseasonal conclusions at the site.

Aside from the pioneering study by Coutts (1970), these studies investigate shell growth rates by measuring the distances in a year of growth in *A. stutchburyi*, and other than a winter notch, they do not systematically investigate the banding phenomena as a means to explore palaeoseasonality. These early studies express the technicalities of microbanding analysis using the available resolution and limited physiological understanding dissuading an in-depth study into microbanding over annual cycles (Coutts 1970:338, Samson 1995:30, Higham 1990:100).

Many archaeological methods have been used to understand seasonality and the way humans moved and subsisted in early New Zealand. While these studies all vary in method, they all share the broader aim of addressing economic dimensions to prehistory. These studies use seasonal data to investigate resource scheduling, human movement driven by food demand, and reveal how hunter-gatherer economics and seasons controlled human subsistence.
**Wairau Bar**

**Location**

Wairau Bar is found at the north eastern corner of New Zealand’s South Island (Figure 8). The location of this site is undoubtedly strategic considering that within a 100 kilometre radius, estuarine, marine, mudflats, lagoons, flat plains, deep forest, and alpine environments were available to the settlers, each of these niches provide their own unique food group. Moreover, the location on the leeward coast of the country provided more favourable conditions for the East Polynesian settlers.

![Map of Wairau Bar](image)

*Figure 8. Location of Wairau Bar. Shaded area marks the possible extent of the archaeological site. (Source: Brooks et al. (2009:260)).*

**History of excavations**

Unearthing of archaeological evidence at Wairau Bar started with fossicking and accidental discovery in the 1920s, followed by the first human burial being found local boy Jim Eyles in 1939. The first phase of systematic excavation commenced when the Canterbury Museum investigated the site in 1942 and this continued over to the 1950s (Brooks et al., 2011, Duff, 1942, 1950, 1956). The second phase of archaeological investigations continued with the Canterbury Museum during the 1960s mainly by archaeologist Owen Wilkes; however rising tension between iwi meant this ceased for several decades to follow (Brooks et al., 2011, Duff,

Excavations at Wairau Bar in 2009 took place primarily as part of an essential step in the repatriation and reburial of Koiwi tangata (koiwi) to Te Runanga a Rangitāne o Wairau (Rangitāne). The core objective was to find archaeologically sterile land on Wairau Bar to rebury koiwi. The secondary objective was research driven and aimed to gain a better understanding of New Zealand’s settler community. This included understanding the stratigraphic variation of the site, extent of damage from ploughing, investigate evidence for structures, and create a clearer impression of subsistence economics through a well provenanced midden analysis (Brooks et al., 2009).

Archaeological evidence from the 2009 excavation included material culture, evidence of structures, and midden features. The largest midden feature was found as part a cluster of five anomalies which shared similar fluxgate radiometric readings within approximately 5 meters of each other. The excavation details of this midden feature are described in detail later in this chapter.

**Summary of site significance**

Wairau Bar has many features that make it one of the most significant cultural and scientific archaeological sites in New Zealand, in that there is likely to be information within the corpus of data from Wairau Bar that address core questions in New Zealand archaeology. Although the current thesis focuses specifically on a methodology for seasonal studies, these methods have the potential to address some of these questions. The following issues are relevant:

1. The site is likely to be a first-settler site, meaning it can act as a cultural reference point for understanding key aspects of culture change in New Zealand prehistory.
2. The site is geographically placed in one of the most abundant regions for moa in New Zealand. This means the role of big-game in settler society and the mechanics of moa decline can be addressed.
**Oven Pit 1**

A detailed explanation of the midden deposit and the sample is summarised in Chapter 3 under the “Materials” section. Relevant to the background of Wairau Bar is to explain the midden as part of the wider archaeological site. The feature was one of five large anomalies seen in fluxgate radiometric scanning. The midden deposit was within a stone lined oven. The feature spans nearly 6 meters and is 1.2 meters deep (Brooks et al., 2009, Jacomb et al., 2014). Morphology aside, there are other attributes making this feature unique, these are presented below.

**Sample significance**

Radiocarbon dating of moa egg shell in Oven Pit 1 sample provide dates to a period sometime between 1320 – 1350 AD (Jacomb et al., 2014). DNA analysis of the moa egg shell fragments inside Oven Pit 1 also confirm over 31 moa eggs are in the sample (Oskam et al., 2011). Additionally, mtDNA analysis of moa egg shell fragments also established that one moa egg was strewn through the high volume midden, from the top through to the bottom (Oskam et al., 2011). Further, there was no visible evidence of stratigraphic layering in the midden.

Fragments from a single egg through this deep single-layered deposit raises several durational questions, some which this thesis addresses are:

- Was the consumption of food from this deposit over a single feeding event?
- Or, was the food consumed over a long period of time, meaning the refuse could represent a secondary deposit cleaning or “rake-in” event?
- Alternatively, was there a different unconsidered event that resulted in the mono-layered midden deposit?

These topics are explored in Chapter 6 when the archaeological results are discussed in the context of duration.
Chapter 3

Materials and methods

Chapter summary

This chapter begins by presenting the factors that affect physiological and biological growth in the New Zealand cockle (*Austrovenus stutchburyi*). After establishing how and why cockles deposit shell material in varying manners, backgrounds of the control and archaeological samples are described. Following the materials section, the three main stages of the methodology are described.

Materials – *Austrovenus stutchburyi* growth factors and markers

Growth and physiology in bivalves

Cockles are made up of inorganic, calcareous deposits and organic elements. These are deposited in the shell in a predictable manner. The transverse section of the shell displays two types of deposition (Figure 9). The first are growth increments and the second are lamina (Figure 10) (Pannella, 1975, Sheppard, 1985).

![Diagram of Austrovenus stutchburyi and the relevant anatomical terms used in this thesis (images amended from Beu and Raine (2009:41).](image)

Figure 9. Diagram of *Austrovenus stutchburyi* and the relevant anatomical terms used in this thesis (images amended from Beu and Raine (2009:41)).
Growth increments in the *A. stutchburyi* are “repetitive units of contemporaneous growth detectable across all layers in accreting tissue” and are used by archaeologists to address temporal questions (Sheppard, 1985). This thesis refers to growth increments as “microbands”. Each microband consists of calcium carbonate and a fine layer of conchiolin. Shell calcification is interrupted by conchiolin deposition and is then followed by calcium carbonate deposition (i.e. each microband starts with a strip of conchiolin and is followed by the calcium carbonate). The outer lamina of the shell provides a visual impression of these deposits (Sheppard, 1985), while the middle and inner lamina provide limited or no visual record of microbands (Higham, 1990, McKinnon, 1996, Orsman, 2011) (Figure 10).

Calcium carbonate and conchiolin reaches the shell by forming in the extrapallial fluid. Extrapallial fluid sits between the inner surface of the shell and the mantle to process particular compounds that create shell material. Calcium, calcium bicarbonate, and carbon dioxide form crystallised calcium carbonate in the extrapallial fluid. These crystals grow as increments in the shell matrix managed by the mantle of the shell (Dodd, 1965, McKinnon, 1996, Sheppard, 1984, 1985).

The gaping and closing (feeding) mechanisms of the cockle control the energy access for the growth patterns in the shell to occur. When the shell is closed, calcification is interrupted and the process of conchiolin and calcium carbonate deposition begins (McKinnon, 1996, Pannella, 1975). The manner of microband deposition and how it aids archaeological investigations are described in the following section.
**Austrovenus stutchburyi** physiology and growth

*A. stutchburyi* shells have been used in several archaeological studies in New Zealand to examine palaeoseasonality (Coutts, 1970, Coutts and Higham, 1971, Higham, 1990, McFadgen and Sheppard, 1984, Rowland, 1977, Samson, 1995). The body of knowledge has expanded vastly since studies were piloted from the 1970s, especially that surrounding physiology and the manner of shell deposition in the species. This development has revealed complexities behind growth factors and banding interpretation. The increased knowledge has also resulted in a need for some changes to the way archaeologists use the cockle to ask temporal questions. Alongside refining archaeological techniques, fisheries and marine science researchers have explored questions regarding optimal growth conditions. These advances are directly relevant to archaeologists using *A. stutchburyi* to ask temporal questions, by identifying the importance of specific external factors. Clearer biological understanding coupled with advances in microscopy means data from cockles can be extracted with more confidence than when first proposed by Coutts in the 1970s and tested by others through the 1990s.

**Internal growth factors**

Internal time-keeping mechanisms (endogenous mechanisms) exist in many species as a way to enable the organism to predict and prepare for external events that are advantageous to survival (Naylor, 1984). Over the majority of the 1980s and early 1990s endogenous mechanisms were thought to be acutely present in the *A. stutchburyi* gaping and closing feeding technique in a circa-tidal (12.4/24.8 hour) pattern (Beentjes and Williams, 1986). However subsequent research has since proven that these are not as deeply endogenous as first assumed, and the species feeding patterns follow a far looser internal regime, which is highly influenced and maintained by external factors (Beikirch, 1995, Williams, 1998). So much so, that over a short period (no more than a week) the feeding rhythm is lost if predictable tidal patterns are not maintained (Beikirch, 1995, Hewitt and Norkko, 2007, McKinnon, 1996, Vander Putten *et al.*, 2000, Williams, 1998). Temporal programming in *A. stutchburyi* to an externally predictable process (in this case, circa-tidal immersion) aids
feeding, however the depth of this programming is loose - endogenous mechanisms are only rhythmic if exogenous rhythms are maintained. Endogenous gaping and closing is altered or paused if tides are not following the typical 12.4 hour cycle.

The external factors are therefore assumed to be stronger contenders for growth patterns observed, meaning the record of tidal and environmental events are more reliable. Feeding behaviours are synchronous to consistent tidal patterns, however the manner (width, size, thickness, density) of these depositions are based on how much food is available to the cockle, and this is controlled by factors such as solar and lunar tides, seasons, phytoplankton blooms, and frosts. This loosely managed endogenous program also means anomalies present in banding patterns which are shared across the matrix of many specimens from the same sample can be assumed to be environmental events. Similar to dendrochronological approaches, if these markers also share adjacent band patterns it suggests they are synchronous, aiding sclerochronological techniques and temporal relativity studies.

**Spawning**

Spawning is an internally controlled phenomenon which effects shell deposition in *A. stutchburyi*. The energy required for successful spawning means energy that is usually spent on depositing shell material is redirected to complete the spawning process (Booth, 1983, Larcombe, 1971, Marsden, 2004, McKinnon, 1996, Stephenson and Chanley, 1979). Shell growth usually ceases during this period (Larcombe, 1971, Marsden and Pilkington, 1995, McKinnon, 1996, Schöne, 2008). Spawning occurs occasionally over the spring and mostly summer periods in *A. stutchburyi* (Booth, 1983:259, McKinnon, 1996, Stephenson and Chanley, 1979). Study samples have spawned for a short period (around a week), and on very rare cases “trickle spawn” through several months of the year (Booth, 1983, Stephenson and Chanley, 1979). Differentiating a spawning event to a winter in the cockle was characterised in McKinnon’s (1996) study that identified visual differences in cross section. The annual winter macro-band usually leaves a deep notch on the external surface of the shell; however the spawning event does not (McKinnon, 1996). Therefore, microbands can be measured for the annum with more confidence. Additionally, spawn bands often do not extend all the way

**External growth factors**

Events which exist outside of an organism also determine its survival. The parameters which enable the *A. stutchburyi* to survive and deposit shell is predominantly energy access (Cameron, 1999, Coutts, 1974, Hallmann et al., 2009, Larcombe, 1971, Norkko et al., 2006, Peake et al., 2006). Cockles filter feed on phytoplankton, so the factors which determine phytoplankton reaching cockles are the primary (although not exclusive) factors determining the manner of shell deposition.

**Food Availability**

Throughout decades of *A. stutchburyi* research, there remains strong consensus that energy availability is the strongest factor contributing to the growth of the cockle (Beikirch, 1995, Cameron, 1999, Larcombe, 1971, Marsden, 2004, Marsden and Pilkington, 1995, Marsden et al., 2014, McKinnon, 1996). Phytoplankton is available when the incoming tide immerses the shell. The frequency of immersion controls the frequency of feeding events, which in turn controls shell growth. Environmental factors control the manner by which phytoplankton reach the cockle. The most significant of these are the lunar and solar patterns which determines the season, the spring-neap cycle, and tidal frequency (Beikirch, 1995, Coutts, 1970, McKinnon, 1996), ontogenetic age (McKinnon, 1996, Samson, 1995), population density (Kennish, 1980, Larcombe, 1971), distance from shoreline (Cameron, 1999, Marsden and Pilkington, 1995, Peake et al., 2006), storm events (Brockington and Clarke, 2001, Burchell et al., 2013, McKinnon, 1996, Schöne et al., 2005), and thermodynamic variation (Higham, 1990, McKinnon, 1996). These factors are described below with reference to how they can be identified to aid archaeological investigations.
**Season**

Seasonal growth variation is observed in most *A. stutchburyi* growth studies (Coutts, 1970, 1974, Higham, 1990, Larcombe, 1971, McKinnon, 1996, Samson, 1995). Season is reflected in the shell growth rate because the food availability and temperatures change over seasons (Coutts, 1974, Gibbs and Vant, 1997, McKinnon, 1996). Generally, late spring and summer are more active growth periods compared to winter and autumn (Bull, 1984, Coutts, 1970, 1974, Hewitt and Norkko, 2007, Higham, 1990, McKinnon, 1996, Orsman, 2011, Samson, 1995). Latitude appears to have slight control on the general length of microbanding growth periods (Orsman, 2011), where the northern and warmer regions display more active shell growth periods than in the cooler southern regions. Seasonal variation is consistent across New Zealand. In winter periods *A. stutchburyi* deposits a thick notch and the peak shell-growth period is mid-summer. This seasonal growth consistency found across many studies is summarised in Table 1.
Table 1 Summary of *Austrovenus stutchburyi* seasonal growth investigations and relevant findings for temporal analysis. N.I = not investigated.

<table>
<thead>
<tr>
<th>Author</th>
<th>Sample region</th>
<th>Seasonal cycles</th>
<th>Proposed macro-notch phase</th>
<th>Proposed microband period</th>
<th>Spring-neap tide visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higham (1990)</td>
<td>Shag Mouth, Otago</td>
<td>Growth peaks in summer and lowest in winter</td>
<td>Annual. Winter.</td>
<td>N.I</td>
<td>N.I</td>
</tr>
<tr>
<td>McKinnon (1996)</td>
<td>Papanui Inlet, Otago</td>
<td>Growth peaks in spring-summer and lowest in winter</td>
<td>Annual. Winter.</td>
<td>Tidal. Summer only.</td>
<td>January and February only</td>
</tr>
</tbody>
</table>
This thesis is guided by these investigations and assumes that shell growth rates and microband deposition is most likely to peak in spring and summer, to be at their lowest in autumn, and to cease in winter (Figure 11). The majority of these studies were based on control samples from the Otago region, unlike this study which provides data from Wairau River Mouth, Blenheim. Regional growth variation is witnessed in other bivalve species across the world (Burchell et al., 2013, Clark, 1979, Custer and Doms, 1990, Fritz et al., 1991, Hallmann et al., 2009, Karney et al., 2011, Keen, 1979). Otago samples are exposed to cooler conditions than Wairau Bar, meaning there could be variation in the timing of the seasonal markers.

**Identifying seasons**

In a standard low-resolution light microscope an *A. stutchburyi* cross section displays two types of banding: dark, thick macro-bands which are flanked by smaller fainter microbands (McKinnon, 1996) (Figure 12). In most bivalves, macro-bands are often markers of winter, and the microbands are often related to daily or circa-tidal periodicity. The macro-band is the
most recognisable yearly record in the shell cross section, and is commonly used for annual checks to be used in analyses (i.e. one winter to another is one year).

![Cross-section of the Austrovenus stutchburyi](image)

Figure 12 Cross-section of the *Austrovenus stutchburyi* which displays the macrobanding phenomena. Between each darker macroband are very fine micro-bands which are usually indistinguishable to the naked eye.

Coutts (1970) suggested finer bands (microbands) between each winter event were possible daily or sub daily tidal events, however later texts critiqued this conclusion for the absence of results (Coutts, 1974, Coutts and Higham, 1971, Higham, 1990, Samson, 1995). Even so, this was not disproven as a theoretical concept - rather, these issues arose from technical constraints of microscopy. Subsequent research has proven these ideas were probably correct for growth during warmer months (McKinnon, 1996). Shell cross-section analysis by Coutts (1970) provided some fundamental concepts that aid this thesis; the idea that relative microband density and periodicity over a death year enables season and duration calculations is particularly useful.

**Spring-neap tides**

Within monthly tidal systems there are patterns called spring and neap tides (Figure 13, Figure 14). These exist because there are two parameters simultaneously determining the degree of the rise and fall of the tide at any moment; these are solar tides, and lunar tides. The effect they have on the tide varies independently based on the position of the earth in relation to the sun (solar tide) and the moon (lunar tide). The earth acts as the pivot point and shares the pull of the moon and sun at perpendicular positions (i.e. there is 90° between the sun and
the moon). During a spring tide the moon and sun are on the same plane meaning there is augmented tidal height variance. For the cockle, this means there are two weeks of each month where there is phytoplankton access that lasts longer than the other two weeks, due to the amount of food access varying according to tidal sizes. There are four identifiable spring-neap cycles over a total lunar cycle (28 days), meaning each seven days the peak of either spring or neap tide occurs.

*Spring tides*

The tides during a spring tide have the most variation in water height, occurring during new moons and full moons (Figure 13). There are usually two of these each month.

