

Declining foraging efficiency and moa carcass exploitation in southern New Zealand

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Abstract

The application of foraging theory to understanding carcass exploitation is a relatively recent development. The methodology developed by archaeological and ethnoarchaeological research on butchery/transport studies has been integrated into a behavioral ecological framework to create models that can be used to understand archaeological carcass exploitation. In this paper, I use such a model to examine how New Zealand foragers altered their use of moa carcasses as the availability of these large birds declined. Moa data from the Shag River Mouth site in southern New Zealand are analyzed to test changes in butchery/transport and skeletal element breakage patterns expected with resource depression and declining foraging efficiency. This research shows that at Shag Mouth, field processing of moas increased and marrow, and possibly grease extraction intensified over time.

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1. Introduction

Early zooarchaeological models of prey body-part transport decisions predicted that the kind and number of skeletal parts carried back to a home base depend upon the “utility” of those parts and the distance from a carcass to the home base [10,21,31,32,50,54,55]. For vertebrates, utility is typically specified for skeletal parts in terms of meat, marrow, and grease content [10,11], and is more correctly termed “food utility” [39]. Elements are ranked in terms of their food utility, and decisions about body-part transport by foragers are assumed to have been made based on this ranking. In general, foragers are expected to process large animals in the field and discard low-utility body parts in order to create more transportable units [9,12,39,38,46,47], with higher utility elements transported back to the home base for consumption.

These early studies examined carcass butchery and transport decisions in a manner similar to those found in foraging theory models of behavioral ecology. However, only recently have researchers explicitly linked carcass exploitation to foraging theory models, providing a theoretical link to these middle-range studies [45]. In particular, patch choice models have been used to examine body-part transport decisions (e.g. [13,16,40,44] and references therein). Patch choice is used to determine in which patches a forager will pursue prey and how long they should spend in each patch. However, when applied to human carcass exploitation, the scale of analysis is reduced so that the models are used to examine how human predators forage across individual carcasses, selecting and transporting elements based on the utility of each element [9,21]. In this paper I discuss the theoretical assumptions and predictions that models based in foraging theory entail when applied to human foragers. I then apply these models to the moa assemblage from the Shag River Mouth site in southern New Zealand.

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As with many other Pacific Islands, the human colonization of New Zealand led to the extinction of many native animals, the best known examples of which are the moas (Aves: Dinornithiformes). These ten species of birds [14,26] went extinct 100–200 years after Polynesians colonized New Zealand in the 13th century [3,57]. Moas were much stockier in build than most other ratites with individuals that weighed up to 250 kg. The abundance of moa remains in archaeological middens attests to the significant role that human predation played in the decline and eventual extinction of moas [1,2,57].

In previous research, I used foraging theory models to demonstrate how human foraging patterns responded to the decline in the availability of moas at the Shag River Mouth site [42–44]. The site is located on the east coast of the South Island of New Zealand (Fig. 1), and was

occupied from AD 1250 to AD 1450 [6]. Moas were the largest terrestrial vertebrate in New Zealand, and thus they are assumed to be high-ranked resources for human foragers. As the availability of moas declined over time at Shag Mouth, the proportion of smaller game pursued increased so that more effort was required to produce the same net gains resulting in a decrease in overall foraging efficiency. In addition, the decline in foraging efficiency was significant enough so that foragers also increased the number of resources pursued, as well as the number of patches or environments exploited. This decreased foraging efficiency was shown to result from resource depression, a reduction in the availability of high ranked prey due to human foraging efforts [17], rather than to environmental changes or technological innovations. Thus, foragers were responding to a situation of declining resource availability that they created.

