LATE WOODLAND NANTUCKET DIET

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Cover: Part of a group of about 100 seals (probably Harbor seals) hauled out on the rocks of the jetties at the entrance to Nantucket Harbor 9 January 1991.

ABSTRACT

Carbon and nitrogen isotope studies for seven human burials of the Late Woodland Period between cal A.D. 1100 and 1450 at Nantucket Island, Massachusetts, provide data for evaluating proposed human diets of coastal southeastern Massachusetts. Analyses of botanical and zoological remains in archaeological deposits, 17th century historic reports and optimum foraging models suggest the constitutents of the proposed diets. The measured isotope values of these dietary items contribute coefficients for mixing equations for dietary $\delta^{13}C$ and $\delta^{15}N$ values deduced from the isotope values of bone collagen. And, finally, computer analysis of the multiple linear mixing equations gives allowable ranges of the percentages of dietary groups in the diet. The results consistently argue for a high (50%) fish and sea mammal diet at Nantucket that also included either 35%-45% animals of the saltmarsh and eelgrass beds of the harbors (i.e., lobsters, eels and probably geese) or up to 30% maize. Supplemental dental and $\delta^{13}C$ (bone apatite) analyses reject a high maize alternative.

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4/6/91

INTRODUCTION

Many sixteenth and seventeenth century European explorers of the southeastern coast of New England remarked on the stature and appearance of the inhabitants. "These people are the most beautiful and have the most civil customs that we have found on this voyage. They are taller than we are.... They live a long time, and rarely fall sick,...their end comes with old age" (Verrazano in 1524 at Narragansett Bay, RI; Wroth 1970:137-140). They are "tall, big boned men: well conditioned, excelling all others that we have seene: so for shape of bodie and lovely favour, I think they excell all the people of America; of stature much bigger than we" (John Brereton at the Elizabeth Islands, MA; 1602:4,10). "The men are of stature somewhat taller than our ordinary people, strong, swift, well proportioned..." (Martin Pring in 1603 at Plymouth, MA, in Howes [1969: 72]). Considerable practical interest attends the answer to the question we pose here: what were these coastal native Americans eating?

Analyses of botanical and zoological remains in archaeological deposits, 17th century historic reports and theoretical frameworks such as optimum foraging models, suggest various diets for Late Woodland and Contact period peoples of the coast of Massachusetts. For the purpose of testing alternative human diets, the values of stable isotope ratios and some elements in bone and dental caries have been shown to be related to the diet. For this study we determined the $\delta^{13}C$ and $\delta^{15}N$ isotope values for samples of bone collagen from seven radiocarbon-aged Late Woodland Nantucket Island burials and for a range of Nantucket dietary items. These data contribute coefficients for a set of linear mixing equations for the $\delta^{13}C$ and $\delta^{15}N$ of the total diet. The very high $\delta^{13}C$ and relatively high $\delta^{15}N$ values measured for human bone collagen allow us to reject a diet of less than 34-60% ocean fish and sea mammals. The remainder consists of small amounts of terrestrial C_3-based foods, bivalves, gastropods, and crabs, and either a large quantity of such foods as lobsters, eels and geese from high $\delta^{13}C$ food webs based on spartina and eelgrass of the shallow marine waters of Nantucket, or, alternatively, the high $\delta^{13}C$ maize. The very low incidence of caries before cal A.D. 1450 supports a low maize hypothesis. Strontium and zinc measurements on Nantucket human bone suggest a large amount of fish and/or maize in the diet, and $\delta^{13}C$ values of bone apatite indicate that about 84% of the diet consisted of animal products. The consistency of all these studies argues for a diet that is made up primarily of marine animals, with most of the energy deriving from marine animal fat and protein, and a small amount of marine or terrestrial C_4 vegetables.

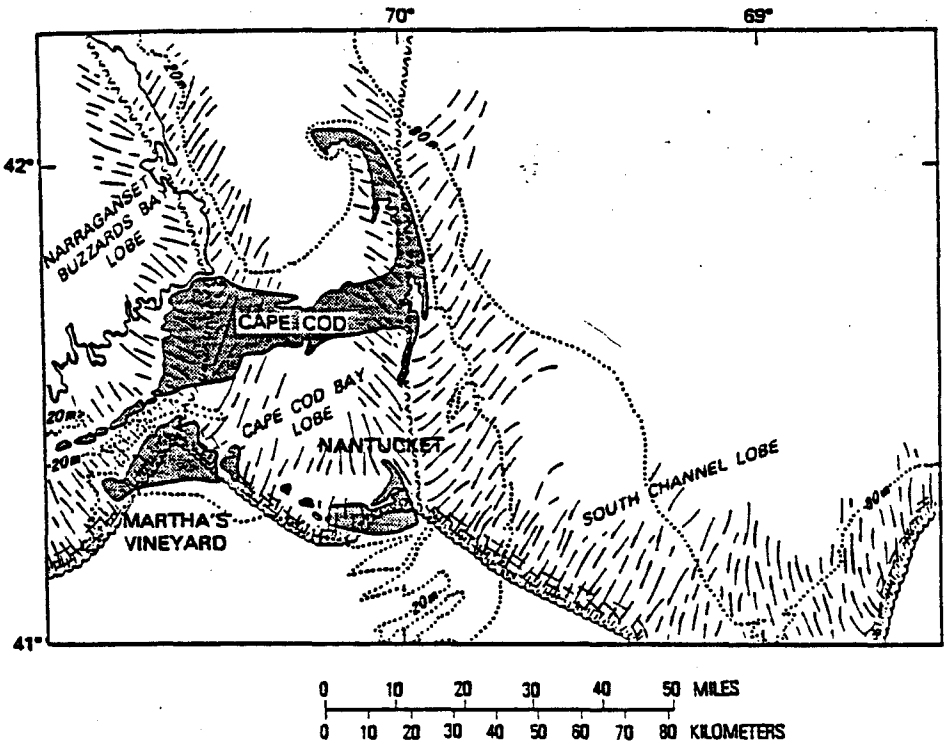

Figure 1. Map showing location of Nantucket, Martha's Vineyard and Cape Cod, the glacial lobes, and inferred limit of the late Wisconsinan ice (Oldale 1985).

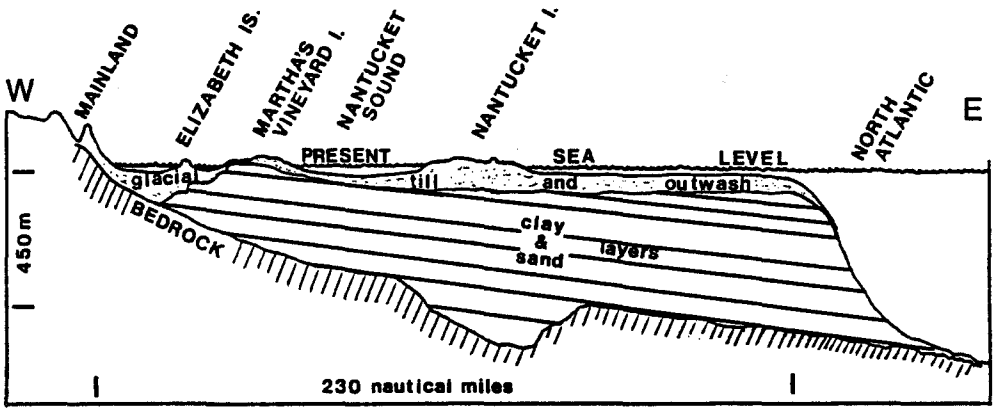

Figure 2. Diagrammatic cross-section showing surficial glacial deposits, substrate of tertiary/cretaceous sand and clay, and bedrock at Nantucket (after Kohout et al. 1977:383).

BACKGROUND.

Geology. Nantucket is a small sandy island 40 km south of Cape Cod. The last Wisconsinan ice sheet at its maximum extent more than 18,000 years ago covered most of the island (Figure 1), and an end moraine may be traced from Nantucket through Martha's Vineyard and Long Island to New Jersey. In retreat to the north the ice fronts of the Cape Cod and South Channel lobes, their meltwater and climatic processes laid down the sequence of ice contact deposits, outwash plains and aeolian deposits consisting of clay, silt, sand, gravel and occasional boulders that today form Cape Cod and The Islands. The morainal hills, sand plains, barrier beaches, salt and fresh marshes, harbors and kettle ponds of Nantucket sit atop the Coastal Plain formation, which here lies below sea level (Oldale 1981, 1985; Figure 2).

Compared to many parts of the United States, the climate is rainy, often foggy, and has warmer winters and cooler summers than the adjacent mainland due to the temperature moderating effects of the ocean. There is a 165 day frost-free growing season, May 7 to October 17 (Langlois 1977), more than adequate for maize.

Sea Level. When the ice front was at its maximum advance, sea level was perhaps 100 meters lower than today, and a large amount of the continental shelf was dry land (Oldale 1976). Evidence for this is given by mammoth and mastodon teeth dredged up by fishermen on Georges Bank and elsewhere off the coast of Massachusetts (Oldale 1987). As the ice has melted sea level has risen, and the sea has transgressed and eroded the shores on all sides of Nantucket for the past 5000 years (Oldale 1985, 1986; Gutman et al. 1979). Once a high place on the mainland with fresh water lakes to the north, it is today only a small unstable sandy island surrounded by the sea. Storm seas, which erode the shores, also deposit useful resources, such as live surf clams, scallops, quahogs, fish, lobsters, whales and firewood on island beaches (Little and Andrews 1982, 1986).

Ground water. Rainwater is stored in a lens-shaped ground-water aquifer floating on saltwater in the sandy substrate of the island (Walker 1980; Kohout et al. 1977). Ponds occur where the land is lower than the water table; in areas of clay deposits, there are perched ponds. With an area of about 130 square kilometers, there are no rivers, and freshwater input into tidal creeks and harbors is inadequate to create estuaries as they are normally defined (W. Tiffney, personal communication 1989).

Soils. The soils (Langlois 1977) which developed on the post-glacial surface show the influence of the glacial substrate. For example, the sand and gravel outwash deposits are acidic, very porous and too droughty for agriculture. A very limited number of small patches of good agricultural land exist on the island.

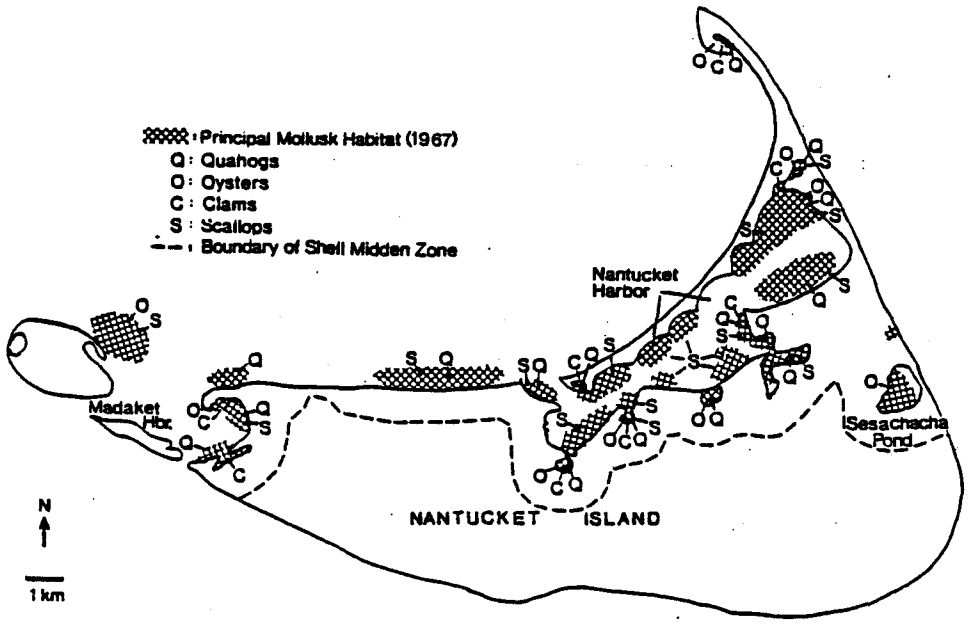

Figure 3. Principal shellfish habitat at Nantucket (after Zube and Carlozzi 1967; J. C. Andrews, personal communication 1984), and prehistoric shell midden zone adjacent to modern shellfish habitat (Little 1986).

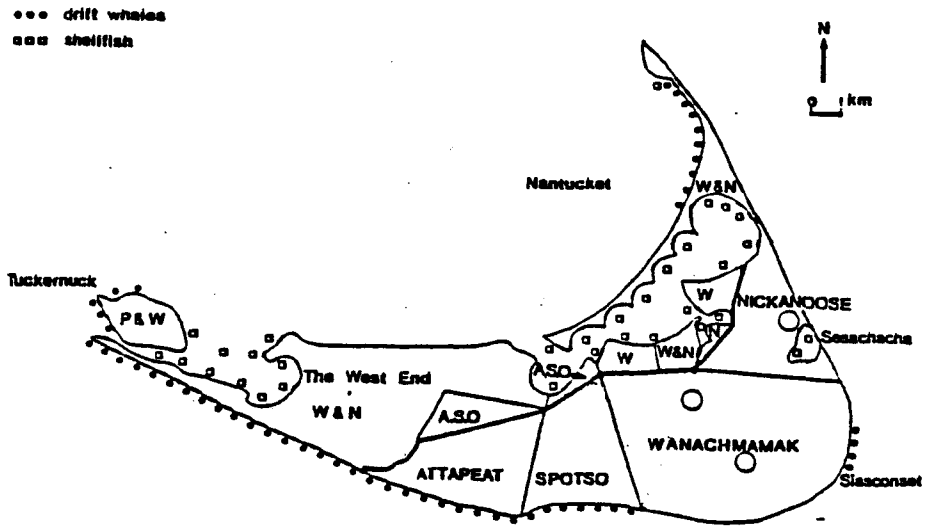

Figure 4. Territories of the major sachems at Nantucket and Tuckernuck in the late 17th century; place names are shown lower case. Lands sold the English by 1684 are marked by the grantor's initials (including O: Obadiah, P: Pattacohonnet). Circles indicate approximate locations of meeting houses (after Little 1982a).

Pollen Studies. Peter Dunwiddie, from pollen cores taken from a bog and pond at Nantucket, reports that mixed oak forests dominated the vegetation on the island throughout most of the Holocene. Patches of heathlands and grasslands probably existed only in exposed coastal areas with poor soils, and following fire or forest clearance by humans. By increases in grasses, composites and other agricultural weeds, the pollen record demonstrates rapid forest clearance after English settlement about 1660 A.D. (Dunwiddie 1989, 1990).

CULTURAL HISTORY OF NANTUCKET.

Archaeology. Archaeological studies, including a survey funded by the Department of the Interior through the Massachusetts Historical Commission in 1978 (Little 1979; Luedtke 1980), provide a substantial database for research and cultural resource management. Sites have been located, collections inventoried, and analysis begun (Carlson 1990; Little 1983, 1980b; Luedtke 1986). All styles of northeastern projectile points are found here, including eastern Clovis, with an emphasis on Middle and Late Archaic and Middle and Late Woodland styles. Barbed bone harpoon points and stone whaletail forms are rare (Little 1979). The local glacial drift contains most of the lithic materials used by prehistoric Nantucketers for stone tools, except soapstone (steatite), New York cherts, and Pennsylvania jasper (Luedtke 1987). The sites predominantly have southeasterly aspects, with protection from the northwest winter winds (Little 1985b). Woodland shell middens, which are located along the shores of harbors and tidal creeks, contain evidence of fish, crustaceans, birds, turtles, deer and occasional seal and whale (Little 1984, 1986; Little and Andrews 1982, 1986; Figure 3); we attribute the lack of Archaic Period shell middens to coastal erosion (Pretola and Little 1988). Sometime after Nantucket became an island, most of the native animals were extirpated, leaving only birds, snakes, bats, mice and voles; deer and rabbits have been reintroduced.

Explorers and English Settlers at Nantucket. Historians know little about Nantucket during the early Contact period, because European mariners tried to avoid the dangerous shoals which defend the island on the south and east (Howes 1969). In addition, as a result of European expeditions which captured Indians from the Cape and Islands to exhibit or sell, Nantucket in 1634 was full of as many as 3000 (Macy 1792) probably hostile Indians (Howes 1969). This can account for the relatively late date, 1659, at which Thomas Mayhew purchased a piece of land from the Nantucket Sachems, and the recorded history of the island began.

After 1659, about 34 Englishmen, in part to escape Massachusetts' Puritanism, moved their families and livestock from the north shore of Massachusetts to Nantucket Island, which was claimed by both Sir Ferdinando Gorges and the Earl of Stirling. By 1670, the island was under the jurisdiction of Fort James, New York, and by 1692 became a part of the province of Massachusetts (Byers 1987; Macy 1792; Starbuck 1924; Worth 1913).

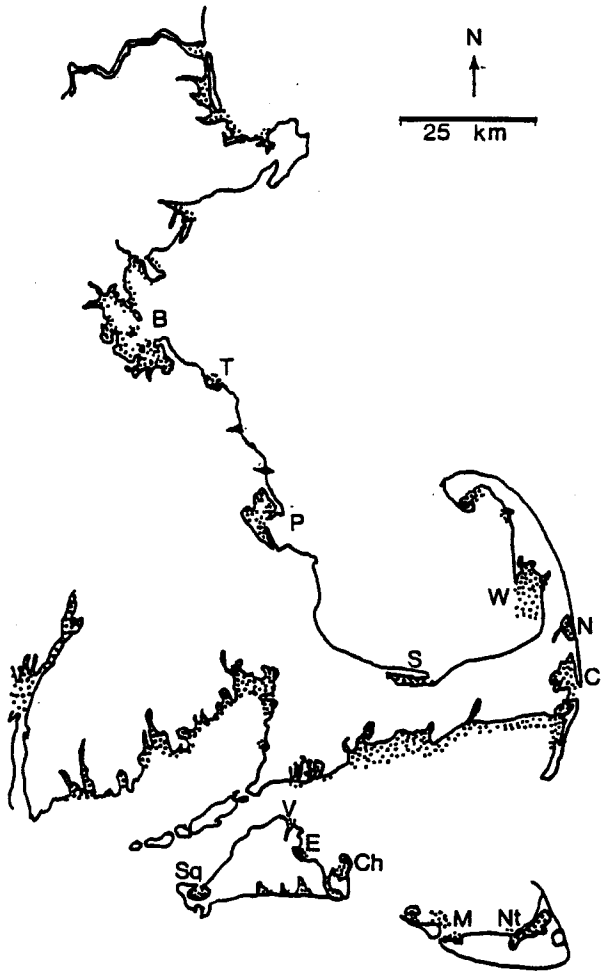

Figure 5. The distribution of shellfish beds (dots) along the coast of Massachusetts in 1909 (after Belding 1909), showing the discreteness of their locations (which are subject to change with time [Little and Andrews 1986]). Estuaries considered in the text are indicated by letters, B: Boston; T: Scituate; P: Plymouth; N: Nauset Harbor; S: Sandy Neck; C: Chatham; W: Wellfleet; Sq: Squibnocket Pond; V: Vineyard Haven; E: Edgartown Harbor; Ch: Chappaquiddick; M: Madaket; NT: Nantucket.

The Indian sachemships or townships that were the primary political, social and economic groups on the Cape and Islands (Salwen 1978; Simmons 1986) do not show the degree of organization required to be called 'tribes'. Deeds indicate at least five sachemships on Nantucket, each with a sachem or squaw sachem and his or her relatives, as well as its common Indians (Little 1982a). Figure 4 shows the lands sold to the English through 1674 by five sachems, Obadiah, Spotso, Attapeat, Wanachmamack and Nickanoose as determined by analysis of deeds and memoirs.

