

Explaining subsistence change in southern New Zealand using foraging theory models

Lisa Nagaoka

Abstract

New Zealand provides one of the earliest examples of foraging theory applications to archaeological situations (Anderson 1981). Since this landmark study, significant developments over the last twenty years have led to an increasing number of detailed analyses examining the effects of resource depression on human foraging. In particular, foraging theory analyses have become better at documenting resource depression and integrating butchery/transport studies into these analyses. Using the faunal data from the Shag River Mouth site, I illustrate how these methodological advances have resulted in a more comprehensive understanding of the processes of subsistence change in southern New Zealand.

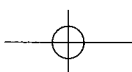
Keywords

New Zealand; foraging theory; subsistence change; zooarchaeology; resource depression.

Introduction

Although foraging theory models were originally designed for application in an ecological time frame, a growing number of archaeological studies demonstrate that these models are productive for understanding subsistence change over a larger time scale (e.g. Broughton 1999; Butler 2001; Cannon 2000; Grayson and Cannon 1999; Janetski 1997; Simms 1987; Szuter and Bayham 1996; for a review of anthropological and archaeological applications, see Winterhalder and Smith 2000). Not only have these models been important in explaining subsistence change, but they also elucidate the dynamic relationship between humans as predators and their prey. In particular, through the concept of resource depression, the decline in the encounter rates of prey resulting from human foraging practices (Charnov et al. 1976), these models examine the impact of human foraging on prey abundances and consequently on human subsistence patterns.

One of the earliest archaeological applications of foraging theory to demonstrate the



effects of resource depression comes from New Zealand. Anderson (1981) used the prey and patch choice models of MacArthur and Pianka (1966) and MacArthur (1972) to study shellfish collecting at Palliser Bay on the southern end of the North Island. Anderson assumed that net caloric returns from shellfish were mainly based on size. Many archaeological studies since support this relationship between prey size and net returns (e.g. Broughton 1999; Hames and Vickers 1982; Schmitt and Lupo 1995). Using the foraging models, Anderson predicted that if size was an indication of net returns, then individuals larger than the mean size across all species should be harvested. Indeed, Anderson found that foragers were utilizing shellfish based on size, starting with the larger species. As these larger taxa were 'over-exploited', foragers harvested smaller individuals as well as smaller taxa. After a hiatus in the settlement of the area, the shellfish populations appear to have rebounded, increasing in size. After the area was reoccupied by humans, the pattern of declining size in the shellfish exploited was repeated. Thus, the effect of human predation on shellfish was a decline in the abundance of large shellfish species, as well as a reduction in the average size of shellfish taxa exploited.

As an early use of foraging theory models, Anderson's Palliser Bay research on shellfish clearly demonstrated how the models could be used to understand the effects of human foraging on prey populations, and their subsequent effect on human subsistence patterns. Since then, explicit use of foraging theory to explain subsistence change in New Zealand has been lacking. However, the interpretations of changes in vertebrate taxa in southern New Zealand appear to be influenced by foraging theory. Southern New Zealand differs from the rest of New Zealand, and Polynesia as well, in that the inhabitants were foragers rather than horticulturalists. The tropical crops grown elsewhere in Polynesia would not grow in the temperate environment of the south. In southern New Zealand, resource depletion, particularly of large-bodied vertebrates such as moas and seals, has been an important explanation of subsistence change. The remains of moas, an order (Dinornithiformes) of large, wingless birds, fill many early middens from archaeological sites in the South Island of New Zealand. Within 200–500 years after human colonization, moas were extinct (Anderson 1989). The abundance of moa remains from archaeological contexts has led some to propose that moas are a prime example of overkill (e.g. Martin 1984; Diamond 2000). While the exact cause of moa extinction can be debated, it is clear that moas were once an important dietary resource, and that their decline is linked to human foraging practices. Their extinction, along with the decline of other taxa such as seals, led to dramatic changes in resource exploitation. Specifically, a shift in exploitation is described from moas and seals to smaller taxa, such as other birds and fish (Anderson 1982, 1983; Anderson and McGlone 1992).

This interpretation of changes in vertebrate exploitation in southern New Zealand can easily be translated into a foraging theory context. Within foraging theory models, resource depletion is encompassed in the term, resource depression (Charnov et al. 1979). So, within southern New Zealand, initial subsistence practices focused on large-bodied prey such as moas and seals. With the resource depression of moas and seals, human foragers expanded their exploitation patterns to focus on smaller taxa. This translation of subsistence change is similar to that of Anderson's shellfish study where prey size is a proxy to net returns, and human predation leads to a shift in the size of the prey exploited.

Since Anderson's study, there have been significant methodological advances in applying foraging theory models to archaeological data that have allowed archaeologists to better articulate the finer details of the models in a quantitative manner. In this paper, I examine two specific developments. First, over the past twenty years a significant amount of research has focused on documenting the effects of resource depression, providing insight into the process of subsistence change. Second, foraging theory models are being used to explain changes in butchery and transport decisions. In both cases, ethnoarchaeological studies have helped integrate archaeological data into the foraging theory analyses by documenting the variables that affect foraging decisions, and by identifying potential proxy variables. In addition, archaeological research has resulted in improved quantitative measures for documenting change, as well as more rigorous assessments of alternative explanations. My research takes advantage of these advances to create a more detailed and empirically derived picture of subsistence change in southern New Zealand. I analyzed the vertebrate faunal assemblage from the Shag River Mouth site using foraging theory models to generate predictions about subsistence change resulting from declining abundances of moas and seal. The Shag Mouth site is located on the east coast of the South Island of New Zealand, and has a long history of excavations (Fig. 1; Anderson and Smith 1996). I chose to analyze the faunal sample from the 1988 High Dune excavations because it produced a large dataset from a well-stratified, well-dated and well-documented excavation (Anderson et al. 1996). The deeply stratified sequence at the Shag River Mouth site also provides an opportunity to examine subsistence change across time at a single locality.

Documenting the effects of resource depression

Resource depression is the decline in encounter rates of prey due to the foraging behavior of predators (Charnov et al. 1976). The effects of resource depression can be documented by measuring changes in foraging efficiency (the net return per unit of time) and diet breadth (the number of resources exploited) (Broughton 1999; Grayson and Cannon 1997). Since the prey choice model predicts that high-ranked prey are always pursued upon encounter, they are particularly susceptible to resource depression (Bayham 1979; Broughton 1994a, 1994b, 1997, 1999). As discussed above, body size is often used as an alternative measure for net returns. Since moas and seals were the largest bodied vertebrates in prehistoric New Zealand, it can be assumed that they were high-ranked prey. As encounter rates with these high-ranked resources declined, they contributed less to the diet. With less focus on higher return prey, foraging efficiency declines. If high-ranked prey abundances and foraging efficiency decline significantly, then the mean foraging return rate may drop to the point where adding lower ranked taxa to the diet becomes profitable, and thus diet breadth may expand.