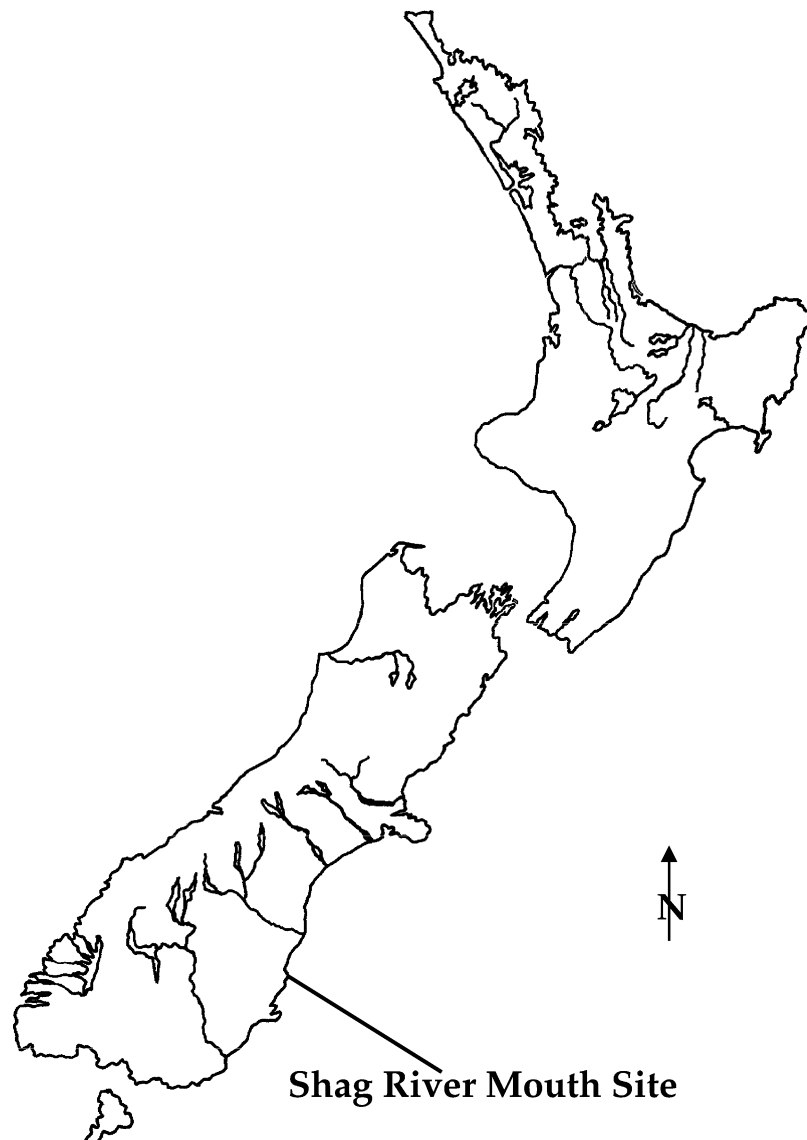


Fig. 1. Location of the Shag River Mouth site in New Zealand.

This demonstrated decline in foraging efficiency means that Shag Mouth offers a valuable dataset with which to consider carcass exploitation. Resource depression and the corresponding decline in foraging efficiency should have affected how foragers butchered, transported, and utilized moa carcasses over time. Using patch choice models of foraging theory, several expectations about carcass exploitation are generated and tested.

2. Foraging theory and carcass transport and processing decisions

Much of the early work on carcass exploitation used models that were similar in structure to foraging theory models. Foragers were assumed to have transported elements based on their utility, which is analogous to the net return rate used in foraging theory. Thus, the formal incorporation of carcass exploitation studies into a foraging theory framework was a relatively simple step. Initially, the specific model used to explain butchery and transport decisions was the marginal value theorem (MVT) [13,44], which had been designed to account for foragers who consume their prey at the point of capture [17]. However, in most situations, humans are better characterized as central place foragers, who forage from a “home base” and return prey to that base for consumption [15,16]. Central place foraging models differ from the Marginal Value Theorem in that they incorporate the additional travel costs associated with central place foraging.

Orians and Pearson [48] developed two central place models, for which foragers make choices that maximize net returns per foraging trip. The greater the distance is and the higher the transport costs are, the greater the net returns per trip should be. One problem with the application of Orians and Pearson’s models to human foragers is that they were designed for non-human predators that transport their prey whole. Human predators, on the other hand, often butcher prey that are too large to carry whole, and it is these butchering decisions that are not taken into account in Orians and Pearson’s models. To address this limitation, Cannon [16] created an archaeological model that incorporates Metcalfe and Barlowe’s [38] research on transport and processing decisions into Orians and Pearson’s central place foraging model. Cannon’s central place forager prey choice model can be used for understanding both prey choice and processing/transport decisions, but I focus on the latter for the purpose of this analysis.

Cannon’s model assumes that foragers will maximize the “delivery rate” when making butchering and transport decisions [16:4]. Delivery rate is similar to the net return rate, except that in addition to handling costs and transport costs, it also includes processing costs.

Cannon differentiates between butchering that is associated with handling costs and butchering considered as processing costs. Handling costs incorporate the time required to transform the carcass into a load that can be carried, while the processing costs include the extra butchering done to maximize the utility of the elements transported. The assumption is that handling costs should be relatively constant across prey of the same species and size. Thus, changes in butchering practices are expected to relate to differences in the way prey are processed.

The amount of time a forager spends butchering, in particular processing a carcass, is affected by both transport distance and prey encounter rate. If prey encounter rates decrease, but transport distance remains unchanged, then field processing of prey may decline [17]. Instead, each individual carcass should be exploited more intensively so that a broader range of elements will be returned. However, foragers tend to deplete resources in a particular pattern such that transport distance increases with declining prey encounter rates [24]. In general, foragers will first exploit resources around the home base. When local areas around the central place are being exploited, transport costs are relatively low. In such cases, less field processing should occur and a relatively broad range of high and low return elements will be transported. As resource availability declines locally and foragers expand their foraging radius, distance to prey, and thus transport costs increase. In such situations, processing time is expected to increase in order to maximize the utility of the load transported. Foragers should be more selective not only about what is pursued, but also about what portions of those prey items are returned to the central place. That is, they will tend to maximize the delivery rate by processing the carcass so that the utility per load transported back to the central place is high [16].

At Shag Mouth, moa abundance declined significantly during the occupation of the site [43]. Thus, if the distribution of moas across the landscape followed the pattern described above, then foragers had to travel farther over time to exploit them. As transport distance increased, time spent processing moa carcasses should have also increased. Foragers should have become more selective about what they transported, with fewer lower utility elements being transported over time.

