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Using Stable Isotope Analysis to Determine Deer Behavior

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Undergraduate Honors Thesis
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Introduction
Animals and their environment are linked. With the influence of cultural ecology, anthropologists have recognized the relationship between human strategy and the structure of the biotic environment and the specific behaviors of animals. Through the reconstruction of past environments, archaeologists have explored this basic premise. Isotopic analysis is a method for such exploration. On one hand, it has been used in paleodiet studies, in which aspects of diet are determined based on isotope ratios from bone and teeth. On the other hand, wildlife ecologists use isotopes to understand the habits and preferences of animals they manage, such as deer. While many people have used stable isotopes to study both human and faunal diet, and have extended this to environment, few people have used faunal diet as an indicator of human choice. My research builds upon these studies, in an effort to use isotopes as indicators of past white-tailed deer (*Odocoileus virginianus*) diet to gain insight to human hunting strategy.

For several decades, anthropologists have recognized that one strategy horticulturalists use as a method of game procurement is garden hunting (Linares 1976). The practice has been both observed in the tropics (Peterson 1977) and postulated for past human groups (Neusius 1996). Archaeologists look for indications of garden hunting through variations in the faunal assemblage, such as high frequencies of animals normally attracted to fields, or lower than expected frequencies of animals known to have been abundant in natural habitats. Deer present a special problem to the zooarchaeologist because in addition to being a garden pest, they are also a primary resource that is often hunted in environments away from gardens. As a result, it is unclear whether or not to categorize deer as garden hunted. Stable isotope analysis can indicate if the deer were
preferentially feeding on maize, from which we may infer if they were garden pests. In this way, by determining deer behavior, we can provide insight to human choice.

Isotopic analysis has been used to determine the diet of prehistoric humans (e.g. Tykot 2003, Pate 1997), and recently has been extended to studies of animal diet and behavior (e.g. Emery 2000). These analyses use carbon 12 to carbon 13 ratios ($\delta^{13}C$) in bones or teeth to show general dietary patterns during the time of formation. Most plants can be characterized by one of two basic pathways—C3 or C4—due to the way carbon dioxide is fractionated during photosynthesis (Tykot 2003). Generally speaking, grasses native to hot, arid environments—including maize—are C4 plants, whereas other plants from temperate regions are C3, including the trees and shrubs that constitute "browse". This is reflected in animal tissue through different ratios of carbon isotopes, depending on the proportion of C3 to C4 plants consumed.

The sites chosen for this study are the Ripley site and Ashmore Farm site, both Late Prehistoric, post AD 1000 sites, representing a time when Native Americans were developing economies dependant on maize, beans and squash. The two have a potential difference in site function, which may provide a good comparison between deer that were procured through garden hunting and those through regular hunting methods. Ashmore Farm is a Monongahela hamlet site located in Washington County, PA. Since the Monongahela were maize bean squash horticulturalists, garden hunting is likely. In contrast, the Ripley site, located in Chautauqua County, N.Y., has long been considered an Erie Indian village, but Neusius et al. (1998) argue that it actually is a mortuary encampment. This means that deer recovered at Ripley may represent non-garden hunting means of meat provisioning.
Background

Garden Hunting

To understand garden hunting, one has to understand horticulturists. As defined by Sutton and Anderson (2004) horticulture is a type of small-scale agriculture that is relatively low intensity, involving less energy input, less crop output and more land use. Alternatively, cultivation is more intense, involving more energy investment in less land, through the use of machines or draft animals. Rather than utilizing the large fields that most Europeans conceptualize as agriculture, horticulture employs smaller fields or gardens (though they may be part of a larger complex) frequently cultivating multiple species together, called multicropping. The food produced is primarily for subsistence, and surplus is limited, though it is sometimes used as tribute or for trade.

Horticultural practices significantly modify the landscapes, creating a new anthropogenic ecosystem. Clearing new fields, planting crops and in some cases, fallowing older fields, increases plant diversity, which in turn attracts insects and animals that provide a ready protein source. Exploiting this situation is called garden hunting, and has been documented in modern horticultural groups. Most of this work has been done in the tropics (Vickers 1989), though archaeological evidence has been collected in many places, like the Southwest United States (Speth and Scott 1989).

The garden hunting model assumes first that horticulture increases biodiversity in the new ecosystem (Neusius 1996 and Linares 1979). Clearing fields creates edge environments, which attract pioneer plants (weeds) to grow near and within the crops. As fields turn to fallow, the new forest growth further increases diversity. This attracts insects and herbivores that in turn attract insectivores and carnivores. Animals that
would otherwise destroy crops are exploited as a supplemental protein to a primarily vegetarian diet. This has the double benefit of allowing horticulturalists to stay closer to their home range to hunt, and does not conflict with cultivation activities.