Before the effects of resource depression can be assessed, an important assumption of the prey choice model must be addressed. The model assumes that prey are distributed homogeneously across space so that each prey type has an equal chance of encounter (Stephens and Krebs 1986). However, in reality, prey distribution is often clumped so that encounter is non-random. In such cases, patches must be defined that create more homogeneous

Figure 1 Location of the Shag River Mouth site.



distributions. The predictions of the prey choice model can then be applied to each patch separately. Often it is difficult to define patches that represent different environments because many taxa crosscut environmental zones (Broughton 1999; Cannon 2000). As an alternative, researchers have created patches based on hunt types and prey characteristics (Smith 1991; Stiner et al. 2000). For the Shag Mouth assemblage, I was able to divide the vertebrate taxa into three analytical patches based on location: coastal, inland and offshore (Nagaoka 2000). The coastal patch is comprised of taxa such as seals, seabirds and inshore fish that can be exploited from along the shore. The inland patch contains taxa such as moas, pigeons, quails and ducks that inhabit the region inland from the coast. The offshore patch is comprised mainly of fish species that are taken off the coast, probably via canoes. The effects of resource depression are examined for each patch separately.

Given that moas and seals were high-ranked taxa within their respective patches, the prey choice model predicts that foraging efficiency and diet breadth should change with the decline of these large-bodied, high-ranked taxa. Most measures of foraging efficiency examine the relationship between high-ranked and low-ranked taxa. For example, Anderson's shellfish data document shifts in the relative abundance of different sized shellfish

as a measure of the change in the relationship between high- and low-ranked prey. However, Anderson's analysis of changes in shellfish exploitation consisted of visually comparing the shape of frequency distributions. More recent studies use indices that summarize the relative abundance of high- and low-ranked taxa in one value for each sample. These values can then be plotted and their relationship to changes across time can be tested statistically.

Two types of indices have been used: an evenness index (Nagaoka 2001) and an index of the proportion of a high- to low-ranked taxon (e.g. Bayham 1979; Broughton 1994a, 1994b, 1997, 1999; Cannon 2000; Janetski 1997; Nagaoka 2000). The evenness index measures the proportional abundance of each taxon (Magurran 1988). The greater the index value, the more even the distribution is across taxa. At Shag Mouth, within the inland patch, the low evenness values for the lower layers show that the distribution across taxa was very uneven (Fig. 2). Foraging within the inland patch appears to have specialized on moas during this early period. Over time, the assemblage becomes more evenly distributed across taxa indicating that foraging has become more generalized. This shift in evenness suggests that moas were comprising an increasingly small proportion of the inland sample, and thus foraging efficiency was declining.

The evenness index is not commonly used to measure foraging efficiency because the rank order of prey in terms of expected net returns is not taken into account (Nagaoka 2001). Instead, the index describes the shape of the frequency distribution when taxa are ordered from most abundant to least abundant. It is thus possible that evenness may not change, even though the relative abundance of high- and low-ranked prey abundances is changing dramatically. Given this limitation, the index is most useful when high-ranked taxa are also the most abundant taxa, as was the situation with the Shag Mouth sample (Nagaoka 2001).

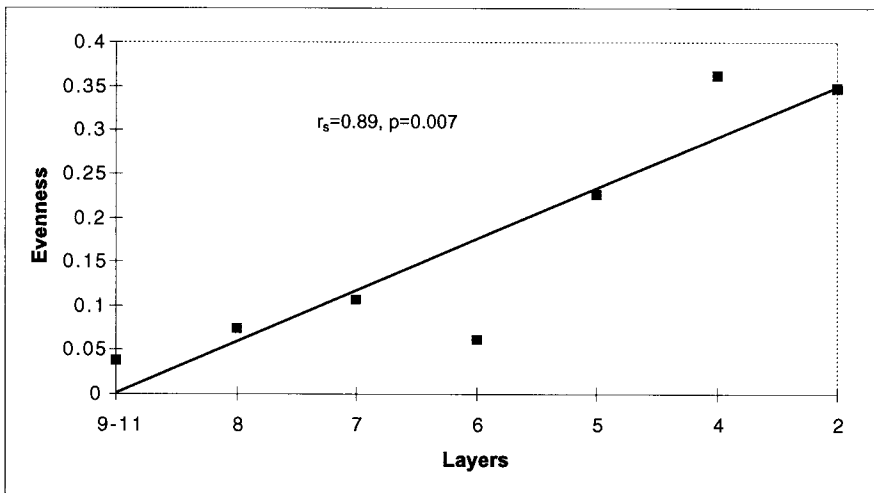


Figure 2 Plot of the evenness index for the inland patch by stratigraphic layer. Layer 2 is the uppermost layer.

A more commonly used measure is an index that compares the proportion of a high-ranked/large-bodied taxon to a low-ranked/small-bodied one (Σ high-ranked/ Σ (high-ranked + low-ranked)). In North America, the most commonly used index to measure changing foraging efficiency is the artiodactyl index, which compares the relative abundance of artiodactyls to the comparatively smaller leporids (Bayham 1979; Broughton 1994a, 1994b, 1999; Cannon 2000 Janetski 1997). The larger the index value, the greater the proportion of the large-bodied taxon in the sample, and thus the higher the foraging efficiency.

To document changes in foraging efficiency in the inland patch at Shag Mouth, moas, as the high-ranked taxon, were compared to the extinct New Zealand quail (*Coturnix novaeseelandiae*), a significantly smaller bird species (Σ moas/ Σ (moas + quails)). The moa-quail index declines significantly over time, indicating that moas were contributing less to the inland sample (Fig. 3). Thus both measures of foraging efficiency, the evenness index and the moa-quail index, suggest that early exploitation of resources within the patch specialized on moas, with smaller-bodied and thus lower-ranked taxa comprising a larger part of the diet later on.