![Diagram showing the lunar and solar position and associated tidal pulls during a spring tide.](image)

*Figure 13.* Diagram showing the lunar and solar position and associated tidal pulls during a spring tide.

*Neap tides*

During a neap tide there is approximately 10 - 30% less change between low and high tidal height. It occurs at first and third quarter moon phase, when the Moon's tidal effect is perpendicular with the Sun's tidal effect (Figure 14). There are usually two of these each month.

![Diagram showing the lunar and solar position and associated tidal pulls during a neap tide.](image)

*Figure 14.* Diagram showing the lunar and solar position and associated tidal pulls during a neap tide.
The ability to identify the spring-neap tides in *A. stutchburyi* is a useful tool for cross checking time of death calculations. Using the spring-neap tidal markers in bivalves in Northern Alaska (Hallmann et al., 2009) has aided the time of death analyses in species while also providing data of lunar patterns. Shorter and longer relative predictable feeding patterns across a month in *A. stutchburyi* may assist fortnightly estimations during archaeological application of microbanding analysis, and understand any lunar harvesting patterns.

**Tidal periodicity**

The microbands between two macro-bands are finer, smaller, and generally indistinguishable to the naked eye. Decades of research across many species of bivalves has shown that the primary trigger causing microband deposition is either a daily or tidal cycle (this varies across species). Should each microband deposition mark a feeding event, this would be expected to be every 12.4 hours. Tidal periodicity matching any microband periodicity in the *A. stutchburyi* was refuted for many years but research by McKinnon (1996) showed that there is a strong relationship between tidal and microband periodicity over warmer months.

**Ontogenetic Age**

Ontogenetic age effects microband growth. Older bivalves produce more gametes than younger individuals at the cost of increasing flesh weight and shell size, thus slowing their growth (Larcombe, 1971:45). Studies have shown *A. stutchburyi* reach their total length by the age of 12 years, and thereon deposition of the shell is linear (McKinnon, 1996). Linear growth is when the allometric path of the shell growth stops and is instead packed tightly downward thickening the ventral margin. Most bivalves develop this linear growth pattern (Hallmann et al., 2009) (Figure 15), *A. stutchburyi* best displays growth between the ages of 4 – 12 years (Figure 16) (McKinnon, 1996:52).
Figure 15. Image of the transverse section of the Alaskan bivalve Saxidomus gigantea showing the linear growth pattern that develops in bivalves over ontogenetic age. Image on the left is a younger shell, where microbanding responds to tides predictably, image on the right shows a senile shell which exceeds the best-fit model (Source: Hallmann et al, 2009:2357).

Figure 16. Growth rate and age model for Austrovenus stutchburyi. (Source McKinnon, 1996:52).

Senile bivalves of many species commonly follow different growth trajectories, such as adding layers of shell matrix on top of extant shell rather than extending the edge (Schone, 2013). These growth patterns can often distort and interrupt banding behaviours in shell species and have analytical implications for archaeology. No comprehensive research into the growth patterns of senile A. stutchburyi has been undertaken to properly understand the implications for archaeological analysis.
Identifying responsive specimens based on age refines archaeological sample selection methods to ensure that the most appropriate samples are chosen for palaeoseasonal analysis. If archaeological samples have little or no microband data this can be attributed to the ontogenetic age of the specimens. Additionally, it enables the examination of the shellfish exploitation at a site. Specifically, within the context of Wairau Bar’s midden feature it may display the virgin ecosystem being exploited by humans which contains comparatively old specimens.

**Population density**

There are two main ways population density effect shell deposition in the cockle: the first is the relationship between food availability and population size, and the second is competition for available physical space (Kennish, 1980, Larcombe, 1971, McKinnon, 1996). Population density is often high for *A. stutchburyi* in modern collections so the physical space and energy required to grow is shared within a population.

Considerations of population density in *A. stutchburyi* can expose food collecting practices by looking at relative size and age across the midden sample (Swadling, 1977:12). For example, if specimens are large but of relatively young ontogenetic age, this correlates with a possible low density population, which can infer details of shellfish harvesting systems.

**Distance from shoreline**

Distance from the shoreline affects the growth rate of the *A. stutchburyi* (Cameron, 1999). High tides provide food for cockles. As the tide moves up the estuary the concentration of phytoplankton decreases as it mixes with the fresh ground water table (Cameron, 1999). This means organisms that live closer to the shoreline have higher growth rates than those living further from the shoreline (Dobbinson *et al.*, 1989, Larcombe, 1971:23-25).

The ability to measure relative seasonal growth rates within the lifetime of *A. stutchburyi* specimens can be used to analyse the location of collection within the estuary. Location can aid the archaeological understanding of shellfish collection and harvesting practices. For example, if an archaeological sample is composed of mixed ontogenetic age specimens, and all
share densely packed shell growth, this supports the likelihood that the shellfish gatherers were foraging further up the estuary (Swadling, 1972). This information is useful when considering questions about shellfish harvesting patterns in early New Zealand.

**Thermodynamic control and water surface temperature**


In New Zealand prehistory the “little ice age” is a period of climatic cooling which effected Māori economic activity (McFadgen, 2008). Records of water cooling in the New Zealand archaeological record are important to identify because it significantly contributes to palaeoclimate reconstruction and understanding the environment people settled, by gauging the relative differences in growth rate across several years. This may be possible in *A. stutchburyi*.

**Storm events**

Storms can interrupt sub-daily food access for *A. stutchburyi* which can stop shell growth. The impact that storms have on shell growth depends on the length and intensity of the interruption (Beikirch, 1995, Hewitt and Norkko, 2007, Schöne, 2008). The main types of storm impacts *A. stutchburyi* are exposed to are: turbidity, flooding, and frosts.

Turbidity and flood events change the sediment and nutrient access for *A. stutchburyi*. Immersing the shell with sporadic and varying levels of nutrients interrupts the feeding, and
once an unmanageable amount of variation is reached, shell deposition ceases until the
feeding routines are restored (Beikirch, 1995, Brockington and Clarke, 2001, Norkko et al.,
2006). This response is common in most estuarine species because the “...adaptability to
abrupt salinity and nutrient productivity changes seems essential in an estuarine species living
near stream mouths liable to sporadic flood” Beu (2006:282).

Similar to thermodynamic sea-surface temperatures, air-surface temperature also contributes
to the way A. stutchburyi accesses food. Intertidal species are exposed to both aerobic and
anaerobic metabolic conditions (Panella and MacClintock, 1968). When the tide is low
aerobic metabolic processes occur in A. stutchburyi. During a frost, A. stutchburyi burrows
lower into the sand to ensure that aerobic processes continue and to avoid the extreme air
surface temperature. Cockles can experience a period of arrested growth during frosts because
less food is available in the deeper sediment. Frosts mainly occur during winter in New
Zealand; however, they also occur through spring and autumn in southern New Zealand. The
ability to identify frost events reinforces the ability to detect seasons. If a period of growth in a
specimen has several grouped arrested growth patches they can be tested as frost patches by
examining adjacent growth areas to determine time of death.

While the above external factors control the growth of the A. stutchburyi, other less-examined
factors should not be discounted. Salinity, foreign contaminants, and a number of other
factors present in estuarine ecosystems may affect the growth rates of A. stutchburyi (Lazareth
et al., 2003, Marsden, 2004, McKinnon, 1996). This thesis considers well-investigated factors
that closely correlate to growth patterns in the cockle, while acknowledging that there could
be additional un-explored triggers growth patterns.

**Materials – control sample**

Once day a month between October 2011 and December 2012 ten live A. stutchburyi were
collected from the Wairau Estuary (Figure 17). These specimens created the control collection
data to shape models of growth over seasons. It is agreed that the control collection should
come from a location near to the archaeological sample (Coutts and Jones, 1974, Samson,
1995, Schöne and Gillikin, 2013). The control collection in this study is highly likely to be from the same estuary as the archaeological collection. Samples were collected within 200 – 300 meters of the archaeological site.

![Image of Wairau Estuary](image)

Figure 17 Aerial photograph of the Wairau Estuary marking the locations for Austrovenus stutchburyi control collection in red (Source: Google Maps 2014).

Control samples were collected at a low tide on the 20th day of each month unless otherwise specified (Table 2). Sample collection dates were plotted with NIWA tidal height and periodicity records (NIWA, 2012-2013) to create a data base used to examine microband periodicity recorded in the control specimens for each month. February and June samples were not collected due to volunteer absence.

<table>
<thead>
<tr>
<th>Sample month</th>
<th>Date collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>Saturday 20</td>
</tr>
<tr>
<td>November</td>
<td>Tuesday 20</td>
</tr>
<tr>
<td>December</td>
<td>Thursday 20</td>
</tr>
<tr>
<td>January</td>
<td>Friday 20</td>
</tr>
<tr>
<td>March</td>
<td>Thursday 8</td>
</tr>
<tr>
<td>April</td>
<td>Friday 20</td>
</tr>
<tr>
<td>May</td>
<td>Sunday 20</td>
</tr>
<tr>
<td>July</td>
<td>Friday 20</td>
</tr>
<tr>
<td>August</td>
<td>Monday 20</td>
</tr>
<tr>
<td>September</td>
<td>Thursday 20</td>
</tr>
</tbody>
</table>

Table 2. Collection dates for monthly control sample. Dates were used to plot the amount of recorded tides which passed since the previous month’s collection. February and June samples are missing due to volunteer absence.
The samples were shucked and cleaned the same day as collection. Using McKinnon’ (1996) and Orsman’s (2011) conclusions on ontogenetic age and growth rate responsiveness in A. stutchburyi, samples between the age of 4-12 were targeted for analysis. Only complete valves were selected, and the condition of the ventral margin and external surface needed to show no damage. Similar high-resolution banding analyses for palaeoseasonal studies across the Americas, Asia, and Europe create very accurate and clearly resolved banding data from control-collections that are much smaller than in earlier decades. Most of the collection samples representing a total year, display significant relationships to environmental events in less than 15-50 specimens (Black, 2009, Burchell et al., 2013, Groke and Gillikin, 2008, Hallmann et al., 2009, Karney et al., 2011, Schöne and Gillikin, 2013). This is in stark contrast to samples sizes from the pioneering studies in earlier decades that needed to accumulate hundreds, and in some case thousands, of samples to identify seasonal models of growth in shellfish (Coutts, 1970, Evans, 1972, Fritz et al., 1991, Kennish, 1980, Quitmyer et al., 1985, Richardson et al., 1980, Samson, 1995). Developments in microscopic technology means that the sample size for this type of analysis is much smaller than previously required and alongside the scope of this thesis with limited access to microscopic-resources, the following specimens were chosen to compose the control collection for growth analysis (Table 3).

<table>
<thead>
<tr>
<th>Sample month</th>
<th>SEM specimen label</th>
<th>Ontogenetic age</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>Jan 1</td>
<td>6</td>
</tr>
<tr>
<td>January</td>
<td>Jan 2</td>
<td>9</td>
</tr>
<tr>
<td>January</td>
<td>Jan3</td>
<td>10</td>
</tr>
<tr>
<td>March</td>
<td>March 1</td>
<td>8</td>
</tr>
<tr>
<td>March</td>
<td>March 5</td>
<td>5</td>
</tr>
<tr>
<td>May</td>
<td>May 3</td>
<td>3</td>
</tr>
<tr>
<td>July</td>
<td>July 3</td>
<td>5</td>
</tr>
<tr>
<td>October</td>
<td>Oct 3</td>
<td>4</td>
</tr>
<tr>
<td>November</td>
<td>Nov 5</td>
<td>7</td>
</tr>
</tbody>
</table>
Materials – archaeological sample

A review of Wairau Bar’s archaeological significance and background has already been addressed in Chapter 2, the following summary focuses on the midden deposit from Oven Pit 1 which is the basis for this study. The spatial details are described and are followed by a summary of the stratigraphic details. The faunal details are also summarised within a stratigraphic context. This section finishes with an explanation of the archaeological specimens and the associated stratigraphic details.

Spatial details

Excavations at Wairau Bar over January 2009 were part of a program of repatriating human remains removed earlier in the twentieth century (Brooks et al., 2009). Living floors, middens, and food preparation areas were excavated. During investigations five large (~6 meters in diameter) cooking pits in a circular distribution were found (Figure 18), one of which was excavated and sampled for analysis, this deposit was labelled “Oven 1” (Jacomb et al., 2014). Inside “Oven 1” a 1 x 1 meter column sample called “Column Sample A” (CSA) was excavated and contained A. stutchburyi which are the specimens used for the archaeological application of this study.
Figure 18. Plan of Wairau Bar excavation areas. Area 4 and 5 is in red square and this is magnified with the overlaid image to show the circular array of large features. “Oven 1” is the anomaly with red-lined square plotted over it (Source: Brooks et al, 2009:260)

**Stratigraphic details**

Oven Pit 1 was 6 meters in diameter and 1.2 meters deep (Brooks et al, 2009). CSA was divided into 25 x 25 centimetre quadrants (NE, NW, SE, SW) and generally sampled in 100 millimetre spits per natural layer, but because of the nature of the matrix (shell, large bone,
large stones), the true values of the spits varied between 130-250mm. The profile of layers are summarised as follows (Brooks et al., 2009, Jacomb et al., 2014) (Table 4).

Table 4. Summary of stratigraphic depths and matrixes of Oven Pit 1 (based on Jacomb et al., 2014).

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>0 – 200 mm</td>
<td>Plough zone. A mixture of topsoil and fragmented midden.</td>
</tr>
<tr>
<td>Layer 2</td>
<td>200 – 1200 mm</td>
<td>Pit fill. A mixture of shell and bone midden in an ash and soil matrix. The lower 500 mm (spit 4 and 5) was dominated by ashy soil, gravel, and fire cracked rocks with less faunal remains.</td>
</tr>
<tr>
<td>Layer 3</td>
<td>1200 mm – base of excavation</td>
<td>Sterile grey, silty, subsoil overlaying a layer of large oven stones.</td>
</tr>
</tbody>
</table>

Figure 19. Illustration of “Oven Pit 1” and Column Sample A (CSA) from the 2009 Wairau Bar excavation. Layer 2 was excavated in 5 spits which are shown on here and the midden refuse from these spits composed the archaeological collection for this study (Not to scale).

Layer 2 contained all the faunal refuse sampled. Layer 2 was excavated in 5 spits (spit i – v) (Figure 19). Fauna included moa egg shell and moa bone, 20 species of other birds, marine mammals (pinnipeds), dog (Canis familiaris), fish, and shellfish including A. stutchburyi (Jacomb et al., 2014). The A. stutchburyi samples for this analysis are all derived from spits i – iv. There were no specimens from spit v which met the conditions of an intact complete valve with an undamaged ventral margin. Layer 2 contains fragments of a single moa-eggshell strewn from top to bottom of the refuse (Oskam et al., 2011), suggesting midden deposition into the oven occurred in one phase (Jacomb et al., 2014). Some of this moa egg-shell was
radiocarbon dated to suggest deposition occurred between 1320 – 1350 AD (Jacomb et al., 2014).

**Methods**

This section describes methods specific to preparing and analysing *A. stutchburyi* using scanning electron microscopy (SEM). It begins by explaining the methods for sample selection, followed by stages involved in sample preparation, and explains techniques and technical details necessary for SEM for both the control and archaeological collection.

**Control collection**

**Sample selection**

Sections were made from the left valve of *A. stutchburyi* unless these were damaged, in which case the right valve was used. Veneridae are eqivalue, therefore this thesis works on the assumption both valves grow at the same rate and will produce identical results (McKinnon, 1996, Powell, 1979, Sheppard, 1984). Specimens were chosen based primarily on the condition of the ventral margin and ontogenetic age. The archaeological specimens are noticeably larger than any control specimens, which meant choosing specimens based on ideal ontogenetic age sample selection was difficult. Considering the majority of specimens were very old, the youngest possible samples of the available specimens were chosen. This was based on the thickness of the ventral margin which is an indicator for linear growth. The stratigraphic details and SEM analytical applications of each specimen is summarised are summarised in Table 5.
Table 5 Summary of stratigraphic and SEM imagery technique used for archaeological specimens used in this study.