Garden hunting can be detected in the archaeological record, if with some difficulty. Several different tests must be used to determine the existence of garden hunting, as any single one is inconclusive by itself. The distribution of animals expected of a dense forest environment is different from open meadow or forest-edge environments, which would more closely mirror the distribution of horticultural anthropogenic environment. These include animals like rabbits, squirrels, mice (Neusius 1996). Therefore, faunal assemblages that include more of these open environment garden pests, especially if they appear in different frequencies than is predicted by environment reconstruction, are more likely to be the result of garden hunting than forest hunting.

Neusius (1996) argues that this strategy is non-selective, relying on what is attracted to the garden rather than actively pursuing particular species, and some of the animals would be smaller and secondary resources according to the optimal forage theory. Conversely, Linares (1976) argues that the increased diversity allows people to be choosier in what game they take, in other words, it is a selective strategy. In either case, the faunal assemblage is still different from the expected assemblage based on the natural environment, favoring open-environment animals that are easily trapped.

Speth and Scott (1989) have a totally different theory. They argue that while initially the garden attracts large game, as population increases, people quickly deplete local game. Because horticulture provides a more stable food source, hunters are actually
more able to engage in high risk strategies, such as large-game hunting. Thus, while
garden pests would still remain part of the diet, larger game may have been hunted with
more intensity. Therefore, deer may not necessarily be considered a garden pest, having
been obtained at long distances from the community.

The white tailed deer (*Odocoileus virginianus*) is a good illustration of this
problem. It is an edge browser, and has large potential to be a garden pest, as many
farmers in North America know (Cormie and Schwarcz 1993). As large game, however,
it is considered a primary resource, sought after for the large amount of meat available for
its body size. On one hand, deer could have been caught as part of a garden hunting
strategy, in line with Neusius's (1996) theory. On the other hand, the deer could have
been hunted as primary resources in the forest. One possible solution to the problem is
determining where they were feeding. While it is possible that a deer was caught its first
time in a garden, or that deer were tracked in the forest after eating the crops, because the
premise of garden hunting is that via their feilds people essentially lured animals to be
trapped, a deer that has significantly fed on maize is more likely to have been garden
hunted than not.

*Isotopes*

Stable isotope analysis has been used to study diet for decades. Most research
focuses on human diet (e.g. Katzenberg et al 1995, Schwarcz et al. 1985), but many
people are starting to look at the diet of other animals, using them as a baseline for human
diet (e.g. Katzenberg 1989). There are several studies of Maya deer, in which they are
used as an indicator of the introduction of maize agriculture (Emory et al 2000, van der
Merwe et al 2000). Several different isotopes can be used in this kind of analysis, all of
which indicate different things. Stable carbon in animals is an indicator of which plants they were ultimately consuming, even if indirectly through the food chain.

Carbon isotopes vary in plants according to differences in fractionation during photosynthesis. There are two main photosynthetic pathways: Hatch-Slack, or C4 and Calvin-Benson, or C3. C4 plants are grasses that evolved in hot, arid environments, like maize. C3 are trees, shrubs and grasses that evolved in temperate regions like maple or greenbriar. Every plant has their own δ¹³C value, but overall C4 plants are less negative than C3.

Just as atmospheric CO₂ undergoes fractionation in plants, carbon continues to be further fractionated as it moves through trophic levels. The average δ¹³C value for modern C3 plants is -26.5‰, and -12.5‰ for C4 (Price 1984). While there is some variation dependant on size, for large animals, collagen is enriched by about 5 ‰ due to fractionation during the metabolic process (Chisholm 1989). Therefore, for modern deer, the expected δ¹³C value for 100% consumption of C3 plants is -21.5‰ (-26.5 ‰ + 5.0‰), and 100% consumption of C4 is -7.5‰ (-12.5‰ + 5.0‰). The process of fractionation continues as carbon moves up through the food chain, though because we are only looking at deer, it is not pertinent to this discussion.

Factors other than just photosynthetic pathway affect δ¹³C values. Through various means, the environment changes how plants adsorb atmospheric CO₂ (van Klinken et al 2000, Ehleringer 1991). Temperature and relative humidity determine stomatal conductance, or the ability of plants to exchange gases via pores—stomata—on the underside of leaves. Water stress usually occurs when humidity is down and
temperatures are up. Basically, during hot and dry weather, stomata close in order to retain water, but in doing so, more $^{13}$C is fixed, resulting in less negative $\delta^{13}$C values.