The assumption behind the indices used to document changes in foraging efficiency is that the changes are due to resource depression. However, to determine if resource depression is causing these changes, other alternative explanations must be ruled out. It must be demonstrated that 1) the decline in high-ranked prey abundances was due to human foraging rather than natural environmental change; 2) the advent of technological improvements such as mass capture techniques did not lead to an increase in the capture rate of the low-ranked taxon; and 3) the decline in foraging efficiency was not linked to increases in the abundance of lower-ranked prey (Broughton 1999; Grayson and Cannon 1999; Madsen and Schmitt 1998). There is little question that moa decline and extinction was due to human action through habitat alteration and predation rather than to climatic

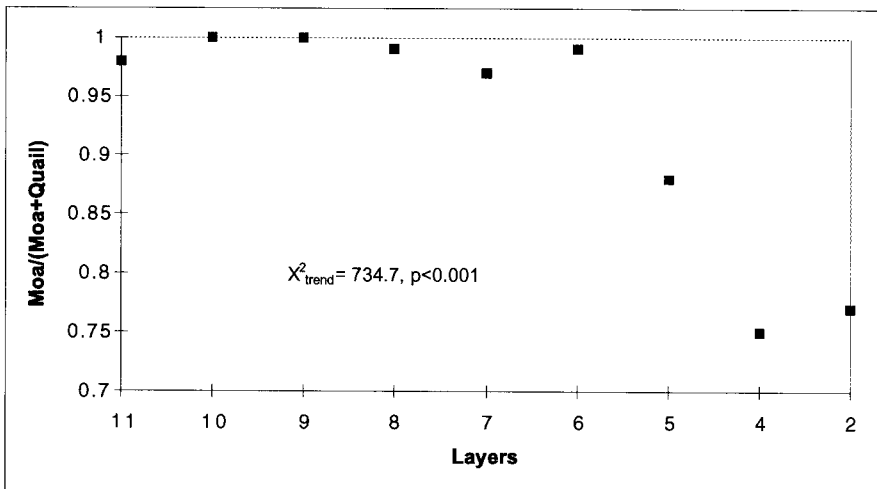


Figure 3 Plot of the moa-quail index for the inland patch.

change (Anderson 1989). There is also no evidence for technological advances in quail harvesting, such as mass capture techniques. According to ethnographic accounts, Maori captured quail individually by placing snares in the grass along tracks formed by the quails (Anderson 1994: 169; Best 1942: 237), a technology which also may have been used to capture moas. Thus, only the third explanation requires more careful examination.

Quail population abundances may have increased during the prehistoric era due to the creation of more open habitat resulting from widespread deforestation (McGlone 1983). Pollen analysis has documented an increase in open habitat around the Shag Mouth site during the period when the site was occupied (Boyd et al. 1996). To determine if quail abundances increased due to the creation of new habitat, an index similar to the moa-quail index was used to compare the proportion of quail in the Shag Mouth assemblage with that of a forest bird, the New Zealand Pigeon (*Hemiphaga novaeseelandiae*) ($\Sigma \text{quail} / \Sigma (\text{quail} + \text{pigeon})$). The quail-pigeon index increases slightly, but the change is not statistically significant (Fig. 4). Thus, while more favorable habitat for quails appears to have been created around the site, these changes did not have a significant impact on the proportion of pigeons and quails within the entire inland patch. Thus, with the alternative explanations ruled out, it appears that the changes seen in the foraging efficiency measures are due to resource depression of moas.

Given this decline in foraging efficiency within the inland patch, diet breadth might also have increased. Diet breadth can be measured using richness (Broughton and Grayson 1993; Nagaoka 2001) and by a regression analysis of sample size and richness (Grayson and Delpech 1998; Nagaoka 2000). Richness measures the number of taxa (NTAXA) exploited. Within the inland sample, richness increases significantly (Fig. 5), and is not correlated with sample size, a problem that often plagues this measure (Grayson 1984). The regression analysis shows that the regression line for samples from the upper layers have a steeper slope and a larger Y-axis intercept than for the samples from the lower

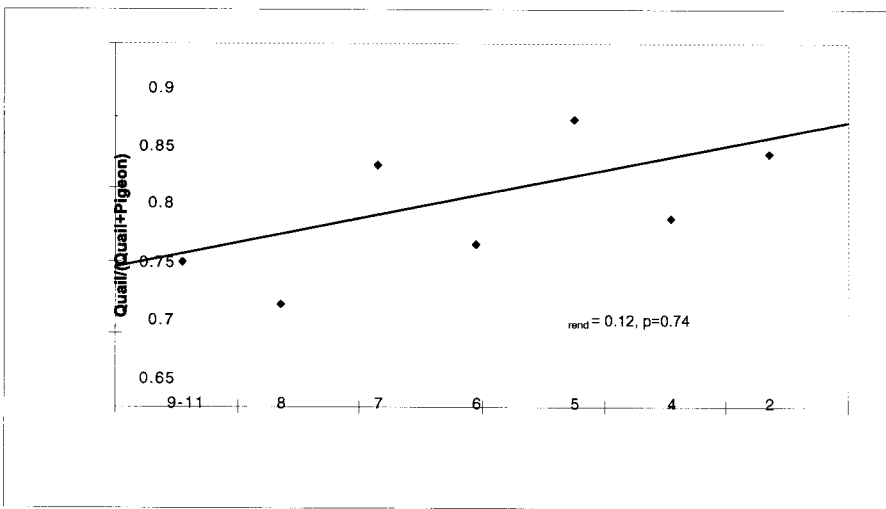


Figure 4 The quail-pigeon index by layer.

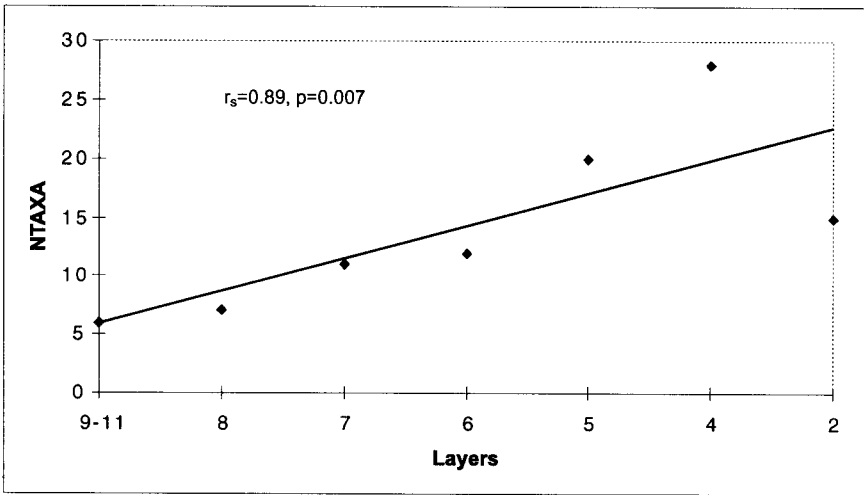


Figure 5 Plot of the richness (NTAXA) for the inland patch.