<table>
<thead>
<tr>
<th>Bag no.</th>
<th>Area</th>
<th>Layer</th>
<th>Spilt</th>
<th>Quadrant</th>
<th>SEM analysis inventory number (Spit . bag number)</th>
<th>Type of SEM used</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>J</td>
<td>2</td>
<td>iv</td>
<td>SW</td>
<td>4.3</td>
<td>JEOL</td>
</tr>
<tr>
<td>16</td>
<td>J</td>
<td>2</td>
<td>iv</td>
<td>SW</td>
<td>4.1</td>
<td>JEOL</td>
</tr>
<tr>
<td>1</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SE</td>
<td>3.1</td>
<td>Damaged during preparation</td>
</tr>
<tr>
<td>1</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SE</td>
<td>3.2</td>
<td>JEOL</td>
</tr>
<tr>
<td>38</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>NE</td>
<td>3.3</td>
<td>JEOL</td>
</tr>
<tr>
<td>38</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>NE</td>
<td>3.4</td>
<td>JEOL</td>
</tr>
<tr>
<td>38</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>NE</td>
<td>3.5</td>
<td>JEOL</td>
</tr>
<tr>
<td>43</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>NE</td>
<td>3.6</td>
<td>JEOL</td>
</tr>
<tr>
<td>51</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>NE</td>
<td>3.7</td>
<td>JEOL</td>
</tr>
<tr>
<td>32</td>
<td>J</td>
<td>2</td>
<td>ii</td>
<td>NE</td>
<td>2.1</td>
<td>Zeiss</td>
</tr>
<tr>
<td>25</td>
<td>J</td>
<td>2</td>
<td>i</td>
<td>NE</td>
<td>1.1</td>
<td>Zeiss</td>
</tr>
<tr>
<td>25</td>
<td>J</td>
<td>2</td>
<td>i</td>
<td>NE</td>
<td>1.2</td>
<td>Zeiss</td>
</tr>
<tr>
<td>30</td>
<td>J</td>
<td>2</td>
<td>i</td>
<td>SW</td>
<td>1.3</td>
<td>Zeiss</td>
</tr>
<tr>
<td>1</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SE</td>
<td>3.11</td>
<td>JEOL and Zeiss</td>
</tr>
<tr>
<td>5</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SW</td>
<td>3.8</td>
<td>Zeiss</td>
</tr>
<tr>
<td>49</td>
<td>J</td>
<td>2</td>
<td>ii</td>
<td>NE</td>
<td>2.2</td>
<td>Zeiss</td>
</tr>
<tr>
<td>16</td>
<td>J</td>
<td>2</td>
<td>iv</td>
<td>SW</td>
<td>4.2</td>
<td>JEOL and Zeiss</td>
</tr>
<tr>
<td>30</td>
<td>J</td>
<td>2</td>
<td>i</td>
<td>SW</td>
<td>1.4</td>
<td>Zeiss</td>
</tr>
<tr>
<td>5</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SW</td>
<td>3.9</td>
<td>Zeiss</td>
</tr>
<tr>
<td>35</td>
<td>J</td>
<td>2</td>
<td>iii</td>
<td>SE</td>
<td>3.12</td>
<td>Damaged during preparation</td>
</tr>
<tr>
<td>2</td>
<td>J</td>
<td>2</td>
<td>ii</td>
<td>SE</td>
<td>2.3</td>
<td>JEOL</td>
</tr>
<tr>
<td>22</td>
<td>J</td>
<td>2</td>
<td>ii</td>
<td>NE</td>
<td>2.4</td>
<td>Zeiss</td>
</tr>
</tbody>
</table>

**Sample preparation**

Valves were sonicated in a “Sonicor” ultrasonic bath (Sonicor© SC-220T USA) with deionised water. After air drying for 8 - 24 hours, valves were coated in an NUPLEX™ “Lockfast” K36 (2:1) epoxy coating and laminating resin on both the interior and exterior surface (Sheppard,
The hardening of the resin was prompted in a thermotec oven (Contherm® thermotec 2000 Oven CAT-2050 USA) between 60-70°C for 20 - 30 minutes, and then continued to dry at room temperature for a further 24 - 36 hours. After resin setting, specimens were sectioned along the transverse plane using a diamond HTR-15 blade 8” (diameter) x .025” (width) which was attached to a Hillquist® thin section machine under water irrigation (Figure 20).

Figure 20. Image showing the location of resin and transverse plane of sectioning for bivalve cross-sectional analysis (Source: Hallmann et al. 2009:2358).

One half of the sectioned specimen was mounted to a steel slide with the cut face attached against the slide using the same epoxy resin, and dried in the same manner as the first phase of resin drying. Specimens were cut parallel to the slide using the same blade to an approximate 10 - 20 millimetre thickness (Figure 21).

Figure 21. Illustration of a transverse sectioned bivalve mounted against a metal slide showing the anatomical terms for orientation.
Specimens were then sonicated in the ultrasonic cleaner for 3 minutes, and again between every polishing upgrade thereafter. The sections were then polished using increasingly finer abrasive wet-and-dry paper in 400, 600, 800, 1200, 2000, 2400, 3200, 4000, 6000, 8000, 12000 grit paper (Micro-surface Finishing Products© U.S.A). A quality control technique based on ceramographic manual hand-grinding was adopted to ensure micro-scars were removed from the previous stage of polish (Chinn, 2002:39-40, Marinescu et al., 2000). This involved polishing in a linear path which rotated 90° per grit-upgrade. Between each polish specimens were examined at 40x magnification under an OLYMPUS light reflective microscope (OLYMPUS® V.M.T JAPAN) which showed the scar-path of the polishing. Any remaining perpendicular scars were attributed to the previous coarser gritted paper, indicating the most recent polish had not been completed (Chinn, 2002). This real-time control ensured the upgrading process was creating optimal surfaces for SEM analysis absent of deep-scarring. The final stage of polishing was with a 1 micron diamond solution on a MD sur© cloth. The finished surfaces were cleaned with water-free ethanol.

**Scanning electron microscopy and X-ray electron dispersive spectroscopy**

**Scanning electron microscopy background**

Backscatter electron imaging in the scanning electron microscope involves the detection of high-energy electrons originating from the primary electron beam accelerated into a specimen and then ejected from the surface after elastic collisions with the atomic nuclei of the sample material (Goldstein et al., 2003, Karney et al., 2011). The newly ordered backscattered electrons reach the electron-detector which collects the signal and is processed by the computer to record the image (Goldstein et al., 2003).

Scanning Electron Microscopy Composite Backscatter Detection imagery (BSE) was conducted using both the Zeiss Sigma VP field emission gun scanning electron microscope fitted with the HKL INCA Premium Synergy Integrated ED/EBSD system (Oxford Instruments, Oxfordshire, United Kingdom) (Zeiss). This microscopy is able to perform high resolution imaging (up to 1.7nm at 15 kV and 3.0nm at 1 kV). BSE images were also collected
on the JEOL JSM-6700F field emission scanning electron microscope (JEOL) at the Otago Centre for Electron Microscopy (OCEM). X-ray Electron Dispersive Spectroscopy (EDS) element linear mapping was conducted using the Zeiss microscope. The two microscopes were used interchangeably based on access and logistics. Details of BSE and EDS data extraction and analysis are described below.

**Carbon coating**

All specimens were carbon coated using an Emitech K575x Sputter Coater depositing 20μm of carbon on the surface of the specimen to reduce electron conduction while inside the SEM. The specimens were then mounted on a stage using double-sided carbon tape (NISSHIN EM © LTD). Carbon coating and steel slides prevent any conductive attributes shell specimens from accumulating; this results in clearer SEM imagery.

**SEM images created used JEOL BSE**

Samples were imaged using a JEOL JSM-6700F field emission scanning electron microscope (JEOL Ltd, Tokyo, Japan) fitted with a JEOL 2300F EDS system (JEOL Ltd, Tokyo, Japan). Areas of the specimen were imaged using the secondary electron detector (LEI) and backscatter electron detector (COMPO). LEI detection was used to navigate the sample efficiently during image collection. COMPO detection shows differences in chemical composition on the surface of a sample (Goldstein et al., 2003). COMPO detection of back scattered electrons was used to analyse and record images in specimens. Secondary and Backscatter electron microscopic images were obtained in the JEOL, operating at 20kV and 10μA. A sample height-dependant working distance (WD) of 8.0 to 10.1 millimetres was used.

**SEM images created used Zeiss BSE**

Backscatter electron imagery was also conducted using the Zeiss Sigma variable pressure field emission gun scanning electron microscope (Carl Zeiss Incorporated, Oberkochen, Germany) (Zeiss). High-vacuum was best suited to the shell-samples, with a voltage of 15kV, and minimum of 10 amps. A variable sample height-dependant working distance (WD) of 3.4 to
16.1 millimetres was used to resolve images on the AsB detector with a shooting speed of 1.51 minutes per image.

**EDS analysis using Ziess SEM**


EDS analysis shows the relative elemental composition of a specimen (Goldstein *et al.*, 2003). EDS analysis was trialled as a technique on a live-collected *A. stutchburyi* sample in this study to evaluate the tool as a method for identifying trace elemental fluctuations over seasons. Data obtained from EDS analysis was processed using the AZtec software (7.0) (Oxford Instruments Nanoanalysis, Oxfordshire, UK). Liner mapping of EDS data enabled a continual line to plot the distribution elements, which this thesis utilised from a winter notch to a winter notch in specimens (Figure 22). EDS linear mapping was conducted on the final three years of a test-specimen at the most variable outer lamina (Beikirch, 1995, Orsman, 2011), producing three total sets of data representing three full years (2012-2011-2010).
Figure 22. Diagrammatic illustration showing how EDS linear mapping records were used to test the relative distribution of elements in a bivalve to test any fluctuations across an annual cycle.

X-ray collection time for mapping was sample dependant, varying between 30 minutes to 1.5 hours. “Dead time” is the amount of time the EDS detector uses to process and collect X-rays, and is a proportion of x-ray collection time (Goldstein et al., 2003). A lower dead time ensures a more accurate record of elemental composition in a sample. The average dead-time in the trial samples for this study was 15% which is a common level in EDS analysis (Goldstein et al., 2003). Counts per second (CPS) is a value showing the amount of X-rays received by the detector per second, the CPS value in this research was variable due to the nature and orientation of the shell samples.

Palaeoseasonal analyses most commonly considers traces of Magnesium (Mg), Aluminium (Al), Manganese (Mn), Strontium (Sr), Barium (Br), and Uranium (U) (Andrus, 2011, Dodd, 1965, Gillikin et al., 2008, Groke and Gillikin, 2008, Klein et al., 1996, Lazareth et al., 2003, Peake et al., 2006, Schöne, 2008, Schöne and Gillikin, 2013, Vander Putten et al., 2000). The nature of EDS analysis means records of these elements could be all collected and examined simultaneously (Goldstein et al., 2003).
Chapter summary

This chapter has reviewed the growth patterns in *A. stutchburyi* and provided a methodology of shell section preparation and analysis using scanning electron microscopy in the form of backscatter electron detection and electron dispersive X-ray spectroscopy. The following chapter presents the results from the analysis of the control collection.
Chapter Four

Control collection results

Chapter Summary

This chapter presents the results from the control collection of *A. stutchburyi*. Presentation of the results begins with the identification of the relationship between microbands and tidal periodicity over a year. This is followed by an analysis of spring-neap cycles to understand if these are reflected in the distribution of microbands. After this, the thesis reports the trialled electron dispersive X-ray spectroscopic (EDS) results in an attempt to identify particular trace elements that may fluctuate with seasons. The last section of this chapter presents a concise summary of the results which guide the analysis of archaeological material.

Results

**Aim 1 – Strength of relationship between microband count and tidal count.**

To use Backscatter Electron (BSE) imagery to identify the strength of the relationship between tidal and microband periodicity subsequent to the final macro-notch in the *A. stutchburyi* microstructure.

The microbands in ten live-collected shells were counted from the ventral margin to the first winter notch to gain a total value which was considered the “microband periodicity”. The counts were repeated within each sample three to five times, and only considered for analysis if within 10% of the mean count per specimen (n = 10, counts = 3-5, total counts = 30-50) (Jackson, 1994). Tidal records from Port Underwood (~25 kilometres north-east from Wairau Estuary) were recorded (NIWA, 2012-2013) and back-plotted against the known date of collection. Additionally, the beginning dates of microband growth were calculated by comparing the mean microband counts to low tide periodicity which had occurred since mid-spring (late October - early November, McKinnon 1996).
Microband and tidal periodicity

A chi-squared test ($X^2$) was carried out on the mean microband count and known tidal periodicity to examine the probability of the relationship between the two variables. The selected level of significance ($\alpha$) was 0.05 and the sample size gave 5 degrees of freedom ($v$). Results from the chi-square analysis show that the number of microbands observed in the samples which were collected between October and late February was consistent with tidal information (November $X^2$ test $p= 0.489$, January $X^2$ test $p=0.494$; Figure 23, Table 6). During this growth phase microbands are clearly visible using BSE SEM (Figure 24). After March and until July, microbands are deposited sporadically and are vague (see microbanding from a May sample Figure 25, Figure 26, Appendix A). During this period the expected values (based on NIWA tide data) and observed number of microbands is significantly different (March $X^2$ test $p= 1.915E^{-7}$, May $X^2$ test $p= 2.103E^{-7}$, July $X^2$ test $p= 1.355E^{-11}$; Table 6, Figure 23 and Figure 27).

![Graph](image)

Figure 23. Low tide counts with microbands counts for ten samples spread across six different months and seasons of 2011-2012. The bars represent one standard deviation about the mean for the microband count specific to each month.
Figure 24. Image of *Austrovenus stutchburyi* section with a red box to spatially reference bottom image. Bottom image is a montage compilation of BSE COMPO images at 400 x magnification from JEOL SEM of the “January 1” sample from the ventral margin (bottom) moving backward toward winter (top). This displays the distinct and uninterrupted microbands over the “peak growth season”. Red lines are scale points representing 10μm. Note: Winter notch is not present in BSE image.
Table 6. Results of counts between tides and microbands in a chi-square test. The results show a p-value over the summer months (November to January) which indicate that there is no statistically significant difference between tidal and microband periodicities, while after March \(X^2\) the p-value indicate a statistically significant difference between tidal and microband periodicities.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Mean microband count</th>
<th>One standard deviation between trials</th>
<th>Low tide count from 1 November to collection date</th>
<th>(X^2) p-value between mean microband count and low tide count that month</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>November</td>
<td>36.4</td>
<td>5.41</td>
<td>38</td>
<td>0.489</td>
</tr>
<tr>
<td>January 1</td>
<td>149.5</td>
<td>4.24</td>
<td>156</td>
<td>0.494</td>
</tr>
<tr>
<td>January 2</td>
<td>161</td>
<td>3.53</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>January 3</td>
<td>168.5</td>
<td>4.94</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>March 1</td>
<td>199</td>
<td>7.07</td>
<td>248</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>March 3</td>
<td>225.5</td>
<td>13.43</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td>March 5</td>
<td>212.5</td>
<td>20.5</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td>May 3</td>
<td>225.5</td>
<td>11.93</td>
<td>389</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>July 3</td>
<td>240.3</td>
<td>13.74</td>
<td>507</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Figure 25. COMPO BSE image of a May sample at 450 x magnification. This image is an example of growth in specimens after March which have poorly-visible microbanding that is sporadic and interrupted by patches of shell matrix without microbands (as in the matrix shown between red notches). Red arrow indicates direction of growth.
Figure 26. COMPO BSE image at 400 x magnification of a July sample showing the vague and irregular microbanding during growth after February. Red arrow indicates direction of growth.

Figure 27. An extrapolation of the relationship between tides and microbands over the colder months with linear trend lines. Microband counts of the March – July samples coordinated against the low tides counts of the remaining cold months showing the number of tides does not relate to the number of bands present in the shell.
**Peak growing season**

A chi-squared test was carried out on the mean microband count and known tidal periodicity to examine the probability of the relationship between the two variables to show there is consistent microband deposition with tidal periodicity between November and late January (November \(X^2\) test \(p = 0.489\), January \(X^2\) test \(p = 0.494\); Figure 23, Table 6). Within that time period the early December to late January microbanding period also reflects spring-neap tidal cycles, this time period will be identified as the “peak growing season” because microband deposition responds to both tidal frequency (as already shown) and height (Figure 28). McKinnon’s (1996) research also identified a spring-neap cycle growth pattern occurring during February, and the same results are indicated in the March samples when the microbands are back-plotted from the tidal dates from in research. However, the absence of a February sample prevented the spring-neap microband responses from being examined. The standard deviation of the microband counts is smaller over the peak growing season compared with the same growth from March onward. One standard deviation about the mean microband count during the peak growing season remains low, where the total amount of tides give the calculated death date to have an error of 5.4 – 9.8 low tides, which is only 2.5 to 4.5 days, respectively (Table 7). However, one standard deviation about the mean microband count in the March sample, and monthly samples thereafter (May and July), range between 11 – 16.5 low tides, which suggests the likelihood of the relationship between microband deposition and tidal periodicity is low (Table 7). This is supported by the chi-squared \(X^2\) p-values from March onward which are larger than the \(\alpha\) value (0.05) and thus suggest there is a statistically significant difference between microbands counts and tidal counts (see Appendix A).

A dual trend line was fitted to the microband and tidal counts after March. The plots show a strong relationship between tides and microband counts during early November to late January for microband accumulation which no longer applies after March. After March there is a departure between the tidal counts as cumulative microband plateau (see diverting trend line paths over colder seasons in Figure 27, and microband count plateau in Figure 28).
Figure 28. Mean microband and low tide accumulations for November 1st 2011 to October 20th 2012 with microband growth season, peak growth season, and microband plateau labelled. Orange plots are extrapolated microband counts based on results and McKinnon (1996).

Table 7. Table showing low standard deviation about the mean microband count in peak growing seasons (in bold) until the March period (NA = Not applicable).

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean microband counts since previous winter</th>
<th>One standard deviation about the mean microband count</th>
<th>Low tide accumulation since 1 November</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>0</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>36.4</td>
<td>5.41</td>
<td>38</td>
</tr>
<tr>
<td>January</td>
<td>160.7</td>
<td>9.8</td>
<td>150</td>
</tr>
<tr>
<td>March</td>
<td>254.8</td>
<td>16.5</td>
<td>250</td>
</tr>
<tr>
<td>May</td>
<td>222.3</td>
<td>11.93</td>
<td>389</td>
</tr>
<tr>
<td>July</td>
<td>204.3</td>
<td>13.74</td>
<td>507</td>
</tr>
</tbody>
</table>

**Distances between microbands across the year**

Overall distances between adjacent microbands during peak growing season (around early-December to through to late-January) are larger than those during other parts of the microband growth months (Figure 29).
Figure 29. Graph of mean microband distances in the “January 1” sample. The results show there are larger distances during the peak-growing period in mid-December and January (as indicated by the left arrow) than microbands deposited in the early phase (as indicated in the right arrow) (see Appendix A).