Historic Records. From early English proprietors' and County records, we learn that the Indians kept dogs, burned their planting fields in April, planted corn, harvested in October, used reeds, flags and beach grass for making mats and baskets, caught fish in weirs and owned bows (Little 1976). Both the historic Indians and the English owned canoes, probably dugouts, for water transport and fishing (Little 1981d), and some wigwams served as dwellings until the late 18th century (Little 1981a, 1981c). The Indians spoke and, after 1663, wrote in a dialect of Massachusett (Little 1980a, 1981b; Goddard and Bragdon 1988).

According to a report of the Reverend James Freeman (1807), the original Nantucketers were acquainted with boiling but not with roasting, and cultivated only maize, beans, squashes and tobacco.

> "They could now and then kill a bird; and there were a few deer;.... Fish could be obtained in the harbours, and on the coast; and shell fish were abundant. During winter however, they frequently suffered the extremities of famine. Their clothes were sometimes skins, but for the most part coarse mats, made of grass" (Freeman 1807:35).

Other first-hand observers of historic Nantucket wrote:

> "The natives of Nantucket were a kind people, and very friendly to each other.... If the English entered their houses, whilst they were eating, they would offer them such as they had, which sometimes would be very good. At their feasts they had several sorts of good food, and very good strong beer" (Z. Macy 1792).

> "The better sort among them were quiet, peaceable and industrious, and occupied the land around their dwellings with gardens, wherein they raised corn and vegetables of various kinds, some of which they sold to the English. They frequently had fruit trees in their gardens and near their houses" (O. Macy 1842 in Starbuck 1924:612).

The Whaling Industry and Indian Epidemic of 1763. Documentary evidence from deeds and court records (Little and Andrews 1982) as well as traditional legends show that a number of western sachems came from Martha's Vineyard in the mid seventeenth century to carry on drift whaling, i.e., extraction of oil and baleen from the carcasses of dead and stranded whales. Massasoit, sachem of the Pokanokets, had a role in assigning the rights to drift whales at Nantucket. After 1690, Indians provided whaleboat crews for shore-based whaling on the European model, and, after 1712, for western North Atlantic pelagic whaling between Greenland and North Carolina (Little 1981e, 1988a). The lay system of sharing the proceeds and the light cedar whaleboats may have been southern New England or eastern Long Island Indian innovations (Little 1981e).

In 1763, the year the Nantucketers first hunted whales off the coast of Africa, an epidemic called "yellow fever", with an 87% mortality rate, essentially destroyed the Nantucket Indian community (Little 1990).

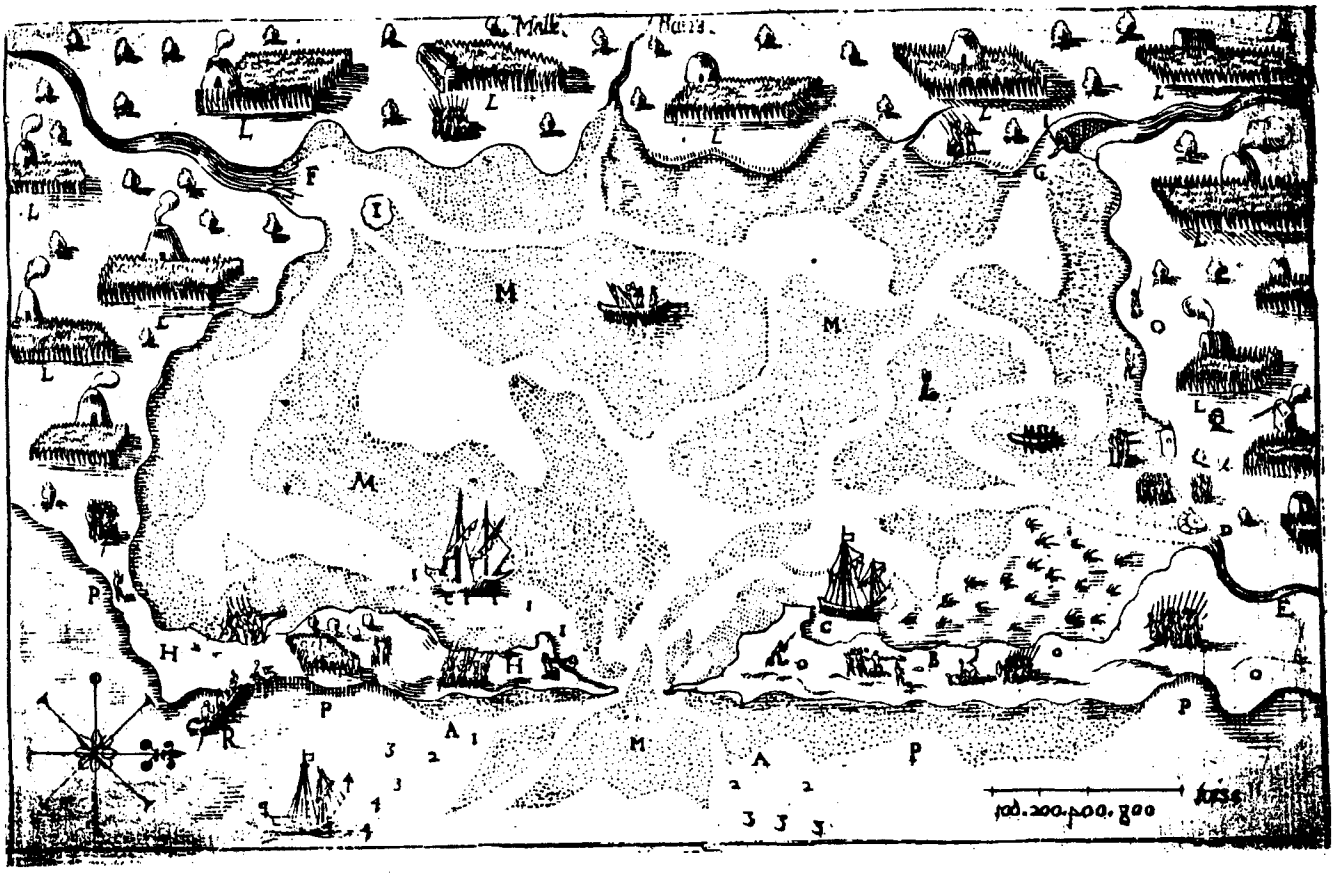

Figure 6. Sketch of Nauset Harbor, Cape Cod, in 1605-6, showing Indian wigwams with cornfields (Champlain 1880).

Hypotheses Concerning Estuarine Settlement Patterns. The distribution of shellfish beds along the coast of Massachusetts is not only discrete, but correlates with harbors and modern urban settlements. From the north, we can name Boston, Scituate, Plymouth, Barnstable, Wellfleet, etc., by their shellfish beds (Figure 5).

We can also associate shellfish beds with the territories or towns of specific sachems (Little 1988b). For example, the four sachemships on Martha's Vineyard each include a harbor (Nohtooksaet of Gay Head [Sq], Mankutoukquet of Chilmark [V], Tewanticut of Tisbury [E], and Pahkepannassoo of Chappaquiddick (Ch)), and for Cape Cod ("Francis, the Nauset sachem" [NCD 1:5] and Mattaquason of Monomoyick [Chatham]). Nantucket has two harbors, Madaket (M) and Nantucket (NT), and the traditional "two tribes" (Freeman 1807) were led by Wanachmamack and

Nickanoose on the east and Attapeat and partners on the west. With time the sachemships were divided among heirs, and boundaries moved (Little 1982a; Figure 4).

Shell middens are found in the vicinity of shellfish beds. At Cape Cod, McManamon and Bradley (1986) propose that dispersed sites on Nauset harbor, with high concentrations of shell, lithics and bone, represent the year-round village of Nauset, described in the summer of 1605 by Champlain (Figure 6) and as early as 3500 B.P. by archaeological evidence (see also Renouf 1984). The borders of all harbors and tidal creeks at Nantucket also exhibit dispersed shell midden sites (Figure 3). At Nantucket, Martha's Vineyard and Nauset, the large Woodland shell concentrations lie on the SE of hillsides near shellfish beds (Little 1985b, 1988b; McManamon 1984; Ritchie 1969), and Little (1985b) has proposed that protection from the prevailing Northwest winter winds would have confined people in winter to sheltered sites on the southeast of hills. Carlson (1990) has shown that the fish bones identified at one locus of the Quidnet Site, Nantucket, are from fish only available in summer; except for an otolith, the bones of codfish, a locally common fish of fall, winter and spring, are notably missing. In summary, shell middens, the major archaeological deposits on the Cape and Islands, are not telling us unambiguously about seasonality, degree of sedentariness or dietary components other than shellfish, deer and a small amount of a wide variety of seafoods.

Prehistoric Burials. Most Contact/Historic Period Indian burials in New England have been found in sizeable cemeteries of 50 or more flexed burials, usually associated with European grave goods, and a head orientation toward the southwest, the location of both the after life and the source of maize and beans (Robbins 1959; Simmons 1970:64; Williams [1643] 1936; Kelley et al. 1987a). A number of small cemeteries commonly have single flexed burials with no preferred orientation and no grave goods (Little 1985a; Haaker 1984). ^{14}C dates of cal A.D. 1020 (1133) 1250 (Fowler 1956; uncorrected 800 $\pm$80 B.P.; oyster shell; Note 1) and cal A. D. 999 (1030) 1166 (Pretola and Little 1988; uncorrected 960 $\pm$80 B.P.; charcoal) for one such cemetery in Rhode Island and one at Nantucket supports the proposal (Bradley et al. 1982:57) that isolated flexed burials are prehistoric. As late as 1623, Edward Winslow of Plymouth (1841:363) reported that an ordinary Indian was buried in or near his wigwam, which was then abandoned. Two ossuaries have been reported on Cape Cod (Bradley 1989), one with a calibrated age of cal A.D. 1110 (1225) 1290 (average of three determinations, human bone with assumed 25% oceanic carbon; McManamon and Bradley 1986).

A site inventory from newspapers of the past 100 years, published reports, and interviews (Little 1979, 1982b, 1983, 1985a), includes reports of 35 unmarked prehistoric burials at Nantucket, all located in areas containing shell middens and thus adjacent to modern shellfish habitat (Fig. 3). Since the passage of the Massachusetts Unmarked Burial Laws in 1983, five prehistoric burials have been professionally recorded (Kerber and Simon 1987; Kerber 1987; Massachusetts Historical Commission files). Because of the Holocene transgression of the sea and the bone preservation, we assume that most of these archaeological bone remains date to some time after 3000 B.P.

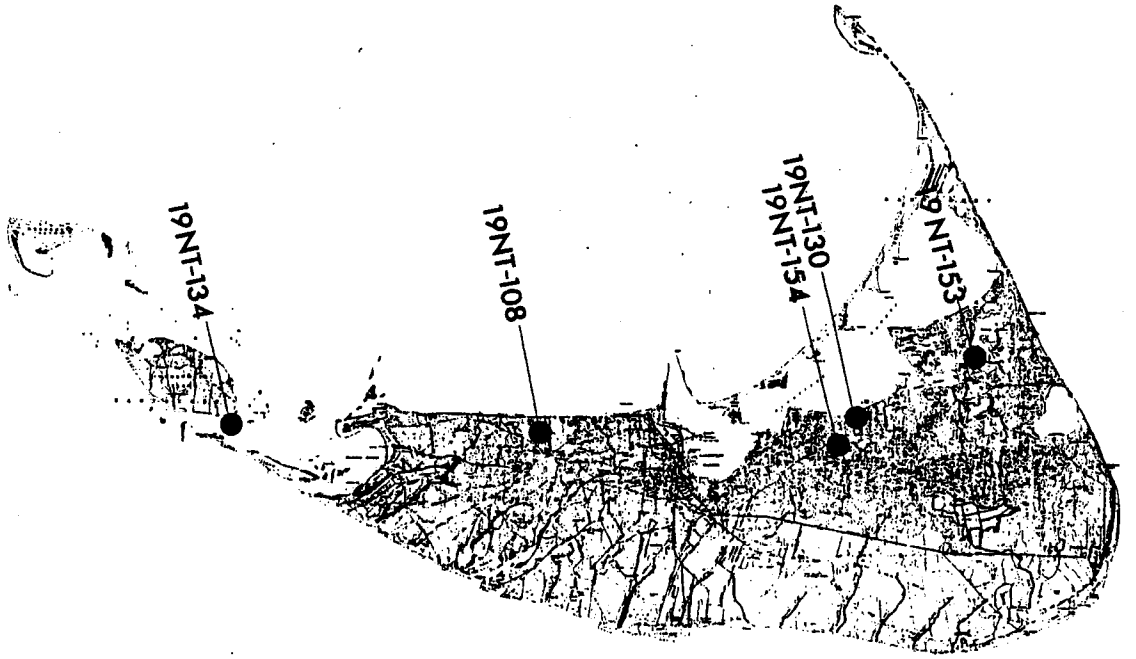

Figure 7. Approximate site locations for seven Late Woodland Nantucket burials.

No reported Nantucket burial has had clearly associated diagnostic grave goods (see also Stockley 1964), although in eleven instances, whelk shells were associated with burials. Although the substrate and even grave fill sometimes contained shell and Early, Middle or Late Woodland lithic or ceramic artifacts, excavators have not been convinced these were grave goods. Burials were predominantly single, lying on their side in a fetal position, situated on southeasterly facing hillsides overlooking shell middens less than 100 m away (Little 1985b). The head orientation of Indian burials at Nantucket was random in direction (Stockley 1964; Little 1985a). The Miacomet Christian Indian Burial Ground discovered and preserved at Nantucket in 1987 contains up to 220 extended burials, mostly victims of a so-called Yellow Fever epidemic of 1763, which were buried by the English town officials in rows with their heads to the west (Little 1990; Simon 1988). All other Indian burials at Nantucket have resembled those presumed to be of the prehistoric period on the mainland.

Most of the burials on Nantucket that have been examined for pathology demonstrate good health, including a low dental caries rate, which suggests that they date from a pre-maize period, with a low carbohydrate to protein and fat ratio (Little 1982b; Trinkhaus 1982; Clabeaux 1973; Walker and Erlandson 1986; Magennis 1986). However, the absence of dental caries resulting from dietary

maize cannot give evidence for a date, because the onset of maize cultivation at Nantucket has not been dated. Radiocarbon aging of samples had the highest priority for this study.

Bone Samples. The present laws in the Commonwealth of Massachusetts, while recommending the preservation of burials in situ when possible, allow scientific studies on human remains recovered from legally permitted salvage excavations of unmarked burials, with reburial after a certain period of study (Massachusetts Acts and Resolves 1983, Chapter 659). Seven prehistoric Nantucket burials provided very small samples of bone for analysis (Appendix I; Little 1982b; Figure 7). Bulldozers during development projects on private land had disturbed the Wauwinet Road and Polpis Road burials (Kerber 1987; Kerber and Simon 1987). Road or beach erosion disturbed the TCM burial (Anderson 1977), the three Tuckernuck burials in 1964, and the Quaise burial in 1916 (Little 1982b).

A very small sample of bone collagen from each burial was radiocarbon dated by AMS or radioactive decay methods. Table 9 gives the conventional radiocarbon ages ($\delta^{13}C$ corrected [Stuiver and Polach 1977]). These ages require correction for the reservoir age of the marine carbon in the diet, and calibration to correct for the changes in ^{14}C production in the atmosphere (Stuiver, Pearson & Braziunas 1986). At Nantucket, food chains based on the spartina in the saltmarshes may contain chiefly modern atmospheric carbon (see the $\delta^{15}N$ data in Figure 8), but fish feeding only upon oceanic food chains could have a certain amount of oceanic carbon, which is older in radiocarbon age by about 400 years due to what is called the reservoir effect (r.e.) (Little, in preparation; Tauber 1981). Calibrated for an assumed diet of 25% marine carbon, three burials have dates about cal A.D. 1408 and four have dates of about cal A.D. 1220 (Table 9). To resolve the question of the r.e. correction for coastal human diets will require radiocarbon measurements of oceanic fish flesh or of charcoal associated with radiocarbon-dated burials.

The Use of Stable Isotopes as Diet Indicators. During photosynthesis plants fractionate the carbon isotopes, ^{12}C, ^{13}C and ^{14}C, because of their small differences in mass (O'Leary 1988). Botanists have found that there are three metabolic pathways used by plants, the C_3 or Calvin-Benson pathway, the C_4 or Slack-Hatch pathway, and the CAM or Crassulacean Acid Metabolism pathway, each of which fractionates carbon isotopes differently (O'Leary 1988; van der Merwe 1982). The $^{13}C/^{12}C$ ratio measured by a mass spectrometer is expressed in the delta (δ) notation as:

$$\delta^{13}C = ([^{13}C/^{12}C_{sample}]/[^{13}C/^{12}C_{PDB\ standard}] - 1) \times 1000 \text{ o/oo},$$

and represents the fractionation relative to a Peedee belemnite (marine limestone) standard per mil. Most temperate North American plants use a C_3 pathway, and most plants using a C_4 or CAM pathway, with isotope ratios up to 18 o/oo higher than those of C_3 plants, are found in the tropics

(O'Leary 1988; van der Merwe 1982). Reflecting the 7-8 o/oo $\delta^{13}C$ difference between oceanic and atmospheric carbon, $\delta^{13}C$ values for marine resources have been found to be about 8.0 o/oo higher than those for terrestrial foods (Chisholm et al. 1982; DeNiro 1987; Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Tauber 1981).

Early studies showed that the carbon isotope ratios of diets are preserved in consumers (DeNiro and Epstein 1978). On this basis, researchers have used a simple mixing equation (Note 2) (Fry et al. 1984) to deduce the proportions of C_3 to C_4 (specifically Zea mays, or maize) plants from the carbon isotope ratios of non-marine consumers' bone collagen, and the relative amounts of marine (oceanic or coral reef environments) and terrestrial foods in the diet of non-maize consumers (Chisholm et al. 1982; Schoeninger et al. 1983; Sealy and van der Merwe 1986; Walker and DeNiro 1986; Keegan and DeNiro 1988).

Similar studies show that $\delta^{15}N$, or $([(^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{air}] - 1) \times 1000$ o/oo, in bone collagen also reflects the $\delta^{15}N$ content of the diet (DeNiro and Epstein 1981). $\delta^{15}N$ is strongly enriched in marine phytoplankton, and moderately enriched in fresh water plants, while nitrogen-fixing plants of coral reefs and salt marshes (Spartina) have the low δ15N values of most temperate terrestrial plants and of air (Capone and Carpenter 1982; DeNiro 1987; Schoeninger et al. 1983; Walker and DeNiro 1986). A number of studies have used these variations, which are easiest to interpret in the absence of maize, to analyze the marine vs terrestrial dietary components of human diet (Schoeninger et al. 1983; Schwarcz et al. 1985; Walker and DeNiro 1986; Keegan and DeNiro 1988).

Current criticisms of dietary reconstruction from isotope values of bone collagen, especially for prehistoric coastal inhabitants for whom up to 90% sea animal diets have been derived, focus on the increased possibility of protein poisoning with a daily input of more than 300 g of protein (50% of daily energy requirement) (Speth 1989; Eaton and Konner 1985; Noli and Avery 1988). Chisholm et al. (1982), Kreuger and Sullivan (1984), Schwarcz et al. (1985), Schoeninger (1989), Sealy and van der Merwe (1986), and van der Merwe (1989) have suggested that for diets with adequate protein, isotopes in bone collagen (protein), reflect only the protein portion of the diet. Since nitrogen is only found in proteins, we will assume that measurements of bone collagen only speak for the protein portion of the diet, and will use protein weighting (Schoeninger 1989; Speilmann et al. 1990) for the nitrogen components and test protein weighting for the carbon components of the equations developed here.