To determine if the delivery rate of elements transported changed over time, the mean utility or average returns per element for a given sample is examined. Mean utility is calculated by multiplying each specimen within a sample or assemblage by the corresponding utility value for that element [13]. The utility for all specimens is then summed and divided by the total number of specimens for the sample. Each sample is represented by a single value, which can then be used to statistically examine mean utility amongst samples.

Samples with a high mean utility have a large proportion of high utility elements. If a broader range of elements is represented, then the mean utility for that layer will be lower. Thus, for the Shag Mouth moas, since encounter rates are known to have declined and travel costs are expected to have increased, mean utility of the elements transported is expected to have increased over time as foragers maximized their delivery rate.

3. Foraging theory and skeletal element breakage decisions

In addition to changing butchery and transport patterns, if foraging efficiency declines significantly, foragers may also try to extract more calories from the skeletal elements transported back to the site through activities such as marrow and grease extraction [13]. The Marginal Value Theorem (MVT) can be used to make predictions about the nature of this resource exploitation. The MVT assumes that the time allocated to foraging within a patch will depend on the net return rate of that patch, and the average return rate for all exploited patches, taking into account the costs of moving between those patches [17]. When high-ranked prey are abundant in all patches, the average return rate is high. In this situation, foragers are expected to focus on exploiting high return prey types, moving on to the next patch as soon as the returns drop to the average for all patches. Thus, when the average return rate is high, the amount of time spent in each patch will be relatively short. The MVT also assumes that foraging behaviors affect prey abundances, often leading to declines in encounter rates over time. Thus, as patch and average return rates across all patches decline due to resource depression, more foraging time is allocated within each patch. In other words, each patch is used more intensively. In addition, patches that once had net returns below the average return rate may now be cost-effective to exploit.

Although the MVT was developed to deal with the spatial distribution of prey types [17,48], archaeologically it has been used to examine if skeletal elements transported back to a home base were exploited more intensively over time [13]. Since exploitation of bones occurs at the site, travel costs are not an issue, thus the MVT is an appropriate model. The scale of analysis is changed so that each skeletal element is considered a patch. The prediction made from the MVT is that with declining foraging efficiency, foragers should increase the time allocated to extracting resources out of productive skeletal elements. In other words, when foraging efficiency is low, elements transported back to the home base will be used more intensively through activities such as marrow and grease extraction [13]. In addition, the number of skeletal elements exploited may expand to include lower ranked elements.

Marrow and grease extraction both require that individual elements be broken, but the nature of the fragmentation differs for each activity [49]. Building on Lyman's [33] distinction between the intensity and extent of fragmentation, Wolverton [56] developed a model that applied these concepts to identify marrow versus grease exploitation. The breakage patterns associated with marrow versus grease extraction are expected to differ because marrow and grease are distributed differently across and within elements. Marrow is typically found in certain elements, and usually only in parts of those elements (e.g., long bone shafts). To obtain marrow, the marrow cavity need only be broken open or "breached" [41:224]. Therefore, marrow extraction can be characterized by the extent of fragmentation, i.e., the proportion of specimens that were broken, which can be measured by calculating the percentage of unbroken elements (% whole). A decrease in % whole indicates that a larger proportion of skeletal elements were broken over time, suggesting that marrow extraction increased.

In contrast to marrow, grease is associated with all elements, thus a broader range of elements are likely to be exploited. In addition, grease, though it occurs in high abundance in cancellous bone, is not limited to certain portions of elements like marrow. Therefore, all portions of an element may be fragmented to extract grease. It is assumed that more intensive grease extraction is characterized by smaller bone fragments. The smaller a skeletal element is fragmented, the more grease that can be extracted from it because there is more surface area from which to draw grease. Thus, grease extraction is characterized by the intensity or degree of fragmentation [34,56], which can be measured by the ratio of the number of fragmented specimens in the sample (NISP) to the minimum number of elements represented by those specimens (MNE) [20,34]. NISP:MNE has previously been used to measure both marrow and grease extraction [13,44]. However, it is a better measure of just grease extraction because it indicates fragment size [34,56], and fragment size is not related to marrow extraction efficiency.

For the Shag Mouth moa, the MVT predicts that the time allocated to marrow and grease extraction is likely to have increased if the decline in foraging efficiency is significant enough to warrant more intensive exploitation of relatively low utility and low ranked resources. Like other flightless birds, long bones of moa had medullary cavities that contained marrow. More intensive use of marrow-bearing skeletal elements should result in a decline in the proportion of whole bones (% whole) over time. In addition, there should be variation in element breakage based on the amount of marrow available across elements. Kooyman [28] estimated the marrow cavities for tibiotarsi to be the largest with a range of 120-960 cc, while tarsometatarsi were

80–730 cc, and femura were 140–240 cc. Thus, tibiotarsi should be relatively high ranked in terms of marrow extraction. Elements such as phalanges, which have small marrow cavities are low ranked and should only be exploited after foraging efficiency has declined significantly.

Unlike marrow, grease extraction is a more time consuming process. Grease is found within the bone structure and is less accessible than marrow, thus extracting grease from elements typically entails fragmenting and boiling the bone. This process requires more energy with fewer caloric returns, therefore grease should be a lower ranked resource than marrow. As such, grease will be exploited after marrow extraction is added to foraging behaviors, and only after foraging efficiency has declined significantly to warrant the exploitation of such a low return resource.