**Microband growth start date**

Results from the October sample suggest that, while the winter macronotch is no longer forming (i.e. shell deposition rate begins to increase), microband deposition for the new growth season had not yet begun. A small amount of shell matrix was present but there were no distinct microbands after the macronotch (Figure 30, Figure 31). Samples from the November sample displayed microbands after the final macronotch, indicating that microband deposition for the Wairau Estuary began between 20 October and 20 November. Similar results were found in McKinnon’s (1996) estimations of microband growth start phases. To refine the accuracy of this month-long “microband start phase” for Wairau Estuary, microband growth results were counted and compared to known low tidal counts for date predictions from the first microband (NIWA, 2012-2013). November samples gave a mean microband count of 36.4 ± 5.41 (Table 7). This count was tested as a low tide marker to calculate the first date of microband deposition. The results indicated that this occurred between 28 October and 3 November (NIWA, 2012-2013). The chi-squared $X^2$ p-value which
gave the strongest probability for a start date of microband deposition within that date frame was 1 November, which was also the case for all January samples (November $X^2$ p = 0.48, January $X^2$ p = 0.49) (Table 8). Meanwhile, March chi-squared results show microband deposition starts slowing (see March cumulative microband count drop in Figure 23, Figure 27, Figure 28, Table 6). The chi-squared $X^2$ p-values from March samples indicate that predicting the start date of microband deposition cannot be done.

Table 8. $X^2$ p-values during November and January show there is most confidence in microband growth starting 1 November (in bold). During March the $X^2$ p-value reduces to be outside of the 95% confidence range.

<table>
<thead>
<tr>
<th>Monthly sample</th>
<th>Number of runs of microband counts</th>
<th>$X^2$ p-value if tested growth start date is 28 October 2011</th>
<th>$X^2$ p-value if tested growth start date is 1 November 2011</th>
<th>$X^2$ p-value if tested growth start date is 3 November 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>5</td>
<td>0.05</td>
<td>0.48</td>
<td>0.07</td>
</tr>
<tr>
<td>January</td>
<td>6</td>
<td>0.17</td>
<td>0.49</td>
<td>0.23</td>
</tr>
<tr>
<td>March</td>
<td>6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Figure 30. October sample showing macronotch (marked with red arrow) followed by a small amount of shell matrix.
Figure 31. Magnified COMPO BSE image of October sample showing macronotch followed by a small amount of shell matrix. No microbands were visible as picture shows.

**Aim 2 – Identify any relationship between microband bundles and the timing of spring-neap tides**

To use Backscatter Electron (BSE) imagery to establish any correlation between spring and neap tides and microband width in the microstructure of *A. stutchburyi*.

The width between each microband was recorded to the nearest 0.01μm using the digital measuring tool on the JEOL and Zeiss SEM in BSE imagery. The distance between each microband was plotted (n=3 rounds of measurements per sample, total sample n=10, total measurement batches n = 30) alongside the tidal heights and dates of the same period.

**Synchrony between microband distances and spring-neap cycles**

Relative microband distances displayed a relationship to spring-neap tide patterns between early-December and late-January (Figure 33). During a spring tide microband distances give measurements that were wider, these were found in bundles of 12–16 counts which fits closely with the amount of tides in a spring-neap tidal cycle (13-15 tides every seven days).
Similarly, neap tide cycles deposited tightly packed microbands in bundles of 13-17 which also fits the 13-17 tides per week mode (Figure 33). Months outside of early-December and January did not reflect spring-neap tide cycles in the microband distances (Figure 32). It is likely February growth produces similar spring-neap microband patterns, this is also inferred in March samples where back-plotting to the estimated February period displays the spring-neap patterning, however due to the absence of a February sample, any spring-neap patterns proposed in February must be treated with caution.

Figure 32. Late November period of growth showing microband deposition is distinct but absent of any spring-neap cycle bundles.
Figure 3. Spring-neap tidal cycles from 1 November 2011 to 20 January 2012 at Port Underwood matched the relative microband distances. The red line shows relative microband distance fluctuations over a year, and blue lines indicate spring (S) and neap (N) phases seen in tidal and relative microband distances.
Synchrony between microband morphology and spring-neap cycles

Data also shows that during the warmer month phases where spring-neap cycles are visible, there are also slight morphological differences to microbands over the cycles. Spring tides deposit a single distinct band which is often flanked by one, and in some instances two, fainter indistinct bands before the next distinct band. While the neap tidal cycles create more distinct microbands which are bundled tightly and without occasional vague adjacent bands (Figure 34).

Figure 34. COMPO BSE image of a January sample showing an example of the spring-neap cycles visible during the peak growing phase. Bundles of loosely packed microbands match spring tides (S) and bundles of tighter more distinct microbands match neap tides (N).

Aim 3 – EDS analysis to identify seasonal variation in elements

To test whether Electron Dispersive X-ray Spectroscopy (EDS) linear mapping in the *A. stutchburyi* can identify fluctuations in trace element distributions across an annual cycle resulting from seasonal thermodynamic processes.
EDS linear mapping was tested on the March 5 specimen to investigate seasonal fluctuations in elements. Within the specimen the three final years were analysed by examining the EDS mapping readings of shell matrix between a macro-notch (winter) to the previous macro-notch (other winter). The data from all three years which were tested provided no usable results. Detectable elements using EDS in the experiment were Carbon, Calcium, Oxygen, Sodium, Sulphur, Chlorine, and in two of three maps Silicon (Figure 35, Figure 43, Figure 52). None of the trace elements which were likely to show seasonal fluctuations (Magnesium (Mg), Aluminium (Al), Manganese (Mn), Strontium (Sr), Barium (Br), and Uranium (U)) gave high enough CPS counts to be recorded using EDS. Sudden drops and spikes (Figure 44 - Figure 51) shared across elements in the single year are attributable to notches and voids in the linear path which intersect with the irregular external surface of the shell. These notches are voids of shell matrix and distort EDS data by instead recording the EDS composition of the next immediate surface which is either the resin or slide the sample is mounted on.

**Final year of growth - 8 March 2012 to winter of 2011**

EDS results from the final year of growth showed no significant variation across time that can be correlated to season (Figure 36 - Figure 42). None of the elements likely to fluctuate over seasons were detectable using EDS mapping (Figure 35).
Figure 35. Total relative spectra of elements present in the final year of death in the "March 5" sample. These are then divided into each element across the linear map, as seen in graphs below:

Figure 36. BSE image showing the linear mapping EDS path across the external lamina of March3 sample in the final year of life.
Figure 37. Line spectra of Calcium CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.

Figure 38. Line spectra of Oxygen CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.

Figure 39. Line spectra of Calcium CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.
Figure 40. Line spectra of Sodium CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.

Figure 41 line spectra of Sulphur CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.

Figure 42. Line spectra of Chlorine CPS levels present from death (left) to the previous winter (right) in the “March 5” sample.

**Second-to-last-year of growth - winter notch 2011 to winter notch 2010**

EDS mapping results from the winter of 2011 to the winter of 2010 were collected and also showed no significant variation across time that could be correlated to season (Figure 44 - Figure 51). Additionally, none of the elements likely to fluctuate over seasons were traceable
in EDS extraction (Figure 43). Sudden drops and spikes shared across elements in the year between 2011 and 2010 align due to voids in the shell matrix on electron beam, causing fluctuations because the elemental reading is from the slide surface rather than the shell.

Figure 43 Total relative spectra of elements present in the year between winter 2011 and winter 2010 in the “March 5” sample. These are then divided into each element across the linear map, as seen in graphs below:

Figure 44. BSE image showing the linear mapping EDS path crossing the external lamina of winter 2011 (left) to the previous winter of 2010 (right) in the March 5 sample.
Figure 45. Line spectra of Calcium CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the "March 5" sample.

Figure 46. Line spectra of Oxygen CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the "March 5" sample.

Figure 47. Line spectra of Calcium CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the "March 5" sample.
Figure 48. Line spectra of Sodium CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the “March 5” sample.

Figure 49. Line spectra of Sulphur CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the “March 5” sample.

Figure 50. Line spectra of Silicon CPS levels present from winter of 2011 (left) to the previous winter of 2010 (right) in the “March 5” sample.
Figure 51 line spectra of Chlorine CPS levels present from winter 2011 (left) to the previous winter of 2010 (right) in the “March 5” sample.

**Third-to-last-year of growth - winter notch 2010 to winter notch 2009**

EDS mapping results from the winter of 2010 to the winter of 2009 were collected and showed no significant variation across time that could be correlated to season (Figure 53 - Figure 60). None of the elements likely to fluctuate over seasons were traceable in EDS extraction (Figure 52).

Figure 52 Total relative spectra of elements present in the year between winter 2010 and winter 2009 in the “March 5” sample. These are then divided into each element across the linear map, as seen in the following graphs.
Figure 53. BSE image showing the linear mapping EDS path across the external lamina of winter of 2010 (left) to the winter of 2009 (right) in the “March 5” sample.

Figure 54. Line spectra of Calcium CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.

Figure 55. Line spectra of Oxygen CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.
Figure 56. Line spectra of Calcium CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.

Figure 57. Line spectra of Sodium CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.

Figure 58. Line spectra of Sulphur CPS levels present from Winter 2010(left) to the previous winter of 2009 (right) in the “March 5” sample.
Figure 59. Line spectra of Chlorine CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.

Figure 60. Line spectra of Silicon CPS levels present from winter 2010 (left) to the previous winter of 2009 (right) in the “March 5” sample.

Calcium, Oxygen, and Carbon gave the strongest CPS readings in the sample, as expected in a calcium carbonate sample (Figure 35, Figure 43, Figure 52). The other detectable elements (Sulphur, Silicon, Sodium, and Chlorine) show no seasonal patterning within the three consecutive years that were mapped.

**Findings**

1. Results show that the number of microbands observed in the samples which were collected between October and late February was consistent with tidal information. After February there is a statically significant difference between microband and tidal periodicity until the following mid-spring (late-October early-November).

2. Between March to October microband deposition plateaus rapidly, no longer allowing the analysis of microbanding as a reliable marker for time-predictions.
3. Between December and January, spring-neap cycles contribute to the manner of microband deposition through relative microband width and morphology. Other periods of the year show no relationship to spring-neap tidal cycles. It is likely growth during early February also responds to spring-neap tidal cycles (McKinnon, 1996).

4. Based on true-tidal periodicity, *A. stutchburyi* samples at Wairau Estuary appear to begin microband deposition 1 November, giving the highest chi-squared $X^2$ p-value. Between 28 October and 3 November the chi-squared $X^2$ p-value is calculated to be the date range when microband deposition started based on the mean microband count within a single standard deviation. Within this date range, 1 November has the strongest chi-squared $X^2$ p-value giving the least statistically significant difference between tides and microband counts.

5. EDS linear mapping as a technique to measure trace element analysis for palaeoseasonal reconstruction is not an appropriate tool to detect smaller level trace elements. However it does provide a relative record of more dominant elements and with software in mapping across specimens provides potential in archaeological techniques for other biological rhythms and age estimations in other species, the tool is relatively affordable, fast, and accessible.
Chapter 5

Archaeological application results

Chapter summary

The results from the control sample of shells collected from Wairau Estuary guided the analysis and interpretation of the archaeological specimens. A methodology was applied to the archaeological specimens to create data informing time-of-death in A. stutchburyi. This chapter presents the results from analysis of the archaeological specimens, beginning with the ontogenetic age results which determined the accuracy of microband data created from the archaeological sample. The chapter then presents what the microband results suggest about time-of-death for each individual specimen. The calculated time of death for each specimen is then examined within each stratigraphic unit to investigate the timing of collection events represented across the stratigraphic profile within the CSA deposit (Brooks et al., 2009, Jacomb et al., 2014). Lastly, it examines these shellfish-death results within the wider context of the archaeological deposit, and presents four possible interpretations of what types of shellfishing collection events are represented by the archaeological sample.

Results

Aim 1 - Time of death per specimen

To identify time of death of a sample of cockles within the annual cycle.

Ontogenetic age of specimens

All specimens were analysed with the COMPO BSE detector SEM at 80 – 150 x magnification to identify the number of winter notches and calculate the ontogenetic age at death for each specimen. The ontogenetic age results show that all specimens were over 12 years of age and some were possibly as old as 23 years of age (mean age at death across sample = 17.57 ± 3.07 years) (Table 9). These results mean the entire archaeological sample are outside of the “age
responsiveness” period of ontogenetic growth for reliable growth estimates (McKinnon, 1996) (Figure 61). This greatly limited the accuracy of time-of-death calculations for the specimens. However, microband deposition was still evident during the final year of life in some of the specimens, and this provided data to conduct analyses - but with less anticipated precision than with the control sample.

Table 9 Summary of archaeological specimens and their ontogenetic age range based on macrobands (winter notches) seen in the COMPO BSE on SEM at 80 - 150 x magnification. Table shows all of the specimens were senile and did not fall within “age responsive” growth range. (N.A = Not Applicable).

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Ontogenetic age</th>
<th>Within “age responsive” range?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>19-23</td>
<td>No</td>
</tr>
<tr>
<td>1.2</td>
<td>12-13</td>
<td>No</td>
</tr>
<tr>
<td>1.3</td>
<td>21-23</td>
<td>No</td>
</tr>
<tr>
<td>1.4</td>
<td>15-17</td>
<td>No</td>
</tr>
<tr>
<td>2.1</td>
<td>13-14</td>
<td>No</td>
</tr>
<tr>
<td>2.2</td>
<td>13-14</td>
<td>No</td>
</tr>
<tr>
<td>2.3</td>
<td>17-18</td>
<td>No</td>
</tr>
<tr>
<td>2.4</td>
<td>12-13</td>
<td>No</td>
</tr>
<tr>
<td>3.1</td>
<td>Edge damaged</td>
<td>N.A</td>
</tr>
<tr>
<td>3.2</td>
<td>16-18</td>
<td>No</td>
</tr>
<tr>
<td>3.3</td>
<td>19-21</td>
<td>No</td>
</tr>
<tr>
<td>3.4</td>
<td>19-24</td>
<td>No</td>
</tr>
<tr>
<td>3.5</td>
<td>16-19</td>
<td>No</td>
</tr>
<tr>
<td>3.6</td>
<td>17-18</td>
<td>No</td>
</tr>
<tr>
<td>3.7</td>
<td>19-20</td>
<td>No</td>
</tr>
<tr>
<td>3.8</td>
<td>18-21</td>
<td>No</td>
</tr>
<tr>
<td>3.9</td>
<td>20-23</td>
<td>No</td>
</tr>
<tr>
<td>3.11</td>
<td>19-21</td>
<td>No</td>
</tr>
<tr>
<td>3.12</td>
<td>Edge damaged</td>
<td>N.A</td>
</tr>
<tr>
<td>4.1</td>
<td>13-14</td>
<td>No</td>
</tr>
<tr>
<td>4.2</td>
<td>15-16</td>
<td>No</td>
</tr>
<tr>
<td>4.3</td>
<td>16-18</td>
<td>No</td>
</tr>
</tbody>
</table>
Figure 61. Diagram showing the growth curve found in McKinnon’s (1996) research for optimal age responsiveness, and the area in red showing the area which the archaeological specimens of this study fit (far outside the age responsive range) (edited image source: McKinnon 1996:52).

**Specimens with and without microbanding at the ventral margin**

Microbands were visible at the ventral margin in 16 of the 20 specimens (80%). Based on the results from Chapter 4 this indicated they had died during the microband growth period (which is between November and late February). Meanwhile, the remaining four specimens had no microbands in the shell matrix along the ventral margin, suggesting growth was either outside the microband deposition period, or these specimens were too senile for clear microband growth to occur (McKinnon, 1996). The specimens without any recordable microbands on the ventral margin are examined in more depth later in this chapter. The 16 specimens which had microbanding on the ventral margin were analysed for time-of-death. The relative stratigraphic distributions of specimens with and without microbands at the ventral margin through CSA are explained below.
**Ventral margin and banding classes**

The specimens which displayed microbanding at the ventral margin were separated into two sub-groups for analytical purposes. The first group were specimens which had visible microbands fully spanning the final year of shell growth without interruption; they are void of microbandless patches (i.e. microbands span from the final macronotch to the death margin). This subgroup was called “Class A”. The second group were specimens which had one or more interruption of microbands growth during the final year of growth (i.e. one or more period of arrested growth during the microband growth phase). Events which cause arrested microband deposition, such as storms or flooding, span an unknown length of time which microband analysis and time-of-death predictions must account for (Beikirch, 1995, Larcombe, 1971, McKinnon, 1996, Schöne and Gillikin, 2013). These are called “Class B” specimens. The purpose of this sub grouping was to refine time-of-death estimations because those which provide uninterrupted data (Class A) are more accurate than those which do not (Class B). Based on the results from the control collection both Class A and Class B specimens died between early November and late February because there were microbands deposited on the ventral margin of these specimens. Refining the time frame for Class A specimens can be done more accurately than Class B.