Carbohydrates and fat, available from both plants and animals, provide the basic human energy source (Noli and Avery 1988), and, with proteins, contribute to the bone apatite carbon isotope value (Kreuger and Sullivan 1984). There remain a number of interpretive problems concerning the transformation between diet and animal tissues (Sillen et al. 1989; Price et al. 1985; Nelson 1991).

Maize and Its Introduction to the Northeast. According to an overview of the archaeology of southern New England (Dincauze 1990), although ceramics appeared in New England about 3000

B.P., defining the Woodland Period, archaeological evidence for horticulture is scarce. A major anthropological issue today concerns the date of introduction and the intensity of prehistoric use of maize in this region (Smith 1989). Herb pollen and charcoal deposit density increased at Cape Cod before European settlement in the early 1600's (Winkler 1985), and the onset of an herb pollen rise in Rhode Island dates between cal A.D. 1283 and 1398 (625$\pm$55 B.P., lake sediments; Bender et al. 1978), but at Nantucket, pollen studies have not yet identified maize pollen or kernels nor indicated clearing of land for horticulture until English settlement about 1660 (Dunwiddie 1989,1990). A maize kernel was dated at Martha's Vineyard at cal A.D. 1169 (1252) 1277 (790 $\pm$ 80 B.P. [Y-1653], charcoal, no $\delta^{13}C$ correction, Ritchie 1969:52), but Ceci (1980, 1982, 1990) predicted we might not find any significant coastal use of corn in the northeast until the arrival of European trade and explorers sometime before A.D. 1600. McBride and Dewar (1987) report that, while tropical cultigens may have arrived in Connecticut about 1000 B.P. (uncalibrated), they had no immediate effect on settlement patterns or technology. However, a settlement pattern change took place on the Connecticut River about 450 B.P. (uncalibrated), which they attribute to contact with Europeans and/or increasing reliance on maize. Bumsted (1980) reported a date of cal A.D. 1297 (1418) 1472 (510 $\pm$ 125 B.P., uncorrected) for butternuts associated with maize at a Vermont site.

A tropical C_4 plant such as maize suddenly intensified in the diet of North Americans who had previously eaten primarily from the C_3 food web, markedly raised their bone collagen $\delta^{13}C$. Van der Merwe and Vogel (1978) found that bone collagen from individuals of New York, Illinois, Ohio, and West Virginia between 5000 B.P. and 1350 B.P. (uncorrected, uncalibrated) (diet chiefly C_3 food web) showed an average $\delta^{13}C$ of -21.4 o/oo, while individuals living between A.D. 1000 (about cal A.D. 1050) and A.D. 1300 (uncorrected, uncalibrated) showed a $\delta^{13}C$ as high as -11.8 o/oo. Assuming a simple mixing relationship between the $\delta^{13}C$'s of the diet (Note 2), -11.8 o/oo represents a maize component of up to 69% of the diet protein (van Der Merwe and Vogel 1978). To explore the possibility of determining to what extent maize and marine foods were utilized in prehistoric Nantucket, Massachusetts, we initiated an isotope study of prehistoric human bone collagen and foods from the island.

TABLE 1. NANTUCKET LATE WOODLAND SITES, CALIBRATED RADIOCARBON AGES AND FLORAL AND FAUNAL REMAINS

Ram Pasture 1 (Stockley 1965; Waters 1965; Little 1984): cal A.D. 900 (1015) 1157 (1010±100 B.P., charcoal, no $\delta^{13}C$ correction); deer, dog, vole, pilot whale, eider, teal, sand shark, sturgeon, sea robin, oyster, quahog, ribbed mussel, clam, etc. (no scallop); hickory nut, beach plum, cherry.

Marshall Site pit (Pretola and Little 1988): cal A.D. 1390 (1459) 1550 (385±95 B.P., clam shell, no δ^{13} correction): scallop, quahog, oyster and clam (in order of abundance), deer, sturgeon, striped bass, white perch, winter flounder and other unidentified remains.

Quaise UMass Field Station pit (Luedtke 1980:111,126; Luedtke 1989, personal communication): cal A.D. 1280 (1399) 1450 (565±145 B.P., charcoal, no $\delta^{13}C$ correction); oyster, quahog, whelk, clam, ribbed mussel, slippershell and bone (by weight, mammal 63% [76% deer], fish 37% [24% sturgeon; 24% cod] and bird <1%).

TABLE 2. NAUSET, CAPE COD LATE WOODLAND FEATURES, CALIBRATED (AND CONVENTIONAL, ALL $\delta^{13}C$ CORRECTED) RADIOCARBON AGES AND FLORAL AND FAUNAL REMAINS (Fitzgerald 1984; Borstel 1984):

#323; Age: cal A.D. 1640 (1673, 1753, 1796, 1945) 1950 (180±115 B.P., charcoal); cal A.D. 1500 (1656) 1810 (590±110 B.P., M. mercenaria); quahog and maize kernel.

#308.33; Age: cal A.D. 1270 (1393) 1480 (910±145 b.p., M. mercenaria); Bone: 80% mammal, 14% fish, 6% bird; quahog, oyster, clam.

#341.24; Age: cal A.D. 1240 (1318) 1440 (970±120 B.P., M. mercenaria); cal A.D. 1000 (1163) 1270 (890±150 B.P., charcoal); cal A.D. 1050 (1255) 1380 (1090±155 B.P., M. mercenaria); 53% mammal, 43% fish, 4% bird; carbonized seeds and nuts, quahog, clam.

#341.21; Age: cal A.D. 1180 (1302) 1430 (1000±145 B.P., M. mercenaria); cal A.D. 770 (971) 1130 (1375±155 B.P., M. mercenaria); 85% mammal, 9% fish, 6% bird; quahog, clams, terrestrial and marine mammals, reptiles.

#308.51; Age: cal A.D. 1060 (1266) 1390 (1075±150 B.P., M. mercenaria); quahog, oyster, clam.

#341.23; Age: cal A.D. 1000 (1266) 1450 (1075±110 B.P., M. mercenaria); cal A.D. 1040 (1238) 1340 (1110±150 B.P., M. mercenaria); 94% mammal (includes deer), 2% fish, 4% birds; quahogs, carbonized seeds.

BASES FOR DIETARY HYPOTHESES.

Archaeological Evidence for Diet in Late Woodland Nantucket. Because most of the 35 burials are associated with shell midden, we examine the contents of the shell middens for prehistoric foods at Nantucket. Most of these middens have multiple components, and artifact styles indicate dates from the Middle (cal 400 B.C. - cal A.D. 960) and Late Woodland (cal A.D. 960 - 1460) Periods (Little 1979; Pretola and Little 1988). Table 1 shows all the reported archaeological Late Woodland foods from Nantucket (see Appendix 3 for list of archaeological foods reported from Nantucket). Lacking substantial contemporary archaeological faunal studies, assumptions as to prehistoric mammals in the Nantucket diet must be made with caution.

At Nauset, Cape Cod, Fitzgerald (1984) and Borstel (1984) report a number of dated sites with floral and faunal remains (Table 2), but do not distinguish marine species from terrestrial within mammal, fish and bird categories.

Reports from Nantucket and Cape Cod generally rank oysters and quahogs as the predominant shellfish in Late Woodland components, followed by clams and then all other shellfish (Little 1979; Luedtke 1980; Hancock 1984), but Ritchie (1969) reported a strong scallop dominance in six Late Woodland components at Martha's Vineyard (Ritchie 1969:217). Pretola and Little (1988) report that scallops dominated a single Late Woodland pit feature at Nantucket. Changes in the distribution of eel grass, which provides necessary habitat for scallops, may have caused this difference.

Roots, stems and leaves of plants would not normally leave archaeological evidence in most New England sites. Charred seeds and other plant remains resistant to decay have not been studied at Nantucket, nor have the plant recoveries at Nauset been classified as to species (Fitzgerald 1984; Largy 1984, 1987). Fish bone also has a low incidence of reports, again in part because of its fragility and in part because the methodology has not been adequate for its recovery or identification. One would not expect to find large marine mammal bones at middens, as they would surely be discarded at the shore. The south shore, the most rich in whale resources (Little and Andrews 1982), has also lost the most to erosion. Lobster and crab shells, made of chiton, do not weather well. Two additional hypotheses exist: that fish, crab, lobster and various plant remains constituted only a small part of the diet, or that people did not discard fish bones and crustacean shells in shell middens. The methods and locations of sites of catching, cleaning, and preserving fish, as well as possible cultural behavior connected with the proper disposal of fishbones, provide arguments for the latter (Black and Whitehead 1988; Hayden et al. 1987).

Table 3 lists Late Woodland foods for areas of southeastern New England that have a greater range of species and more analytic studies on plant remains than have been reported for Nantucket (see also Carlson 1988).

Although dietary reconstruction will require better dating control and faunal analysis than has been carried out on Nantucket, we must start from the archaeological record here presented.

TABLE 3. ARCHAEOLOGICAL LATE WOODLAND DIET FROM COASTAL SOUTHERN NEW ENGLAND (Little 1985a:23; Lavin 1988; Ritchie 1969; Speck and Dexter 1948; Eteson, Crary and Chase 1978; Eteson 1982; Fitzgerald 1984; Largy 1984,87)

Shellfish and crustaceans: oyster, quahog, clam, scallops, knobbed and channelled whelk, surf clam, moonshell, mussel, Jonah and blue crab.

Fish: cod, sturgeon, spiny dogfish, scup, tautog, striped bass, bluefish, goosefish, sand shark, searobin.

Fauna: Deer, raccoon, fox, muskrat, black bear, sea mink, otter, beaver, squirrel, grey, harbor and harp seal, pilot whale, waterfowl (brant, geese, black eider, merganser, mallard, scaup, loon, swan, black duck, other ducks, auk, cormorant, gull), turkey, heath hen, meadow vole (Microtus pensylvanicus [sic]), turtles, snakes.

Floral Material: blackberry/dewberry, huckleberry, sweet fern, bunchberry, pin cherry, pea family, clover, Buckwheat family, knotweed/smartweed, hickory, hazelnut, acorn, pigweed (Amaranthus sp.), pokeweed (Phytolacca sp.), Chenopodium sp., elderberry, American lotus, sumac, deer vetch, butternut, maize.

TABLE 4. ETHNOHISTORICAL DIET IN EASTERN MASSACHUSETTS (Brereton 1602 for Elizabeth Islands; Champlain 1605 at Cape Cod; Mourt 1622 for Cape Cod; Wood 1635 for Lynn; Williams 1643 for Narragansett Bay; Gookin 1674 for Massachusetts; Crevecoeur 1782 for Nantucket).

Mollusks and crustaceans: clams, quahogs, scallops, mussels, oysters, whelks, surf clams, lobster, crabs.

Salt water fish: cod, mackerel, breame (scup), herring, thornback, hake, rockfish, dogfish, tunnies, anchovies, bonits, salmon (Brereton 1602); shad, eels, alewives or a kind of herring (Gookin 1674); cod, scup, sturgeon, striped bass, salmon, tomcod (frostfish), mackerel, tautog, herring-like, eel, haddock-like, lamprey, mummichog (Williams 1643); striped bass, bluefish, tomcod, mackerel, tautog, herring, flounder, eel, sea bass, cod, smelt, perch, shadine, pike, shark (Crevecoeur 1782); skate, cod, turbot, herring, shad, bass (Mourt 1622); catfish, dogfish, halibut, skate, alewives, sturgeon, salmon, cod, haddock, hake, thornback, bass, herring, shad, smelt, mackerel, frostfish, eel, lampery (Wood 1635).

Animals: deer, rabbits, seals, porpoises, grampus, whales.

Birds: geese, brant, teal, black ducks, oldwives, mallard, other ducks, cranes, bitters, hernshawes, penguins, doves, mewes, cormorants, heath hens, partridge, pidgeon, turkies, eagles, swans.

Reptiles: tortoises, snakes (dietary [Brereton 1602]).

Vegetables: corn, common beans, squashes, pumpkins, peas, salad herbs; for smoking: tobacco, pokeweed.

Fruits: Indian fig or prickly pear [probably Opuntia humifusa], grapes, cherry, peach, hurtleberries (blue/huckle), barbary-like, strawberries, rasberries, gooseberries, cranberries, plums.

Roots: Jerusalem artichokes; ground nuts or Indian potatoes (Apios tuberosa); sassafras, turnips

Nuts: oak acorns, chestnuts, walnuts, beech nuts, hazelnuts.

Ethnohistoric Evidence for Diet in Coastal Southeastern New England. An approach to reconstruction of prehistoric diet that includes perishable material lies in historic reports (Warner 1972; Rainey 1956; Carlson 1988; Table 4). Samuel de Champlain visited the outer Cape at Nauset and Chatham 20 July 1605, and 2 October 1606. There he found people who "are not so much great hunters as good fishermen and tillers of the land" [my emphasis] (Champlain 1880:124). He reported a planting field of Indian corn (Zea mays) near each dwelling (Figure 6). "We saw many Brazilian beans, and many squashes of various sizes, very good for eating; some tobacco, and roots which they cultivate, the latter having the taste of an artichoke [Jerusalem artichokes]" (Champlain 1880:82). He also mentioned oysters, fish, and walnuts (probably hickory; 1880:121,124).

In 1674, Daniel Gookin (1970) of mainland Massachusetts recorded:

> Their food is generally boiled maize, or Indian corn, mixed with kidney-beans, or sometimes without. Also they frequently boil in this pottage fish and flesh of all sorts, either new taken or dried, as shads, eels, alewives or a kind of herring, or any other sort of fish..., venison, beaver, bears flesh, moose, otters, rackoons, or any kind that they take in hunting.... Also they mix with the said pottage several sorts of roots; as Jerusalem artichokes, and ground nuts, and other roots, and pompions, and squashes, and also several sorts of nuts or masts, as oak-acorns, chestnuts, walnuts; these husked and dried, and powdered, they thicken their pottage therewith.

John Brereton (1602) with Bartholomew Gosnold at the Elizabeth Islands; Champlain (1605); Mourt's Relation [1622] (1986); William Wood of Lynn [1635] (1865); Roger Williams [1643] (1936) of Narragansett Bay; Gookin [1674] (1970); and St. Jean de Crevecoeur [1782] (1971) for Nantucket, each provide similar food lists, which include vegetables, maize, squash, beans, fish and marine mammals (Table 4). The highest ranking fish historically from Table 4 (see also Carlson 1988), cod, mackerel, eel, herring, alewife, shad, striped bass, shark/dogfish, salmon and tomcod (except for a codfish otolith, sand shark and striped bass), have not yet been identified in a Nantucket shell midden.

In our day of supermarkets and extinct species, we observe with wonder the large number of potential foods historically available in coastal southeastern New England. People living off the land and sea would of course have been aware of species seasonality, reliability, locations to catch, gather, fish, trap or hunt, etc. Many present day Nantucket families add quality to their diets by collecting live lobsters, scallops, surf clams and other seafood washed up on the beaches (Little and Andrews 1982), as well as by hunting deer, fishing and collecting oysters, clams and quahogs, and, of course, berrying.

TABLE 5. OPTIMUM DIET MODEL PREDICTIONS FOR NANTUCKET (based on risk, abundance*, seasonality, high energy and report of preservation+ (Perlman 1980; Noblick 1977; Tables 2,3,4).

Nuts and seeds: hazelnut, beechnut, oak acorns+, beach peas, hickory nuts+.

Fish: striped bass*+, alewives+, shad+, herring, eels*, bluefish, smelt*, sturgeon*, white perch+, scup*+,

Mammals: Deer, seal, porpoise, whale*

Shellfish and crustaceans: oysters, quahogs*, softshell clams*+, surf clams, mussels, whelk, moon shells, scallops, lobster*+

Birds: ducks*, geese*, pigeons*, brant*, swans*

Roots: cattail, Jerusalem artichoke, sassafras, ground nuts

Berries: blueberries, currants, strawberries*, bunchberries, cherries, beach plums, grapes, elder berries, etc.

Historical, Nutritional and Optimum foraging models. Studies of nutrition and optimum foraging strategies (Bennett 1955; Bumsted 1980; Claassen 1986; Draper 1977; Eaton and Konner 1985; Erlandson 1988; Meehan 1982; Perlman 1980) weigh the importance of possible dietary items (Table 5), and the nutritional values of possible diets.

Eaton and Konner (1985) find a world-wide average hunter/gatherer diet of 3000 KCal per day that is 35:65% by weight animal:vegetable and would provide 251 g of protein (34% of the energy requirements), 71 g of fat, 333 g of carbohydrates. They note that protein, fat and carbohydrates constitute different proportions of wild foods than of modern domesticates and that hunters usually consume their food animals more completely than do urban consumers today. A number of wild foods are quite high in fats and carbohydrates (Table 6). Nuts are high in fats. Some marine foods are high in fat and oils (marine mammals, eel, duck, Brant geese, spiny dogfish [Watt and Merrill 1963; see Speck and Dexter (1948) for Indian use of dogfish liver oil], bluefish, salmon, mackerel and herring). Bivalves, especially quahogs and oysters, are relatively high in carbohydrates seasonally (Sealy and van der Merwe 1986:137; Claassen 1986; Erlandson 1988; Noli and Avery 1988).

Meehan's (1982) measurements for coastal dwellers in Australia near the equator during the months of September, January, April and May of 1972-3 show that the average diet of about 2000 Kcal per day was 63:37% animal:vegetable by weight of the edible portion, which provided a protein intake (140-190 gm per day) that was 16% from shellfish, 49% from fish, 15% from reptiles, birds and mammals and 20% from vegetables. For this diet, vegetables contributed an average of 57% and animal foods contributed 43% of the energy needs. According to Meehan (1982:150-51), the protein use for coastal dwellers appears to be higher than that for inland people.

Similarly, Draper (1977) reports a premodern Eskimo diet (2500 kcal per day) as 200g protein

(32% energy), 185 g fat (66% energy), and 10 g carbohydrates (2% energy), which represents an almost 100% animal diet.

Bennett (1955) found a geographic variable: from a study of historic sources from 1605-1675, he concluded that the diet of historic natives, as one went southward from northern Maine along the coast, changed from an Eskimo-like reliance on animal and fish products to a major reliance on maize. He conjectured that the historic southern New England diet consisted of: 65% grains, chiefly maize; 10% animal and bird carcasses including fat, and 9% fish and shellfish; 8% nuts and leguminous seeds (beans); 4% vegetables and fruits; 2% grain alternatives (potatoes, Jerusalem artichokes, roots); visible vegetable fats (from nuts, acorns) 1%; eggs 1%. Neither sugar, milk, chocolate, or salt was ingested by southeastern Massachusetts Indians before the arrival of Europeans (Bennett 1955).

Perlman (1980) has looked at the return rates or calories per man-hour for a number of different kinds of foods consumed by hunter/gatherers. He shows that if a resource is abundant, people will often collect a great deal of it, especially if it can be stored. In particular (Perlman 1980: Table 6.2), seasonal fish runs, fall deer hunting and large nut gathering provide the largest returns for least effort. Shellfish and hook and line fishing are good sources of food for little effort, and small nut gathering and small game hunting require the largest effort for the least return. Lee (1968), from a world-wide study of ethnological reports, concluded that on coasts above latitude 40° N, fish size and fish density increase, and fishing and sea mammal hunting dominate the subsistance of modern hunter/gatherers. Nantucket lies at 41°N latitude, at the southern end but within the range of dominant fishing and sea mammal hunting.