Archaeologically, the assumption about grease extraction is that smaller fragments will allow for more grease to be extracted, and thus is an indication of more intensive use of skeletal elements. However, recent experimental research by Church and Lyman [18] suggests that the amount of grease that can be extracted from deer (*Odocoileus* sp.) long bones does not increase significantly when the bone fragments are smaller. Therefore, the assumption that increased fragmentation rates implies more intensive use of elements for grease extraction may be faulty. Church and Lyman's experiment was designed to examine grease extraction over a time scale of one hour intervals up to 14 hours. The amount of grease extracted reaches a state of diminishing returns by the third hour across all fragment sizes. However, the data for the first hour of boiling varies from 29% to 63% of the grease extracted depending on fragment size. The smaller the fragment was, the more grease was extracted in that first hour. These data suggest that if bone is boiled for a duration of less than one hour, then increased fragmentation of bone may provide more grease. The shorter boiling time may be more relevant to New Zealand where ceramic vessels were not available and boiling was done by placing hot cooking stones into wooden bowls [4]. If boiling time for grease extraction was a limiting factor such that fragment size mattered, then the MVT predicts that the amount of time that foragers spent fragmenting

skeletal elements for grease extraction should have increased across time if foraging efficiency declined significantly.

4. Changing processing and transport patterns of moas at Shag Mouth

With resource depression and an increase in travel costs due to an expanding foraging radius, the transport of moa carcass parts should narrow through time to mainly high utility elements, i.e., the mean utility of elements per layer is expected to increase (Table 1). Since moas are extinct, it is impossible to derive utility indices for them directly. Instead, I use a utility index developed for kiwis (*Apteryx* spp.), ratite relatives of moas that are endemic to New Zealand [29]. Kiwis, though much smaller than moas, are similar in shape. They, like moas, are stocky and have more robust legs compared to other ratites such as ostriches, which tend to have longer, gracile legs designed for running. To derive his kiwi utility index, Kooyman [29] weighed the meat taken from each element of eight kiwi carcasses, then ranked these values and normalized them by setting the top value at 100 and adjusting the remaining values accordingly.

Using Kooyman's utility data and the number of identified moa specimens in the Shag Mouth assemblage, I calculated the mean utility of elements for each layer. The data are plotted in Fig. 2. Layer 11 is the oldest of the nine cultural strata at Shag Mouth, while the youngest stratum is Layer 2. Layers 9 through 11 were combined because the size of the sample from each layer was relatively small. Over time, there was a significant increase in mean utility of moa elements transported to the site ($r_s = 0.93$, $p = 0.003$). Thus, the range of elements transported narrowed from the initial use of both higher and lower utility elements toward a focus on higher return elements later on. The narrowing of the range of elements transported suggests that distance traveled to procure moas increased over time.

An increase in processing time can be seen in changes in the relative abundance of high and low utility skeletal elements. The percentage of high utility elements (femora, tibiotarsi, fibulae, and cervical vertebrae)

Table 1
Summary of expectations for carcass transport and skeletal element breakage given declining foraging efficiency

	Condition	Predictions	Archaeological Measures
Transport	↓ in local resource availability and foraging efficiency; ↑ in transport costs	↑ in utility of elements transported per load	↑ in mean utility (↑ in high utility elements; ↓ in low utility elements)
Breakage	↓ in resource availability and foraging efficiency	↑ in extent of bone fragmentation due to marrow extraction ↑ in intensity of bone fragmentation due to grease extraction	↓ in %whole ↑ in NISP:MNE

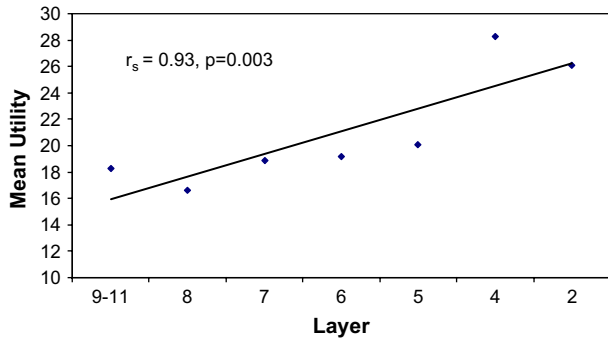


Fig. 2. Mean moa utility across layers. Layer 2 is the youngest; Layers 9–11 are the oldest.

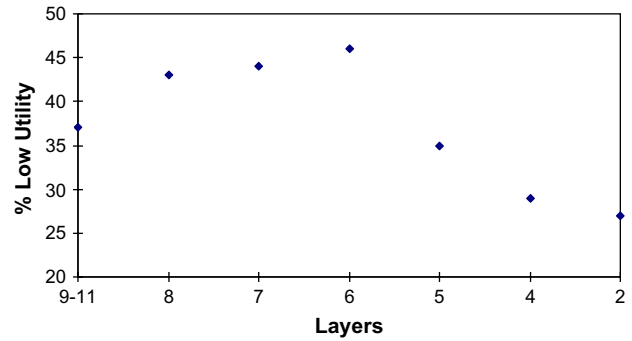


Fig. 4. Relative frequency of low utility elements (phalanges, tarsometatarsi, caudal vertebrae) across layers.

steadily increases as expected (Fig. 3). In contrast, the frequency of low utility elements (phalanges, tarsometatarsi, caudal vertebrae) does not decrease constantly, but rises slightly until Layer 6 before declining (Fig. 4). This pattern suggests that low utility elements may have been initially transported as riders with higher utility elements up until Layer 6. Later, processing time appears to have increased so that these low utility elements were removed and thus became less common in the assemblage.