**Refining the microband-growth-period – Class A**

There was one specimen which had microbands on both the ventral margin and across the final year of death without any periods of arrested growth (Table 10). This specimen was analysed using time of death calculations to clarify when the shell died. The mean microband count with one standard deviation suggests the shell was likely to have been collected between 13 and 17 January (15 January ± 2.75 days) (see Appendix B).
Table 10. Microband analysis and date predictions from the single specimen which did not have any periods of arrested growth.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>No. of trials</th>
<th>Mean microband count</th>
<th>Date based on mean microband count</th>
<th>One standard deviation about the mean</th>
<th>Amount of days present in standard deviation</th>
<th>Time of death date range based on mean microband counts one standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>3</td>
<td>152.66</td>
<td>15 January</td>
<td>5.50</td>
<td>2.75</td>
<td>13 January to 17 January</td>
</tr>
</tbody>
</table>

**Refining the microband-growth-period – Class B**

The remaining specimens which had microbands on the ventral margins were interrupted with one or more period of arrested growth during the final year of life (*n* = 13; Table 11; Appendix B). These specimens were analysed using time of death calculations in a customised approach to account for the arrested growth periods which represent unknown lengths of time (Beikirch, 1995). The technique involved analysing the amount of microbands from the last winter notch to the ventral margin, and the date predictions these values calculated were used to eliminate the earliest stage of the microband growth period. By regarding mean microband count as the earliest date to make time-of-death estimations, the periods of arrested growth are accounted for. After the application of Class B analysis the date range was refined. Before analysis the death dates were anytime between November to February. After analysis this was refined to be between the calculated death date and February. This reductive approach eliminated at least the first week and a half of November across all specimens (Specimen I.D = 2.1, 2.2, 2.3), and in the best case eliminated November, December, and the first three weeks of January (Specimen I.D = 3.2; Table 11; Figure 62).
Table 11. Microband results and date predictions for Class B specimens showing the November to February window can be refined even though there are periods of arrested growth.

<table>
<thead>
<tr>
<th>I.D No.</th>
<th>No. of trials</th>
<th>Mean microband count</th>
<th>Date based on mean microband count</th>
<th>One standard deviation about the mean microband count</th>
<th>Amount of days present in one standard deviation</th>
<th>Earliest date of death (anytime after this date and between late February is time of death)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>3</td>
<td>25.66</td>
<td>13 November</td>
<td>3.55</td>
<td>1.52 days</td>
<td>11 November to 15 November</td>
</tr>
<tr>
<td>2.2</td>
<td>3</td>
<td>24.33</td>
<td>12 November</td>
<td>4.16</td>
<td>2.08 days</td>
<td>10 November to 14 November</td>
</tr>
<tr>
<td>2.3</td>
<td>3</td>
<td>20.66</td>
<td>11 November</td>
<td>1.15</td>
<td>0.5 days</td>
<td>10 November to 12 November</td>
</tr>
<tr>
<td>2.4</td>
<td>3</td>
<td>167</td>
<td>22 January</td>
<td>13.11</td>
<td>6.5 days</td>
<td>16 January to 27 January</td>
</tr>
<tr>
<td>3.2</td>
<td>3</td>
<td>174.667</td>
<td>26 January</td>
<td>8.5</td>
<td>4.25 days</td>
<td>22 January to 30 January</td>
</tr>
<tr>
<td>3.5</td>
<td>3</td>
<td>64.66</td>
<td>2 December</td>
<td>16.56</td>
<td>8.28 days</td>
<td>24 November to 9 December</td>
</tr>
<tr>
<td>3.6</td>
<td>3</td>
<td>97.33</td>
<td>18 December</td>
<td>20.2</td>
<td>10.1 days</td>
<td>8 December to 28 December</td>
</tr>
<tr>
<td>3.7</td>
<td>3</td>
<td>150.66</td>
<td>14 January</td>
<td>7.37</td>
<td>3.68 days</td>
<td>10 January to 18 January</td>
</tr>
<tr>
<td>3.8</td>
<td>3</td>
<td>96.33</td>
<td>18 December</td>
<td>11.06</td>
<td>5.53 days</td>
<td>12 December to 24 December</td>
</tr>
<tr>
<td>3.11</td>
<td>3</td>
<td>93</td>
<td>16 December</td>
<td>13.45</td>
<td>6.72 days</td>
<td>8 December to 23 December</td>
</tr>
<tr>
<td>4.1</td>
<td>3</td>
<td>95.33</td>
<td>17 December</td>
<td>9.01</td>
<td>4.5 days</td>
<td>11 December to 22 December</td>
</tr>
<tr>
<td>4.2</td>
<td>4</td>
<td>78</td>
<td>9 December</td>
<td>4.58</td>
<td>2.29 days</td>
<td>6 December to 12 December</td>
</tr>
<tr>
<td>4.3</td>
<td>4</td>
<td>54</td>
<td>27 November</td>
<td>4.58</td>
<td>2.29 days</td>
<td>24 November to 30 November</td>
</tr>
</tbody>
</table>
Figure 62. Diagram showing death-date-ranges of Class A and B specimens. Date-ranges were calculated using mean microband counts and one standard deviation.
Specimens which have no microbands at the ventral margin - Class C

Class C specimens are the most senile in the collection and are too old to show any microband growth (Figure 63; Specimens I.D = 1.1, 1.3, 3.4, 3.9). Class C specimens are calculated to have been aged between 19 – 23 years old, which is over three times the mean age of a specimen which best-suits time-of-death analysis (McKinnon, 1996). Further, none of the Class C specimens had any resolvable microbands between the winter notch and ventral margin (final year of life), suggesting that the shell matrix was being deposited but was no-longer visibly responding to tides (Figure 64, Figure 65). Additionally, only one of the four Class C specimens showed any microband growth the previous full year, indicating microband deposition was no longer occurring, or visible, during the final few years of life (Table 12).

Figure 63. Graph showing relative ontogenetic age of specimens. The oldest shells are also those which do not have any microbands on the ventral margin (as shown with red bars).
Table 12. Summary of Class C specimens and microband deposition presence in the final year and previous full year of death.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>Microbands in death year?</th>
<th>Microbands in previous full year?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>1.3</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>3.4</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3.9</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 64. COMPO BSE image of specimen 1.1 at 901x magnification displaying the absence of microband deposition through the ventral margin. Dashed line shows the direction toward the next winter where microbands are expected to be plotted.
Figure 65. COMPO BSE image of specimen 3.9 at 1280 x magnification displaying the absence of microband deposition through the ventral margin. Dashed line shows the direction toward the next winter where microbands are expected to be plotted.

**Spring-neap presence in Class A and B specimens**

Results from some of the Class A and B specimens suggested that “peak growth season” attributes are possibly reflected in microbanding (this applies to any samples which were calculated to have died between early December to late January) (Specimen I.D = 1.2, 2.4, 3.2, 3.5, 3.6, 3.7, 3.8, 3.11, 4.1, 4.2). In such cases, microbands were expected to reflect spring-neap tidal cycles in the morphology of the microbands and relative microband distances (as shown in Chapter 4). Only a single specimen reflected slight patterns of spring tidal cycles in the microband morphology during the death phase (Specimen I.D = 4.1; Figure 66). The overall absence of spring-neap cycles on the ventral margins of archaeological samples is likely to be due to the senile condition of samples, where the finer-versions of tidal height responsiveness and tidal varieties are no longer reflected in relative microband distances (Hallmann *et al.*, 2009, McKinnon, 1996) (Figure 61, Figure 67).
Figure 66. COMPO BSE image of specimen 4.1 at 2350 x magnification displaying spring-like microband deposition through the ventral margin.

Figure 67. COMPO BSE image of specimen 2.4 at 1290 x magnification displaying the absence of spring-neap cycles in the microband deposition through the ventral margin. The green boxed image on the right displays the magnified ventral margin of the extremely senile specimen.
Aim 2 - Time of death as a marker for stratigraphic relativity – comparisons of spits

To determine whether the cockles were collected over a short period or whether they represent a series of collection events. This will provide insight into how much time depth is in the deposit.

Stratigraphic distribution of specimens with and without microbands ventral margins

The relative stratigraphic distributions of the 16 specimens which did or did not display microbanding on the ventral margin were different across spit i (n = 2, percentage = 50%) (Table 13) and spit iii (n=7, percentage 78.8%) (Table 15), while all specimens in spit ii and iv had ventral margin microband deposition (percentage of specimens per spit = 100%) (Table 14 and Table 16).

Table 13. Summary of shells in spit i which reflect microband deposition at the ventral margin.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>Microbands present at ventral margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>No</td>
</tr>
<tr>
<td>1.2</td>
<td>Yes</td>
</tr>
<tr>
<td>1.3</td>
<td>No</td>
</tr>
<tr>
<td>1.4</td>
<td>Yes (but damaged)</td>
</tr>
<tr>
<td>% of sample that died during microband growth period</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 14 Summary of shells in spit ii which reflect microband deposition at the ventral margin.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>Microbands present at ventral margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Yes</td>
</tr>
<tr>
<td>2.2</td>
<td>Yes</td>
</tr>
<tr>
<td>2.3</td>
<td>Yes</td>
</tr>
<tr>
<td>2.4</td>
<td>Yes</td>
</tr>
<tr>
<td>% of sample that died during microband growth period</td>
<td>100%</td>
</tr>
</tbody>
</table>
Table 15 Summary of shells in spit iii which reflect microband deposition at the ventral margin.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>Microbands present at ventral margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>Yes</td>
</tr>
<tr>
<td>3.3</td>
<td>Yes (but damaged)</td>
</tr>
<tr>
<td>3.4</td>
<td>No</td>
</tr>
<tr>
<td>3.5</td>
<td>Yes</td>
</tr>
<tr>
<td>3.6</td>
<td>Yes</td>
</tr>
<tr>
<td>3.7</td>
<td>Yes</td>
</tr>
<tr>
<td>3.8</td>
<td>Yes</td>
</tr>
<tr>
<td>3.9</td>
<td>No</td>
</tr>
<tr>
<td>3.11</td>
<td>Yes</td>
</tr>
</tbody>
</table>

% of sample that died during microband growth period 78.8%

Table 16. Summary of shells in spit iv which reflect microband deposition at the ventral margin.

<table>
<thead>
<tr>
<th>Specimen I.D</th>
<th>Microbands present at ventral margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Yes</td>
</tr>
<tr>
<td>4.2</td>
<td>Yes</td>
</tr>
<tr>
<td>4.3</td>
<td>Yes</td>
</tr>
</tbody>
</table>

% of sample that died during microband growth period 100%

**Stratigraphic relativity**

This section examines the time of death in archaeological samples across the deposit as a way of investigating any date groupings or isolations in the CSA stratigraphy. The objective of this section is to examine the temporal relativity of the spits, which aids the durational understanding for the overall deposit. Results from the specimens were grouped per spit to create a death date range within each spit. The method of analysing temporal relativity across stratigraphy is conducted differently depending on the Class-type of specimens. Due to the dominance of Class B specimens, each spit was assigned a “death-date-range”. If any additional Class A specimens were in the deposit, spits would be assigned discrete death dates and these would be used to examine overlapping dates to assess shellfish-collection event(s).
For this sample the most important aspect when designing a model for death date interpretation was to account for the senile condition of the specimens. This thesis has used the most cautious approach by interpreting the death date ranges per spit based on the widest possible death date range found in each spit.

The single specimen from spit i was a Class A type specimen which provided a death date range of 13 to 17 January (Table 17). Spit ii specimens provide a death date range to be anytime from 10 November to the end of the microband growth season (late February) (Table 18). Spit iii specimens appear to have died anytime between 24 November and the end of the microband growth season (late February) (Table 19). Spit iv specimens were collected anytime between 24 November to the end of the microband growth season (late February) (Table 20).

Spit i results are Class A samples, and thus are more precise than the Class B results. The remaining spits (spits ii, iii, and iv) provided Class B results which encompass the Class A death date from spit i. These results mean that there is an overall window of time between 10 November and late February which the shells died.

In short, all samples which were capable of being analysed for microbanding patterns to confidently provide a late spring or summer death date prediction, between 10 November to late February (Figure 68). A single Class A specimen representing spit i was calculated to die sometime between 13 to 17 January. To account for the ontogenetic age and Class B dominance of specimens in the sample, any stratigraphic temporal relativity analysis was treated cautiously and the most conservative interpretation of the results is that the specimens died within the last three weeks of spring to late spring to summer (November to late February) across all four analysed spits (i – iv). An analysis of these stratigraphic results as markers of shellfish-hunting event(s) is described next below.
Table 17. Table presenting the date used to calculate the timing of death for shellfish in Spit i.

<table>
<thead>
<tr>
<th>I.D No.</th>
<th>No. of counts</th>
<th>Mean microband count</th>
<th>Date based on mean microband count</th>
<th>1 Standard deviation about the mean</th>
<th>No. of days present in 1 standard deviation</th>
<th>Date range based on microband counts with error range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>3</td>
<td>152.66</td>
<td>15 January</td>
<td>5.50</td>
<td>2.75</td>
<td>13 January to 17 January</td>
</tr>
</tbody>
</table>

Table 18. Table presenting the date ranges used to calculate the timing of death for shellfish in spit ii. Results from spit ii indicate that specimens died any time from 10 November to late February. Sample which provides widest date range is in bold.

<table>
<thead>
<tr>
<th>I.D No.</th>
<th>No. of counts</th>
<th>Mean microband count</th>
<th>Date based on mean microband count</th>
<th>1 standard deviation about the mean</th>
<th>No. of days present in 1 standard deviation</th>
<th>Earliest date of death (any time after this date and between late February is time of death)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>3</td>
<td>25.66</td>
<td>13 November</td>
<td>3.55</td>
<td>1.52 days</td>
<td>11 November to 15 November</td>
</tr>
<tr>
<td>2.2</td>
<td>3</td>
<td>24.33</td>
<td>12 November</td>
<td>4.16</td>
<td>2.08 days</td>
<td>10 November to 14 November</td>
</tr>
<tr>
<td>2.3</td>
<td>3</td>
<td>20.66</td>
<td>11 November</td>
<td>1.15</td>
<td>0.5 days</td>
<td>10 November to 12 November</td>
</tr>
<tr>
<td>2.4</td>
<td>3</td>
<td>167</td>
<td>22 January</td>
<td>13.11</td>
<td>6.5 days</td>
<td>16 January to 27 January</td>
</tr>
</tbody>
</table>
Table 19. Table presenting the date ranges used to calculate the timing of death for shellfish from spit iii. Results from spit iii indicate that specimens died anytime between 24 November and late February. Sample provides widest date range is in bold.

<table>
<thead>
<tr>
<th>I.D No.</th>
<th>No. of counts</th>
<th>Mean microband count</th>
<th>Date based on mean</th>
<th>1 standard deviation about the mean</th>
<th>Amount of days present in 1 standard deviation</th>
<th>Earliest date of death (any time after this date and between late February is time of death)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>3</td>
<td>174.667</td>
<td>26 January</td>
<td>8.5</td>
<td>4.25 days</td>
<td>22 January to 30 January</td>
</tr>
<tr>
<td>3.5</td>
<td>3</td>
<td>64.66</td>
<td>2 December</td>
<td>16.56</td>
<td>8.28 days</td>
<td>24 November to 9 December</td>
</tr>
<tr>
<td>3.6</td>
<td>3</td>
<td>97.33</td>
<td>18 December</td>
<td>20.2</td>
<td>10.1 days</td>
<td>8 December to 28 December</td>
</tr>
<tr>
<td>3.7</td>
<td>3</td>
<td>150.66</td>
<td>14 January</td>
<td>7.37</td>
<td>3.68 days</td>
<td>10 January to 18 January</td>
</tr>
<tr>
<td>3.8</td>
<td>3</td>
<td>96.33</td>
<td>18 December</td>
<td>11.06</td>
<td>5.53 days</td>
<td>12 December to 24 December</td>
</tr>
<tr>
<td>3.11</td>
<td>3</td>
<td>93</td>
<td>16 December</td>
<td>13.45</td>
<td>6.72 days</td>
<td>8 December to 23 December</td>
</tr>
</tbody>
</table>
Table 20 Table presenting the date ranges used to calculate the timing of death for shellfish from spit iv. Results from spit iv indicate that specimens died anytime between 24 November and late February. Sample which provides widest date range is in bold.

<table>
<thead>
<tr>
<th>I.D No.</th>
<th>No. of counts</th>
<th>Mean microband count</th>
<th>Date based on mean</th>
<th>1 standard deviation about the mean</th>
<th>Amount of days present in 1 standard deviation</th>
<th>Earliest date of death (any time after this date and between late February is time of death)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>3</td>
<td>95.33</td>
<td>17 December</td>
<td>9.01</td>
<td>4.5 days</td>
<td>11 December to 22 December</td>
</tr>
<tr>
<td>4.2</td>
<td>4</td>
<td>78</td>
<td>9 December</td>
<td>4.58</td>
<td>2.29 days</td>
<td>6 December to 12 December</td>
</tr>
<tr>
<td>4.3</td>
<td>4</td>
<td>54</td>
<td>27 November</td>
<td>4.58</td>
<td>2.29 days</td>
<td>24 November to 30 November</td>
</tr>
</tbody>
</table>

Figure 68. Schematic illustration showing the calculated death-date-ranges for each spit from the CSA sample in Oven Pit 1. Not to Scale.
**Aim 3 - Time of death as a marker of shellfish collection events, depositional time depth, seasons present**

Examine the relative timing of cockle death in the deposit to examine any time depth in the deposit.

Although there appears to be no recordable time-depth in the stratigraphic profile of CSA based on the results per spit, there are several other ways date-of-death results in specimens can be used to interpret shellfish collection events in CSA. For example, grouping date results by spit, by date-phase, and by class-type can all give different results which inform discussions surrounding depositional time-depth. Since each approach creates interpretations which have important archaeological implications, these are presented below, and discussed within a wider depositional and archaeological context in Chapter 6.