Claassen (1986) reports that on the southeastern Atlantic coast, the prehistoric shellfish collecting season was late fall to spring, during the fast growth/high carbohydrate phase of the shellfish. She proposes that, while shellfish may provide a supplement of 6-17% to a modern hunter/collector's diet, shellfish provided up to 70% of the dietary meat and up to 50% of the total calories in most prehistoric coastal sites of the southeast and was a seasonal staple source of proteins and carbohydrates for horticultural peoples. Erlandson (1988) also argues that shellfish can provide a staple source of protein, 70-90% of the meat diet, for a diet predominantly of plant foods.

Andrews (1986) discusses methods of fishing at Nantucket and mentions easy-to-catch species such as white perch, eels, summer flounder, etc., which are little known today because of a decrease in abundance. The problem of changes in species abundance made itself felt in the sample collecting for this project. Extinct or rare today, sturgeon, Brant geese, eskimo curlew, heath hens, great auks, passenger pigeons and seabird eggs that were once seasonally abundant, are not available for testing.

Bumsted (1980) notes a certain uniqueness in the cautious Northeastern adaptation to maize, a C_4 plant that has fewer nutritional values than, for instance, wild butternuts.

In the samples obtained for this study we found high $\delta^{13}C$ in the intertidal saltmarsh C_4 grass, Spartina alterniflora (Peterson et al. 1985), and the C_4-like (Brian Fry, 1989 personal communication) subtidal eelgrass (Zostera marina). The inhabitants of Baja California regularly

harvested and ate eelgrass seeds (Felger and Moser 1973), but at Nantucket the plant does not reproduce by seeds (J. C. Andrews 1989, personal communication). From eelgrass found in middens in New Brunswick and Denmark, archaeologists have inferred its use in cooking (as in a New England clambake) or salt production (Rau 1884:222), but we have no evidence for the dietary use by humans of spartina or eelgrass in Massachusetts. A number of seaweeds such as Irish Moss (Chondrus crispus), dulse and kelp can produce edible products that are doubtfully staples.

Canada geese feed chiefly on spartina roots, although today they also eat winter rye, Kentucky blue grass and corn, and Brant geese commonly fed on eelgrass before they nearly became extinct as a result of an eel grass blight in the 1920's (J. C. Andrews 1988, personal communication). Eels also frequent eelgrass meadows, among other habitats. Although most lobster traps today are set near the 100 year-old rock jetty at the harbor entrance, J. C. Andrews (1991, personal communication) reports that old timers at Nantucket have told him that lobsters, once more abundant than today, commonly lived in holes that they dug in sand in eelgrass meadows on shoals near the island. He has caught lobsters from habitat such as this at Nantucket.

CAM plants are succulents adapted to the xerophytic conditions usually found in the tropics (Vogel and van der Merwe 1977:239), and two such plants, Opuntia humifusa and Yucca filamentosa, fruit-bearing cacti of beaches and dry sands at their northern and eastern limits in southeastern Massachusetts (Fernald 1970:1043,438), are marginally distributed at Nantucket Island. These plants, which are eaten by rabbits (J. C. Andrews, 1988 personal communication), could have been significant dietary items about A.D. 1000-1450, if temperatures at Nantucket during the medieval warm period (Lamb 1982) were warmer than today.

We can now group Nantucket foods into four categories, terrestrial animal (deer, dog, raccoon, fox, muskrat, vole, and land birds, freshwater fish), marine animal (sea mammals, fish, crustaceans, waterfowl and shellfish), terrestrial plants, and marine plants. We list in Table 5 as possible staples the foods remarked upon as abundant, seasonally or year-round, and those which historical observers said were preserved by sun-drying and smoking for later use.

To sum up our expectations for historic and prehistoric diets at Nantucket, a diet of the Contact period, perhaps A.D. 1534 - 1635, might have consisted of maize, squash, beans, Jerusalem artichokes, possibly cultivated native plants, nuts, fish, marine mammals, waterfowl, and shellfish. A diet of the Middle Woodland, cal A.D. 70 (244) 420, might have consisted primarily of shellfish, deer, fish, native plants and no maize. For the Late Woodland coastal diet of cal A.D. 900-1550, shellfish and other animals of eelgrass meadows and saltmarsh were probably dietary staples, along with fish and terrestrial plants and animals. An alternative hypothesis is that maize, beans and squash provided for part of the Late Woodland diet. Other C_4 dietary possibilities, prickly pear, yucca, eel grass seeds or seaweeds may have been minor constitutents of the diet. In the next section, we evaluate these hypothetical diets of Nantucketers by isotope tests.

TABLE 6. ISOTOPE VALUES (o/oo) FOR THE NANTUCKET HUMAN DIET AND ITS CONSTITUENTS. Bone Chemistry Laboratory, Harvard University (Medaglia, Little and Schoeninger 1990) and University of Wisconsin. All Nantucket except those with a *. For site locations, see Appendix II. Species and diet from Bigelow and Schroeder (1953); Fernald (1950); Little and Andrews (1986); the flesh of animals was measured, unless otherwise specified.

Material:	$\delta^{13}C$ o/oo;	$\delta^{15}N$ o/oo
Human Bone:		
MS 3197:	-10.4;	15.5
MS 3198:	-11.0;	14.1
MS 3199:	-10.3;	15.3
MS 3735:	-9.6;	15.3
MS 3736:	-10.4;	16.7
MS 3737:	[-13.4];	15.0
MS 3738:	-10.6;	15.1
avg:	-10.4;	15.3
conversion	(-5.0;	-2.5)
AV HUMAN DIET:	-15.4;	12.8

1. TERRESTRIAL MAMMALS AND C_3 PLANTS:

1a. Terrestrial Mammals (diet: C_3 plants):

Odocoileus virginianus, Deer:	-24.1;	4.4

1b. Terrestrial C_3 Plants:

Salicornia virginica, Samphire:	-24.8;	4.7
Cakile edentula, Sea Rocket:	-28.0;	1.5
Lathyrus maritima, Beach Peas:	-23.8;	-0.4
Amelanchier sp., Shadberry:	-26.7;	-0.1
Atriplex patula, var. hastata, Orach:	-27.2;	2.2
Sambucus canadensis, Elderberry:	-26.5;	2.2
*Phaseolus vulgarus, Aunt Dixie's bean heirloom), Common bean:	-27.9;	-1.0
Rubus sp., Blackberry:	-25.0	
Vaccinium angustifolium, Blueberry:	-25.8	
avg. 1b plants:	-26.2;	1.3
AVG 1a & 1b (1:2):	-25.5;	2.3

2. FRESHWATER PLANTS AND FISH:

Typha angustifolia, Cattail roots:	-28.1;	8.2
Acorus calamus, Sweet Flag roots:	-26.3;	7.5
Morone americana, white perch (diet: fish, invertebrates):	-23.9;	10.3
AVG 2:	-26.1;	8.7

3. MARINE CARNIVORES (FISH AND MAMMALS):

Marine Fish (diet: fish):

Pomatomus saltatrix, Bluefish:	-18.7;	16.2
Roccus saxatilis, Striped Bass:	-18.3;	16.6
avg. marine fish:	-18.5;	16.4

Marine mammal and fish (diet: fish and invertebrates):

*Phoca vitulina (Mass.), Harbor Seal flesh:	-17.2;	14.7
*Hippoglossus hippoglossus (Mass.), Halibut (occ. eats seabirds):	-17.8;	14.5
avg. mar. mammal & fish:	-17.5;	14.6
AVG. 3 (3:1 fish):	-18.3;	16.2

4. NEARSHORE CARNIVORES (diet: invertebrates, etc.):

Pseudopleuronectes americanus, Winter Flounder:	-17.5;	10.7
Lunata heros, Moon Shell Snail:	-15.9;	9.3
Busycon canaliculatum, Channeled Whelk:	-16.1;	10.9
Cancer borealis, Jonah Crab:	-17.0;	10.6
Stenotomus chrysops, Scup:	-16.6;	12.6
AVG. 4:	-16.6;	10.8

5. HARBOR CARNIVORES (diet: invertebrates, fish fry, etc.; habitat includes eelgrass meadows):

Homarus americanus, Lobster:	-13.7;	11.8
Anguilla rostrata, Eel:	-13.4;	9.8
Tautogolabrus adspersus (omnivore, diet includes eelgrass), Cunner:	-13.5;	10.5
Ammodytes americanus, Sand Eel:	-14.8;	11.7
AVG. 5 (5:5:1:0):	-13.5;	10.8

6. HERBIVOROUS SEAFOWL (diet: includes spartina roots):

Branta canadensis, Canada Goose:	-13.6;	6.8
AVG. 6:	-13.6;	6.8

7. MARINE BIVALVES, edible portion (diet: suspension feeders):

Mercenaria mercenaria, Quahog:		
flesh:	-18.6;	5.3
stomach:	-22.2:	6.8
Mya arenaria, Clam:		
flesh:	-16.1;	7.2
stomach:	-19.1;	6.3
Crassostrea virginica, Oyster:		
flesh:	-18.6;	2.8
stomach:	-20.5;	—
Mytilus edulis, Blue Mussel:	-21.0;	7.2
Geukensia demissa, Ribbed Mussel:	-15.1;	4.7
Argopecten irradians, Bay Scallop:	-14.0;	6.3
AVG. 7:	-18.0;	5.4
AVG. 6 and 7 (1:1):	-15.8;	6.1

8. C_4 or C_4-like Plants:

*Zea mays, 8-rowed northern flint Corn:	-10.7;	4.0
Spartina alterniflora, saltmarsh grass:	-12.0;	1.2
Zostera marina var. stenophylla, Eel grass:	-7.2;	5.6
AVG. 8:	-10.0;	3.7

MISCELLANEOUS:

CAM Plant, Opuntia humifusa:	-14.1;	-0.7
Helianthus tuberosus, Jerusalem artichoke:	-25.9;	6.7
*Harbor Seal fat:	-23.9;	—
Deer Fat:	-30.3;	—
Deer bone:	-21.2;	3.2

(weighting factors judgmental)

ISOTOPE MEASUREMENTS

Samples of a broad range of food items, plants, fish, shellfish, deer, etc., from Nantucket were collected for study by Christopher Medaglia and Elizabeth A. Little under the direction of Professor Margaret J. Schoeninger at the Bone Chemistry Laboratory, Harvard University, Cambridge, and at the University of Wisconsin. $\delta^{13}C$ and $\delta^{15}N$ isotope ratios were measured using standard techniques (Medaglia et al. 1990; Appendix I, II; Table 6). Because of the variation in isotope values between individuals in a species, between tissues of an individual, and between laboratories (Appendix 4), these data, which often consist of one value per species, can be used only for initial guidelines (Fry and Sherr 1984).

Trophic Levels and Food Chains.

In large animals the various tissues have isotopes of differing mass, a poorly understood process (van der Merwe 1982; Nelson 1991). Most of the fractionation may take place in plants, with the isotope values of the nutritional components of plants reflected in the corresponding tissues of both herbivores and omnivores (van der Merwe 1982). The $\delta^{13}C$ values of proteins measured in bone collagen for Late Woodland New York State humans are translated by +5 o/oo from the diet base, but almost unchanged isotopically ($\Delta^{13}C$ = 0 o/oo, where Δ implies a change in $\delta^{13}C$ between trophic levels) from terrestrial herbivore collagen and C_3 plant protein (van der Merwe 1982; Figure 8a). Data for marine food chains suggest a small $\Delta^{13}C$ of about 1.3 o/oo (Haines and Montague xxxxx

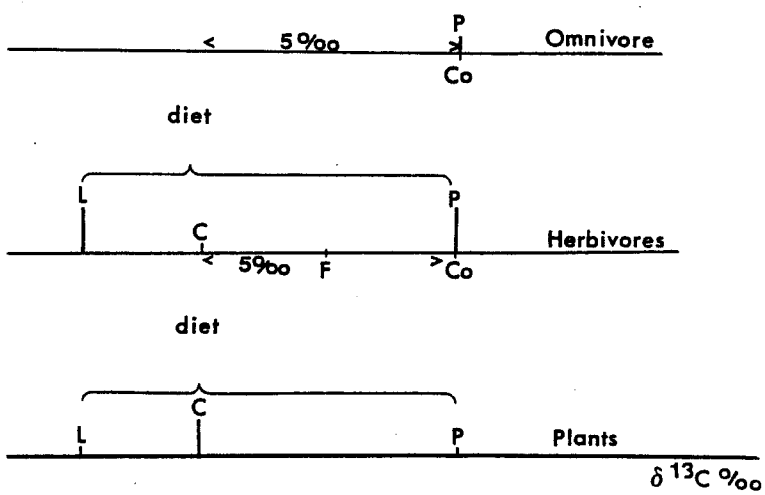

Figure 8a. Schematic diagram of ^{13}C fractionation between trophic levels in the diet of Illinois and Ohio Archaic humans (van der Merwe and Vogel 1978; Vogel and van der Merwe 1982). Co: bone collagen; P: protein; C: carbohydrate; L: lipids; F: flesh.

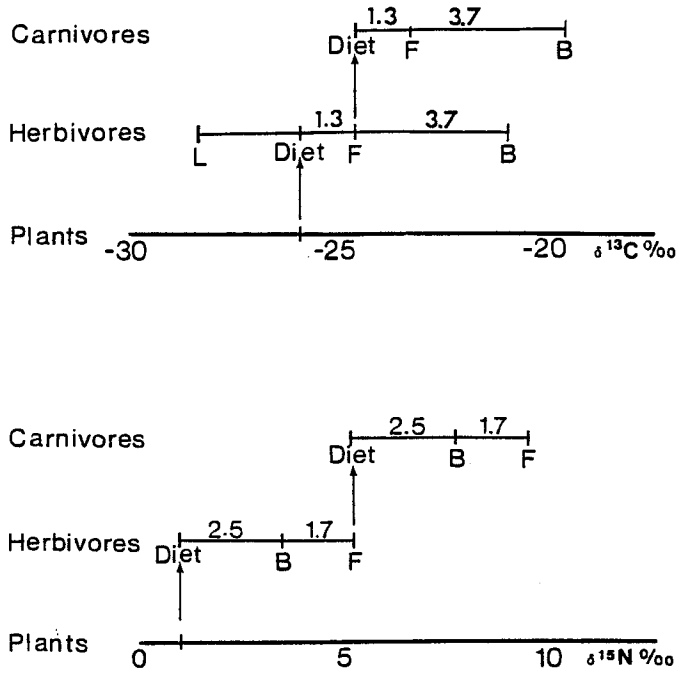

Figure 8b. Schematic fractionation values and changes (Δ) in stable carbon-and nitrogen-isotope ratios of bone collagen and protein dietary materials by trophic level. $\Delta^{13}C$ = 1.3 o/oo and $\Delta^{15}N$ = 4.2 o/oo. L: lipids; F: flesh; B: bone collagen (protein).

1979; Smith and Epstein 1970; Figure 8b). Some variation between trophic levels may be introduced by incomplete consumption of the prey and metabolic processes in the consumer. Although uncertainty exists for the exact magnitude of some of the parameters, the fractionation relations used in this paper, for chiefly marine resources, are illustrated schematically in Figure 8b:

$\delta^{13}C$ (diet) + 5.0 o/oo = $\delta^{13}C$ (consumer bone collagen) = $\delta^{13}C$ (consumer flesh) + 3.7 o/oo
$\delta^{15}N$ (protein diet) + 2.5 o/oo = $\delta^{15}N$ (consumer bone collagen) = $\delta^{15}N$ (consumer flesh) - 1.7 o/oo

(DeNiro and Epstein 1981; Hayden et al. 1987; Keegan and DeNiro 1988:329; McConnaughey and McRoy 1979; Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Schoeninger 1985; Van der Merwe 1982; Van der Merwe and Vogel 1978). On the average for Nantucket the $\delta^{13}C$ value of deer bone differs from that of deer flesh by +2.9 o/oo, and the $\delta^{15}N$ value of deer bone differs from that of deer flesh by -1.2 o/oo (Medaglia et al. 1990). These values do not differ significantly from those derived from the literature.

Under these assumptions, the $\delta^{13}C$ of the flesh of a consumer is 1.3 o/oo higher than that of its diet, and the $\delta^{15}N$ of the flesh of a consumer is 4.2 higher than that of its protein diet. In other words, the isotope values of a given tissue increase by $\Delta^{13}C$ = 1.3 o/oo and $\Delta^{15}N$ = 4.2 o/oo as the trophic level increases. The constancy of this relation reveals itself in isotope values of a food chain based on similar tissues of plants and animals (Fig. 8b).

Peterson et al. (1985) have shown that the $\delta^{13}C$ and $\delta^{15}N$ values of a species (ribbed mussel) living in a saltmarsh depend upon the isotope values of the mixture of foods in its environment. Figure 9 shows the quadrilateral $\delta^{13}C$-$\delta^{15}N$ space within which may be found the bases of the food chains in Nantucket waters which we have investigated. Spartina in the saltmarsh (a terrestrial C_4 plant of high $\delta^{13}C$, low $\delta^{15}N$) and upland plants at Nantucket (terrestrial C_3 plants with low $\delta^{13}C$ and low $\delta^{15}N$ values), are largely nitrogen-fixers and hence low in $\delta^{15}N$ (Schoeninger et al. 1983). Detritus of both plants contributes to runoff into the harbor, which provides food directly or as metabolized or oxidized detritus (Thayer et al. 1978; McConnaughey and McRoy 1979; Fry and Sherr 1988; Peterson and Fry 1987). Hence, the resources of the harbor, such as bivalves, fish, crustaceans and waterfowl, are lower in $\delta^{15}N$ (i.e., more terrestrial) than those based on the plankton (a marine C_3 plant) of Nantucket Sound and eelgrass (a marine C_4-like plant of high $\delta^{13}C$, relatively high $\delta^{15}N$). The bay scallops, as Figure 9 suggests, do indeed live among eelgrass, and the ribbed mussel was found growing on a spartina plant near the shore edge of a salt marsh. Spartina and upland plant detritus mixed in the tidal creeks, provide food for the oyster with a low $\delta^{15}N$ and intermediate value of $\delta^{13}C$. Our data, although often limited to a single sample of a species, indicate a number of

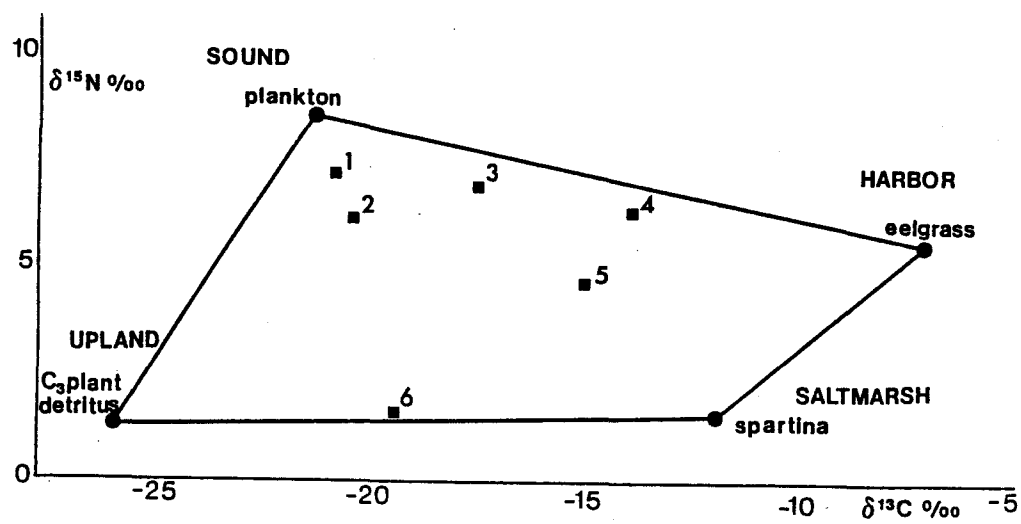

Figure 9. Schematic diagram of the isotope values of the bases of food chains in Nantucket waters (solid circles): plankton, eelgrass, spartina, and terrestrial C_3 plant detritus. The isotope values for consumers (bivalves) flesh, are shown by solid squares: in the Sound, blue mussels (1), quahogs (2); in a harbor, clam (3), scallop (4); in a salt marsh, ribbed mussel (5); up a harbor creek, oyster (6). Plankton value from Falmouth, Mass. (Peterson et al. 1985). The average nitrogen isotope values of the bivalves, 5.4 o/oo, suggest a diet of $\delta^{15}N$ = 1.2 o/oo, reflecting the terrestrial component of their environment.

interesting research projects in Nantucket Harbor.