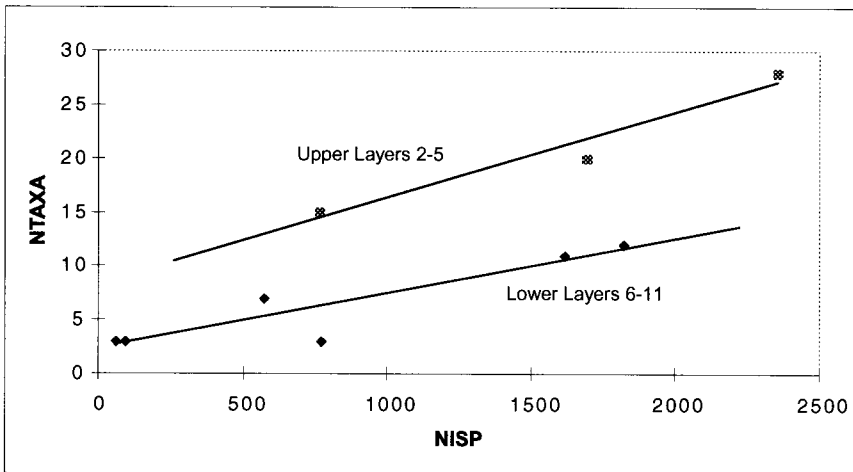


Figure 6 Regression analysis comparing richness (NTAXA) and sample size (NISP) for the upper and lower layers of the inland patch sample.

layers (Fig. 6). The statistically significant differences between the regression lines indicate that taxa were being added at a greater rate in the later period. Both measures of diet breadth support the prediction that foraging efficiency declined significantly, so that diet breadth within the inland patch expanded to include more low-ranked taxa.

The analysis of the coastal patch data, which is presented elsewhere (Nagaoka 2000, 2001), also shows a significant decline in foraging efficiency and an increase in diet breadth that appears to be due to resource depression of seals. A consequence of the resource

depression occurring in the coastal and inland patches is that time allocation across patches shifted. The offshore patch may have had the lowest net return rate since it does not appear to have been utilized significantly until the late occupation of the site. The marginal value theorem (MVT) predicts that if a patch is not used initially, it will be added only after the mean foraging return rate for the other patches declines below the expected return rate of the new patch (Charnov 1976). In addition, the MVT predicts that patch residence time will increase as the mean foraging return rate across all patches declines. To determine if this shift in the use of the offshore patch is linked to changes in resource depression in the other two patches, changes in the proportion of high-ranked patch-specific taxa should reflect this shift in patch use as foraging efficiency declines (Broughton 1999). For example, barracouta (*Thyrsites atun*), the most abundant species taken within the offshore patch, is compared to moas from the inland patch ($\Sigma \text{ moa} / \Sigma (\text{barracouta} + \text{moa})$). The decline in the index indicates that barracouta exploitation in the offshore patch is increasing significantly relative to moa exploitation in the inland patch (Fig. 7). The index comparing barracouta to seals also shows a similar trend (Nagaoka 2000). Thus, it appears that, as foraging efficiency declined within the inland and coastal patches, more foraging effort was being spent in the low-ranked offshore patch. Indeed, over time, human foraging may have affected barracouta populations in the offshore patch as well. The mean size of the barracouta harvested may have declined over time, although the samples are likely too small to be statistically significant (Leach et al. 1999).

In sum, my research supports the basic interpretation of a shift in the size of prey exploited from larger to smaller prey due to the effects of human predation, as seen in the decline of foraging efficiency. However, my analysis expands further on this interpretation. In addition to a significant decline in foraging efficiency, there is an increase in the number of resources exploited to include more low-ranked, i.e. smaller, taxa. In addition, different patterns of resource use emerge from the three patches. Within the inland patch, foragers specialized on moas until late in the sequence. In the coastal patch, resource

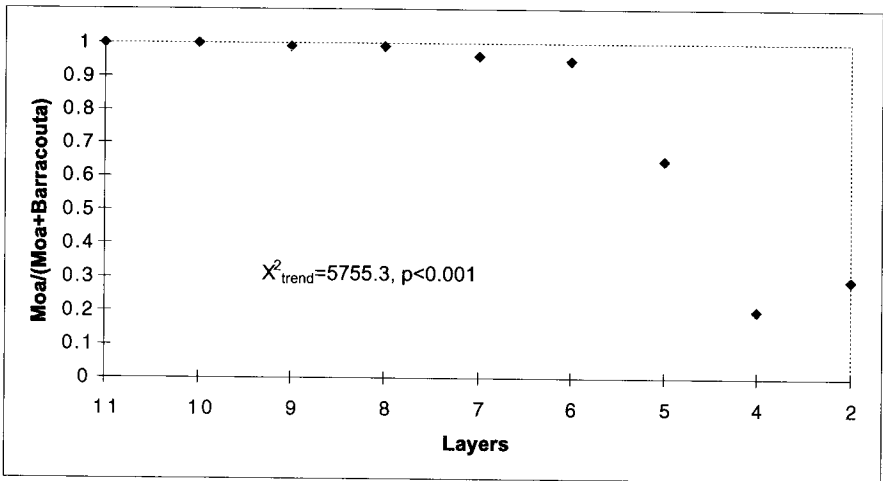


Figure 7 The moa-barracouta index by layer.

exploitation was more generalized across several taxa. Only after the foraging efficiency in the other two patches declined did exploitation of resources in the offshore patch become important. Late in the occupation, offshore patch use increased, with barracouta becoming the most common resource exploited from the site.

Explaining changes in butchery and transport patterns

Over the last twenty years, studies of butchery and transport decisions have become better integrated into general dietary studies through the use of foraging theory models. Simple models of transport decisions predict that the kind and number of skeletal elements transported back to a central place will depend upon the net returns or 'utility' of those elements and the distance to the home base (Binford 1978). In general, the model assumes that foragers will process large animals in the field and discard parts of the carcass in order to create more transportable units (O'Connell et al. 1988, 1990), which reduces transport costs while maximizing net returns per load (Bettinger et al. 1997; Bird and Bliege Bird 1997; Metcalfe and Barlow 1988). Those elements that are transported will tend to be of higher return or utility. For vertebrates, utility is specified for skeletal elements in terms of meat, marrow and grease (Binford 1978, 1981). Elements are ranked in terms of their utility, and decisions about body part transport are made based on this ranking.

More recently, explanations of changes in butchery and transport decisions have been explicitly linked with foraging theory models, in particular the patch choice models. Instead of examining the exploitation of prey types within and across patches (Charnov 1976), the scale at which the patch choice models are applied is scaled down to treat as patches individual prey items that have already been harvested (Broughton 1999). When the scale shifts from prey types to individual prey items, patch choice models examine how much time a forager spends extracting resources from a large prey item before moving to the next one. When the patch choice models are applied in this way, the assumption is that the prey captured must be large enough so that the animal needs to be processed to transport. For such large animals, if transport costs are not changing significantly over time, then the marginal value theorem (MVT) predicts that, as encounter rates of prey and overall foraging efficiency decline, the amount of time a forager spends extracting resources from a carcass should increase (Broughton 1994, 1999; Charnov 1976). In other words, foragers will use each prey item more intensively. Thus, foragers should exploit an increasing proportion of each individual animal, starting with the high return portions of the animal and adding more and more lower-ranked portions as encounter rates decline. By using the MVT to examine changes in transport decisions over time, changes in skeletal element representation may be linked to declines in foraging efficiency that result from resource depression.