The canopy effect is another environmental factor. It is due essentially to the partial pressure of CO$_2$, though this is affected by rotting leaf litter and the amount of light available. Partial pressure of CO$_2$ is the relative abundance of internal/intercellular CO$_2$ ($C_i$) to CO$_2$ in the air ($C_a$). The higher the $C_i/C_a$, the more negative the $\delta^{13}$C values. In very dense and closed canopies, rotting leaf litter respires $^{13}$C depleted CO$_2$, which can significantly increase the $^{13}$C levels (Tieszen 1991, van der Merwe and Medina 1991). Less light also raises $C_i$, making the $\delta^{13}$C values more negative. This can occur independently of respiration, in less dense canopies, though they frequently occur together, with additive affects (Tieszen 1991).

These factors result in regional and temporal variations in $\delta^{13}$C values. On a grand regional scale, van Klinken et al (2000) shows how $\delta^{13}$C values across Eurasia and North Africa change, with North-South (temperature) and Atlantic-continental (humidity) trends. Smaller scale regional effects include water stress in arid environments or the canopy effect in the tropics. Over time, global and regional climate change is recorded in $\delta^{13}$C values (Van de Water 1994). Seasonal changes in weather are a very fine scale, and therefore will not show up in archaeological records. However, over the course of a year, $\delta^{13}$C values of a particular plant will change depending on factors like water stress (Cormie and Schwarcz 1996, Gearing 1991). Thus carbon isotopes are also sensitive to environmental affects, whose interference needs to be accounted for in dietary studies.
Sites

The Ripley and Ashmore Farm sites were chosen for this study because in addition to being readily available at IUP, both the Monongahela and Erie peoples had economies dependant on maize, beans and squash. These sites also potentially had different functions, which may provide a good comparison between two different game procurement strategies.

The Ripley site (NYSM 2490, 30CH6) is located in Chautauqua County, New York, several miles east of the Pennsylvania/New York border, on a small knoll on the Lake Erie bluffs. It is close enough to the shore that portions of the site have eroded into the lake. While technically in Erie Lake Plain/Erie lowlands, the boundary between that and the Allegheny plateau is only a few kilometers south of Ripley. Overall, southwest New York State is considered to have a humid continental climate; however, the two sections are notably different. Both have cold, snowy winters, but the Erie lowlands have warm dry summers and the Allegheny plateau has cool wet summers. Perhaps most notable for horticulturalists, the number of frost free days are significantly higher in the Erie lowlands, while the Allegheny plateau has higher precipitation, though the majority of precipitation in either region does not occur during thing growing season (Neusius an Neusius in print).

The presence of the Ripley site has been known since the early 19th century. Its first formal, though unpublished excavation was in 1904 by M. R. Harrington, followed two years later by Arthur Parker's investigations, who did publish his results (Parker 1907). It was not excavated again, until 1957 by an avocational archaeologist, Jordan Christensen's, which lasted until 1959, which was not published, though he published a
record of more amateur archaeology from 1962-1965 (Conklin 1989). During this time, there was extensive collecting. The most recent excavations at Ripley were in 1988 by the New York State Museum in collaboration with Indiana University of Pennsylvania (Neusius and Neusius in print and Sullivan 1996).

The initial investigations at Ripley determined that it was an Erie Indian village and cemetery. Little is known about the Erie because they were wiped out by the Seneca around AD 1650. This site fits in with a pattern of defensible, stockaded villages with periodic relocations due to shifting cultivation associated with the Erie, in that the earthen ring surrounding the site was assumed to support a stockade. This dates back to Parker's excavations in 1906. Neusius et al. (1998), however, disagrees. Instead, they argue, that the site is actually a multi-component mortuary site, based on dating, food residues, faunal assemblage, lithic debitage, feature assemblage, and spatial structure of the site. Not all indicators point to a mortuary site in that a higher diversity of activities are expressed than would be expected; however, it is reasonable to believe that the Ripley site is more complicated than a simple fortified village.

The bone selected from the Ripley site is from Parker's excavation. Compared to the bone from the later excavations, the bone from the Parker collection was significantly larger; this is most likely to due to a biased sampling technique on his part, but also the bone may have been fragmented as a result of another century of land use. While he did save large pieces of bone, Parker did not record provenience, and thus that information is lost. Otherwise, the bone is very well preserved.