In Figure 10 we can see immediately the dominating influence of the base of the simple food chains on the isotope values of organisms higher in trophic level. Deer consume upland C_3 plants, freshwater fish consume freshwater organisms. Phytoplankton constitutes a major source of carbon and nitrogen for the marine carnivores, bluefish and striped bass, several trophic levels higher. Using the trophic relations from Figure 8b, the predicted isotope values for the diets of nearshore invertebrate-eating fish, crabs and gastropods would be, on the average: $\delta^{13}C$ = -17.9o/oo; $\delta^{15}N$ = 6.6 o/oo, which are remarkably close to the average measured isotope ratios for marine bivalves, $\delta^{13}C$ = -18.0 o/oo and $\delta^{15}N$ = 5.7 o/oo. The trophic relations between the prey/predator pairs (Table 7): clam and moonsnail, quahog and whelk, average to: $\Delta^{13}C$ = +1.4 o/oo, and $\Delta^{15}N$ = +3.9 o/oo, which approximate the values of Figure 8b. In Fig. 10 the predicted diet of harbor carnivores, most of which live in eelgrass meadows and, unlike whelk and moonsnails, have the agility to catch scallops, strongly implicates prey such as the jet-propelled bay scallop that shares this habitat. Deduced values of $\delta^{13}C$ and $\delta^{15}N$ are shown for the now almost extinct Brant goose, which subsisted primarily on eelgrass.

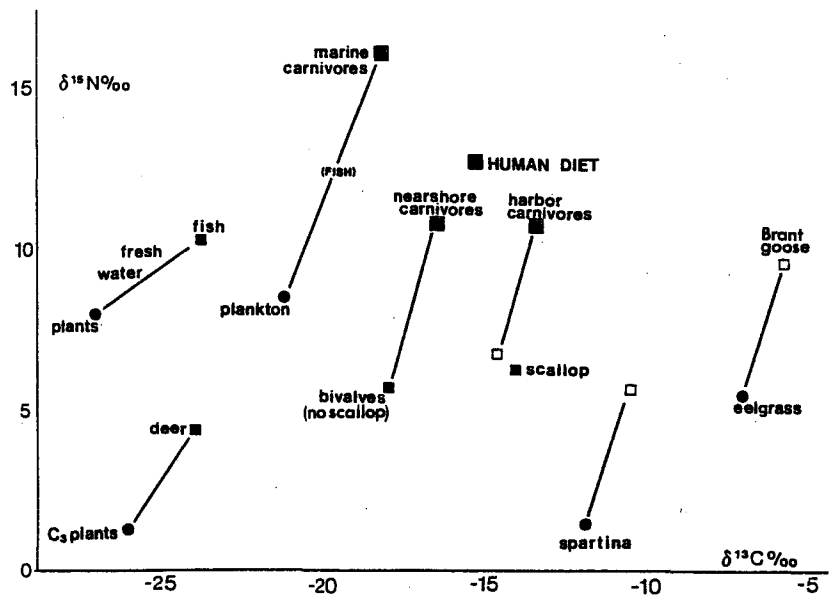

Figure 10. Schematic diagram of simple food chains at Nantucket. Average stable carbon- and nitrogen-isotope ratios for the human diet and for groups of dietary items and their change (Δ) with trophic levels (plants: solid circles, herbivores: squares, and carnivores: outlined solid squares). Plankton value from Falmouth (Peterson et al. 1985). For each trophic level change, approximate values from the literature are: $\Delta^{13}C$ = +1.3 o/oo and $\Delta^{15}N$ = +4.2 o/oo, by which are deduced the values shown as open squares. For marine carnivores, the base of the food chain is plankton; for near shore and harbor carnivores, the base of the food chains appear to be chiefly spartina and upland plant detritus.

THE LINEAR MODEL.

In order to simplify the discussion, we first group the foods into categories, either of similar species or similar isotope values. Table 7 shows 8 categories of foods: 1, C_3 plants and deer; 2, fresh water plants and fish; 3, marine carnivores (fish-eating fish and sea mammals); 4, nearshore carnivores (crabs, gastropods); 5, harbor carnivores (lobsters, eels); 6, bivalves; 7, sea fowl; 8, C_4 plants (maize), with corresponding average isotope values. We have no evidence for the dietary use of spartina roots, eelgrass, or prickly pear cactus, but will group them with the C_4 plant, maize, which they resemble isotopically and nutritionally. In order to further simplify the dietary constituents, we coalesce 1 and 2, and 6 and 7, thereby reducing our total to six groups (Table 8; Figure 11).

The proportions of each constituent have been set judgmentally for this initial pilot study, but our results will show that the amount of groups 1, 2, 4, 6 and 7 in the possible diet is quite small. By contrast, values for groups 3, 5 and 8 are critical, since there can be a solution for a diet only if the human diet (δ^{13}C[human bone collagen] - 5 o/oo; δ^{15}N[human bone collagen] - 2.5 o/oo) lies within

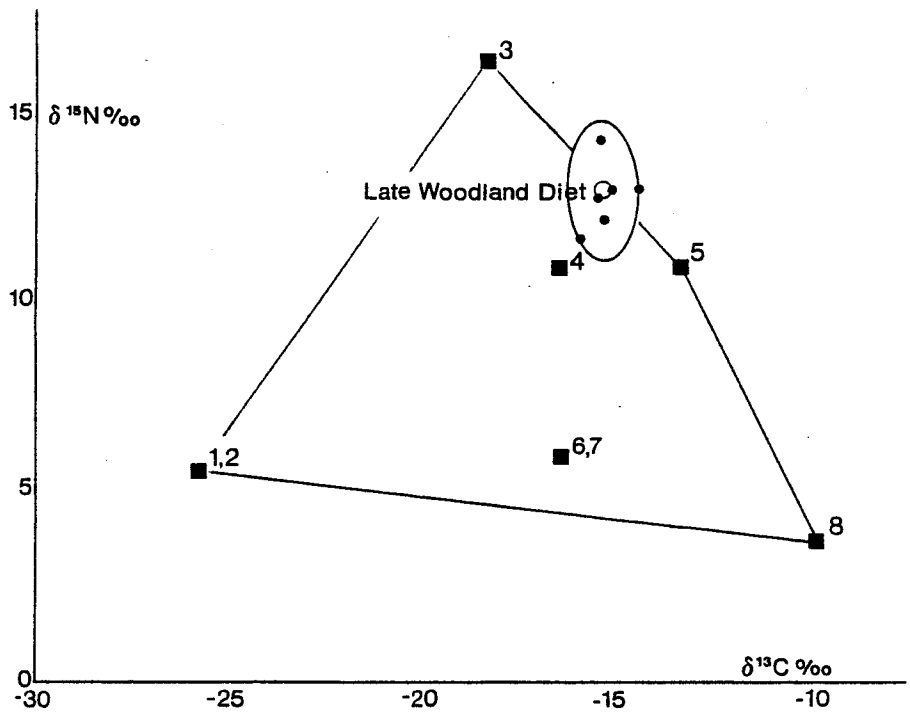

Figure 11. Average isotope ratios of groups of similar Nantucket dietary items (squares) and of the Late Woodland Nantucket diet (dots; small open circle is average value; large open ellipse gives range of values; see Table 7). 1,2: C_3 plants and animals; 3: marine carnivores; 4: nearshore carnivores; 5: harbor carnivores; 6,7: bivalves and goose; 8: C_4 plants.

TABLE 7. NUTRITIONAL VALUES IN DIETARY ITEMS (grams per 100 Kilocalories) (Watt and Merrill 1975; Waselkov 1987:120).

A) Selected items illustrating the range of protein, fats or carbohydrates.

FOOD:	P	F	C		P	F	C
Deer:	16.7	3.2	0	Bluefish:	17.5	2.8	0
Beach peas:	7.5	0.5	17.1	Squalus acanthius:	11.3	5.8	0
Chenopodium (Orach):	9.8	1.9	17.0	whale meat:	13.2	4.8	0
Jerusalem artichoke:	3.1	0.1	21.5	Scup:	17.0	3.0	0
Pokeberry:	11.3	1.7	16.1	whelk:	20.3	1.8	0
blueberries:	1.1	0.8	24.7	crab:	18.6	2.0	0.5
beans:	6.6	0.4	18.1	lobster:	18.6	2.1	0.5
pumpkin:	3.8	0.4	25.0	eel:	8.5	7.3	0
prickly pear:	1.2	0.2	15.5	clams:	15.2	2.1	4.4
hickory nuts:	2.0	10.2	1.9	quahogs:	13.2	0.8	8.6
beechnuts:	3.4	8.8	3.6	mussels:	14.5	2.1	4.7
white perch:	16.4	3.4	0	oysters:	14.1	3.0	6.4
pickerel:	22.2	0.6	0	scallops:	18.9	0.2	4.1
Halibut:	20.9	1.2	0	duck (wild):	9.1	6.8	0
Herring:	9.8	6.4	0	corn:	3.1	1.0	22
Striped Bass:	18.0	2.5	0				

B). Averaged nutritional values of six food groups of Nantucket diets.

Food (i):	P_i, Protein g/100 kcal	F_i, Fat g/100 kcal	C_i, Carbos g/100 kcal
1,2 Terrestrial plants and deer, freshwater plants and fish:	9.4	2.5	10.7
(3) Marine carnivores (fish, seal),			
no fat added:	15.7	3.7	0.0
fat added:	7.9	6.9	0.0
(4) Near shore carnivores (crab, whelk)	18.6	2.3	0.2
(5) Inshore carnivores (Lobster, eel):	13.6	4.7	0.2
(6,7) Seafowl and Marine Bivalves (1:1):	12.1	4.2	5.6
(8) Maize:	3.1	1.0	22.0

TABLE 8. AVERAGE MEASURED $\delta_i{}^{13}C$ AND $\delta_i{}^{15}N$ VALUES, AND ESTIMATED $\delta_{ip}{}^{13}C$, $\delta_{ic}{}^{13}C$, $\delta_{if}{}^{13}C$ (o/oo) VALUES OF EDIBLE PORTIONS OF NANTUCKET FOOD GROUPS.

i	Foods in diet:	$\delta_i{}^{13}C$; $\delta_i{}^{15}N$	$\delta_{ip}{}^{13}C$	$\delta_{ic}{}^{13}C$	$\delta_{if}{}^{13}C$
1,2	Terr. plants and deer: Fresh water plants and fish (1:1):	−25.8; 5.5	−22	−27	−29
3	Marine carnivores:	−18.3; 16.2	−14.5	—	−22
4	Nearshore carnivores:	−16.6; 10.8	−14.5	−20	−22
5	Harbor carnivores:	−13.5; 10.8	−11	−16	−18.5
6,7	Seafowl and bivalves (1:1):	−15.8; 6.1	−13.3	−18.3	−21
8	C4 or C4-like plants:	−10.0; 3.7	− 5	−10	−12.5

the bounds of the dietary constituents. If we have found all the high $\delta^{13}C$ food groups, groups 3, 5, and 8 determine the high $\delta^{13}C$ limit in the diet.

Figure 11 shows graphically that a major portion of marine carnivores (fish and mammals) (group 3) provided the high nitrogen isotope values for the Late Woodland Nantucket diet. The high $\delta^{13}C$ of the diet requires staples such as various marine predators (lobsters, eels) (group 5) living in eelgrass meadows and saltmarshes and probably herbivores (Brant geese). Alternatively a limited amount of group 8 (C_4 plants) may have replaced some of these high $\delta^{13}C$ marine foods. We explore these relations quantitatively using algebra.

LINEAR EQUATIONS:

A model with three equations describes the mixing of the isotope values of dietary components into the total ^{13}C and ^{15}N values of the diet, one for constraints on the dietary percentages, one for the ^{13}C isotope, and one for the ^{15}N isotope. If D_i is the percentage of kilocalories of a given food group, i, in the diet, and $\delta_i{}^{13}C$ and $\delta_i{}^{15}N$ are the isotope values of those groups, the three general equations have the following form:

Equation 1. Total diet $= 1 = \Sigma_{i=1-n} D_i$, where $0 < D_i < 1$
Equation 2. $\delta_{diet}{}^{13}C = \Sigma_{i=1-n} \delta_i{}^{13}C\, D_i$
Equation 3. $\delta_{diet}{}^{15}N = \Sigma_{i=1-n} \delta_i{}^{15}N\, D_i$.

Converting isotope measurements of consumer bone collagen into isotope values of diet by adding - 5 o/oo to the $\delta^{13}C$ bone value and -2.5 o/oo to the $\delta^{15}N$ bone value, the average isotope values for the Late Woodland Nantucket diet (Table 6) are: $\delta_{diet}{}^{13}C = -15.4$ o/oo; $\delta_{diet}{}^{15}N = 12.8$ o/oo. Using Table 8 for isotope values of dietary groups, the basic equations 2 and 3 become:

Equation 2: $-25.8D_{1,2} -18.3D_3 -16.6D_4 -13.5D_5 -16.3D_{6,7} -10D_8 = -15.4$
Equation 3: $5.5D_{1,2} +16.2D_3 +10.8D_4 +10.8D_5 +5.9D_{6,7} +3.7D_8 = +12.8$

A number of adjustments can be made to the basic equations 2 and 3. Since nitrogen is found only in protein, nitrogen isotope values reflect only the protein components of the dietary constituents (Schoeninger 1989). Thus, we obtain the contribution of the $\delta_i{}^{15}N$ values of the protein components of various food groups (i) to the total isotope value of the diet, $\delta_{diet}{}^{15}N$, by weighting or multiplying each D_i in the nitrogen isotope equation (Eq. 3) by p_i/P, where p_i is the amount of protein in g/100 kcal of that food group (i) (Table 7b), and the total protein, $P = \Sigma_{i=1-n} p_i \times D_i$ (gm/100 kcal).

Equation 3_p: $\Sigma_{i=1-n} (p_i/P)\ \delta_i^{15}N\ D_i = \delta_{diet}^{15}N$, or

$$\Sigma_{i=1-n}\ p_i(\delta_{diet}^{15}N - \delta_i^{15}N)\ D_i = 0, \text{ and}$$

$$69D_{1,2} - 53D_3 + 37D_4 + 27D_5 + 95D_{6,7} + 28D_8 = 0$$

Similarly, protein can be weighted in basic equation 2, which becomes:

Equation 2_p: $\Sigma_{i=1-n} (p_i/P)\ \delta_i^{13}C\ D_i = \delta_{diet}^{13}C$, or

$$\Sigma_{i=1-n}\ p_i(\delta_{diet}^{13}C - \delta_i^{13}C)\ D_i = 0.$$

Solutions to the Diet Equations. Now we have three linear equations involving six unknown quantities or variables (D_i) and 12 constants. With only two or three unknowns, we could find an exact solution, but with four or more unknowns, we can only find constraints on their ranges. In order to test the sensitivity of this dietary model to changes in parameters, the tabulated solutions for a number of variations of equations 1,2 & 3 are given in Appendix 5.

Algebraic manipulations of the basic equations, with protein weighting the $\delta^{15}N$ equation (3_p) lead to the following results (D_i are percentages of the total dietary kilocalories) (Little and Little in preparation; see Speilmann et al. [1990] for another approach to the solution of this problem):

$D_{1,2}$: 0 - 13; D_3: 35 - 50; D_4: 0 - 34; D_5: 0 - 63; $D_{6,7}$: 0 - 19; D_8: 0 - 46.

If these consumers were not eating maize ($D_8 = 0$):

$D_{1,2}$: 0 - 2; D_3: 35 - 37; D_4: 0 - 8; D_5: 58 - 63; $D_{6,7}$: 0 - 4; D_8: 0.

If they ate 46% maize:

Solution A: $D_{1,2}$: 13; D_3: 41; D_4: 0; D_5: 0; $D_{6,7}$: 0; D_8: 46.

Although we can not find an exact solution for Equations 1, 2, and 3, we have found a range of alternative solutions. Remembering that the sum of all the D's = 100%, the results show that here, as in all of the solutions we have found, the percentage of D_3 is high and constrained, either D_5 or D_8 is high, and $D_{1,2}$, D_4, $D_{6,7}$ are low, sometimes very low. These numerical results confirm the graphical results derived from Figure 11.

The percentages for groups 3 and 5 or 8 are high because the $\delta^{13}C$ and $d^{15}N$ values of the diet are very high. Changing the $\delta_{diet}^{13}C$ by -1 o/oo, the $\delta_{diet}^{15}N$ by -0.5 o/oo, or protein weighting increase the allowed ranges somewhat but have a small effect on the overall results (Appendix 5).

Addition of Extra Fat. For a daily dietary intake of 2500 kilocalories, and using the relations lg P = lg C = 4 kcal energy and lg F = 10 kcal (Waselkov 1987; Watt and Merrill 1975) and Table 7b, we can derive the percentages contributed by protein, carbohydrates and fat to the daily diet. The diet derived above as Solution A ($\delta^{15}N$ protein weighted) for D_8 = 46%, consists of 34% protein, 44% carbohydrates and 22% fat. If this diet includes less than 15% D_8, it consists of over

85% animal foods, which makes it very high in protein, 343g/day, substantially exceeding Speth's (1989) 300 g/day. C_3 carbohydrates are limited because of the high $\delta^{13}C$ values of the diet. Therefore, to allow for a valid marine mammal diet, extra fat (g/kcal) should be added in Table 7b in place of half the protein in group 3. Although half is fairly arbitrary, this addition is not a fudge factor. First, lean whale meat provided the only nutritional values available (Table 7) for marine mammals (Watt and Merrill 1975). Secondly, world-wide nutritional studies consistently find that a coastal fisherman's diet requires extra fat (Speth and Speilmann 1983:8; Lee 1968). Draper (1977) cites evidence that prehistoric coastal peoples such as Eskimos, who ate the entire marine animal (Eaton and Konner 1985) including gut contents, livers (and liver oil) and the blubber, had high protein and fat diets (32% protein, 66% fat, 2% carbohydrates). Although many continental herbivores are low in fat, especially seasonally (Speth 1989), marine mammals, particularly of cold high latitudes, carry thick layers of blubber for insulation.