The MVT models assume that foragers are consuming their prey at the point of capture and, therefore, that transport costs are not a factor. However, when prey abundances near the site decline to the point where foragers need to go farther afield to obtain these resources, transport costs will be incurred, and they will increase as distance increases (Hames and Vickers 1982; Hamilton and Watt 1970). Central-place foraging models were designed to handle situations where predators forage from a 'home base' and return their

prey to that base for consumption (Cannon 2000; Smith 1991). From these models we can predict that, as transport costs increase due to increasing distance to prey, foragers will become 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 forage for larger, higher-return items in order to maximize their returns per trip (Orians and Pearson 1979; Schoener 1979). If distance to prey capture is increasing within a patch, then the proportion of each animal returned may decrease, focusing on the parts of the animal that provide higher return rates. These predictions differ from the MVT in that, although changes in foraging efficiency are a factor, increasing distance to harvest determines what is transported.

The kinds of elements transported will depend on their rank based on their net returns. Traditionally, elemental net returns have been measured using utility indices that reflect the amount of meat, marrow and grease associated with each skeletal element (Binford 1981). The relationship between skeletal element representation of an assemblage and nutritional value is examined graphically by plotting utility against a measure of skeletal element representation on an assemblage-by-assemblage basis. As with the foraging efficiency indices described above, Broughton (1999) created a simpler means of measuring changes in utility by creating an index that incorporates both a measure of utility and skeletal part frequency. Mean utility measures the average returns or utility per element for each stratigraphic layer or temporal unit (Broughton 1999). Each layer or sample is represented by a single number, which can then be plotted to examine changes in mean utility among samples. The larger the value for the mean utility, the greater was the proportion of higher-ranked elements being transported. The relationship of mean utility for each sample across time can then be tested statistically.

For the Shag Mouth assemblage, moas and seals, as the largest vertebrate taxa, are likely to have been butchered before transport. Two different patterns of transport emerge for the two taxa. The mean utility of moa elements returned to the site increases significantly (Fig. 8). Higher-utility elements comprised a larger portion of the elements transported over time, indicating that foragers were becoming more selective about the moa portions returned to the site. A decline in the number of tracheal rings and gizzard stones found at the site also supports the notion that foragers were becoming more selective, by field processing moas in such a way as to discard low-return portions and transport increasingly higher-return elements. The changes in moa skeletal element representation suggest that resource depression of moas occurred locally at first, causing foragers to hunt further from the site. With increasing distance to hunting areas, transport costs increased, resulting in more field processing and increasingly selective transport of moa portions.

The pattern of transport for seals is much different. As shown in Figure 9, the mean utility for seal elements decreases significantly over time. The range of elements transported back to the site expands to include a greater proportion of low utility elements over time. As the encounter rates with seals declined, foragers appear to have been less selective, intensifying their use of each individual. The increase in the range of elements transported back to the site indicates that increasing transport costs were not a factor in transport decisions. Instead, it appears that, in contrast to moas, the use of seals was becoming more intensive rather than selective. More of each individual seal was being returned to the site as overall foraging efficiency declined.

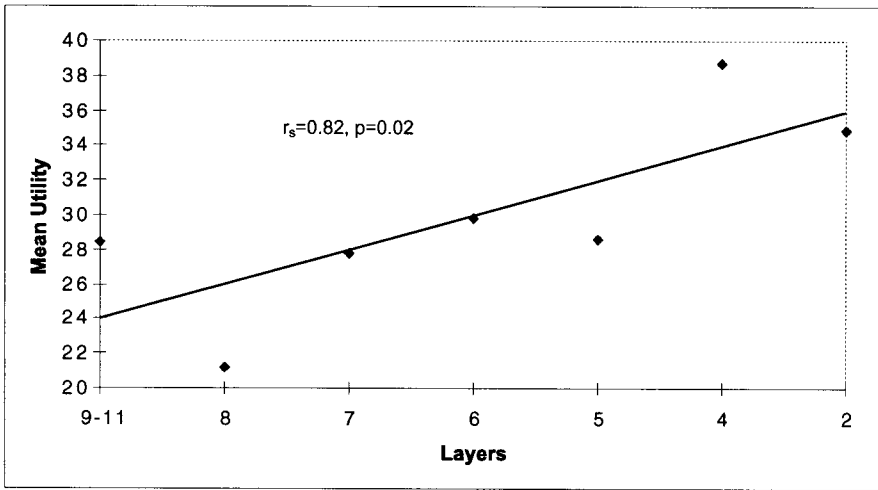


Figure 8 Plot of moa mean utility across layers.

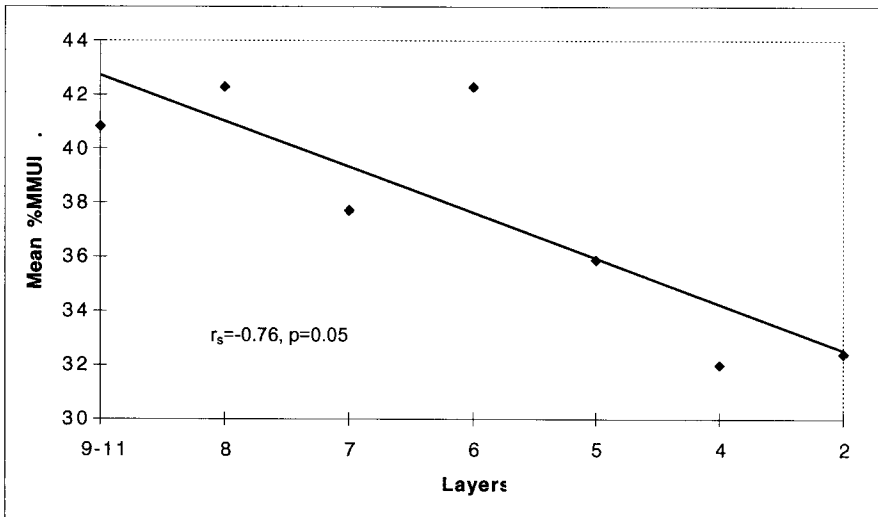


Figure 9 Plot of mean utility for seal elements across layers.