Ashmore Farm (36Wh675) is located in Washington County, Pennsylvania, in South Strabane Township. It is in the uplands of Charters Creek Valley, in the Kanawha
Section of the Allegheny Plateau province (Chiarulli 1998). It is part of the unglaciated plateau, with rolling uplands. The soils are acidic silt loams, though they are neutralized by the limestone bedrock. The vegetation has undergone significant change since precontact. Cultivation and urbanization has reduced forest size; many wild species are foreign intruders, and several domestic species such as chestnut and white pine (Fenneman 1938).

Ashmore Farm was initially investigated by a local avocational archaeologist, Ron Eisert, following the discovery of artifacts in a plowed section of the ridge (Eisert and Boyce 1985). This was followed by a Carnegie Museum-sponsored excavation. Archaeological Services of Indiana University of Pennsylvania excavated the site again in the summer of 1997. In accordance with State Act 70, the site was surveyed in preparation for the development of a shopping mall.

The results of the excavations at Ashmore farm indicate that it is a Monongahela hamlet site (Chiarulli 1998). Typical Monongahela upland village sites have a circular plan with a central plaza, surrounded by stockades and/or shallow trenches. The Ashmore site, on the other hand, had significantly smaller density of artifacts that is usual for true village sites, as well as lacking a clear circular village pattern. Furthermore, typical villages contain evidence of subsistence activities such as hunting, fishing, and cultivation of maize, beans, and squash; the Ashmore site, on the other hand, has minimal maize present, and an inordinately large amount of fish, considering its distance from the stream. Therefore, Ashmore farm is more similar to a seasonal hamlet than an actual village.
The bone selected from the Ashmore Farm site was from Archaeological Services’ excavation in 1997. Unlike the Ripley bone, this does have provenience. This bone was more fragmented and did not seem to be as well preserved as Ripley, with a chalkier and desiccated appearance.

Method

One of the first decisions that must be made is from which source one is going to obtain samples. There are two main sources of carbon from archaeological faunal remains—teeth and bone. These two are very different—they develop differently in the animal, are composed of slightly different materials, and as such are affected differently by diagenesis. Teeth consist mainly of apatite, whereas bone is, essentially, apatite and collagen. The stable carbon signature is locked in at the time of tissue formation. Teeth develop at different ages, and are complete relatively early in life, so their signature reflects early diet. Bone, on the other hand, is replenished every few years, so the signature reflects the latter years of an animal’s diet (Tykot 2003). Since I am looking at adult feeding patterns, bone was used as the sample source.

Bone has two main components, the organic and the mineral portion. The organic portion accounts for about 30% of dry, fat-free bone, about 90% of which is collagen (Price 1989). Collagen is the protein, living portion of the bone. It is what gives bone its shape, though not its hardness. The mineral portion of bone is commonly referred to as carbonate, apatite (Garvie-Lok et al 2004), bioapatite or biological apatite (Lee Thorp and van der Merwe 1991) and hydroxyapatite (Koch et al 1997). Because the chemical formula for the carbonate portion is very similar to, but distinctly different from inorganic apatite, there are a variety of names that are all used to refer to the same thing. The
mineral portion consists of a structural carbonate lattice with carbonate adsorbed to this lattice’s surface (Koch et al 1997).

Collagen and carbonate are generally agreed to represent different portions of an animal’s diet (see Lee-Thorp et al. 1989, Armelagos et al. 1989). Collagen, being a protein, is disproportionately affected by the ‘energy’ or protein portion of the diet, whereas carbonate is reflective of ‘whole diet’, or the mixture of all carbohydrates, proteins and fats (Tykot 2003, Chisholm 1989, van der Merwe 1989). This problem is most pronounced in omnivores in which the protein component consists of meat in addition to plant materials; however, herbivores receive their protein entirely from plants, and so this is not an issue. For deer, the collagen is just as reflective of whole diet as the carbonate.

Diagenesis is a major concern when working with prehistoric isotopes. When bone interacts with the soil matrix, the changes that occur can significantly obscure the results. It affects fossils most acutely, and so in that case, tooth enamel is preferred because it is the most resistant to fossilization (Lee Thorp and van der Merwe 1991). Apatite and collagen preserve differently depending on soil and ground water chemistry. Collagen is least likely to be preserved over a long period of time; however, the fossilized equivalent maintains the same isotopic ratios as modern collagen (DeNiro and Weiner 1988). Carbonates, on the hand, adsorb carbonates onto the lattice surface, and therefore more susceptible to diagenesis. The extraction method must be more precisely controlled in order to remove the adsorbed carbonates without destroying the structural carbonate (Garvie Lok et al 2004). Most problems with diagenesis occur with bone much older
than what is used in this study, and therefore was not a real problem, though I was worried about the preservation of the Ashmore bone.