The addition of fat to the basic equations (with protein weighted $\delta^{15}N$) gives:

$$D_{1,2}: 0 - 5;\ D_3: 50 - 60;\ D_4: 0 - 15;\ D_5: 0 - 35;\ D_{6,7}: 0 - 7;\ D_8: 15\text{-}40.$$

By adding fat to group 3, D_3 increases to compensate for the smaller fraction of protein of that group, and all the allowable ranges decrease. Groups 3 and 5 or 8 (some of which is required) still dominate the diet.

If only dietary proteins build bone collagen, then protein weighting for the food groups in the $\delta^{13}C$ equation (equation 2_p as well as 3_p) also is a reasonable assumption:

Solution B: $D_{1,2}: 0 - 1;\ D_3: 50 - 52;\ D_4: 0 - 3;\ D_5: 35 - 48;\ D_{6,7}: 0 - 2;\ D_8: 0 - 15.$

Taking D_i's totalling 100% from near the midpoints of the ranges of Solution B, a 2500 kilocalorie diet would consist of about 243 g protein (38% of daily energy requirement), 135 g fat (55% of energy needs) and 53 g of carbohydrate (8% of energy needs). These values for protein match reasonably well Meehan's (1982) 140-190 g, Draper's (1977) 200 g, Eaton and Konner's (1985) 251 gm, and Speth's (1989) maximum 300 g. To add a fourth constraining equation, we can set 250 g as a fixed value of daily protein in equation 4: $2500\ \Sigma_{n=1\text{-}8} p_i D_i = 250$ g. Solutions to the four equations, 1,2,3 and 4, with $\delta_{diet}{}^{13}C = -15.7$ o/oo and $\delta_{diet}{}^{15}N = 12.3$ o/oo are:

$$D_{1,2}: 0\text{-}7;\ D_3: 45\text{-}53;\ D_4: 0\text{-}21;\ D_5: 13\text{-}37;\ D_{6,7}: 0\text{-}10;\ D_8: 6\text{-}20.$$

The parameters can be changed to test different assumptions, but we have demonstrated a feasible diet with significant fat and protein components, Solution B, as an alternative to a high C_4 plant diet, Solution A, for the Late Woodland at Nantucket; Solution B includes over 79% animal products.

Summary. Note that the addition of extra fat raised D_3 and lowered D_5, but most other changes (see also Appendix 5) do not in any significant manner change the domination of the groups 3,5 or 8 over

groups 1,2, 4 and 6,7. Since Solution B, for basic equations with fat added and protein weighted $\delta^{13}C$ and $\delta^{15}N$, satisfies our expectations for a low or non-maize alternative for a Late Woodland Nantucket diet with a reasonable protein percentage, I shall use it in further discussion. However, the greatest value of the set of dietary equations with computer solutions lies in its ability to test different dietary models, not to provide right answers.

As many diets allowed by the three equations (Spielmann et al. 1990) yield the same bone collagen ratios, this exercise shows we cannot choose between two alternatives, C_4 plants (Solution A) or lobsters and eels (Solution B). However, with due allowance for omissions, extinctions, imprecise and inadequate data, we can draw some fairly strong conclusions from these results:

l) to fulfill the high $\delta^{15}N$ requirements of the Nantucket diet, a substantial part of the diet, about 50%, must consist of group 3, marine fish and sea mammals with diets chiefly of plankton-based fish and invertebrates. This food group also can provide substantial fat to the energy diet.

2) to fulfill the high $\delta^{13}C$ requirements, at least 32% of the diet must be group 5 (harbor carnivores, lobster, eels) or group 8 (C_4 plants).

3) Group 1 (terrestrial animals, vegetables), and group 2 (freshwater fish and plants), group 4 (crabs and gastropods) and group 6,7 (Canada geese, bivalves) can be included in the diet only in minor amounts.

DISCUSSION.

Figure 12 illustrates the relative ^{13}C and ^{15}N content of some marine and terrestrial, historic and prehistoric diets, and shows that the isotope values measured for Late Woodland Nantucket diets most closely resemble those of prehistoric Danish or Maine fishermen. The diets of Maine and especially of California island fishermen, with slightly higher $\delta^{15}N$ and slightly lower $\delta^{13}C$ values, reflect a lesser use of marine protein from eelgrass meadows and saltmarshes (Walker and DeNiro 1986) or a lesser use of C_4 plants than the diet at the island of Nantucket.

As late as 1605, Champlain commented that the Nauset men were "not so much great hunters as great fishermen..." (Champlain 1880:124), and Crevecoeur in 1782 reported, "Before the arrival of the Europeans, [the Nantucket aborigines] lived on the fish of their shores...." (1971: 103). Fish- and invertebrate-eating fish and mammals, such as bluefish, striped bass and seals (group 3), with

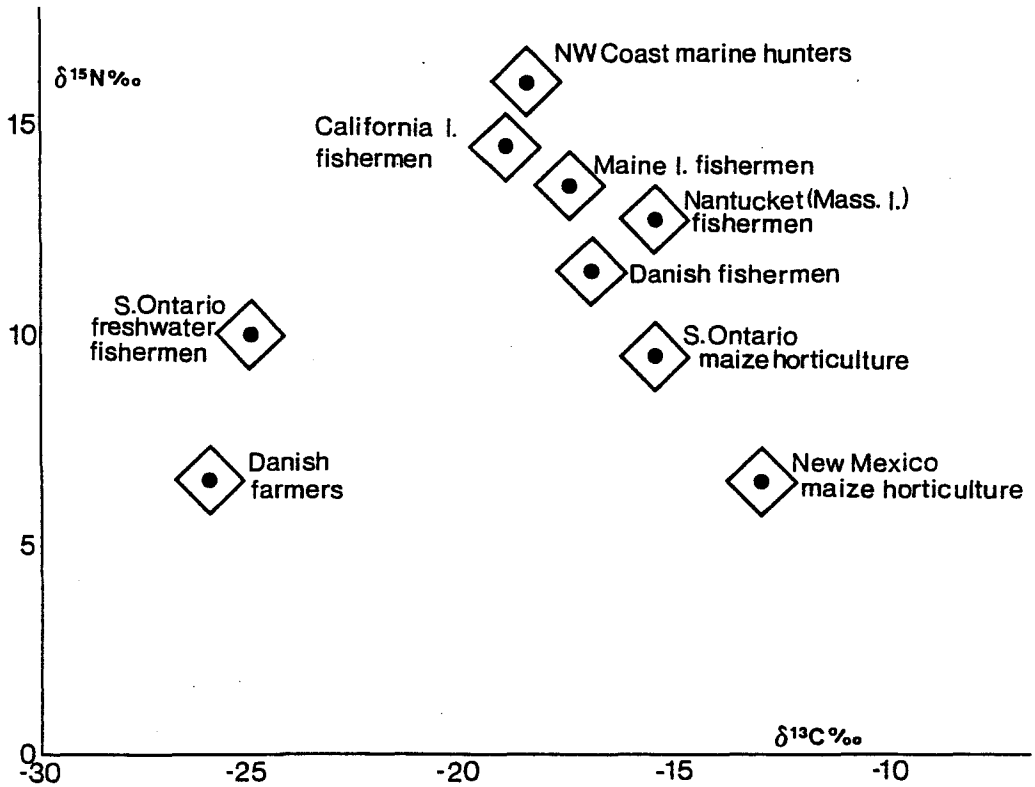

Figure 12. Average $\delta^{13}C$ and $\delta^{15}N$ values for diets of marine mammal hunters, marine fishermen, freshwater fisher/gatherers, farmers and maize horticulturalists showing the differences between C_4 (maize), C_3 plants and several marine diets (Chisholm, Schwarcz and Nelson 1983; Medaglia et al 1990; Moore 1988; Schoeninger, DeNiro and Tauber 1983; Schwarcz et al. 1985; Walker and DeNiro 1986; Table 6). The dietary values have been converted from bone collagen values (- 5 o/oo).

high $\delta^{15}N$ values and high fat content, clearly constituted a large percentage of the Late Woodland Nantucket diet. The small amount of fish and marine mammals reported in the archaeological record at Nantucket has misled us about the importance of these dietary items.

Lobsters, eels, scallops, Brant geese, cactus, seaweeds and maize could all provide high $\delta^{13}C$ input, but were they staples? Lobsters and eels are often mentioned in the literature of the early explorers and settlers of New England as a staple food, available all year round. "Lobsters are there infinite in store in all parts of the land, and very excellent" (Brereton [Elizabeth Islands] 1602:226). "Our bay affording many lobsters, [the Indians] resort every spring-tide thither (Mourt [Plymouth] 1622:62). "Lobsters be in plenty in most places, very large ones,...these are taken at low water, among the rocks....The Indians get many of them every day for to baite their hooks withall, and to eate when they can get no Basse...." (Wood [Lynn] 1635:37,100). "In the summer these Indian

women when Lobsters be in their plenty and prime, they drie them to keepe for Winter, erecting scaffolds in the hot sun-shine, making fires likewise underneath them, by whose smoake the flies are expelled, till the substance remain hard and drie" (Wood 1635:101). "Our bay is full of lobsters all the summer and affordeth variety of other fish; in September we can take a hogshead of eels in a night with small labor, and can dig them out of their beds all the winter" (Mourt 1622:84). "[March 24] Squanto went at noon to fish for eels; at night he came home with as many as he could well lift in one hand....They were fat and sweet; he trod them out with his feet, and so caught them with his hands...."(Mourt 1622:59). "There be a great store of salt water Eeles...: some take a bushel in a night..., eating as many as they have need of for the present, and salt up the rest against winter" (Wood 1635:37). Note that lobsters are available inshore chiefly in summer, and eels were especially available between September and March; these two don't make such an odd couple after all - they are seasonally complementary. The abundance of both lobsters and eels has decreased in the past 350 years in coastal southeastern Massachusetts.

Although scallop shells are rare in Nantucket and Nauset (Cape Cod) shell middens, they dominate one dated Late Woodland feature at Nantucket (Pretola and Little 1988) and six Late Woodland components at Martha's Vineyard (Ritchie 1969). People probably ate Brant geese and other waterfowl, including their eggs (J. C. Andrews, 1991 personal communication), but we lack Brant samples to test. We have no archaeologic or ethnographic evidence for the consumption of prickly pear cactus, yucca, eelgrass or seaweeds, but there exists a general presumption that maize was eaten in southeastern New England during the Late Woodland (Ritchie 1969; Luedtke 1980).

The American coastal diet frequently included dogs, and many coastal middens or ceremonial graves contain their remains (Burleigh and Brothwell 1978; Butler and Hadlock 1949; Ceci 1990; Kerber et al. 1989; Little 1982b; Ritchie 1969; Wing 1978). For a Middle Woodland Squantum, Massachusetts, dog, Nelson (1989) reports ^{13}C(collagen) = -13.1 o/oo, which converts into a flesh value of $\delta^{13}C$ = -16.8 o/oo, close to the value of the Nantucket human diet. Eating such a dog would not have raised the $\delta^{13}C$ value of the Nantucket diet, unless it replaced deer in the diet.

Strontium and Zinc as Dietary Indicators. If trace elements are not soil contaminants, they may offer useful data on diets or pathologies (Schoeninger 1979; Toots and Voorhies 1965). Marine fish have low Sr and Zn; terrestrial herbivores have medium Sr and Zn; and marine mammals have high Sr and high Zn values (Connor and Slaughter 1984). Maize and New England nuts have low zinc and strontium levels, while legumes such as beans are high in strontium (Furr et al. 1979; Price et al. 1982; Buikstra et al. 1989). Deer at Nantucket show low zinc and medium bone strontium values, Zn = 68 ppm; Sr = 340 ppm; the values of Zn and Sr for humans are both very low, Zn = 76 ppm; Sr = 151 ppm (Appendix 2), resembling the low values for some Alaskan coastal peoples that are attributed to a high percentage of fish in the diet (Connor and Slaughter 1984; Sillen and Kavanaugh 1982). However, at Nantucket, low Sr and Zn can also indicate a diet high in maize or

nuts. Because the amounts of Sr and Zn in foods can vary with location, they must be measured on local animal and fish flesh and plant foods before being used in diet models.

Caries as a Dietary Indicator. Maize intensification in the diet often had nutritional penalties (Huss-Ashmore et al. 1982:455; Kelley et al. 1987a). Those who have studied prehistoric Nantucket burials (Anderson 1977; Trinkaus 1982; Kelley in Kerber 1987; Kelley in Kerber et al. 1987; Roberts 1991) as well as 56 burials at Cape Cod (Magennis 1986), and 21 at New Jersey (Clabeaux 1973), note the near lack of caries and the exceptional health of the prehistoric coastal Indians compared with historic skeletons. In a late seventeenth century Narragansett Indian cemetery in Rhode Island, for example, 77% of 53 individuals showed caries along with other pathological conditions of the bone (Kelley et al. 1987b). A number of authors have suggested that changes in the rate of caries and in the location of carious teeth could serve as an indicator of the addition of refined sugars or carbohydrates (maize, flour, molasses, sugar) to a diet consisting primarily of protein and fat (Walker and Erlandson 1986; Kelley et al. 1987b; Robinson et al. 1985; Magennis 1986; Clabeaux 1973). With a diachronic model (Figure 13) we can begin to test these assumptions.

Our initial data show that the caries rate (percentage of teeth with caries) is small but measurable at about 4.8% for 56 individuals from a Cape Cod ossuary (Magennis 1986), three of which were dated at an average of cal A.D. 1143$\pm$143 (McManamon and Bradley 1986; 0% oceanic carbon, see Note 1), and an average caries rate of 2% for six Late Woodland individuals from Nantucket (Anderson 1977; Kelley in Kerber 1987; Kelley in Kerber and Simon 1987; Roberts 1991). The earliest maize kernels (8-rowed Northern flint corn) in the Northeast date to about the middle of this time period in upstate New York, cal A.D. 1039 (1166) 1225 (880 $\pm$ 60 B.P., charcoal, no corrections; Ritchie 1980), and at Martha's Vineyard, Mass., cal A.D. 1169 (1252) 1277 (790 $\pm$ 60 B.P., charcoal, no corrections; Ritchie 1969) (Figure 13), and do not correspond to a change in $\delta^{13}C$ values or caries rates at Nantucket. The caries rate after A.D. 1400 increases to 33% for 56 individuals dating to about A.D. 1650-1670 at Narragansett Bay RI (Kelley et al. 1987a), which implies an increase in maize or other sugars in the diet, but the carbon-13 isotope values, already high, do not change. Figure 13 demonstrates that studies of dentition and possibly $\delta^{15}N$ may be more useful than $\delta^{13}C$ to distinguish additions of high ^{13}C foods such as maize in the diet on the coast of New England, where staples from the C_4 and C_4-like food web already contribute high $d^{13}C$ values to the diet. Additional studies of dentition and $\delta^{15}N$ values at Nantucket, especially those dating outside of the current range of ages, could provide useful information on possible diachronic dietary changes on the coast.

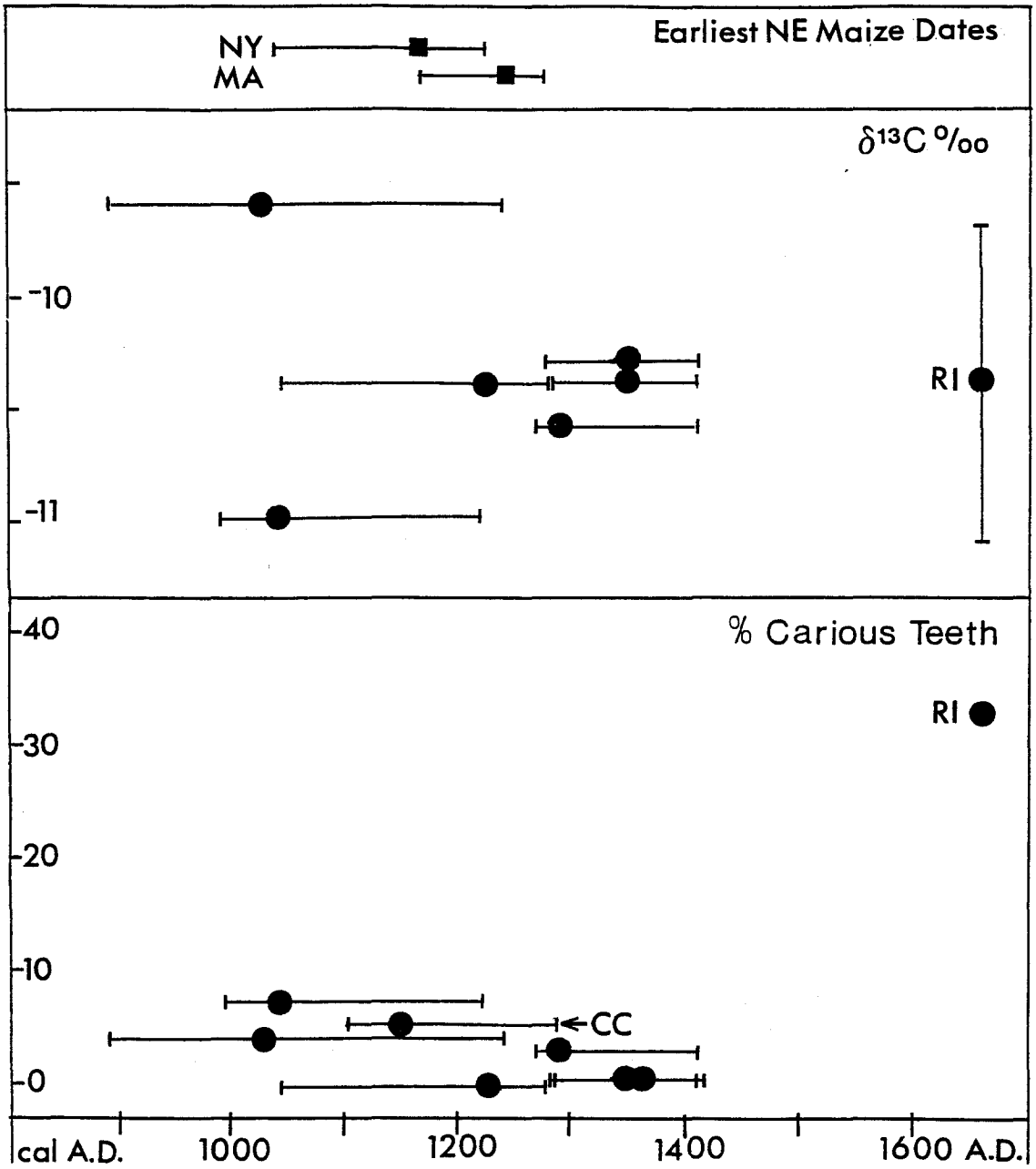

Figure 13. Diachronic exhibit of $\delta^{13}C$ values, percentage of carious teeth and the introduction of maize in the Northeast (Ritchie 1969,1980). Conventional radiocarbon ages have been calibrated to cal A.D. $\pm\ \sigma$ (25% marine carbon; Table 9). Coastal New Englanders include six Late Woodland individuals of Nantucket (N), 56 individuals of the Late Woodland Cape Cod ossuary (CC) (Magennis 1986), and 56 coastal Rhode Islanders (RI) of an historic period cemetery, A.D. 1650-1670 (Kelley et al. 1987a). Between A.D. 1450 and 1650, the percentage of carious teeth shows a marked increase, but the values of $\delta^{13}C$ do not indicate a change in diet.

TABLE 9. CONVENTIONAL AND CALIBRATED RADIOCARBON AGES (STUIVER, PEARSON AND BRAZIUNAS 1986, STUIVER AND PEARSON 1986, STUIVER AND REIMER 1986) FOR NANTUCKET LATE WOODLAND DIET STUDY. $\delta^{13}C$ data from radiocarbon study do not necessarily provide good dietary values [Kreuger pers. comm.]).