**Scenario 1 – a series of many collection events over a single late-spring to summer period**

Date of death results for the archaeological specimens can be treated as individual date markers to suggest that *A. stutchburyi* in the midden were collected over multiple periods between 10 November and late February. This interpretation accounts for the senile condition and Class B nature of the specimens. The likelihood of this scenario is also supported by the specimens showing no sign of resource exhaustion by remaining extremely senile, thus they were probably collected over a shorter time period (a single annum) from a pristine environment (Swadling, 1977:12). Further, two specimens provided microband dates which do not overlap, eliminating the likelihood of a single large scale shellfish collection occurring within one tidal cycle (Specimen I.D 1.2 death dates are 13 to 17 January while Specimen I.D 2.3 death dates are 22 January to late February) (Figure 62). An in-depth discussion of deposition in Oven Pit 1 considering Scenario 1 follows in Chapter 6.
**Scenario 2 – a series of two or three collection events over a single late-spring to summer period**

Start dates in the date-ranges from the Class B specimens can be grouped as approximate date markers to suggest that *A. stutchburyi* were collected over a few large-scale collection events between 10 November and late February. The first phase can be considered a collection event between November and December (I.D = 2.1, 2.2, 2.3, 3.5, 3.6, 3.8, 3.11, 4.1, 4.2, 4.3), while the latter two stages are events in January (I.D = 1.2, 2.3, and 3.7). Effectively this approach divides the results into early and late shellfishing phases in the 10 November to late February period. This grouping accounts for the likelihood that Class B start dates in the date-ranges are all close to true death dates (i.e. the arrested growth periods may have been very short-lived events). This approach also accounts for the senile condition and Class B nature of the specimens. Moreover, this model also enables the two separate January dates to represent distinct collection events.

**Scenario 3 – an unknown number of collection events spread over several late springs to summer periods**

Date of death results for the archaeological specimens can be treated as individual date markers to suggest that *A. stutchburyi* in the midden were collected over multiple periods between 10 November and late February over a series of late spring to summer periods. This interpretation is theoretically similar to Scenario 1 in that it considers *A. stutchburyi* were collected over several collection events; however it accounts for the fact the microbanding results do not prove that the shellfish were collected in the same annual cycle. This scenario of collection events shares the same strengths as Scenario 1 although it does not account for the consistent senile condition of specimens. If the shellfish were collected over several annual cycles the ontogenetic age should slowly drop with time as the population is slowly harvested, meaning some younger and smaller shellfish should be expected to be in the midden deposit (Swadling, 1977:12).
Scenario 4 – a single collection event between late spring and summer

Date of death results for the archaeological specimens are also possibly skewed from the extremely senile condition of the specimens, meaning there is a chance that the date of death for all specimens is somewhere between 10 November to late February and part of a single shellfish collection event. In this model, attempts to refine this date range further than 10 November to late February are discouraged because the senile specimens may not have been deposited the same way the control specimens were. While this type of collection event is less likely, the results allow for this type of interpretation because the senile condition of the sample may have skewed the microbanding results. In this scenario, the two clearly separate hunting events found in January (Specimen I.D = 1.2 and 2.3) are also considered skewed due to ontogenetic age, and the only reliable date range is to accept shells died in one collection event between 10 November and late February.

Findings

- All archaeological specimens were very mature or senile, suggesting the *A. stutchburyi* specimens probably came from a pristine population which had not been previously exposed to human-predation.
- An effective way of mitigating incorrect date predictions due to unknown lengths of arrested microbanding in the final year of life is to operate the Class A, B, and C analytical structure this study created.
- Nearly all the archaeological specimens were collected in the microband-growth-period. Refined reductive dates support the shellfish collection dates to be between 10 November and late February.
- The senile condition of the entire sample prompts caution for finer grained estimates. In such a case, it is feasible to propose the most reliable dates are anywhere between 10 November and late February.
- The absence of visible stratigraphic layers in the midden from Oven Pit 1 is likely to be correct, but not confidently tested with the microbanding results due to the senile
condition and Class B nature of *A. stutchburyi* providing coarser date ranges. Nonetheless, results did confirm late-spring to summer collection(s).

- Shellfish death dates can be interpreted in four main ways when exploring the collection events represented in CSA. This chapter has shown the microband results can be applied to argue that:
  - There was a series of many collection events over a single late-spring to summer period.
  - There was a series of two or three collection events over a single late-spring to summer period.
  - There was a series of many collection events over several late-spring to summer periods.
  - There was a single shellfish collection event over a single late-spring to summer period.
Chapter 6

Microbanding methodology and archaeological application - discussion and conclusions

Chapter Summary

The experiments in this thesis are the first high-precision investigation into palaeoseasonality at Wairau Bar. This chapter begins with a discussion of the methodology, which focuses on the reliability of the method, potential ways to mitigate analysis of samples which do not meet criteria set for the application of this technique, a consideration of seasonal results from this project and others, and the potential of trace element analysis in palaeoseasonality for New Zealand archaeology. Following this, the archaeological results are discussed within the context of early prehistoric New Zealand. In particular this section considers the results in light of resource use and settlement patterns. The same results are used to examine the durational time-depth and temporal relativity in Oven Pit 1.

Methodological

In 1970 it was proposed *A. stutchburyi* can be used in palaeoseasonal investigations by analysing the relationship between cumulative annual cycles, and by examining the microbands present each winter to calculate time of death (Coutts, 1970, Coutts and Higham, 1971). Distance measurement for cumulative annual cycles through index analyses were tested, refined, and confidently applied to several archaeological investigations in New Zealand. The use of microbands was disregarded due to an assumed lack of reliability surrounding the periodicity of microband deposition, an argument which was underpinned by expectations of technical limitations (Higham, 1990, Samson, 1995). Since then marine physiobiological investigations have proven microbanding in *A. stutchburyi* is circa-tidal during the warmer months (McKinnon, 1996). This study has refined, tested, and applied these recent conclusions to present an advanced method for palaeoseasonal analysis in New Zealand archaeology. The key methodological findings of this research include: the
applicability of the technique to certain parts of the year, ways to mitigate the effect of samples which do not qualify for analysis, and limitations of the control sample. The first aim of this research was to establish a methodology for interpreting palaeoseasonal data. Within this aim three key objectives were created. These are discussed below.

**Objective 1 - To use Backscatter Electron (BSE) imagery to identify the strength of the relationship between tidal and microband periodicity subsequent to the final macro-increment in the Austrovenus stutchburyi microstructure.**

**The seasonality of the palaeoseasonal method**

Results from this research show that microbanding in *A. stutchburyi* is synchronous with tidal periodicity between November and late February in the Wairau Estuary. This means any sample which was harvested outside of the November to February window does not qualify for microbanding analysis (Figure 69). This introduces possible errors in timing-calculation if methods are not applied correctly. Specifically, it is important that microbanding is visible on the ventral margin of the shell. If microbanding is not clearly visible, it must be assumed that the shell died outside of the November to February time window. A method to ensure the growth is outside of the November to February window is to analyse the amount of microbands after the final winter notch to the end of microband deposition (there will be shell matrix without microbanding at the ventral margin). If the prediction of a death after February is correct, the mean microband count is likely to be close-to, or slightly greater-than 240, this represents the approximate number of tides between 1 November and the end of February (this number varies each year slightly based on lunar patterns).
Figure 69. Diagram showing the amount of confidence microbanding analysis gives for time-of-death predictions across an annual cycle using *Austrovenus stutchburyi* based on results from this investigation.

Chapter 4 showed the method can accurately measure the date of death for samples that died between November and February, providing data which is within two or three days of the true date of death. However, outside of this date range, poorly visible, irregular, or completely absent microbands mean the application of this technique cannot be applied with confidence. This palaeoseasonal technique is therefore seasonal in itself, in that it only works in certain parts of the year.

Similar conditions have been found using fish otoliths in Alaska for palaeoseasonal reconstruction (Van Neer *et al.*, 2004). It was argued that these strict conditions for the correct use of the palaeoseasonal analysis means this type of methodology is best applied to short-lived or single-event deposits, and should only be applied to samples which died within the times of the year where the method can be confidently applied (Van Neer *et al.*, 2004:471). This thesis has applied the method to an archaeological deposit which qualifies under both of these conditions because the deposit is proven to be a phase single-deposit with the same eggshell fragments scattered from the top to the bottom of the matrix and the single cultural layer at the site (Jacomb *et al.*, 2014, Oskam *et al.*, 2011). Thus, the conditions of short-lived or single-event deposits proposed by Van Neer *et al.* (2004) is met. In other applications if there
is an absence of microbanding on the ventral margin, specimens cannot be systematically analysed using this technique. However, this information can coarsely provide a time-of-death of the specimen by eliminating any time between Novembers to February. This provides a rough sub-annual marker of time which can supplement additional analysis and other research aims which may not require extremely accurate date predictions.

**Mitigating the seasonal conditions of this technique - what to do about an absence of microbands**

Nearly all coastal archaeological sites in New Zealand have evidence of shellfish consumption, and this strong presence suggests year round-access to shellfish was likely. The methodology presented in this thesis cannot calculate date-of-death year-round, however additional analysis to ensure similar high-resolution dating can be achieved for the periods outside of November to February. Measuring the distances across cumulative yearly growth (as done by Higham 1990 and Samson 1995) can be applied; this is a method that provides wider date ranges than those created in this thesis, however remains informative for palaeoseasonal investigations. In addition to Coutts’ (1970) index analysis, there are stable isotopic variations to aid the examination the time-of-death of specimens which died outside of November and February. The New Zealand Blue Mussel (*Mytilus edulis*) shows a strong correlation between variation in sea-surface-temperature (and therefore seasons) and stable isotopes O$^{18}$ and O$^{16}$, thus the variations in Oxygen values shows roughly when the shell was harvested. This method has already been applied to some New Zealand archaeological investigations with very informative and reliable results (Higham, 1990, 1996, Till, 1984, Till and Blattner, 1985).

Other than bivalves, there are other incremental structures within other collected marine species which are quantitatively analysed and could aid the analysis of samples which do not meet the selection criteria of this technique. Red cod (*Pseudophycis bachus*) otoliths have seasonal growth variations and have been applied to an palaeoseasonal investigations in New Zealand to create promising results (Higham and Horn, 2000). Similar to stable isotopic analysis, this palaeoseasonal technique could be applied to deposits which have *A. stutchburyi* samples that do not have microbanding on the ventral margin. In addition, it has been
discovered that species which deposit microbanding in otoliths may also host the same seasonal growth variations in their vertebrae (Van Neer et al., 1999), an unexplored but promising technique for New Zealand archaeologists. In short, there are several quantitative avenues to mitigate the inapplicability of this method to samples which do not clearly display growth periods inside of November to February, both within A. stutchburyi and to other species commonly found in archaeological deposits. While none are likely to provide the level of precision this technique provides, the level of accuracy is still sufficient when addressing the research aims New Zealand archaeologists commonly ask when applying these techniques.

**Calculating a start date for the microband growth period**

The control collection provided results which suggested it was likely that the start date of microband growth was the 1 November in the year of 2011. These results contributed to the model which guided the calculated dates for the microband-growth-period of the archaeological collection. The true accuracy of this, however, is subject to criticism. This assumption relies on total responsive synchrony of the population within the estuary. It also assumes that the microband growth period starts on 1 November every year. Additionally, the deposition of microbanding does not explicitly follow calendar dates; instead, it follows the environmental, solar, and lunar patterns. This means any climatic or thermodynamic variation between 2010 and the period of archaeological collection may impact the true calendar start date of microband deposition.

The obstacle of a control sample not explicitly reflecting an observed sample is not unique to this research. It is a common issue found in any archaeological investigation that designs a model based a live-controlled sample (Bamforth, 2002, Dincauze, 1987, Hardesty, 1980, Salmon, 1978). Such limitations are often partially offset by testing the results against other known bodies of data, which in this case would be any form or palaeoseasonal data. This research set out to use trace elemental mapping to test and supplement the microbanding data, however the null results left the microbanding methodology without a comparative data set. However, there are other methods of testing microband growth; the most obvious is to
test the model this research used for seasonal growth against others. A comparison of the results in this research with those of Beentjes and Williams (1986), Beikirch (1995), Higham (1990), Larcombe (1971), McKinnon (1996) and Samson (1995) show a broad agreement between the microband growth period found in this research, and the seasonal growth rates in the earlier studies on a monthly level. These comparisons support the proposition that the drop in growth rates after March makes growth analysis is increasingly unreliable (as proven in Chapter 4). Due to the regional variety between each site, these comparisons must be treated with caution. Nonetheless, these similar findings give broad support to the results from this research.

Duration and temporal relativity investigations using this method are slightly more hindered by the start-date of the microbanding period, but not entirely. Coutts (1970:874) proposed the relative timing of shellfish collection can be determined by:

“... counting the number of daily growth bands from the last macro-ring to the shell margin. Providing the approximate date when the macro rings are laid down is known, the date of death of individual shellfish may be estimated.”

This approach can be applied across an archaeological sample to estimate the overall amount of tides which has passed between specimens to explore the relative timing of death in specimens. This informs the amount of tides represented within an archaeological sample and can be used to explore the time-depth within the deposit, as well as temporal relativity between samples, regardless of whether the microbanding growth period is assigned calendar dates.

Although already noted in Chapter 3, it is worth repeating the imperative of having a control collection which was sourced from a nearby region to the archaeological sample (Andrus, 2011, Burchell et al., 2013, Clark, 1979, Custer and Doms, 1990, Groke and Gillikin, 2008, Hallmann et al., 2009, Schöne and Gillikin, 2013). Regional growth variation in shellfish species is common across the globe, and especially so in New Zealand’s temperate sub-tropical climate. The control-results of this study are ideally only applied to archaeological specimens
from the Wairau Valley and the north-eastern corner of the South Island. This means any further investigations using this method which is not from the north-eastern corner of the South Island must create a new custom control collection.

**Cost – time and resources**

This type of palaeoseasonality study requires a considerable amount of time and resourcing. The most ideal control sample is composed from specimens which are collected monthly over several years from the same estuary, and at the absolute minimum are collected to span an entire year (Andrus, 2011, Burchell *et al.*, 2013, Hallmann *et al.*, 2009, Higham, 1990, McKinnon, 1996, Samson, 1995, Schöne, 2008, Schöne and Gillikin, 2013, Schöne *et al.*, 2005). Preparation for this longer period of sample preparation is essential when taking on this type of project, researchers must be aware that the first year(s) is likely to be solely dedicated to monthly control sample accumulation before systematic analysis of growth patterns can commence. Also, the need for the control sample to come from a estuary nearby the archaeological site means access to the estuary for a single year round is likely to require around 100 volunteer hours and flexibility to access samples at a low tide on the set date, or, strong financial and logistical support to access the estuary and transport samples each month. The 100 hours is based on an estuary which was fairly easy to access for the volunteer, and time predictions are likely to be far higher if the study estuary is remote. While the sample size was much smaller than Samson’s (1995) sample (*n* = 3384) the majority of time in this research was similarly spent designing and compiling the control sample (Samson, 1995:98). SEM analysis of shell samples is a relatively new form of analysis meaning the level of trialling various forms of methods, materials, analytical tools, software, and appropriate time-investment into each stage is labour and resource intensive. While this thesis has teased out many sample specific issues and hurdles and addressed many of these obstacles there could be to be some unexplored stages within SEM of shell sections which may take time and finances to trial and correct. Based on the materials, costs, and skills established during this thesis, a general prediction can be made that once the technician is competent at microbanding
analysis using SEM, the sample preparation to analysis stage generally take between 20 – 26 hours per sample (Table 21).

Table 21. Summary of time and costs expected for SEM analysis based on the techniques established in this thesis (note: the financial cost excludes the costs of materials).

<table>
<thead>
<tr>
<th>Task</th>
<th>Time cost</th>
<th>Financial cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample preparation</td>
<td>15 hours</td>
<td>Varies</td>
</tr>
<tr>
<td>SEM data collection</td>
<td>3-7 hours</td>
<td>$500 – 1250</td>
</tr>
<tr>
<td>SEM data analysis</td>
<td>2-4 hours</td>
<td>Varies</td>
</tr>
<tr>
<td>Total</td>
<td>20-26 hours</td>
<td>$500 – 1250 plus labour</td>
</tr>
</tbody>
</table>

**Sample size**

Considering the aforementioned investment required to create a control sample for analysis, it is therefore reasonable to suggest that reducing the sample size can mitigate the amount of resources and time the control collection takes to create. Reducing the sample size has implications for the accuracy date-predictions, as with any control sample in a study a large sample provides a more realistic impression of the true distribution of behaviours. As already explained in Chapter 3, sample sizes for growth analysis in specimens is far smaller than those from studies in earlier decades, although the preparation of samples are equally if not more labour intensive for the preparation of SEM. Due to the scope of this thesis and the costs involved in SEM, 10 live specimens were used to create the control collection which made the model for seasonal microband growth patterns, and of those, only one was tested under Electron Dispersive X-Ray Spectroscopic mapping (EDS). While these specimens still provided data which showed statistically significant seasonal patterning in microband deposition, the microbanding model is likely to be greatly improved should the sample be larger.
Objective 2 - To use Backscatter Electron (BSE) imagery to establish any correlation between spring and neap tides and microband width in the microstructure of the Austrovenus stutchburyi.