In the end, I chose to work with collagen. Firstly, the collagen extraction method is very well tested and widely accepted. Secondly, the process is somewhat more forgiving because collagen is not quite as susceptible to diagenesis as carbonate (Lee Thorp and van der Merwe 1991, Garvie-Lok et al 2004). Finally, and most importantly, the nitrogen in collagen allows for the integrity of the collagen to be easily checked.

I adapted the DeNiro and Epstein (1981) method, adding a soak in NaOH in order to remove humic contaminants (Emery et. al. 2000, Harrison and Katzenberg 2003). I chose this method mainly for its simplicity—it was a tested method that I could perform in our labs with minimal equipment. After a few attempts with both modern and a couple of unfortunate prehistoric bone samples I settled on the following method.

I started with 1 to 2 grams of bone, which I cleaned manually with a toothbrush and water, using a scalpel to remove discolored bone. Then I manually crushed the bone sample with a mortar and pestle to a coarse grain (2 mm or finer). The crushed bone was soaked in 100 mL of 1 M hydrochloric acid (HCl—a strong acid) for 20 minutes in order to demineralize the bone. Once the carbonate portion of the bone was dissolved, the resulting pseudomorph particles were translucent specks. The solution was then filtered through glass fiber filters. The filtrate was discarded.

In order to remove the humic contaminants (the organic compounds from the soils) the residue was soaked in 100 mL of 0.125 M sodium hydroxide (NaOH—a strong base) for 20 hours. It is imperative at this point that the pseudomorphs not be left in the NaOH for too long, lest the collagen start to deteriorate (Harrison and Katzenberg 2003).
The solution was again filtered, the residue rinsed several times to achieve neutrality, and the filtrate discarded.

The bone was then solubilized (effectively, dissolved) by adding 100mL of slightly acidic water (0.001 M HCl, or a pH of 3, which was best tested after adding to the collagen). This was heated overnight at 90°C. The solution was filtered, and the residue discarded. The filtrate was then freeze dried. The samples were sent to Dr. Jason Curtis at Florida University Department of Geological Sciences’ Center for Isotope Geoscience for analysis. He was recommended by Dr. Michael Rosenmier of University of Pittsburgh, who was originally going to analyze the samples, but was unable to accommodate collagen.

Results:

Carbon to nitrogen ratios are one measure of the quality of collagen results. All the literature discusses this in terms of the atomic ratio; however, the (CHN analyzer) reports in elemental percent, therefore I give both. Atomic ratio refers to the number of atoms; whereas elemental percent refers to the actual weight of the elements (it may also be referred to as percent weight). The conversion between the two is simple: carbon has 14 atoms and nitrogen has 12 atoms; therefore, multiplying the elemental percent ratio by 14/12 results in the atomic ratio. For example, modern collagen has an elemental percent ratio of about 2.7; multiplied by the number of carbon atoms (14) that is 37.8, divided by the number of nitrogen atoms (12) the resulting atomic ratio is a little over 3.1. Modern collagen has an atomic ratio of about 3.2 (Ambrose 1992). (see figure 3) Note that these are approximations; the ‘exact’ number is somewhere between the 3.1 and 3.2.

According to DeNiro (1985), if the C:N atomic ratio is between 2.9 and 3.6, the collagen
is still intact enough to give accurate results. According to this measure, since my range for C:N atomic ratio is 2.9 to 3.3, all of my results should be accurate (see fig. 1).

Results are reported in standard δ format (a ratio of a ratio), where

\[
\delta^{13}C = \left( \frac{\left( ^{13}C/^{12}C \right)_{\text{sample}}}{\left( ^{13}C/^{12}C \right)_{\text{standard}}} - 1 \right) \times 1000\%
\]

Note the δ (a lower case Δ). Whereas Δ indicates the difference between two numbers, a ratio, δ is the difference between two ratios, a ratio of a ratio. Basically, δ^{13}C is the ratio of the ^{13}C:^{12}C ratio of the sample to the ^{13}C:^{12}C ratio of the standard. The standard for δ^{13}C is the limestone fossil of the mollusk *Belemnitella americana* from the Cretaceous Peedee belemnite (PDB) carbonate from South Carolina (Boutton 1991). It is important to note that this is reported in per mil, and not percent.