Site Name, # Material, Lab #, $\delta^{13}C$ o/oo	Conv.Age (Lab #)	Cal A.D. Date (for 0, 50 or 100% marine dietary carbon)(Stuiver et al. 1986)
Polpis, 19NT-154		
human collagen, MS3199	610±90 B.P. (Beta-21916)	1279(1312,1353,1384)1414 (0%) 1409 (1450) 1521 (50%) 1500 (1644) 1710 (100%)
mercenaria shell, +1.1 o/oo	1130±80 B.P. (GX-16690)	1070 (1218) 1290
TCM, 19NT-108		
human collagen, MS3197 -10.2 o/oo	610±80 B.P. (GX-14301-G)	1281(1312,1353,1384)1410 (0%) 1413 (1450) 1515 (50%) 1500 (1644) 1700 (100%)
mercenaria shell, +1.5 o/oo	1055±60 B.P. (GX-15789)	1193 (1276) 1325
Charcoal, -27.2 o/oo	1546±49 B.P.(GX-15790-AMS)	431 (536) 564
Quaise-1916, 19NT-130		
human collagen, MS3738 -9.9 o/oo	650±105 B.P. (GX-15353-G)	1270 (1290) 1410 (0%) 1390 (1435) 1500 (50%) 1460 (1576) 1690 (100%)
O.virginianus, deerbone -20.6 o/oo	530±115 B.P. (GX-15788-G)	1290 (1409) 1450
Tuckernuck-3, 19NT-134-3		
human collagen, MS3736 -9.0 o/oo	820±105 B.P. (GX-15351-G)	1045 (1225) 1280 (0%) 1260 (1299) 1410 (50%) 1330 (1443) 1530 (100%)
Tuckernuck-5, 19NT-134-5		
human collagen, MS3737 -10.6 o/oo	840±110 B.P. (GX-15350-G)	1030 (1216) 1270 (0%) 1240 (1289) 1400 (50%) 1320 (1433) 1510 (100%)
Wauwinet, 19NT-153		
human collagen, MS3198	940±105 B.P. (Beta-18835)	990 (1039) 1220 (0%) 1150 (1252) 1290 (50%) 1270 (1342) 1450 (100%)
Tuckernuck-1, 19NT-134-1		
human collagen, MS3735 -10.1 o/oo	970±165 B.P. (GX-15352-G)	890 (1027) 1240 (0%) 1030 (1226) 1420 (50%) 1190 (1318) 1460 (100%)

TABLE 10. APATITE AND COLLAGEN MEASUREMENTS (Geochron). Percentage of Animal Food in Diet = [7-(δ^{13}Cap-δ^{13}Ccol)]/[7-3.3], where δ^{13}Cap - δ^{13}Ccol = 7 for herbivores and 3-3.3 o/oo for carnivores (after Kreuger and Sullivan 1984). Apatite and some collagen measurements courtesy H. Kreuger.

		δ^{13}Ccol	δ^{13}Cap	δ^{13}Cap -δ^{13}Ccol	% Animal Diet
19NT-108	TCM	-10.2	-6.4	3.8	80-86%
19NT-130	Quaise-1916	-10.3	-7.0	3.3	93-100%
19NT-134-3	Tuckernuck-3	-9.6	-6.1	3.5	88-95%
19NT-134-5	Tuckernuck-5	-10.5	-6.5	4.0	75-81%
19NT-134-1	Tuckernuck-1	-10.0	-6.3	3.7	83-89%
Averages:		-10.1	-6.5	3.7	83-90%

Bone Apatite as a Dietary Indicator. Fat, carbohydrates and protein of the diet provide energy, and the isotope value, δ^{13}C, of the energy diet is reflected in bone apatite, the carbonate component of bone (Kreuger and Sullivan 1984). Kreuger and Sullivan (1984) report that δ^{13}C apatite - δ^{13}C collagen is about +7 o/oo for herbivores, a minimum of 3 o/oo for carnivores and has intermediate values for omnivores. If an herbivore has an apatite-collagen difference of 7 o/oo and a carnivore has an apatite-collagen difference of 3 o/oo, then an omnivore has an animal diet of (see Note 2): [7 - (δ^{13}Cap-δ^{13}Ccol)] / [7-3]%. The δ^{13}Capatite-δ^{13}Ccollagen difference will increase beyond 3 o/oo if the diet increases in plants, or decreases in fat. Measured values of δ^{13}C for apatite and collagen (Table 10) show that the Nantucket Late Woodland diet has an average δ^{13}Capatite-δ^{13}Ccollagen of +3.7 o/oo for five humans in this study, and therefore is very high in protein and fat input, reflecting a diet of 75-93% (average 84%) animal food. In short, analysis of three linear dietary equations expressing bone collagen isotope values, shows that the Late Woodland Nantucket diet derived chiefly from groups (3) and (5) or (8), and the apatite measurements strongly favor group 5 (animals) over group 8 (plants).

Diet and Energy Diet Calculations. On the basis of familiarity with the three linear dietary equations, we now propose a preliminary model with largely estimated parameters for the δ^{13}C value of the energy diet of a Nantucket marine hunter/gatherer (Figure 14). Measured δ^{13}C values of flesh (which includes protein, fat and carbohydrates) are lower than the δ^{13}C values of protein (van der Merwe 1982). Measured δ^{13}C values for fat are lower than those of flesh for the same animal: seal, -6.5 o/oo, and deer, -6.2 o/oo (Table 6); for C_3 herbivore, -5.4 o/oo (van der Merwe and Vogel

1978), for an average of -6 o/oo (see also van der Merwe 1982), and protein might be 3.0 o/oo higher than flesh (van der Merwe 1982). Estimating the $\delta_{ip}{}^{13}C$ values of protein from the measured values, $\delta_i{}^{13}C$ and p_i, for foods (Tables 7b and 8), the estimated relations: carbohydrate $\delta_{ic}{}^{13}C = \delta_{ip}{}^{13}C$ - 5 o/oo (van der Merwe 1982) and fat $\delta_{if}{}^{13}C = \delta_{ip}{}^{13}C$ - 7.5 o/oo, provide a set of protein $\delta_{ip}{}^{13}C$'s (Table 8) that are on the average 3.3 o/oo higher in ^{13}C than the flesh values used heretofore.

Now, Equation 2_p, $\Sigma_{i=1-n} (p_i/P)\delta_i{}^{13}C\, D_i = \delta_{diet\,p}{}^{13}C$, together with D_i's, provides the value of ^{13}C for the protein alone in the diet. Assuming D_i values from Solutions A and B, $\delta_{diet\,p}{}^{13}C = \sim$ -12.3 to -13.2 o/oo, which is approximately the bone collagen value - 2.3 o/oo. Similar calculations give $\delta_{diet\,f}{}^{13}C$ = -20.7 to -21.2 o/oo, and $\delta_{diet\,c}{}^{13}C$ = -10.4 to -16.2 o/oo. The carbohydrate values have the most variability, as they are most sensitive to the assumed quantity of maize. In Figure 14 the value for $\delta_{diet}{}^{13}C$ is the sum of the amounts (grams) of P, C and F each multiplied by their isotope values, and equals -15.7 o/oo, essentially the -15.4 o/oo we have been using in this paper for the diet.

We should logically use the bone collagen ^{13}C isotope value, -10.4 o/oo, subtracting 2.5 o/oo for fractionation, for the dietary protein ^{13}C isotope value in solving our linear equations for protein components. The solution of these linear (protein weighted) equations gives very standard results:

$$D_{1,2}\text{: } 0 - 5;\ D_3\text{: } 52 - 60;\ D_4\text{: } 0 - 10;\ D_5\text{: } 0 - 42;\ D_{6,7}\text{: } 0 - 8;\ D_8\text{: } 0 - 42.$$

Using the same values for D_i's, $\delta_{ip}{}^{13}C$'s, $\delta_{ic}{}^{13}C$'s and $\delta_{if}{}^{13}C$'s, and p_i's, c_i's and f_i's, we can also calculate the isotope value of the energy diet. The energy diet equation (#4) is:

$$\delta_{energy\,diet}{}^{13}C = [4\ \Sigma_{i=1-8}p_i\delta_{ip}{}^{13}CD_i + 4\ \Sigma_{i=1-8}c_i\delta_{ic}{}^{13}CD_i + 10\ \Sigma_{i=1-8}f_i\delta_{if}{}^{13}CD_i] \text{ divided by } [4\ \Sigma_{i=1-8}p_iD_i + 4\ \Sigma_{i=1-8}c_iD_i + 10\ \Sigma_{i=1-8}f_iD_i].$$

In addition to some carbohydrates required for brain glucose production, a certain amount of protein (approximately 6% of the total energy) is needed for tissue building in humans (Draper 1977; Kreuger and Sullivan 1984). We will neglect this consideration for initial modelling. Equation 4, with parameters from Tables 7b and 8, and solution B, gives an energy diet $\delta^{13}C$ of -17.7 o/oo, which is 11 o/oo smaller than the bone apatite average of -6.7 o/oo, or very close to the -12 o/oo diet/apatite difference measured by Kreuger and Sullivan (1984) for herbivores. The energy diet (kilocalories) for herbivores derives chiefly from carbohydrates, but for omnivores the energy diet is a combination of fat, protein and carbohydrate, in which a gram of fat provides about 2.5 times more energy than a gram of protein.

If we assume that the energy diet is equal to the bone apatite value -12 o/oo, we can use equation 4 as a fourth equation added to the three linear dietary equations that gave us Solution B, to derive:

$$D_{1,2}\text{: } 0 - 0.3;\ D_3\text{: } 51;\ D_4\text{: } 0 - 1;\ D_5\text{: } 39;\ D_{6,7}\text{: } 0 - 0.5;\ D_8\text{: } 10.$$

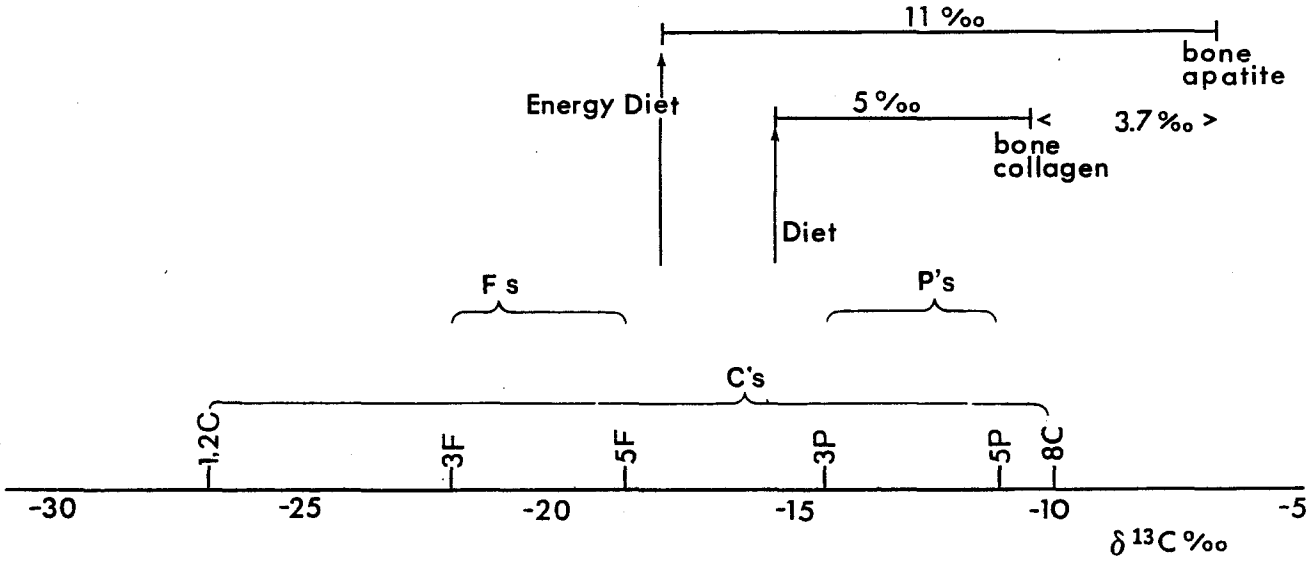

Figure 14. Isotope values of energy diet as calculated from estimated protein, carbohydrate and fat isotope values of the dietary groups (see Tables 7b and 8). Only the chief contributions to P's, C's and F's are shown for simplicity.

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That is, for the Nantucket Late Woodland diets, the carbon isotope value for apatite derives chiefly from the energy of the fat and protein portions of the animals of groups (3) and (5) that provided most of the protein diet. Without added fat in group 3, a common solution to these four equations is not possible. However, while the precision of the solutions has increased over the results obtained with three equations, it now surpasses the accuracy of the approximations for parameters of equations 2, 3 and 4. Good measurements of the isotope values of proteins, fats and carbohydrates within the food chain of humans would provide the necessary data for the precise use of linear equations (see Nelson 1991).

Nutritional Analysis of the Prehistoric Nantucket Diet. Table 11 provides a summary of the findings of this study with respect to the percentages of six food groups in the Late Woodland diet of Nantucket Island. The consistency of the results reinforces the validity of each analysis. Although the $\delta^{13}C$ and $\delta^{15}N$ analyses do not distinguish between groups 5 and 8, the caries and apatite studies indicate a low group 8 component. Marine fat was introduced in order to create a viable protein diet, with a resulting diet for 2500 kcal, P = 245 g (38% of the energy requirements), F = 135 g

TABLE 11. SUMMARY OF CONCLUSIONS ABOUT THE LATE WOODLAND NANTUCKET DIET FROM FIVE TYPES OF DIETARY ANALYSIS.

TYPE OF ANALYSIS	PERCENTAGES OF THE DIFFERENT FOOD GROUPS IN THE KILOCALORIE DIET					
	$D_{1,2}$	D_3	D_4	D_5	$D_{6,7}$	D_8
1. $\delta^{13}C$ and $\delta^{15}N$ of bone collagen:						
	low	high	low	high	low	low
or,	low	high	low	low	low	high
2. Strontium:						
	low	high				
or,	low					high
3. Zinc:						
		high				
4. Caries:						low
5. $\delta^{13}C_{apatite}$:						
	low	[	high		]	low
Conclusion:	low	high	low	high	low	low

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(53% of the energy), and C = 58 g (9% of the energy). The amount of protein is below 300 g (50% energy), the upper limits proposed by Speth (1989). We conclude that the Nantucket diet during the Late Woodland period included substantial amounts of marine fats and proteins, and a limited amount of C_4 plants, and C_3 plants and animals, and resembled diets with high proportions of marine animals of prehistoric coastal dwellers in all parts of the world (Tauber 1981; Chisholm et al. 1982; Meehan 1982; Schoeninger et al. 1983; Sealy and van der Merwe 1986).

Eskimo Diets. At the beginning of this paper, Verrazzano was commenting on the good health of the coastal natives of Block Island. Because of the widespread belief today that a nutritious diet includes milk, leafy vegetables, broccoli, orange juice, lean fish, and no saturated fats, we need to analyze the nutrition of the Eskimo diet (Noli and Avery 1988; Eaton and Konner 1985). Draper (1977) reports that the Eskimo diet can provide all the nutrients needed for health, provided the amounts are adequate and it is prepared by traditional methods (fresh meat every day, not over-cooked). Another Eskimo practice, that of eating the fish and marine mammal livers, oils, and gut contents, as well as meat and fat and parts of bones, provided all the vitamins and minerals they
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needed (Draper 1977). The polyunsaturated fatty acids of marine oils contribute to the low cholesterol levels characteristic of Eskimos on a native diet (Draper 1977:311). A person of European ancestry on a modern American diet needs a period of adaptation to the Eskimo diet, but, except for lactose intolerance and occasional sucrose intolerance, Eskimos do not appear to have unusual adaptational metabolic abilities (Draper 1977:312).

Of considerable interest is that Nantucketers provide a southerly example of the "Eskimo" diet where such a diet is not strictly required (Bennett 1955; Draper 1977; Eaton and Konner 1985). Perhaps the diet is simply available (Perlman 1980): there were in January 1991 on the beaches of Nantucket, 100 or so very lively (probably harbor) seals, a long-dead humpback whale, a recently-dead fin whale, and windrows of shed crab shells (see also Little and Andrews 1982).

Suggestions for Future Studies. This study of carbon and nitrogen isotopes, has greatly narrowed the range of possible diets of Late Woodland Nantucketers. The use of an additional element such as sulfur (Peterson et al. 1985), zinc or strontium, barium and strontium (Burton and Price 1990) or confining the study to proteins (Nelson 1991), with enough supporting measurements of dietary constituents to define additional linear equations, would allow the solution of dietary equations with greater accuracy in a larger number of variables. If an element differs between maize and saltmarsh/seagrass-based foods, it might allow a distinction to be made between them. Strontium and Zinc and $\delta^{13}C$ do not distinguish between maize and estuarine seafoods on the coast of southern New England. Caries seems to be a sensitive indicator, and $\delta^{15}N$ values might well place limits on the use of maize in the diet. For future studies of prehistoric New England diets, measurements of isotope values for each food item's constituents, protein, carbohydrate and fat, could add a precision to our linear equations, and greatly increase our understanding of the sources of energy from marine diets.

CONCLUSIONS.

Diet can vary with age, sex, cultural and social differences, as well as with historical and environmental processes, and the bones of a human population record its variation. Although chemical analysis alone cannot identify the foods in a diet, it can, as we have demonstrated, give strong evidence against the presence of certain foods, and relatively unbiassed evidence for the ranges of percentages of certain groups of foods in the prehistoric diet. The importance of experimental dietary studies, their analysis, and the formation and testing of hypotheses (Platt 1964), for the reconstruction of prehistoric diets from bone measurements cannot be overemphasized (Buikstra et al. 1989; DeNiro and Epstein 1981; Sillen et al. 1989).

There are cultural issues involved in the study of human remains, and Massachusetts advocates the preservation of burials in situ when possible. However, when human remains became available as a result of archaeologically and culturally permitted salvage excavations, their scientific study can produce unexpected and valuable insights into human prehistory, as this paper has shown.

Since the maize diet of coastal Narragansett Indians in the Historic Period was clearly unhealthy, what foods contributed to the notable health of the Nantucketers in the Late Woodland? Our conclusion is: whole, lightly cooked fish, crustaceans, bivalves and marine mammals and their fat. Recent advances in pathological studies of prehistoric burials combined with radiocarbon dating and chemical analysis provide the potential to answer such questions.

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NOTE 1. Radiocarbon ages will be specified as conventional (B.P.; $\delta^{13}C$ corrected), calibrated (cal A.D.), or uncorrected. For an assay made on charcoal with no $\delta^{13}C$ correction, we assume $\delta^{13}C$=-25 o/oo; for shell, we assume $\delta^{13}C$ = 0 o/oo; for calibration, both marine and terrestrial, see Stuiver, Pearson and Braziunas (1986); Stuiver and Pearson (1986); Stuiver and Reiner (1986). The central value of a calibrated age is within parentheses between the + and - sigma ages.

NOTE 2. A simple linear mixing equation can be derived as follows:
Consider two dietary components A and B with $\delta^{13}C$ isotope values -28 o/oo and -12 o/oo, which are mixed into a diet, D, with $\delta^{13}C$ = -15 o/oo. We wish to know the percentage of D that is A and B.