Indeed, an increase in field processing time can also be seen in changes in the relative abundance of the neck elements of moas. Tracheal rings and cervical vertebrae are both neck elements. Cervical vertebrae support sizable amounts of meat as evidenced in their high utility value, however, tracheal rings, the ossified segments of the windpipe, have little to no utility. If field processing increased relative to element utility, then the proportional abundance of tracheal rings should decrease over time. Tracheal ring relative abundance at the site decreases significantly over time while the percentage of cervical vertebrae remains relatively constant (Fig. 5), suggesting that pre-transport processing of moas increased over time.

The evidence suggests that foragers became more selective about what they were transporting in order to maximize net foraging returns. Increased selectivity is

linked to resource depression and increased travel costs as more distant hunting grounds were used. Initially, local populations of moas were exploited and a broad range of high and low utility elements were brought back to the site. As local moa populations dwindled and people traveled farther to obtain them, the cost of transporting their remains back to the site increased. Carcasses were processed not only to create transportable packages, but also to maximize the delivery rate so that mainly high utility elements were transported back to the site.

Taphonomic factors, such as carnivore attrition or differential preservation, have been shown to affect skeletal part frequency [34,35]. Thus, alternative explanations for the pattern of skeletal element representation must be examined. Carnivore attrition can differentially affect the survivorship of elements as well as shafts and ends of elements [36]. For moas, carnivore damage to epiphyseal ends would also significantly affect element identifiability. However, the Shag Mouth faunal assemblage shows surprisingly little carnivore damage, even though domesticated dogs were known to have been present in and around the site [7]. Less than 3% of the assemblage displays evidence of carnivore gnawing. The relatively low percentage of carnivore damage at Shag Mouth and other South Island sites is not uncommon and was first noted in the 1870s by

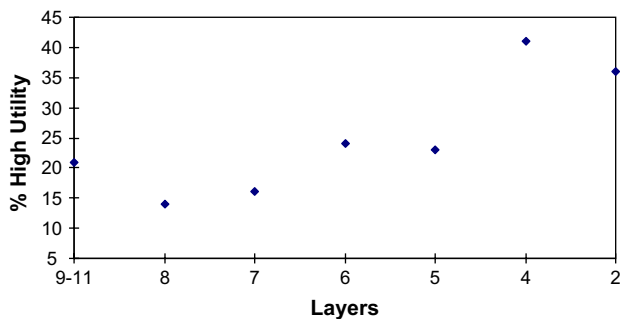


Fig. 3. Relative frequency of high utility elements (femura, tibiotarsi, fibulae, cervical vertebrae) across layers.

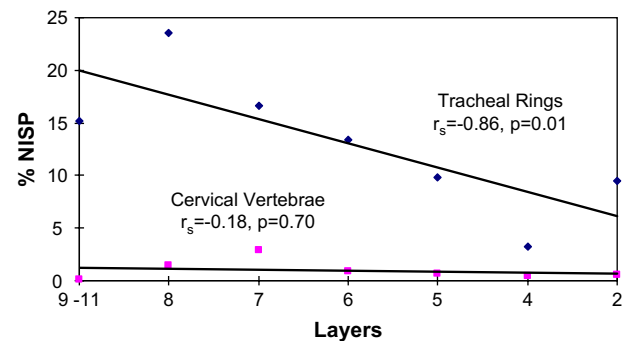


Fig. 5. Relative frequency of moa cervical vertebrae and tracheal rings across layers.

Julius von Haast [23]. Haast, the original excavator of the Shag Mouth site, went so far as to erroneously speculate that the paucity of dog gnawing indicated that dogs must not have had access to the bones, and thus were not domesticated. Whether domesticated or not, the fact remains that dog gnawing appears to have played an insignificant role in skeletal part frequency.

Bone density has also been identified as a factor that can affect skeletal element survivorship. Elements of low density are less likely to preserve than high density elements [31,34]. If bone density and element utility are correlated, then the pattern seen in the mean utility index may alternatively be due to differential destruction of low density bones in the upper layers rather than to changes in transport decisions alone. To determine if bone density affects mean utility data, the skeletal element survivorship was compared to the bone density values for rheas, a ratite relative of moas [19]. Of the nine cultural layers examined, three (Layers 4, 5 and 7) had samples that showed a significant correlation between bone density and skeletal element frequencies (Table 2). Thus, for these layers, the skeletal element representation may be influenced by preservation bias.

To determine if bone density is affecting the pattern of mean utility, the samples are reanalyzed using high density elements that are least likely to be underrepresented due to differential preservation [8]. The densest elements according to Cruz and Elkin's [19] rhea density data are the femur, fibula, pelvis, phalanx, tarsometatarsus and tibiotarsus. Fig. 6 shows that using the high density elements, mean utility still increases significantly over time ($r_s=0.94$; $p=0.005$). Thus, while density is correlated with skeletal element abundance for some layers, the overall trend of increasing mean utility does not appear to be affected by differential preservation.