While transport distance is a significant variable in decisions about body part transport, ethnoarchaeological research has identified several other variables, such as the prey's body size, carrying party size and processing time, that also influence transport decisions and must be examined (e.g. Bartram 1993; Metcalfe and Barlow 1992; O'Connell et al. 1988, 1990). For the Shag Mouth analysis, I examined two alternative explanations for the skeletal element patterns documented: 1) differential preservation of elements that is correlated with survivorship (Lyman 1994); and 2) the advent of efficient transport

mechanisms that would have significantly lowered transport costs (O'Connell and Marshall 1989; Smith 1991; Winterhalder, 1981). It is possible that the pattern of moa and seal elemental transport is an artifact of preservation, where only the densest elements (i.e. those that are least affected by taphonomic factors) are represented. If bone density is a factor in elemental abundance, then density should co-vary with a measure of elemental survivorship (Lyman 1994). For seals, bone density is not correlated with percentage survivorship of elements in any layer. Thus, differential preservation does not appear to be affecting relative skeletal abundances of seals. Bone density studies are lacking for moas or any related species; thus differential preservation cannot be ruled out as a factor in moa element representation.

The use of efficient transport mechanisms, such as snowmobiles and cars, can greatly reduce transport costs so that they are nearly negligible. Canoes were commonly used for short trips and extended voyages in New Zealand and across Polynesia (Best 1925). The rise in importance of the offshore patch during the latter part of the Shag Mouth occupation demonstrates that canoes were important for obtaining resources. It is possible that canoes were used to transport seal carcasses from rookeries located farther down the coast. Thus, while changes in transport costs were not a factor in seal use, it is unknown whether only local populations were exploited or if an efficient transport vehicle such as the canoe was used to exploit populations up and down the coast.

In addition to using the patch choice models to examine skeletal element transport, we can also use them to examine how intensively individual prey items were being used. In particular, using the MVT, we can reduce the scale of analysis one level further to treat individual skeletal elements as patches. When skeletal elements are treated as patches, the prediction from the MVT is that, with declining foraging efficiency, time allocation for each element may increase, i.e. each element may be used more intensively (Broughton 1999). Intensive use of individual skeletal elements may be represented by activities such as the extraction of marrow or grease from bones, which requires that bones be broken to obtain these resources. Grease extraction in particular can be a relatively low-return endeavor because of the costs of extraction. If marrow and grease extraction increases over time, then there should be a corresponding increase in bone fragmentation. Fragmentation can be measured by comparing the number of bone fragments to the number of elements represented (Lyman 1984, 1994). The ratio of the two measures should increase as fragmentation increases. As Figures 10 and 11 show, fragmentation of both moa and seal long bones changes little over time. Thus, foraging efficiency does not appear to have declined enough to make bone breakage for marrow or grease extraction profitable.

This study has shown how foraging theory models are able to integrate explanations about changes in processing patterns with dietary information by linking these changes to resource depression. As high-ranked prey abundances declined in the Shag Mouth assemblage, individual seals were being used more intensively with a broader range of elements being transported over time. Transport costs are not a factor in transport decisions for seals at this site. It is unclear whether this was because only local populations were being exploited or because canoes were being used. The pattern of moa elements returned to the site is very different. Instead of more intensive use, even in the face of declining moa numbers, foragers became more selective about which moa parts were transported. The

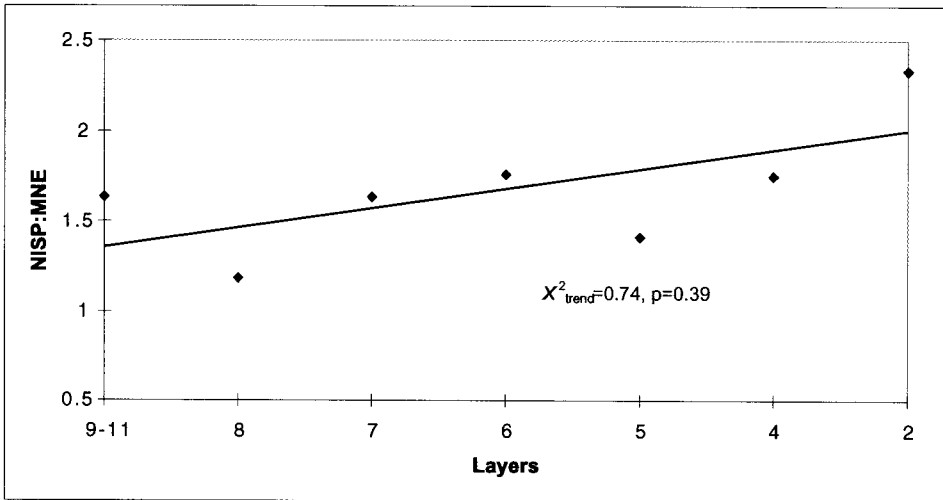


Figure 10 Plot of moa bone fragmentation rates.

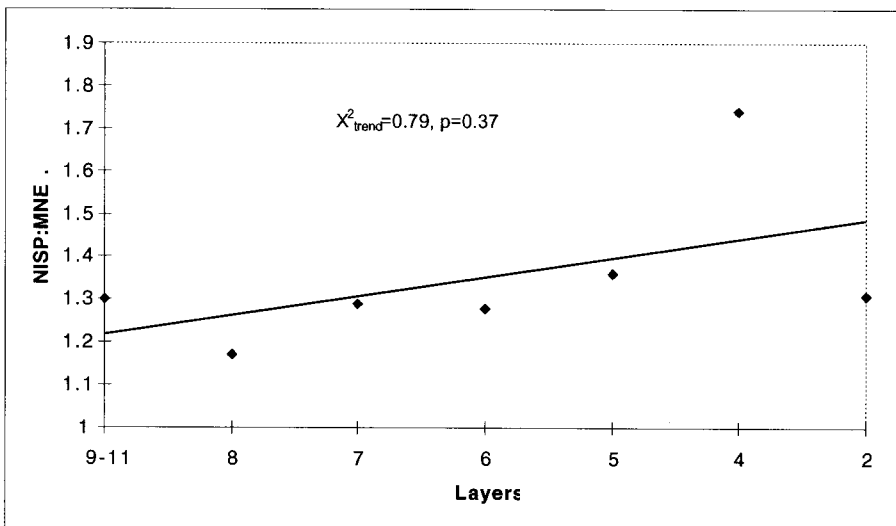


Figure 11 Bone fragmentation rates for seals.

overriding factor in this case is increasing transport costs. Resource depression is still important, but it occurred locally around the site first. Foragers then began traveling to areas farther from the site where encounter rates were higher. With increasing distance to harvest areas, foragers returned less and focused on higher-return portions. If occupation at the site had continued, it is likely that encounter rates in the further reaches would also have declined significantly and moa carcass elements might have been used more intensively (Broughton 1999).