The carbon 13 values from both Ashmore Farm and Ripley are reflective of C3 feeders, indicating that the deer were not feeding extensively on C4 plants, in this case maize (see fig. 2). The mean δ^{13}C values for Ashmore Farm and Ripley are -22.13 % (±0.36) and -22.70 % (±0.56), respectively. The range for Ashmore farm is -22.62 % to -21.58 % and Ripley is -23.56 % to -21.73 %. These are decidedly light samples—the lower range for exclusively C3-feeders according to most literature is between -21.5 % and -26.0 %, with the upper range for C4-feeders around -9.6 % to -6.0 % (Cormie and Schwarcz 1994, Katzenburg et al. 1995).

Linear mixing models are used to help determine what foods account for what percentage of the diet (Schwarcz 1991). Basically, if δ values (of any isotope) are known for plants, essentially the δ value of the animal can be plotted against that to determine the percent each plant makes up of the animals diet. With deer in the Northeast, we are
working with 'maize' (C4) and 'not-maize' (C3) as endpoints, and therefore we are looking for the proportion of C4 plants contribute to the diet. The equation looks like this (Emery 2000):

$$\text{Percent C4} = \left[ \frac{\delta_{\text{collagen}} - \delta_{C3}}{\delta_{C4} - \delta_{C3}} \right] \times 100$$

Basically, the percent of the diet that is composed of C4 plants is determined like a normal percentage—part over whole, multiplied by 100. The difference between the $\delta^{13}$C values of the 'maize' (C4) endpoint and the 'not-maize' (C3) endpoint determines the range, or the 'whole'. The 'part' is the difference of the $\delta^{13}$C values of the collagen and C3, the additional 5% subtracted to account for fractionation. Because the collagen is replacing the C4 in the numerator, we are determining percent C4; determining percent C3 could be determined in a similar manner, with collagen replacing C3 in the numerator. Normally, endpoints are given as -7.5 % and -21.5 %, as stated previously. Since my results are lighter, however, than the average $\delta^{13}$C values given, the percentages come back negative (see fig. 2). It is imperative to correct endpoints, determined by the local flora.

Despite what might be expected, given the heavily maize-influenced $\delta^{13}$C values of humans from the area (Schwarcz et al. 1985, Katzenberg et al. 1995), my results are not that different from the results of other animal studies. In Ontario, Katzenberg (1989) reported on 10 prehistoric, contact period white-tailed deer with a mean of -22.2 ± 0.3 %o. Cormie and Schwarcz (1994) reported on modern white-tailed deer from across North America. The relevant locations were West Virginia (mean= -18.6 ± 1.3 %o), Ohio (mean= -24.7 ± 1.7 %o), Ontario (mean = -22.5 ± 0.2 %o), and Quebec (mean = -21.4 ±
2.4 %—peak at -18.7 % and -22.9 %). Moderate maize consumption gives $\delta^{13}$C values around -18-19 %, which is evident in some of the modern samples; however, the rest of the samples hover below -22%. Therefore, while the results of this study seem very negative, they are not very different for results from the region.

**Discussion:**

The results from this study are lower than the average expected maximum for C3 consumption, and yet the collagen was good. Therefore, there are two issues to discuss: first, what these results mean in general, and secondly, what they mean specifically about the garden hunting question.

As noted previously, $\delta^{13}$C values vary spatially and temporally, and therefore, the context of the bone within the site, and the site within the ecosystem is vital to good interpretation. This includes the basics. For example, the Ripley site probably had at least two different occupations between AD 1300 and AD 1600 (Neusius 1998, Neusius and Neusius in print). As all the bone from the Parker collection was unprovenienced, to which component it belongs cannot be determined. In this case, radiocarbon dates could place the bone in a particular occupation, which in turn links it with ecological data.

Today, $\delta^{13}$C values vary widely by region (Connie & Schwarz 1994), as they would have prehistorically, making extensive paleobotanical and environmental reconstruction significant. Paleobotanical data indicates the importance of wild and domestic plants, whether for sustenance or other activities. More generally, it contributes to environmental data, creating reconstructions that can help determine things like carrying capacity. For this study, this kind of information would have been helpful, including what plants were available locally, and more specifically, which plants were
being cultivated (the latter being somewhat more difficult than the former), as well as carrying capacity, as an indication of the amount of stress the environment was under.