5. Changing breakage patterns of moa skeletal elements at Shag Mouth

A conservative approach to understanding element fragmentation resulting from butchering limits the

Table 2
Results of the Spearman's rank correlation analysis between bone density and % survivorship for moa elements

Layer	Correlation coefficient
2	$r_s=0.33, p=0.29$
4	$r_s=0.70, p=0.001^*$
5	$r_s=0.63, p=0.007^*$
6	$r_s=0.41, p=0.08$
7	$r_s=0.56, p=0.02^*$
8	$r_s=0.30, p=0.44$
9	$r_s=0.24, p=0.41$
10	$r_s=0.40, p=0.60$
11	$r_s=-0.33, p=0.52$

* Significant correlation between density and % survivorship.

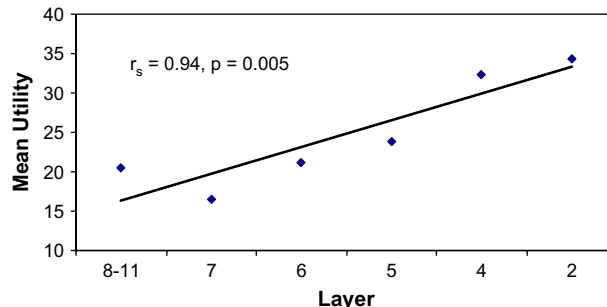


Fig. 6. Mean moa utility for high density elements across layers.

analysis of skeletal elements to those specimens showing clear evidence of human fracturing, such as green fractures, cut marks, and impact marks [e.g., [28,29,30]. However, this approach can exclude parts of the assemblage that might have resulted from butchering, but have no preserved marks from butchering process on the specimens. An alternative approach is to use all specimens in the assemblage and evaluate the taphonomic history of the assemblage for alternative explanations for the patterns [34,56].

The Shag Mouth assemblage is well-preserved and its taphonomic history appears to be dominated by cultural rather than natural taphonomic processes. As mentioned above, there is very little carnivore damage on the Shag Mouth fauna. Differential preservation as indicated by bone density also does not appear to have a significant effect on the assemblage. In addition, less than 15% of the assemblage was categorized as significantly weathered on the Behrensmeier weathering scale [7]. Instead, the presence of human impact fractures on moa bone in the Shag Mouth assemblages suggests that moa bone fragmentation is generally related to human activities. Thus for the purposes of this analysis, I am assuming that bone fragmentation was caused mainly by human butchering practices. Other alternative explanations are examined below.

5.1. Marrow extraction

With declining moa populations, the MVT predicts that the elements transported back to the site should be used more intensively if the decline in foraging efficiency was significant (Table 1). One manifestation of intensification would be an increase in marrow extraction, which would result in a lower proportion of whole skeletal elements. Long bones typically contain the largest amounts of easily accessible marrow. Since moas did not have upper limbs, only moa leg elements (femur, tibiotarsus, tarsometatarsus, and phalanges) are analyzed. The percentage of whole elements (% whole) is used to examine changes in marrow extraction. Of the four skeletal elements, the samples of complete femora, tibiotarsi, and tarsometatarsi were too small to examine

trends across time. Only four tarsometatarsi out of a total of 58 specimens were complete; of the 37 femora specimens, only one was whole; and none of the 290 tibiotarsi specimens were complete. Thus, the small percentage of unbroken skeletal elements across all stratigraphic layers suggests that marrow extraction from these leg elements may have been practiced regularly throughout the occupation of the site.

Phalanges are the one leg element that has a large enough sample of whole elements to examine across time. Of the limb bone elements, phalanges have small marrow cavities, thus they are expected to be low-ranked in terms of marrow utility [10], and should be exploited after other higher-ranked elements such as tibiotarsi. If foraging efficiency declined significantly over time, then low-ranked phalanges may have been used more intensively.

Fig. 7 shows that the percentage of whole moa phalanges declines significantly over time ($\chi^2_{\text{trend}} = 3.83$, $p = 0.05$). The decrease in whole moa phalanges suggests that marrow extraction from low-ranked phalanges increased even though fewer phalanges were being transported back to the site over time. Thus, while marrow extraction from higher-ranked leg elements appears to have been a common practice across time, it is possible that foraging efficiency declined sufficiently to warrant more intensive marrow extraction of low-ranked elements such as phalanges. Differential preservation due to bone density does not appear to have played a role in this pattern since phalanges are relatively high density elements.

5.2. Grease extraction

Another form of intensification is increased grease extraction as reflected by an increase in bone fragmentation. To determine if moa skeletal elements were being used more intensively through time, the ratio of NISP to MNE is calculated using data on the sternum, pelvis, femur, tibiotarsus, and tarsometatarsus. Phalanges, vertebrae, and ribs were not considered because the

element portion for these elements was not recorded, thus MNE could not be determined.

An increase in fragmentation should be represented by a corresponding increase in the NISP:MNE ratio. As Fig. 8 shows, the change in fragmentation rate across time is not significant ($r_s = 0.57$, $p = 0.18$). It appears that foragers did not fragment moa skeletal elements for grease extraction more intensively over time. Thus, foraging efficiency may not have declined enough to warrant the use of this relatively low return resource across all elements.