Conclusions

Foraging theory models provide a rigorous, explicit and predictive framework with which to study changes in human subsistence practices. The challenge has been to translate the application of these models from their ecological contexts to archaeological situations. Much research over the past twenty years has focused on the developing the methodology required to do this. As this analysis demonstrates, the methodology for documenting resource depression has become more rigorous and quantitative with the development of multiple measures of foraging efficiency and diet breadth that can be tested for their statistical significance. The effects of resource depression documented at Shag Mouth are similar to the patterns recorded elsewhere (e.g. Broughton 1999; Butler 2001; Simms 1987), demonstrating the utility of foraging theory models to explain subsistence changes in a variety of contexts. In addition, archaeologists have become better at identifying and evaluating alternative interpretations, and extending the application of these models into new areas of research, such as the study of butchery and transport decisions examined in the Shag Mouth study. More recently foraging theory has even been applied in societies with a farming component (e.g. Barlow 1997; Cannon 2000; Gremillion 1996).

These advances have allowed for the application of foraging theory models in a wide variety of contexts. In some regions, particularly the western US, foraging theory models are used extensively to address questions of subsistence change across a regional level (for a review of research in the region, see Grayson and Cannon 1997; Zeanah and Simms 1997). Since foraging theory studies strive to be rigorous and explicit, they can produce results that are comparable and thus cumulative. With such a database, regional and cross-regional studies can be conducted. In New Zealand, foraging theory models have the potential to be just as productive. To understand regional variability in subsistence practices will require similar studies from multiple sites in the region. Studies have shown that environmental variability can produce different patterns of resource use (e.g. Cannon 2000). Thus, the patterns of change seen at Shag Mouth may not be representative of all sites in southern New Zealand. Only when a regional database is developed can we begin fully to understand the impact that human foraging had on the New Zealand landscape, and the consequences of these changes on human cultural practices.

Acknowledgements

Thanks to Don Grayson, Mike Cannon and Kris Bovy for their advice and input on this paper. This research was funded by a Fulbright Fellowship and a Leakey Foundation General Grant.

*Department of Geography
University of North Texas*

References

- Anderson, A. J. 1981. A model of prehistoric collecting on the rocky shore. *Journal of Archaeological Science*, 8: 109–20.
- Anderson, A. J. 1982. A review of economic patterns during the Archaic phase in southern New Zealand. *New Zealand Journal of Archaeology*, 4: 45–75.
- Anderson, A. J. 1983. Faunal depletion and subsistence change in the early prehistory of southern New Zealand. *Archaeology in Oceania*, 18: 1–10.
- Anderson, A. J. 1989. *Prodigious Birds*. Cambridge: Cambridge University Press.
- Anderson, A. J. 1994. *Traditional Lifeways of the Southern Maori*. Dunedin: University of Otago Press.
- Anderson, A. and McGlone, M. 1992. Living on the edge – prehistoric land and people in New Zealand. In *The Naïve Land* (ed. J. Dodson). Melbourne: Longman Cheshire, pp. 199–241.
- Anderson, A. and Smith, I. 1996. Introduction and history of investigations. In *Shag River Mouth: The Archaeology of an Early Southern Maori Village* (eds A. Anderson, B. Allingham and I. Smith). Research Papers in Archaeology and Natural History, No 27. Canberra: Australian National University, pp. 1–13.
- Anderson, A., Allingham, B. and Smith, I. 1996. *Shag River Mouth: The Archaeology of an Early Southern Maori Village*. Research Papers in Archaeology and Natural History, No 27. Canberra: Australian National University.
- Barlow, K. R. 1997. Foragers that farm: a behavioral ecology approach to the economics of corn farming for the Fremont case. PhD dissertation, Department of Anthropology, University of Utah.
- Bartram, L. E. 1993. Perspectives on skeletal part profiles and utility curves from eastern Kalahari ethnoarchaeology. In *From Bones to Behavior: Ethnoarchaeological and Experimental Contributions to the Interpretation of Faunal Remains* (ed. J. Hudson). Occasional Paper 21, Center for Archaeological Investigations. Carbondale: Southern Illinois University, pp. 115–37.
- Bayham, F. E. 1979. Factors influencing the Archaic pattern of animal exploitation. *The Kiva*, 44: 219–35.
- Best, E. 1925. *The Maori Canoe*. Dominion Museum Bulletin 7. Wellington: The Polynesian Society.
- Best, E. 1942. *Forest Lore of the Maori*. Dominion Museum Bulletin 14. Wellington: The Polynesian Society.
- Bettinger, R. L., Malhi, R. and McCarthy, H. 1997. Central place models of acorn and mussel processing. *Journal of Archaeological Science*, 24: 887–99.
- Binford, L. R. 1978. *Nunamiut Ethnoarchaeology*. New York: Academic Press.
- Binford, L. R. 1981. *Bones: Ancient Men and Modern Myths*. New York: Academic Press.
- Bird, D. W. and Bliege Bird, R. L. 1997. Contemporary shellfish gathering strategies among the Meriam of the Torres Strait Islands, Australia: testing predictions of a central place foraging model. *Journal of Archaeological Science*, 24: 39–63.
- Boyd, B., McGlone, M., Anderson, A. and Wallace, R. 1996. Late Holocene vegetation history at Shag River Mouth. In *Shag River Mouth: The Archaeology of an Early Southern Maori Village* (eds A. Anderson, B. Allingham and I. Smith). Research Papers in Archaeology and Natural History, No 27. Canberra: Australian National University, pp. 257–75.
- Broughton, J. 1994a. Declines in foraging efficiency during the late Holocene: the archaeological