Results from this research suggest that between early December to late January spring-neap cycles are reflected in both relative microband distances and morphology. Similar results were found in McKinnon’s study, but only over January and February (McKinnon, 1996). This information refines the way archaeologists can make date predictions using A. stutchburyi because the spring neap-cycles seen in microbands can be a way of a) quickly identifying the growth period between early December and January, and b) understanding the moon phases over the period of shellfish collection. Evidence of moon phases and shellfishing may eventually show patterning of preferences in any shellfishing collection and harvesting patterns around lunar cycles. Lunar harvesting and moon timings (maramataki) is ethnographically linked to horticultural practices across East Polynesia and the wider Pacific, while fishing practices are often linked to lunar patterning in parts for the Pacific (Ono, 2010, Ono and Addison, 2009, Roberts et al., 2006, Ropiha, 2000, Stimson, 1928). Identifying moon phases in shellfishing collection through the technique in this thesis can contribute to this discourse of maramataki and fishing in prehistoric New Zealand. Additionally, identifying the spring-neap morphological variation has important implications for the accuracy of date-of-death predictions, because archaeologists can now identify false microbands which are often deposited during spring cycles. Spring cycles usually deposit a microband which is flanked by a fainter but resolvable microband which can be mistaken for a tide if not analysed carefully with an understanding of this phenomena, which can skew date-of-death predictions.

Objective 3 - To test whether Electron Dispersive X-ray Spectroscopy (EDS) linear mapping in the Austrovenus stutchburyi can identify fluctuations in trace element distributions across an annual cycle resulting from seasonal thermodynamic processes.

The relative distributions of trace elements using EDS linear mapping was an attempt to account for the periods of the year which provided no microbands, however these results were
null. The trace elements that were expected to be present were not recordable using EDS. The results are therefore evidence EDS mapping is not a suitable tool, rather than discrediting trace elemental analysis for palaeoseasonal investigations. Trace elements in *A. stutchburyi* often exist in very low amounts, varying between 0.00034 mmol/mol to 8.4 mmol/mol (Marsden *et al.*, 2014, Orsman, 2011). EDS analysis extracts data of elements with a stronger presence. Even so, a recent investigation into seasonal fluctuations of trace elements in *A. stutchburyi* showed that only the Barium to Calcium ratio showed temporal variation, possibly attributable to phytoplankton blooms or river flooding, while the remaining trace elements appeared to be controlled primarily by internal biological factors (Orsman, 2011). Orsman (2011) applied the methods to a relatively small sample size (*n* = 17) and suggested the piloting for trace elemental analysis in *A. stutchburyi* is still early enough for reattempted and reconsidered methodologies. Trace elements are therefore still a potential tool to measure time-of-death outside of November to February. EDS linear mapping provides a continual and relative spectra of information from samples which could be important avenues for analysis other palaeoclimatic and environmental predictions, and while this thesis displays EDS’s inability to examine trace elements in *A. stutchburyi*, it is likely to aid similar projects which aim to investigate any recorded change over time in specimens.

**Archaeological**

The archaeological specimens examined in this study suggest that *A. stutchburyi* from Oven Pit 1 at Wairau Bar were collected in late-spring and summer. The results were used to answer two key objectives; first, to identify the time of death of *A. stutchburyi* from a sample, and second, to determine the nature of shellfish collection strategies. This section discusses the results in relation to the other known temporal attributes of Oven Pit 1 and the archaeological site. The possible scenarios of shellfishing are considered within the wider context of the other high-resolution time data. This section also considers the necessary avenues for further methodological and archaeological studies.
**Objective 1 - To identify time of death of a sample of cockles within the annual cycle.**

The data from Objective 1 are presented and explored in Chapter 5 which showed the microbanding and time of death results for the archaeological specimens. These can be summarised as follows:

- All archaeological specimens were very mature or senile, suggesting the *A. stutchburyi* specimens probably came from a pristine population which had not been previously exposed to human predation.
- Nearly all the archaeological specimens were collected in the microband-growth-period. Refined reductive dates support the shellfish collection dates to be between 10 November and late February.
- Shellfish death dates can be interpreted in four main ways when exploring the collection events represented in CSA. The results can be applied to argue there are four possible scenarios of shellfishing during late-spring and summer that are possible.

The outputs of Objective 1 form the basis for carrying out the Objective 2 analysis.

**Objective 2 - To determine whether the cockles were collected over a short period or whether they represent a series of collection events.**

**The shellfish collection models in context – the results in light of other temporal attributes in Oven Pit 1**

Chapter 5 presented the time-of-death results to isolate four main shellfish-collection scenarios. These shellfishing scenarios were examined only within the context of the results created from this research; this section considers them in light of other depositional data created from the midden. This thesis is not the first specialist attempt to understand the collection and deposition processes in Oven Pit 1, meaning there are several important contexts and co-existing bodies of data which aid the way each shellfishing scenario is considered and the overall understanding of the oven deposit. The most relevant of which is:
a) the evidence of fragments from a single moa egg strewn through layer 2 (Jacomb et al., 2014, Oskam et al., 2011), b) radiocarbon dates from the midden (Jacomb et al., 2014), c) the observed ontogenetic condition of other A. stutchburyi shellfish specimens in the midden during this research (discussed in the section “Wairau Bar and the environment - pristine or worked”), and d) the ancient DNA (aDNA) evidence of intensive moa-hunting in the midden (Oskam et al., 2012). Unfortunately the results from the faunal analysis from the deposit are not yet available, meaning any attempt for a systematic consideration of faunal proportions, juvenile or infant bone, and foraging theories cannot be tested to examine the palaeoseasonal results of this research (as done by: Higham, 1976, Higham, 1990, McFadgen and Sheppard, 1984, Rowland, 1977, Samson, 1995). The other dating studies into Oven Pit 1 confirm a rake-in or a form of cleaning secondary deposition is likely, as it is the only way to account for the single moa-egg shell strewn through layer 2 (i.e. people did not collect, consume, and deposit the refuse in a single uninterrupted event). The amount of time taken to create the food refuse material is discussed in relation to the shellfishing evidence, this will inform and test any time-depth and temporal relativity of shellfishing events represented. These are discussed in the following sections.

**Scenario 1 - There was a series of many collection events over a single late-spring to summer period.**

The results from this research support the likelihood of several shellfishing events occurring over a single late-spring to summer period. When this scenario is considered within the wider understandings of the deposit, several masked anthropogenic components are revealed. In this instance, the moa egg consumption evident in the egg-shell fragments was also during the same late-spring to summer cycle, and this was muddled with the other refuse material over a single annual cycle as the shellfishing events accumulated. The results from this analysis therefore represent both shellfishing and moa-egg-collection dates, thus it can be inferred from these results that the moa eggs present in this deposit (n = 31) (Oskam et al., 2011) were collected between late-spring and summer (10 November – late February) in a single year between 1320 and 1350 AD from a pristine and unharvested biozone. What this scenario (and
the other scenarios) mean for resource use, duration, and temporal relativity are discussed later in this chapter.

**Scenario 2 - There was a series of two or three collection events over a single late-spring to summer period.**

The results from this research also support the likelihood of two or three larger scale shellfishing events occurring over a single late-spring to summer period. In this scenario the application of other data from Oven Pit 1 and the implications of these do not significantly vary from that of Scenario 1 - it can still be proposed that the moa eggs present in this deposit \( n = 31 \) (Oskam *et al.*, 2011) were collected between late-spring and summer (10 November – late February) in a single year between 1320 and 1350 AD from a pristine and unharvested biozone. The point of difference between this scenario and Scenario 1 is that there were less shellfishing collection events, and instead there were larger and more intensive collection events; one or two of there were during November and December, while the remaining were in during mid and late-January.

**Scenario 3 - There was a series of many collection events over several late-spring to summer periods.**

The results from this research also support the probability of several shellfishing events occurring over a several late-spring to summer periods (between 5 – 20 years). When this scenario is considered with the wider understandings of the deposit, it suggests the accumulation of midden material took longer than a single year. This scenario also means that the moa egg consumption evident in the egg-shell fragments may have also built up during several yearly cycles (i.e. breeding seasons). The consideration of Scenario 3 alongside the other known properties of Oven Pit 1 can therefore suggest that the results that the moa eggs in this deposit \( n = 31 \) (Oskam *et al.*, 2011) and shellfish were collected between late-spring and summer (10 November– late February) over several years between 1320 and 1350 AD from a pristine and unharvested biozone.
Scenario 4 - There was a single shellfish collection event over a single late-spring to summer period.

The results from this research also support the likelihood of a single large scale shellfishing event occurring over a late-spring to summer period. In this scenario, it can still be proposed that the results that the moa eggs present in this deposit (n = 31) (Oskam et al., 2011) were collected once between late-spring and summer (10 November – late February) between 1320 and 1350 AD from a pristine and unharvested biozone. The difference between this scenario and others is that it suggests the shellfishing collection event was extremely intensive because the food was collected in one continuous and uninterrupted action. Scenario Four proposes shellfishing was within a single continuous low tide collection, which has enormous implications on human settlement, feeding processes, and population sizes considered the quantity of the midden and time taken for shellfishing in a tidal revolution.

The contextual application of the results from this research show that regardless of which scenario was accepted, the midden deposit was from a rake-in of accumulated food refuse, and was a single-phased secondary deposition. It is important to stress that while the deposition of faunal material appears to be a very short-spanned single event, the timing and process for the hunting and collection of these foods could have been a different process. The results from this thesis have investigated that stage of the feature formation to suggest that the collection of A. stutchburyi occurred in the late-spring to summer period(s), from a pristine environment. These results have important ramifications for the archaeological understanding of resource use at Wairau Bar, duration and time-depth within the deposit, and temporal relativity of the feature both internally, and as a benchmark for the remaining anomalies surrounding Oven Pit 1.

Regardless of what scenario is chosen, this analysis has ruled out any evidence of a winter collection.
The archaeological results in perspective

Duration and time-depth in the deposit

The time-of-death in the archaeological specimens from this research identified four scenarios of shellfishing that could have occurred. These scenarios not only help understand the shellfishing events and resource use, they also clarify understandings regarding the duration and time-depth evident in the deposit. The results support the likelihood of very little time-depth occurring between collection events in the midden (Table 22).

Table 22. Summary of durational time-depth evident in Oven Pit 1 based on the results from this research and relevant results from the deposit (Jacomb et al., 2014, Oskam et al., 2011).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duration of time taken to occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1 - There was a series of many collection events over a single late-spring to summer period.</td>
<td>Less than four months</td>
</tr>
<tr>
<td>Scenario 2 - There was a series of two or three collection events over a single late-spring to summer period.</td>
<td>Less than four months</td>
</tr>
<tr>
<td>Scenario 3 - There was a series of many collection events over several late-spring to summer periods.</td>
<td>Less than a few years</td>
</tr>
<tr>
<td>Scenario 4 - There was a single shellfish collection event over a single late-spring to summer period.</td>
<td>A single tidal cycle</td>
</tr>
<tr>
<td><strong>Total span based on all scenarios</strong></td>
<td>Minimum = A single tidal cycle</td>
</tr>
<tr>
<td></td>
<td>Maximum = Less than a few years.</td>
</tr>
</tbody>
</table>

The probability of each scenario can be compared as a means to understand the more probable duration of time taken for the refuse to accumulate. Scenario 1 and 2 give the same durational results (less than four months), while Scenario 3 and 4 strongly differ (a few years and a single tidal cycle, respectively). These results suggest that shellfishing probably occurred during a very short period, and whether these were a single tidal revolution, less than a few
months, or less than a few years, the events were less than the period it took for A. stutchburyi to reflect any young lived shells.

**Temporal relativity**

The relationship between the dates created in this research can also be used to understand the temporal relationships in the deposit. An analysis of the temporal relationships across the site can only be done once other features have been investigated; this thesis has limited the temporal relativity analysis strictly within Oven Pit 1. Temporal relativity within the midden at Oven Pit 1 suggest that the shellfish were collected either within four months of a single year, or in the same four months, repetitively, over several years.

Scenarios 1 and 2 (shellfishing occurring over late-spring to summer cycle) suggest that the shellfish were collected over several events separated by no more than a 4 to 5 weeks, while scenario 3 suggests that the timing between shellfishing was staggered over years. The temporal relativity conclusions of the sample from Oven Pit 1 must be treated with caution because as stressed already; the extremely senile condition of the samples may have skewed the units of measure (days and weeks) needed for analysing the time relationships between shellfishing events.

**Future work and implications**

Both the methodological and archaeological results created in this research can be improved by additional investigations. The grounds for future methodological work lie in further research into the microstructural banding in A. stutchburyi. This research has also identified the need for more archaeological understandings of Wairau Bar and early New Zealand settlement patterns. These are discussed below.

**Methodology**

The methodology presented in this thesis is the first systematic investigation into microbanding of the A. stutchburyi within an archaeological framework, since it was proposed
by Coutts (1970). As such, the research has identified many elements which are worthy of further specialised investigation. Those of immediate importance are:

- Creating region models on microbanding growth of *A. stuchburyi* across New Zealand. The methodology in this thesis can attest to the consensus that for valid growth analysis of a species, the regional control collection is essential. Without the guidance and comparison of a control collection results must be considered very broadly be tested and with supplementary direct palaeoseasonal tools (as done by: Hallmann *et al.*, 2009, Higham, 1990).

- This research also identifies the avenues for trace elemental analysis in *A. stuchburyi* and other seasonally responsive species, palaeoseasonality analysis and palaeoclimatic reconstruction.

- The incorporation of Mutvei’s solution into the methodology for clear microbanding identification is an excellent resource, but should only be applied once any geochemical analysis (such as stable isotope and trace element) is complete (Schone *et al.*, 2005, Wanamaker *et al.*, 2009).

- More reliable start-date-predictions for the microbanding growth period can be created by examining samples from multiple years across the October and November period within each region; this type of study is able to also test for the amount of diversity across regions.

- A similar multi-year analytical approach should be undertaken across the February and March period to reliably identify when the likely periods of microbanding ends across each region. Another likely avenue worthy of analysis is to identify the amount of microbands present in previous years in archaeological specimens. This will create clearer understanding of how long the microbanding period lasted within that specific specimen. The results from the previous years can act as models to investigate both the time-of-death in a specimen while also refining the control collection results. The same approach will also predict the length and intensity of seasons as well as inform climatic predictions and changes.
• Investigations into the umbo (hinge portion) of the *A. stutchburyi* to examine palaeoseasonality and records of annual cycles will be of great benefit to archaeology also, being the elemental portion which lasts the longest in archaeological deposits.

• More broadly, the ongoing development of the understanding of growth patterns of *A. stutchburyi* and refining analytical tools through microscopy and microstructure analysis are particularly important.

• The sclerochronological application of this microbanding technique can act as a Bayesian prior to improve absolute dating methods in New Zealand archaeology. Sclerochronology has the ability to confidently resolve annual and sub-annual events in shell material. Furthermore it is possible to plot the aligned banding results between specimens to create a collective record longer-traced of time create annual and sub-annual events within a local area (Andrus, 2011, Groke and Gillikin, 2008, Schöne and Gillikin, 2013). Sclerochronology is the marine counterpart to dendrochronology and creates an environmental archive based on biological events. In essence, Bayesian analysis is a way to estimate parameters of an underlying or coexisting body of data on an observed data set. Sclerochronological application to Bayesian priors is possible using banding in *A. stutchburyi*. This enables a more contextual approach to radiocarbon dating by considering, quantifying and plotting co-existing parameters which act as anchors to dates, effectively shortening the radiocarbon date (Gelman *et al.*, 1995, Nicholls and Jones, 2001). From a theoretical standpoint, it is a form of non-linear time (evidence of seasonal and lunar revolutions) being used to create a form of constrained time (undated sclerochronological spectra of months and years) to inform and refine complete time (Bayesian analysed radiocarbon dated prehistoric events).

**Archaeological**

The application of this methodology to the archaeological sample has enabled a clearer understanding into shellfishing events, wider resource use, duration and time depth, and temporal relativity of shellfishing at Wairau Bar. During the analysis and discussion there has
been topics which are highlighted to require more analysis for a clearer and more precise impression of events. These are as follows:

- The archaeological component of this research has shown the need for more investigations into the high-resolution dating of Wairau Bar to explore the durational aspects of the settlement. Understanding if the short-lived nature of the midden in Oven Pit 1 is also reflected in the other large closely located deposits has important ramifications for population and demographic understandings, as well as settlement patterns at Wairau Bar.

- Contemporaneous sites in the Wairau Valley and the wider north-eastern South Island should be investigated, in a similar manner to the regional models of Southern New Zealand (Anderson and Smith, 1996) and Northern New Zealand (Allen, 2011, Davidson, 1979, Furey, 2002, Green, 1963b, Sewell, 1984) as a way to understand the wider cultural and geographic landscapes in early New Zealand. The settlement patterns at Wairau Bar can be investigated using data from this research, and these can be tested and improved if the wider archaeological landscape of the Wairau Valley is explored.

- It is also necessary that the systematic analysis of fauna from Oven Pit 1 should be considered in light of seasonal access to test the results of this research, through juvenile bone presence (Smith, 1976, Smith, 1985), migratory species presence, and identify sexual ratios of moa bone which will give impressions of breeding seasons (Anderson, 1989b, Bunce et al., 2003, Huynen et al., 2003, Young, 2012).

- Further palaeoclimatic and palaeoecological investigations into Wairau Valley will improve what the exact faunal and floral properties are in a pristine landscape, which has important implications for the intensity and timing of resource access for the settlers of Wairau.