The fragmentation pattern, however, varies across skeletal element. In particular, the ratio of NISP to MNE for tibiotarsi increases significantly (Fig. 9), and it appears that the slight increase in fragmentation rate seen in Fig. 8 is driven mainly by the tibiotarsi data. Haast [23] in his original excavation noted that, unlike the femora and tarsometatarsi, most of the moa tibiotarsi that he excavated were broken. He surmised that the reason for the varying rates of fragmentation across leg elements was because femora and tarsometatarsi “not having been thought of sufficient value to pay for the trouble of extraction.” [23:94]. More recently, in his original analysis of fracture frequency data on the Shag Mouth moa assemblage, Kooyman [30] also suggested that only tibiotarsi were regularly broken. The tibiotarsus is the largest leg element, and thus it is the element that likely contained the most grease. The differential fragmentation of tibiotarsi may indicate that the decline in foraging efficiency was not large enough to direct significant effort into extracting resources like grease across all elements, but only from the one element with the greatest grease utility. The apparent pattern of differential fragmentation may also be due to other factors, including differential identifiability, differential preservation, or the tool utility of particular elements.

Differential identifiability across elements may cause some skeletal elements to be underrepresented, which would affect the NISP to MNE ratio. In general, as bone fragmentation increases, it becomes more difficult to identify fragments to a particular skeletal element [37].

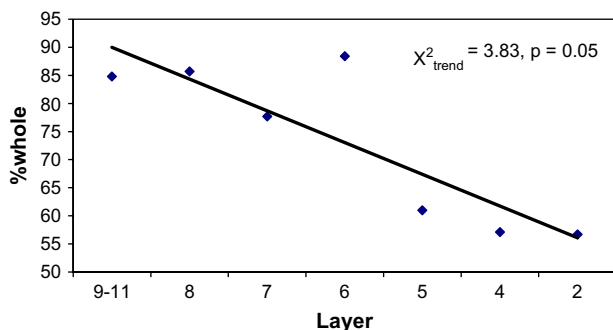


Fig. 7. Percentage of unbroken moa phalanges across layers.

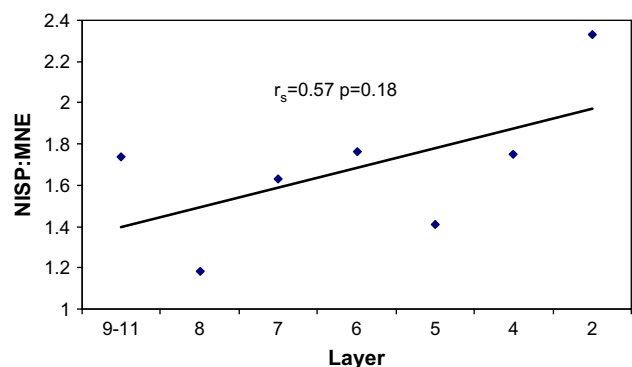


Fig. 8. Moa bone fragmentation across layers.

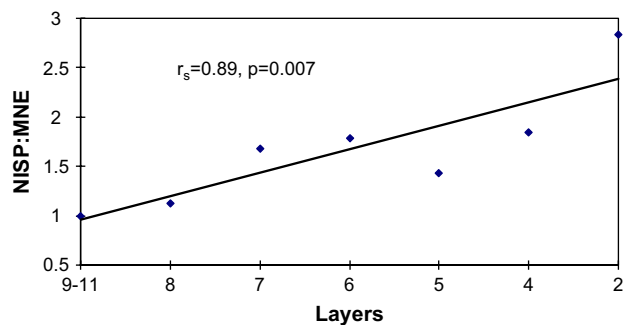


Fig. 9. Fragmentation of moa tibiotarsi across layers.

For moas, the bone structure of tibiotarsi is distinctive, and fragments are identifiable even when pieces are small. Other elements, however, are more difficult to differentiate unless fragments are relatively large. Thus, fragmentation of elements for grease extraction may have increased across all elements, but this increased fragmentation may have also caused a significant decline in the identifiability of fragments for all elements except tibiotarsi.

To examine the effects of identifiability on skeletal element representation, the ratio of the number of unidentifiable and identifiable specimens (NSP) to the number of specimens identified to a particular element (NISP) is calculated [22,56]. For the Shag Mouth sample, only the leg elements are used. NISP is the number of specimens identified to the three leg elements: femur, tibiotarsus, and tarsometatarsus. NSP includes specimens identified to these elements as well as fragments that could only be identified to “leg elements”. If fragmentation increased to the point where the identifiability of leg elements decreased, then the ratio of NSP:NISP should increase over time. Contrary to this expectation, the NSP:NISP ratio did not change across time significantly, indicating that rate of identifiability does not appear to have changed (Fig. 10). Thus, differential identifiability does not appear to be the cause of differential fragmentation rates across elements.

As discussed above, taphonomic factors such as bone density can also affect skeletal element representation. If preservation conditions changed over time to favor more robust elements, then less dense leg elements may be underrepresented in later assemblages. However, according to the bone density data for rheas [19], tibiotarsi element portions tend to have similar density values as other leg elements. Thus, differential preservation does not appear to be a significant factor in the variability in fragmentation rates across elements.