- mammal evidence from San Francisco Bay, California. *Journal of Anthropological Archaeology*, 13: 371–401.
- Broughton, J. 1994b. Late Holocene resource intensification in the Sacramento Valley, California: the vertebrate evidence. *Journal of Archaeological Science*, 21: 501–14.
- Broughton, J. M. 1997. Widening diet breadth, declining foraging efficiency, and prehistoric harvest pressure: ichthyofaunal evidence from the Emeryville Shellmound, California. *Antiquity*, 1: 845–62.
- Broughton, J. M. 1999. *Resource Depression and Intensification during the Late Holocene, San Francisco Bay: Evidence from the Emeryville Shellmound*. University of California Publications Anthropological Records 32. Berkeley: University of California Press.
- Broughton, J. M. and Grayson, D. K. 1993. Diet breadth, Numic expansion, and White Mountain faunas. *Journal of Archaeological Science*, 20: 331–6.
- Butler, V. 2001. Changing fish use on Mangaia, southern Cook Islands: resource depression and the prey choice model. *International Journal of Osteoarchaeology*, 11: 88–100.
- Cannon, M. 2000. Large mammal relative abundance in Pithouse and Pueblo period archaeofaunas from southwestern New Mexico: resource depression among the Mibres-Mogollon? *Journal of Anthropological Archaeology*, 19: 317–47.
- Charnov, E. L. 1976. Optimal foraging, the marginal value theorem. *Theoretical Population Biology*, 9: 129–36.
- Charnov, E. L., Orians, G. H. and Hyatt, K. 1976. Ecological implications of resource depression. *American Naturalist*, 110: 247–59.
- Diamond, J. 2000. Blitzkrieg against the moas. *Science*, 287: 2170–1.
- Grayson, D. K. 1984. *Quantitative Zooarchaeology*. New York: Academic Press.
- Grayson, D. K. and Cannon, M. D. 1999. Human paleoecology and foraging theory in the Great Basin. In *Models for the Millennium* (ed. C. Beck). Salt Lake City: University of Utah Press, pp. 141–51.
- Grayson, D. K. and Delpech, F. 1998. Changing diet breadth in the early Upper Paleolithic of southwestern France. *Journal of Archaeological Science*, 25: 1119–29.
- Gremillion, K. J. 1996. Diffusion and adoption of crops in evolutionary perspective. *Journal of Anthropological Archaeology*, 15: 183–204.
- Hames, R. B. and Vickers, W. T. 1982. Optimal diet breadth theory as a model to explain variability in Amazonian hunting. *American Ethnologist*, 9: 258–78.
- Hamilton, W. J. and Watt, K. E. F. 1970. Refuging. *Annual Review of Ecology and Systematics*, 1: 263–86.
- Janetski, J. C. 1997. Fremont hunting and resource intensification in the eastern Great Basin. *Journal of Archaeological Science*, 24: 1075–88.
- Leach, F., Davidson, J., Fraser, K. and Anderson, A. 1999. Pre-European catches of barracouta, *Thyrstites atun*, at Long Beach and Shag River Mouth, Otago, New Zealand. *Archaeofauna*, 8: 11–30.
- Lyman, R. L. 1984. Bone density and differential survivorship of fossil classes. *Journal of Anthropological Archaeology*, 3: 259–99.
- Lyman, R. L. 1994. *Vertebrate Taphonomy*. Cambridge Manuals in Archaeology. Cambridge: Cambridge University Press.
- MacArthur, R. H. 1972. *Geographical Ecology: Patterns in the Distribution of Species*. New York: Harper & Row.

- MacArthur, R. H. and Pianka, E. R. 1966. On optimal use of a patchy environment. *American Naturalist*, 100: 603–9.
- McGlone, M. S. 1983. Polynesian deforestation of New Zealand: a preliminary analysis. *Archaeology in Oceania*, 18: 11–25.
- Madsen, D. B. and Schmitt, D. N. 1998. Mass collecting and the diet breadth model: a Great Basin example. *Journal of Archaeological Science*, 25: 445–55.
- Magurran, A. E. 1988. *Ecological Diversity and its Measurement*. Princeton, NJ: Princeton University Press.
- Martin, P. S. 1984. Pleistocene overkill: the global model. In *Quaternary Extinctions* (eds P. S. Martin and R. G. Klein). Tucson, AZ: University of Arizona Press, pp. 354–403.
- Metcalfe, D. and Barlow, K. R. 1992. A model for exploring the optimal tradeoff between field processing and transport. *American Anthropologist*, 94: 340–56.
- Nagaoka, L. 2000. Extinction, resource depression, and subsistence change in southern New Zealand. PhD dissertation, Department of Anthropology, University of Washington.
- Nagaoka, L. 2001. Using diversity indices to measure changes in prey choice at the Shag River Mouth site, Southern New Zealand. *International Journal of Osteoarchaeology*, 11: 101–11.
- O’Connell, J. F. and Marshall, B. 1989. Analysis of kangaroo body part transport among the Alyawara of Central Australia. *Journal of Archaeological Science*, 16: 393–405.
- O’Connell, J. F., Hawkes, K. and Blurton Jones, N. 1988. Hadza hunting, butchering, and bone transport and their archaeological implications. *Journal of Anthropological Research*, 44: 113–61.
- O’Connell, J. F., Hawkes, K. and Blurton Jones, N. 1990. Reanalysis of large mammal body part transport among the Hadza. *Journal of Archaeological Science*, 17: 301–16.
- Orians, G. H. and Pearson, N. E. 1979. On the theory of central place foraging. In *Analysis of Ecological Systems* (eds D. J. Horn, G. R. Stairs and R. D. Mitchell). Columbus, OH: Ohio State University Press, pp. 155–77.
- Schmitt, D. N. and Lupo, K. D. 1995. On mammalian taphonomy, taxonomic diversity, and measuring subsistence data. *American Antiquity*, 60: 496–514.
- Schoener, T. W. 1979. Generality of the size-distance relation in models of optimal feeding. *The American Naturalist*, 114: 902–14.
- Simms, S. R. 1987. *Behavioral Ecology and Hunter-Gatherer Foraging: An Example from the Great Basin*. BAR International Series 381. Oxford: BAR.
- Smith, E. A. 1991. *Inujjumiut Foraging Strategies*. New York: Aldine de Gruyter.
- Stephens, D. W. and Krebs, J. R. 1986. *Foraging Theory*. Princeton, NJ: Princeton University Press.
- Stiner, M. C., Munro, N. D. and Surovell, T. A. 2000. The tortoise and the hare: small game use, the broad spectrum revolution, and Paleolithic demography. *Current Anthropology*, 41: 39–73.
- Szuter, C. R. and Bayham, F. E. 1989. Sedentism and prehistoric animal procurement among desert horticulturalists of the North American Southwest. In *Farmers as Hunters: Implications of Sedentism* (ed. S. Kent). Cambridge: Cambridge University Press, pp. 80–95.
- Winterhalder, B. 1981. Foraging strategies in the boreal forest: an analysis of Cree hunting and gathering. In *Hunter-Gatherer Foraging Strategies* (eds B. Winterhalder and E. A. Smith). Chicago: University of Chicago Press, pp. 66–98.
- Winterhalder, B. and Smith, E. A. 2000. Analyzing adaptive strategies: human behavioral ecology at twenty-five. *Evolutionary Anthropology*, 9: 51–72.

Zeanah, D. W. and Simms, S. R. 1999. Modeling the gastric: Great Basin subsistence studies since 1982 and the evolution of general theory. In *Models for Millennium* (ed. C. Beck). Salt Lake City: University of Utah Press, pp. 118–40.