Extensive paleobotanical materials also aid isotopic analysis. Linear mixing models must have accurate endpoints to be effective. Without good endpoints, the results are simply wrong—this cannot be reiterated enough. Since $\delta^{13}C$ values vary regionally and temporally, the most accurate values will come from paleobotanical material on site (Schwarcz 1991). If they are not available for destruction, modern plants can act as a proxy, but with a couple of precautions. First, it must be remembered that the ecosystem has changed since the time period in question, due to reasons including the introduction of foreign species, urbanization and cultivation. Second, the industrial revolution has increased atmospheric CO2. Since 1744, the $\delta^{13}C$ has increased from about 6.5‰ to 8.0‰ in 1990 (Van Kliken et al 2000). When working with isotopes, regional variations needs to be accounted for, and thus, just as faunal data must act as a baseline for human isotope studies, plant materials ought to be the baseline for animal studies.

There are many other isotopes that provide other information, increasing the depth of knowledge about particular bone samples. One of the most common is nitrogen. Nitrogen levels are determined by how the plants obtain nitrogen—through soil or through nitrogen fixing bacteria (Tykot 2003). This is frequently used as an indication of farming, because legumes and the use of fertilizer change nitrogen levels in the soil (Emery 2001). They also vary according to whether the plant's nitrogen source is terrestrial or marine (Schoeninger and DeNiro 1984). Like carbon, fractionation continues to occur as nitrogen moves up through the trophic system; however, because starvation causes the body to process its own muscle as an energy source, this causes
further fractionation and the nitrogen appears to be from a higher trophic level (Gannes et al. 1997). In addition to nutrient stress, water stress may be expressed in the nitrogen levels of animals, but this is tempered by how water stress is expressed in the plants they eat (Cormie and Schwarcz 1996). There are several other useful isotopes, and they are all similarly complex. Their use, however, provides context and clues for interpretation.

Since there is a lot of room for assumptions in isotope studies, the technique is open to misuse. This study is missing many of the afore-mentioned controls. That said, assuming that the $\delta^{13}C$ values actually do indicate a lack of maize in the deer’s diet, there are a number of interpretations that are relevant to the garden hunting question posed in this thesis.

Due to deer’s physiology, they have a relatively predictable feeding pattern. Deer only have one rather small stomach, with limited ability to break down cellulous. As a result, in order to acquire the proper amount of nutrients, the food deer eat has be able to be processed fairly quickly (i.e. at about the same rate it is being eaten). Higher cellulous levels slow down this process because it is more difficult for them to digest. Deer are highly selective, preferring nutrient dense and easily digested plants; while their range of available foodstuffs may be large, they prefer to focus on a few main sources. (Fulbright and Ortega 2006)

Deer’s preferred food is first the leaves and flowers of forbs, net-veined non-woody plants. This is followed by the new leaves and shoots of browse, or woody plants like shrubs and trees. Other forage, including mast, grasses, and lichens, are eaten only when preferred foods are unavailable (Fulbright and Ortega 2006). Maize is the only grass with low enough cellulous levels that deer can easily digest it (Fulbright and Ortega...
2006). Forest edge environments, including those created by fields, are where these food sources are most likely to be found. So, if deer will eat maize if it is available, why do these deer not have any signs of consuming it in this study?

There are three general possibilities that may explain why maize does not appear in the deer's diet, which will be explained in detail. First, perhaps there were effectively no gardens from which the deer could feed. Conversely, maybe there were gardens, but the deer were not eating from them. Finally, while the presence of maize in the deer's diet implies that they were feeding from maize and were therefore garden hunted, the lack of maize in their diet does not imply that they were not being hunted in anthropogenic environments.

Originally, maize was domesticated in Mesoamerica and disseminated northward. The exact route and time of its arrival in the Northeast is hotly debated (see Riley 1990, Hart 1997, Fritz 1995). Macrobotanical remains, however, have been carbon dated to well before the Late Prehistoric (Dragoo 1979, Riley 1990). Isotopic evidence from Ontario, New York, Ohio and Illinois also indicates that by the Late Woodlands/Late Prehistoric maize was integral enough to human diet to appear in their bone (Schurr 1992). Katzenberg et al. (1995) and Schwarcz et al. (1985) in southern Ontario find the distinctive increase in δ¹³C values from AD 400 to AD 1000 indicating the importance of maize by the Late Prehistoric.