Difference in bone breakage patterns across elements may instead be due to the value of the element as a raw material for tools rather than as food [51]. If this is the case, then the nature of the artifacts created from moa elements should dictate the amount of bone breakage. While other moa skeletal elements may have been used as

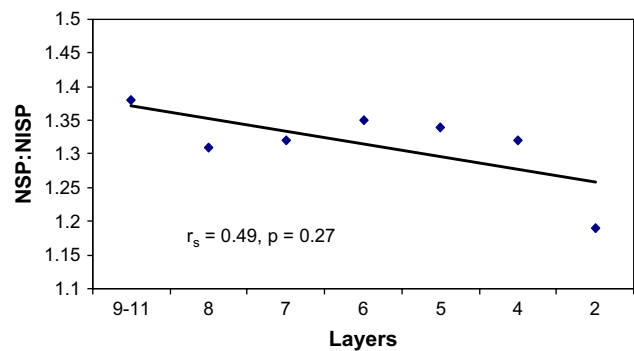


Fig. 10. Identifiability of moa leg elements across layers.

raw material for tools [28], tibiotarsi are the most commonly identified element used for fishhooks and other artifacts. The medial-anterior surface of the bone is large, flat and very thick, from which large, durable artifacts could be made. The increase in tibiotarsi fragmentation relative to other leg elements could indicate that tibiotarsi were being used more intensively for tools. More intensive fragmentation may be related to changes in the size of fishhooks produced from tibiotarsi.

One-piece fishhooks required larger pieces of raw material than composite fishhooks. The shanks of the composite fishhooks were made of wood or shell, with only the point being made of bone. Thus, the manufacture of smaller composite fishhooks could have resulted in more artifacts being made from each piece of bone, increasing the fragmentation rate. If the increase in tibiotarsus fragmentation is a product of a shift in fishhook manufacture, then the frequency of composite fishhooks relative to one-piece fishhooks is expected to increase over time.

At the Shag Mouth site, the type of fishhooks made from bone changes over time (Table 3). Early on, the one-piece fishhooks were common, as they were across southern New Zealand [5,25]. Composite fishhooks and lures occur later. The advent of these later hook types is likely to be due either to changing subsistence practices and/or reduced availability of raw material resources. In either case, the increased fragmentation of tibiotarsi could be due to the manufacture of high numbers of smaller bone hooks. Additional research on changes in the frequency of fishhook manufacturing traits such as cut marks, drill holes, tab and core size is required to determine how tool utility affects moa bone breakage patterns.

There remain two possible explanations for the fragmentation pattern of moa elements at Shag River Mouth. The first is that foraging efficiency did not decline sufficiently to warrant more intensive use of all elements through grease extraction. Instead, only tibiotarsi appear to have been targeted for grease extraction because of its greater utility. Another possibility is that foraging efficiency did not decline significantly enough for foragers

Table 3

The relative abundance of one-piece and composite fishhooks and lures from the Shag Mouth site

Layer	N	Barracouta Lure (%)	Minnnow Lure (%)	Two-Piece Fishhook (%)	One-Piece Fishhook (%)
2	16	18.8	6.3	18.8	56.3
4	36	11.1	5.6	13.9	69.4
5	8			12.5	87.5
6	1				100.0
7	1				100.0
8	1				100.0
9	1				100.0

to intensify grease extraction in any of the long bones. Rather, any differences in the skeletal element representation are due to the elements' use as raw materials for tool manufacture. Thus, tibiotarsi may have been the focus of both grease extraction and tool manufacture.

6. Summary and conclusions

The study of prehistoric carcass exploitation has been relatively limited in New Zealand. Only a few researchers have systematically examined how body parts of large animals such as moas and seals were exploited differentially [e.g., 27,28,30,52,53]. As described above, many of the patterns on moa carcass exploitation documented in this research have been noted in these earlier studies. However, unlike previous research, which studied butchering patterns at the site level, this study examines changes in butchering and bone fragmentation decisions over time. A temporal perspective has allowed for an analysis of change in carcass exploitation as moa populations were declining.

At Shag Mouth, changes in carcass exploitation are linked to declining overall foraging efficiency. Human foraging behavior at Shag Mouth led to a decline in the availability of high-ranked moas and an overall decrease in foraging efficiency [43,44]. At the same time, the spatial distribution of moa changed. They became less available locally so that foragers had to travel farther to hunt them, and thus travel costs increased. Because of the declining encounter rates and increasing travel costs, foragers altered the manner in which they butchered and transported moas to maximize their net returns. In addition, bone breakage patterns were also affected by the decline in foraging efficiency.

More importantly, this research uses foraging theory to integrate changes in carcass exploitation with dietary changes under one analytical framework. Cannon's [16] central place prey choice model works well to set up testable expectations about carcass exploitation as transport distance increases and/or prey availability declines. Thus, butchery/transport practices and skeletal element exploitation are explained within the context of general subsistence trends, providing a better

understanding of how and why carcass exploitation changes over time. The changes in moa carcass exploitation observed in this paper are directly linked to changes in prey availability, prey distribution, and overall foraging efficiency. Thus, this research builds upon previous studies that examined prey and patch choice decisions, and provides a more complete and integrated picture of resource exploitation patterns in southern New Zealand.

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