- Moreover, investigating any available specimens which are within the ontogenetic age of 4 – 12 years will provide more reliable results than those used in this research (McKinnon, 1996).
- There are likely to be at least five equally large midden deposits at Wairau Bar, all of which are within 20 meters of one-another (Brooks et al., 2009, Jacomb et al., 2014). A. *stutchburyi* samples from these deposits can be used to examine the temporal relativity they share with Oven Pit 1. This research can act as a benchmark for temporal analysis of the deposits as a means to understand the types of temporal relationships they share with Oven Pit 1, time data such as calendar dating, sclerochornological dating across samples, palaeoseasonal dating, and durational analysis between the deposits. Such details will shed light on the intensity of resource use and population size, while also refining the results of this research by testing both the methods and interpretations.
- Microbanding analyses of global counterparts have taken the same approach as this research to present techniques which can identify not only whether the shell was collected during low or high tides, but also if during the day or night. These studies were also able to identify the approximate elevation in the intertidal zone from which the shells were being harvested (Hallmann et al., 2009). These collection characteristics would be beneficial to New Zealand archaeologists and are worthy of investigation in the *A. stutchburyi*.
- Palaeoseasonal data is also stored in the geochemistry and incremental microstructures of other fauna from Oven Pit 1, meaning the results of this research can be tested and refined. Thus far, analysis of the red-cod otolith and the blue mussel are species which are proven to provide palaeoseasonal information which should be investigated in Oven Pit 1 to supplement the results of this research.

**Implications of the approach for Wairau Bar**

The results can be used to explore other significant topics central to archaeological investigations at Wairau Bar relating to culture change, moa hunting, and site function. These topics are not central themes to the investigations of this research, however a brief review of the potential role this study has in answering these topics is presented below:
**Wairau Bar and culture change analysis**

The changes which occurred for Māori society to develop may be understood more clearly if the first-settler communities are explored with fine-scale dates that determine event duration. In a basic sense Wairau Bar’s settlers are part of a small handful of colonialists who provide a chronological and cultural reference point for prehistoric culture analysis.

The results from this research can improve the understanding of Wairau Bar’s settler community by using the cyclic-framed lens to see if there was a strong seasonal factor to the reliance of moa and timing of other events. The same time data addresses duration of events and how long the site was occupied which plays a vital part in understanding the role Wairau Bar had in the New Zealand prehistoric landscape.

**Wairau Bar and systematic moa-hunting analysis**

Moa were unarguably the most intensively hunted big-game species in New Zealand’s history, and faunal remains at Wairau Bar are testament to this. Wairau Bar fits into a broader pattern of relatively short periods of duration of occupation (For example early sites such as Shag Mouth, Papatoiwai, and Houhora all demonstrating occupation for no more than a few decadesAnderson et al., 1996, Anderson and Smith, 1992, Anderson and Wallace, 1993). Ratite comparisons coupled with environmental gradients have estimated that the South Island had double the population of moa than the North Island, and within these populations many genera were highly concentrated on the east coast of the South Island (Anderson, 1989b, Young, 2012). Regional moa abundance at Wairau provides a strong base to examine systematic and opportunistic hunting. This means the estimated 4,000-12,000 moa carcasses on site indicate that the majority of meat consumed was moa meat – especially when compared to other faunal data (Anderson, 1989b, Anderson et al., 2004). Although taphonomy coupled with differential collection and analytical strategies influence the estimations of moa population sizes, moa hunting was an extremely strong element of subsistence practices at Wairau (Anderson et al., 2004).
The chronology of occupation at Wairau Bar overlaps with the timing of when moa populations peaked. Moa were therefore likely to be one of the primary prey, and the rate of extinction suggests a determined hunting strategy (Higham et al., 1999, Holdaway et al., 2002). It appears that Wairau Bar was occupied during the height of this resource targeting, because the dates of moa hunting and extinction fall in a perfect alignment with Wairau Bar site occupation (Figure 70). Moa hunting was predicted to have ceased within 50 to 70 years of Polynesian settlement (Holdaway et al., 2002).

![Wairau Bar occupation](image)

**Figure 70.** Linear time lines showing moa populations aligning with Wairau Bar occupation, based on current dating by Holdaway and Jacomb (2000) and Higham et al. (1999)

Wairau Bar was probably occupied before large-scale population decline of moa, meaning it can reveal important information about hunting strategies before they adjusted to the decline of the species. This is important because it allows the systematic dimension of hunting to be investigated, because moa populations were still large – in other words moa had not yet reflected over-kill in the population.

The results from this research can be used to help understand the seasonal scheduling of moa-hunting. Moa remains that are from the same stratigraphic layer as cockles can be assigned the same time of death dates meaning sub-annual moa-hunting strategies and fluctuations to hunting intensities can be examined. The results created in this in this research can also test the analogous ratite predictions used in moa breeding and incubating periods to argue they are correct. It is important to note that these conclusions only apply if the shellfishing and moa egg collection events are generally simultaneous (i.e. within one or two months), and should the midden represent food collection over other seasons (more than late-spring and summer - which the specimens from this research did not reflect) the breeding and hunting findings do not apply. The results in this thesis therefore provide a platform of the other months of the year to be explored to understand any changes or fluctuations to moa hunting patterns, by starting with an understanding of the late-spring and summer months.
Wairau Bar and settlement analysis

Due to a lack of time data, Wairau Bar can become a singular phased village. Finer versions of
time-data, such as those created in this thesis, can test this hypothesis by examining the site
for any seasonal abandonment. The same results can contribute to what is known about the
function of the site by examining the length and timing of occupation.

Food debris, human burials displaying social stratification, debris of manufacture, cooking
remains, blanks and flake discard adzes, and structural posts all suggest more generalised
activities were taking place in the same space to host a more settled, although not necessarily
permanent, village life at Wairau Bar (Brooks et al., 2009, Brooks et al., 2011, Duff, 1942,
features suggests data also suggest that the feeding events analysed in this research were
probably not the only feeding events at Wairau Bar. The diversity of both the material culture
functions as well as activities taking place at Wairau Bar implies the site was a location for
varied specialities and functions and semi-permanently if not permanently occupied.

The pristine landscape across Wairau provided people access to resources which almost
definitely ensured reliable access to prey. Leach (1969) argued that during the early period of
New Zealand prehistory it was likely palaeoenvironment conditions north of the Waitaki
River made it easier for humans to occupy than that south of the River. When this hypothesis
is coupled with the calculated abundance of moa in the north-eastern corner of the South
Island, it can be argued that Wairau Bar was centred in a very reliable palaeo-resource
network during occupation. The surrounding environs were capable of hosting a permenant
or semi-permenant community that had no immediate economic need to abandon the
unfailing biotope. This biotopic dependability which enabled this type of settlement at Wairau
was likely to have been enhanced in the early period by the pristine nature of the
environment.

High-precision radiocarbon dates from samples at Wairau Bar provide a dense cluster of dates
(Higham et al., 1999), when these are considered in light of the mono-layer cultural horizon,
this suggests a short period of occupation. The density of radiocarbon dates were used to
argue that humans occupied the site for 20 years or less (Higham et al., 1999). As explained in Chapter 1, the duration of occupation at an archaeological site generally correlates to site complexity and settlement type. The closely packed radiocarbon dates alongside the diversity of functions evident at the site were used by Higham et al. (1999) to argue that people operated from a permanently occupied but short-term base camp at Wairau Bar.

There are archaeologically grounded theories which suggest that during early New Zealand prehistory the brevity of site occupation is evidence of rapid depletion of big-game resources, where people were based in a site and exhausted the surrounding niche until migrating to another site (Anderson and Smith, 1996). These types of settlements are called “Transient Settlements”. Wairau Bar descriptively fits this model of settlement, and under this framework it indicates a systematic and determined predation of big-game resources until reserves become exhausted (Higham et al., 1999:426). Wairau Bar probably provided reliable food resources which meant people did not need to be highly-mobile to access big-game meat access, and as such people would not have been occupying the site like a base-camp solely during the less-favourable winter months (Coutts, 1969).

The aforementioned studies all present results which mostly propose that Wairau Bar was occupied permanently, but briefly. It fits conceptually within the “transient settlement” model because big-game fauna were hunted intensively and briefly, and once these ran out, the site appears to be abandoned. This model was designed to suit Southern New Zealand sites which provide a very different environ (Anderson and Smith, 1996), meaning the application to the more-northern Wairau Bar could be problematic. Inapplicability of the transient settlement model could also arise from the pristine palaeoenvironment at Wairau, where the rate and tempo of resource exhaustion in a pristine environment followed a different trajectory than those which accurately fit the transient settlement model. These problems can begin to be resolved using results from this research. The results of this research can be used to investigate if the brevity of occupation at Wairau Bar was hinged on systematic and rapid big-game depletion, which then gives inference to permanent occupation of the site.
Wairau Bar may have been a well-established, continually occupied village, covering 11 hectares. The alternative version of settlement at Wairau Bar is this is 11 hectares of short-lived encampments, with a longer overall time-depth. This is equally as likely, considering many other South Island moa-hunting communities seasonally dispersed and regrouped, living in smaller encampments on-and-off until moa populations began diminishing (Anderson, 1982, Higham, 1976, Higham and Horn, 2000). As noted in earlier sections, the midden sample this study uses has moa egg shell fragments from a single egg mixed from the top to the bottom of the matrix to suggest a single depositional event. The single deposition of midden could represent a short lived feeding event, or is refuse material that has accumulated over time. Results from this research can be used to investigate the duration of feature use at Wairau Bar to provide a proxy on settlement duration and seasonal use.

This research therefore provides a tool which can dramatically sharpen what is known about settlement at Wairau Bar. The application to Oven Pit 1 has helped calculate the timing of shellfishing. Applying the technique created in this thesis to the known midden features surrounding Oven Put 1 means future work can significantly clarify what is known about human settlement at Wairau Bar and create the seasonally-relative results needed to provide Oven Pit 1 additional contexts.

The time-of-death results from specimens in the other midden features hold enormous potential to examine the duration of feature use at the site. Further high resolution dating of the surrounding midden deposits using radiocarbon dating, sclerochronology, and palaeoseasonal analyses can test current settlement models. It is also imperative to investigate the lateral continuity across the 11 hectare site to test that the fluxgate radiometric mapping was of a single site (Anschutez, 2001, Dunnell, 1992, Ebert, 1992, Harris, 1979)

**Wairau Bar and the environment - pristine or worked**

The results from this research suggest that the Wairau Valley had not been intensively harvested or hunted at the time of the site establishment. The ontogenetic ages of the archaeological specimens used in this research are all classed as senile and extremely large
valves. Comparison with other early period New Zealand sites where the age of *A. stutchburyi*
was also noted (such as Pleasant River Mouth and Shag River Mouth), shows Oven Pit 1
specimens appear to be markedly older (no specimens under the age 12 unlike other studies)
(Higham, 1990, McKinnon, 1996, Samson, 1995). The faunal analysis carried out on CSA was
not made available to the author, however, a grab sample of 10 Green Mussels (*Perna*
*canaliculus*) from CSA also suggest exploitation of a virgin environment because of the
extremely thick ventral margins (archaeological ventral margins have a mean thickness of 45
millimeters, while the average modern thickness is usually less than ~15 millimeters). The
extremely thick ventral margins suggest allometric linear growth only found during senility
(Powell, 1979). The observed larger size of cockles with other bivalves suggest that the Wairau
Valley biotope - or at the very least the marine resource network in Wairau Bar - was not yet
harvested to an extent where any younger or smaller species were being collected (Swadling,
1977:12). It is of course worth noting the likely preference of early New Zealanders to collect
larger shellfish species (Anderson, 1981, Green, 1963a, Swadling, 1977), and that any forms of
economic marine resource (such as Rāhui), both impact this interpretation (Barber, 2004a).
Evidence in the form of typical East-Polynesian characteristics and radiocarbon dates also
support the likelihood of people settling a pristine environment because there are very few
sites in New Zealand which are earlier than Wairau Bar, and thus the environmental niche
was untouched by humans (Duff, 1942, Higham et al., 1999, Jacomb et al., 2014, Walter,
1996). Further supporting the likelihood of a pristine and unexhausted biotope are the
archaeofaunal and ancient DNA evidence of intensive moa-hunting at Wairau Bar to suggest
that moa populations were not yet reflecting any scarcity, or population reduction from
hunting (Allentoft et al., 2014, Anderson, 1989a, Anderson, 1989b, Anderson et al., 2004,
Holdaway and Jacomb, 2000, Oskam et al., 2012, Young, 2012). The site has typically East
Polynesian attributes, is radiocarbon dated to be one of the earliest sites in New Zealand, and
the observed level of moa hunting all support the results from this research to suggest first-
settlers were hunting within a pristine environment.
Implications of the approach in New Zealand archaeology

The types of results this method creates has direct contributions to other significant research topics in New Zealand archaeology. These are presented below:

Site permanence and transience

Prehistoric settlement types are usually estimated through the richness and breadth of archaeological remains, population size estimates, the distribution of surrounding sites, the surrounding biotope’s resource niche, and the stratigraphic distribution of radiocarbon dates. These factors can provide robust and reliable models for how humans interacted with the landscape at a broad level. Palaeoseasonality evidence is often used to confirm the consistency of these results by providing high precision time information, because often the durational data is far sharper than what radiocarbon dating offers. The type of temporal data the method from this research provides allows for site permanence and transience to be explored with high-resolution.

Role of shellfish in long-term patterns of resource use

Archaeological investigations in New Zealand, and across the world, have associated shellfishing with periods of annual resource scarcity (Meehan, 1982, Meighan, 1969, Nagaoka, 2002, Samson, 1995, Till, 1984). This theory proposes prehistoric gatherers relied on shellfish as the dependable and secure resource which was accessed when other prey species are unavailable (Meighan, 1969). Within the context of early New Zealand, the periods of resource dearth were usually colder months. It is therefore expected that shellfish could act as a stabilising factor of prehistoric economies in colder months; this has been tested by several New Zealand archaeologists. Shellfishing has been proposed by Till (1984) to be a key resource for prehistoric economies during cold months at Pournawea, Long Beach, and Southport 1 in Fiordland. Prehistoric systematic shellfishing in Southern New Zealand during cooler months is attested to also by later research (Anderson and Smith, 1996, Higham, 1990,
Nagaoka, 2002). It has been hypothesised that prehistoric communities on the Otago coastline relied on year-round shellfishing, as stated by Leach (1969:40) who proposed:

“…such quantities of shellfish would have eased the problem of overwintering in the area”

The results created using the microbanding technique can test the “fall-back” nature of prehistoric shellfishing in New Zealand because it can identify when the cockle was collected with high-precision. The same data can clarify the role shellfish had in communities when resources with higher energetic return (such as moa and seal) were accessible over cooler periods of the year (Jon, 1988, Leach et al., 2001, Smith, 2011, Smith, 2004, Whitaker, 2008)(Jon, 1988, Leach et al., 2001, Smith, 2011, Smith, 2004, Whitaker, 2008).

**A proxy for other resource activities**

The technique in this thesis creates data which can act as a proxy for understanding the timing of other seasonal resources. Moa-hunting strategies are likely to have used the seasonally predictable patterns within moa breeding. The results from this thesis can test this model. Sexual distributions of moa probably varied across biozones depending on the stages of the breeding cycle (Turvey and Holdaway, 2005:82, Worthy and Holdaway, 2002), and these predictable prey patterns may have shaped way humans hunted moa (Anderson, 1989b). Analogous ratite studies suggest that moa probably incubated over the spring period (Anderson, 1989b, Davies, 1976, Worthy and Holdaway, 2002, Young, 2012). Archaeologists have proposed that New Zealanders quickly learnt and utilised these patterns to have simultaneously accessed a moa egg and a live-moa in a predictable nesting zone, while also hunting during the favourable warmer months (Anderson, 1989b, Hamel, 1977). Any sub-annual variation in moa hunting can be determined by applying the results from this technique as a proxy for seasonal hunting.
Conclusions

For over four decades New Zealand archaeologists have been aware of the potential contributions that the seasonal growth patterns in *A. stutchburyi* can make to palaeoseasonal studies, while simultaneously facing an emerging struggle with temporal resolution when exploring the timing of events in prehistory. This thesis has presented a technique analysing the microbanding phenomena in *A. stutchburyi* which can identify when the shell died. If the calculated death dates are during particular parts of the year, the technique can also identify whether a shell was collected during a spring or neap tide.

This method cannot calculate time of death for samples which died between March and October because the microbanding periodicity is not tidal. To ensure time of death is correctly calculated it is vital the criterion regarding ventral margin visibility is met. The methodology has an immediate application to palaeoseasonality and resource studies but also has a proven ability to explore duration and temporal relativity in New Zealand archaeofaunal deposits by providing meaningful time units when exploring individual events in prehistory. Since New Zealand’s short prehistory was identified, such issues surrounding the timing of events have been large stumbling blocks (Anderson, 1991, McFadgen *et al*., 1994, Shawcross, 1969). The limitations of this work include the regional applicability of the model, which highlights the need for further studies into creating other regional models. The strict criteria for sample selection means archaeologists must be prepared for alternative approaches to examine time of death in specimens which may have died outside of the microbanding growth period - although this multifaceted approach is not a new proposition for palaeoseasonal investigations in New Zealand, and is now widely regarded the best practice when approaching in palaeoseasonal analysis (Burchell *et al*., 2013, Hallmann *et al*., 2009, Higham, 1990, Samson, 1995, Schöne and Gillikin, 2013).

The new method also provides a stage for microbanding studies to investigate sclerochronological applications. These records will help archaeologists identify both the palaeoclimatic and finer-grained temporal markers needed for better dating prehistoric events.
in New Zealand. The microbanding method can also potentially provide a prior for Bayesian analysis to refine radiocarbon dates.

The methodology was applied to an archaeological sample which came from a single-phase midden deposit at Wairau Bar to explore shellfishing events, duration and temporal relativity, the likelihood of a pristine environment. The results can make contributions to the analysis of sub-annual resource dearth, moa breeding and moa hunting practices, and settlement patterns at Wairau Bar. The results were also used to investigate the duration and time depth, as well as the temporal relationships between shellfishing events in single-phase deposit at Wairau Bar.
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