The first possibility is that there were no gardens at all. Maize was present in this area during the Late Prehistoric. More specifically, it was found at both the Ripley and Ashmore Farm sites (Sidel in press, Chiarulli 1998). This means that people were consuming maize, and maize should have relatively available to deer. If maize was
present on these sites, it must have come from somewhere. Ashmore farm is a hamlet site, as noted previously, and thus fields probably existed nearby. There are, however, debates as to the purpose of Ripley. If Neusius (1998) is correct, and this is a multipurpose mortuary site, then there would not have been fields. The maize found there may have come from the villages where people lived, and if deer were brought from the villages, they should then have evidence of maize consumption. Deer obtained on-site would not have had access to maize; they would have been browsers only. Therefore, while it is likely that there were fields at Ashmore Farm, this is a possible explanation for why maize does not show up in the diet of deer from Ripley.

The second possibility is that the deer were not attracted to the gardens. While this is complicated issue, the basic assumption is that the prehistoric environment was structured differently from our modern one. The argument is ecological, dependant on the deer’s population pressure. Since maize is a second-line food source for the deer, their attraction to it competes with their fear of people. Therefore, if deer were adequately supported by their environment, then they would not have needed to go into the field to feed.

The presence of humans may increase or decrease the deer’s population pressure, as can be seen by the following hypothetical example. If one assumes that the deer start in a state of equilibrium with their environment, when humans expand into the forest to make space for fields they actually decrease population pressure by increasing edge environments. This in turn would cause the deer population to grow. The maize in these fields are also adequate deer fodder, so depending on how tame the deer are, by
consuming maize they may expand their population beyond what the natural environment can support, making them dependant on maize.

If the preceding hypothetical process is applicable to the northeast during the Late Prehistoric, the question is where in that process are these ecosystems? The applicability of the process, much less the answer to that question, cannot be determined without extensive focused environmental and population reconstructions. Deer may have been attracted to, and therefore hunted in, the fallows. There is some evidence of this in journals of European explorers, where either they themselves or the Indians hunted there (Grant 1959, Webster 1983). Doolittle (2002) argues that while there were modifications to the landscape, they were of a more permanent variety than swidden agriculture. Therefore the deer population may have been depleted due to hunting or a learned fear of humans. Much like what Speth and Scott (1989) propose, this would force humans to hunting increasingly further away from their villages, decreasing the chance that deer would have been feeding on maize. Either case is plausible, though more tests are needed.

As Tykot (1996) mentions, referring to the semi-domestication of Mayan deer: “evidence of maize consumption would support the semi-domestication hypothesis while the converse is not necessarily true.” The final possibility, then, is that the deer were still eating in anthropogenic environments, but not feeding from maize. These include both sericulture and fallow fields. There is some ethnographic record of woody plant cultivation in the Northeast at the time of European contact (Doolittle 2000). There is no archaeological evidence of such practices; however, the historic disturbance and humid climates of the northeast are not predisposed to preserving evidence of cultivation. Deer
may also be attracted to browse in fallow fields. Since these are not active, this is not technically garden hunting, though deer might have been hunted in this environment. These activities would be a source of the C3 browse that deer prefer, in the garden ecosystem.

Conclusions

Based solely on the isotopic evidence, one cannot definitively say whether or not garden hunting was occurring in these cases. Though inconclusive, the results are intriguing. While the deer were not eating maize, that alone does not eliminate the possibility of garden hunting. This suggests a new direction in research, focusing more on the isotopic data of local flora.

Generally speaking, archaeologists who simply use isotopic data without delving into its greater complications are abusing the technology. There are a number of archaeologists doing good work, taking all the factors into account. Unfortunately, however, perhaps it is too easy to ignore the fact that without a good context, isotopic data cannot be properly interpreted. That being the case, the results of this study do not have enough context to be properly interpreted, and if I were to continue this research, filling in those gaps and defining parameters would be the first step.

As to the usefulness of isotopes for determining garden hunting in general, these results are promising, but more isotopic analysis is needed. For example, sampling deer from a site where garden hunting is documented would give us an anchor point to compare other data from that region. There is also a growing pool of isotopic data from prehistoric deer, and though none of it is applied to the garden hunting question, it could be used in that manner. Big picture work is as important as the finer details.
There are many issues that can be addressed with isotopic analysis, and my thesis has convinced me that it is a feasible technique for archaeologists to master. That being the case, however, it is almost dangerous because it presents a simple façade to a complicated topic. Therefore, it is useful, but the intricacies need to be kept in mind.
### Figures

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<th>C:N (Atomic)</th>
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<th>Corr d13C (%o, vs VPDB)</th>
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Figure 1
Expected range for moderate consumption of maize by deer (10-30% of diet)

Lower endpoint for maximum C3 based on literature

Figure 2

Figure 3
Figure 4
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