A----------D----------B $\delta^{13}C$ o/oo
-28 -15 -12

If the following relations hold:
1. $D_A + D_B = 1$ and D_A and D_B values are between 0 and 1, and
2. $\delta_A{}^{13}C\, D_A + \delta_B{}^{13}C\, D_B = \delta_D{}^{13}C$,
then, substituting $D_A=1-D_B$ from Eq. 1 into Eq. 2, we derive the following general formula:
$D_B = [\delta_D{}^{13}C - \delta_A{}^{13}C] / [\delta_B{}^{13}C - \delta_A{}^{13}C]$, or 80%, and D_A = 20%
Note that the mixture is closer in $\delta^{13}C$ to its main ingredient than to a minor ingredient.

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APPENDICES

APPENDIX 1.
PROVENIENCES OF PREHISTORIC BONE SAMPLES FOR NANTUCKET PROJECT AT BONE CHEMISTRY LAB, HARVARD 1987-88 AND UNIVERSITY OF WISCONSIN 1989-90.

APPENDIX 2.
NANTUCKET STUDY ISOTOPE VALUES, BONE CHEMISTRY LABORATORY, HARVARD, CAMBRIDGE MA 02138 (Medaglia, Little and Schoeninger 1989) AND (*)UNIVERSITY OF WISCONSIN. Lower case letters give site location, Figure 15. See also Appendix 1 and Figure 14. (^) samples not from Nantucket.

APPENDIX 3.
FOOD REMAINS IDENTIFIED AT 6 NANTUCKET ARCHAEOLOGICAL SITES (Little 1985): (Squam Pond (M52/1), Herracator Swamp (M52/3), Quidnet (Q-6), Quaise 1978, Ram Pasture I (RP-I), and Pocomo (Thompson) (Waters 1965; Stockley 1964; Little 1984; Bullen and Brooks 1947, 1949; Turchon 1979; Luedtke 1980; Carlson 1990; Pretola and Little 1988).

APPENDIX 4.
INTER-LABORATORY COMPARISON OF ISOTOPE MEASUREMENTS.

APPENDIX 5.
COMPARISON OF CONCLUSIONS ABOUT THE LATE WOODLAND NANTUCKET DIET FROM VARIATIONS IN THE LINEAR EQUATIONS FOR $\delta^{13}N$ AND $\delta^{15}N$.

APPENDIX 1. PROVENIENCES OF PREHISTORIC BONE SAMPLES FOR NANTUCKET PROJECT AT BONE CHEMISTRY LAB, HARVARD AND UNIVERSITY OF WISCONSIN 1987-1990 (see Figure 7).

Wauwinet Road Burial, Site 19-NT-153 (Kerber 1987)(MS-3198).

Discovered and excavated by backhoe 12/12/85, while contractor was digging septic tank. Reported to Medical Examiner, State Police and State Archaeologist. Septic tank was installed and pit filled, but contents of backhoe shovel which had contained the burial were saved on ground nearby. Most bones were saved by landowner. Some fragments of shell (including whelk) and of deer or elk antler were reported, not a shell midden; a dog skull, humerus and vertebra reported 5 m to the east of human burial. After a year's study, remains were returned to the Massachusetts Indian Commission for reburial.

Examination of disturbed area and backhoe deposit, in reversed stratification, and test excavations for a cable installation nearby were made under the supervision of the state archaeologist, Brona Simon. Findings were as follows: 1 felsite Levanna-like biface, 1 felsite point tip, 1 untyped chert biface, 13 primary felsite flakes, 1 primary chert flake, 77 felsite flakes, 7 quartzite, 7 quartz, 3 hornfels, and 2 chert flakes. Small amount of fragments of Quahog, oyster, whelk, slippershell, soft shell clam, snail, charred nut husk, fish vertebrae. Lithics and historic ceramics, glass, nails and brick materials found in area suggest possible occupations from Late Archaic period (ca. 4000 B.P.) into the 20th century. Historic plowing and slope wash were processes proposed to explain the deposits and distribution of culturally diagnostic artifacts.

Pathology and physical examination: According to Dr. Marc Kelley, URI, American Indian, male, 28-30 years old, 5'7" (170.7 cm) tall, of prehistoric or early Contact period. Relatively entire skeleton, in good condition. Shovel-shaped incisors, moderate attrition (wear), one caries in 14 (lst molar right max.) (7% of teeth carious). Widespread peristitis in long bones, nonspecific hematogenous infection.

Age: AMS, Beta-18835: 940 $\pm$ 105 B.P., bone gelatin, ^{13}C corrected for total isotope effect both general in nature and during physical and chemical procedures. 1/2 life ^{14}C: 5568 yrs.

Polpis Road Burial, Site 19-NT-154 (Kerber and Simon 1987)(MS-3199).

Discovered and excavated by backhoe digging septic tank for new house 12/12/86. Reported to Medical Examiner, State Police and State Archaeologist. Pit was left open for study. Remains studied by Kelley included fragments of dog skeleton. Remains returned to Massachusetts Indian Commission for reburial after one year's study.

Archaeological examination of site under supervision of state archaeologist, Brona Simon, reported: that a feature with fire-cracked rock and quahog shells was found in bottom of pit excavated for septic tank. The two stone artifacts recovered may or may not have been associated with burial. No other artifacts or categories of cultural material were found, although Levanna-like and small stemmed points were found in loam piles on the project area (after Kerber et al. 1987).

Pathology and physical examination by Dr Marc Kelley, URI: American Indian, Female, 40-45, 5'5" (165 cm). Healed fracture of L radius & large parturition scars in dorsal pubis & preauricular region, implies several offspring. Moderate to high attrition (wear). No caries. Mild to moderate spondylitis of L5. Mild osteophytosis. Excellent condition of bone.

Age: AMS Beta-21916; ETH-3117. 610 ± 90 B.P. Bone gelatin, ^{13}C corrected for total isotope effect general in both nature and during physical and chemical lab procedures; ^{14}C half-life: 5568 years.

Tristram Coffin Monument Burial (Anderson 1977)(MS-3197; 19NT-108).

Discovered by Mrs. Della Brooks of Madaket, eroding out of the center of a dirt road. Reported to Chief Anthony Hopfinger, Nantucket Police Department. Dr. D. B. Voorhees, Medical Examiner, found it to be the remains of a prehistoric American Indian. Salvage excavation by Nantucket Historical Association under the direction of the Reverend E. Anderson. Nearby pit contained shell (quahog, oyster, whelk), deer bones, bluefish bones. Some colonial pipes stems, pottery and a chert Green point were reported nearby. Close to or in burial pit were found: a broken felsite lanceolate biface, flakes, and two worked whelk columella, none clearly associated with the burial.

Physical examination by Dr. Phillips: Male (from pelvis), about 45 years old, about 163.2 cm (from Femur of 42.2 cm [Trotter & Gleser 1958]). No malnutrition, arthritis, injury.

Dental examination by Dr. Slavitz: broad, round face, with flattish facial features, extraordinarily robust upper jaw bone, suggests robust individual. Teeth eroded (worn down). X-ray examination: No dental decay, "indicating a diet essentially free of sugars and low in carbohydrates"; a possible chronic abcess, periodontal bone loss. Age estimate: late middle age. A shovel-shaped incisor is mentioned in report.

Age: GX-14301-G, 610±80 radiocarbon years, bone gelatin; ^{13}C corrected; ^{14}C half-life: 5570 years; 95% NBS Oxalic Acid; ± 1 sigma based on analytical data.

Quaise 1916 Burial (MS-3738; 19NT-130).

NHA-SW-3.A. In 1916, Mr. Arthur R. Thompson found bones, pottery and lithic tools at the very edge of the bluff which overlooks the beach at Quaise near Folger Creek. Associated with these finds was a flat smooth oval stone called a headstone, a shell heap, and a large bowl, shell tempered, together with deer bones (not dog as labelled) (Nantucket Inquirer and Mirror Aug. 5 and 12, 1916). All these finds are curated at the Nantucket Historical Association, with respect, and are available for responsible study. Age: 650 ± 105 B. P. (GX-15353-G; bone gelatin, $\delta^{13}C$ = -9.9 o/oo corrected).

Tuckernuck 1964 Burials (19NT-134).

NHA-T-1. Site at southeast beach of Tuckernuck, in eroding cliff, overlooking small salt pond/marsh. Seven or eight burials. Seven excavated by Shawkemo Chapter, MAS, Bernard Stockley directing. One was salvaged in 1968 by J.C. Andrews. Two were secondary burials (bundles of long bones), and the rest were flexed inhumations with random orientations. No report has been forthcoming. The records are said to be in possession of Mrs. Bernard Stockley of Centerville, Stockley's widow. Most of the osteological remains are in possession of the Nantucket Historical Association, where they are respectfully curated, and available for any responsible study.

Age: #1 (MS 3735): 970 ± 165 B.P. (GX-15352-G, bone gelatin, $\delta^{13}C$ = -10.1 o/oo corrected)
#3 (MS 3736): 820 ± 105 B.P. (GX-15351-G, bone gelatin, $\delta^{13}C$ = -9.0 o/oo corrected)
#5 (MS 3737): 840 ± 110 B.P. (GX-15350-G, bone gelatin, $\delta^{13}C$ = -10.6 o/oo corrected)

APPENDIX 2. NANTUCKET STUDY ISOTOPE VALUES, Harvard University (Medaglia, Little and Schoeninger 1989), (*) UNIVERSITY OF WISCONSIN 8/8/90, and (+) University of Wisconsin and 1991 summary. Lower case letter gives site location, Figure X. See also Appendix I and Figure X. ^ Samples not from Nantucket.

Material, MS Sample Number:	$\delta^{13}C$ (o/oo)	$\delta^{15}N$ (o/oo)	Zn (ppm)	Sr (ppm)
HUMAN BONE:				
Human bone (1340 AD), 3197:	-10.441 ±.016	15.493 ±.034	88.27	143.8
Human bone (1010 AD), 3198:	-11.024 ±.025	14.116 ±.062	69.32	158.4
		14.092 ±.020		
Human bone (1340 AD), 3199:	-10.335 ±.025	15.280 ±.104	72.04	
		15.253 ±.034		
Human bone, 3735:	-9.6	15.3		
Human bone, 3736:	-10.4	16.7		
Human bone, 3737:				
Human bone: 3738:	-10.6	15.1		
DEER BONE (Odocoileus virginianus):				
Deer bone (1700 AD), 3192:			62.10	463.3
Deer bone (325 AD), 3195:	-20.273 ±.021	2.267 ±.030	56.15	369.1
	-20.117 ±.022	2.265 ±.141		
	-20.3*	2.261 ±.044		
	-20.2+	2.3*,2.2+		
3196:	-20.2*	1.8*	76.13	325.4
Deer bone (1987 AD), 3200:	-21.704 ±.017	3.1 ±.042	82.86	291.3
	-21.582 ±.017			
	-21.7*, -21.6+	4.4*, 4.0+		
Deer bone (1985 AD), 3201:	-21.120 ±.032		64.18	252.6
	-21.5*+	3.2*+		
Deer flesh: 3200:	-24.1 ±.023	4.374 ±.070		
		4.344 ±.065		
	-24.0*,-24.1+	4.2*+		
Deer flesh: 3201:	-24.1	4.5 ±.022		
	-24.1*	4.5*		
Deer fat: 3200C:	-30.3*+	(inadequate N2)		

TERRESTRIAL PLANTS:

	$\delta^{13}C$ oo;	$\delta^{15}N$o/oo
3388 (p) Samphire (Salicornia virginica)(Chenopodiacae):		
	-24.82	4.8
	-24.8*+	4.7*+
3389 (s) Sea Rocket (Cakile edentula)	-27.85	0.11±.04
	-28.0*+	1.5*+
3390 (s) Beach peas (Lathyrus maritimus)		
	-23.75	-0.4
	-23.8*,-23.7+	-0.4*+
3391, Shadberry berries (Amelanchier canadensis)		
	-26.70	-0.1
	-26.7*+	+0.2+
3393, Orach leaves (Atriplex patula L. var hastata (L))		
	-27.23±.025+	2.2+
3394, Elderberry blossoms (Sambucus canadensis)		
	-26.47±.03	2.2
	-26.5*+	2.2*+
^3399, Common Bean (Phaseolus vulgarus)		
(Aunt Dixie's Bean)	-27.89	-1.03
	-27.9*+	-1.0*,-0.8+
3396, (n) Blackberry (Rubus sp.)	-25.0*+	+0.6+
3397, (m) Blueberry (Vaccinium angustifolium, var. laevifolium)		
	-25.8*+	3.3+
3719, (u) Jerusalem artichoke (Helianthus tuberosus), uncultivated field near town		
	-25.9*+	6.7*+
^3721, Ground Nut (Apios americana), Concord, Mass., Dr. Shirley Blancke)		
	-28.1+	
3722, Hazelnut (Corylus americana)	-26.9+	2.3+

FRESH WATER PLANTS:

3392 (r) Cattail roots (Typha angustifolia)		
	-28.14	8.2
	-28.0*,-28.1+	8.2*, 8.1+
3395, Sweet flag root (Acorus calamus)		
	-26.48	7.5
	-26.3* +	5.8+

FRESH WATER FISH:

3270, White Perch (Morone americana)		
	-23.9	10.3+.02
	-23.9*+	10.3*+

MARINE FISH (Nantucket Fish Market):

3294, Bluefish (Pomatomus saltatrix)	-18.7	16.18±.02
	-18.7*+	16.2*+
3205, Striped Bass (Roccus saxatilis)	-18.3	16.61±.02
	-18.3*+	16.6*+
3207, Halibut (Hippoglossus hippoglossus) (Nantucket based fishing boat)		
	-17.8±.037	14.47±.02
	-17.8*+	14.5*+

MARINE MAMMAL: 1988 New England Aquarium (MH-88-518 Pv), Stranding at Danvers, Mass.

^3717B, Harbor Seal (Phoca vitulina) flesh:		
	-17.2*+	14.7*+
^3717C, Harbor Seal fat:	-23.9*+	(inad.N2)+

CARNIVOROUS NEARSHORE FISH, MOLLUSCS AND CRUSTACEANS:

3206, Winter Flounder (Pseudopleuronectes americanus):		
	-17.49±.01	10.69±.02
	-17.5*+	10.7*+
3264 (c) Moon snail (Lunata heros):	-15.9	9.3±.04
	-15.9*+	9.3*+
3265 (a) Channelled whelk (Busycon canaliculatum):		
	-16.1	10.7±.10
		11.1±.04
	-16.1*+	10.9*, 11.1+
3267 (a) crab (Cancer borealis):	-17.0	10.6±.02
	-17.0*+	10.6*+
3269 (a) Scup (Stenotomus chrysops):	-16.57±.03	12.61±.0
	-16.6*+	12.6*, 12.7+

CARNIVOROUS INSHORE CRUSTACEANS, FISH

3260 (a) Lobster (Homarus americanus):		
	-13.73±.02	11.81±.03
	-13.7*+	11.8*+
3262 (f) Eel (Anguilla rostrata):	-13.4	9.8±.02

	-13.4*+	9.8*+
3268 (g) Cunner (Tautogolabrus adspersus):		
	-13.5	10.5±.03
	-13.5*+	10.5*+
3720 Sand Eel (Ammodytes americanus)(bluefish stomach contents):		
	-14.8*,-19.3+	11.7*+
HERBIVOROUS WATERFOWL:		
3718 Canada Goose (Branta canadensis):		
	-13.6*+	6.8*+
MARINE BIVALVES:		
3202 (c) Quahog (Mercenaria mercenaria)		
flesh	-18.40±.11	5.3±.10
flesh	-18.86±.03	
	-18.5+	5.3+
stomach	-22.19±.02+	6.8+
3403 (j) soft shell clam (Mya arenaria)		
flesh	-16.06+	7.2+
stomach	-19.06+	6.3+
3404 (k) Oyster (Crassostrea virginica)		
flesh	-18.58+	2.8+
stomach	-20.50+	
3261 (e) Blue Mussel (Mytilus edulis)	-20.70	7.2±.03
	-21.30±.02	
	-21.0*+	7.2*+
3263 (d) Ribbed Mussel (Geukensia demissa):		
	-15.2	3.5±.03
	-14.96±.03	
	-15.1*+	4.7*, 4.1+
3266 (b) Bay Scallop (Argopecten irradians):		
	-14.0	6.3±.0
	-14.0*+	6.3*+
CAM PLANT:3398(t) Prickly Pear Cactus (Opuntia humifusa)		
	-14.21	-0.6
	-14.1*+	-0.7*, -0.8+

C4 (or C_4-like) PLANTS:

^3400, 8-rowed northern Flint Corn (Zea mays)(courtesy of Tonya Largy and Walton Galinet):

	-10.67	1.8
	-10.7*+	4.0*, 2.2+
3401(q) Spartina alterniflora roots:	-11.84	1.6
	-12.0*+	0.7*, 1.0+
3402(p) Eelgrass (Zostera marina var. stenophylla):		
	-5.90±.01	5.2
	-7.2*, 6.8+	5.6*, 5.4+

APPENDIX 3. FOOD REMAINS IDENTIFIED AT 6 NANTUCKET ARCHAEOLOGICAL SITES (Little 1985): (Squam Pond (M52/1), Herracator Swamp (M52/3), Quidnet (Q-6), Quaise 1978, Ram Pasture I (RP-I), and Pocomo (Thompson) (Waters 1965; Stockley 1964; Little 1984; Bullen and Brooks 1947, 1949; Turchon 1979; Luedtke 1980; Carlson 1990; Pretola and Little 1988).

Oyster (Crassostrea virginica)
Quahog (Mercenaria mercenaria)
Soft shell clam (Mya arenaria)
Scallop (Argopecten irradians)
Surf clam (Spisula solidissima)
Knobbed whelk (Busycon carica)
Channelled whelk (Busycon canaliculatum)
Oyster drill (Urosalpinx cinerea)
Moonshell snail (Lunata heros)
Blue mussel (Mytulis edulis)
Ribbed mussel (Geukensia demissa)
Boat shell (Crepidula fornicata)
Blue crab (Callinectes sapidus)

Gray seal (Halichoerus grypus)
Pilot whale (Globicephala melaena)
Humpback whale (Megaptera novaeangliae)
Harbor seal (Phoca vitulina)

White tailed deer (Odocoileus virginianus)
Raccoon (Procyon lotor)
Indian Dog (Canis familiaris)
Gray Fox (Urocyon cinereoargenteus)
Red Fox (Vulpes fulva)
Muskrat (Ondatra zibethicus)
Norway Rat
Meadow Vole/Mouse
Caribou (Rangifer sp.)
Elk (Cervus canadensis)

Walnut
Hickory nut (Carya sp.)
Oak acorn (Quercus sp.)
Beach Plum (Prunus maritima)
Cherry (Prunus serotina)

Loon (Gavia immer)
Eider Duck (Somateria mollissima)
Brant (Branta bernicla)
Teal (Anas sp.)
Gull (Larus atricilla)
Cormorant (Phalacrocorax carbo)
Canada Goose (Branta canadensis)
Eskimo Curlew (Numenius borealis)

Cod (Gadus morhua)
Sturgeon (Acipenser oxyrhynchus)
Sculpin (Myoxocephalus sp.)
Blue fish (Pomatomus saltatrix)
Sand shark (Carcharias taurus)
Sea catfish (Galeichthys felis)
Sea Robin (Prionotus carolinus)
Striped Bass (Roccus saxatilis)
Ray (Dasyatis americana)
Spiny dogfish (Squalus acanthias)
White perch (Morone americana)
Winter flounder (Pseudopleuronectes americanus)

Painted turtle (Chrysemys picta)
Box turtle (Terrapene carolina)

Marine snail: Nassarius trivitata
Polygyra thyroidus
Land snail: Anguispira alternata
Ilyanassa obsoleta

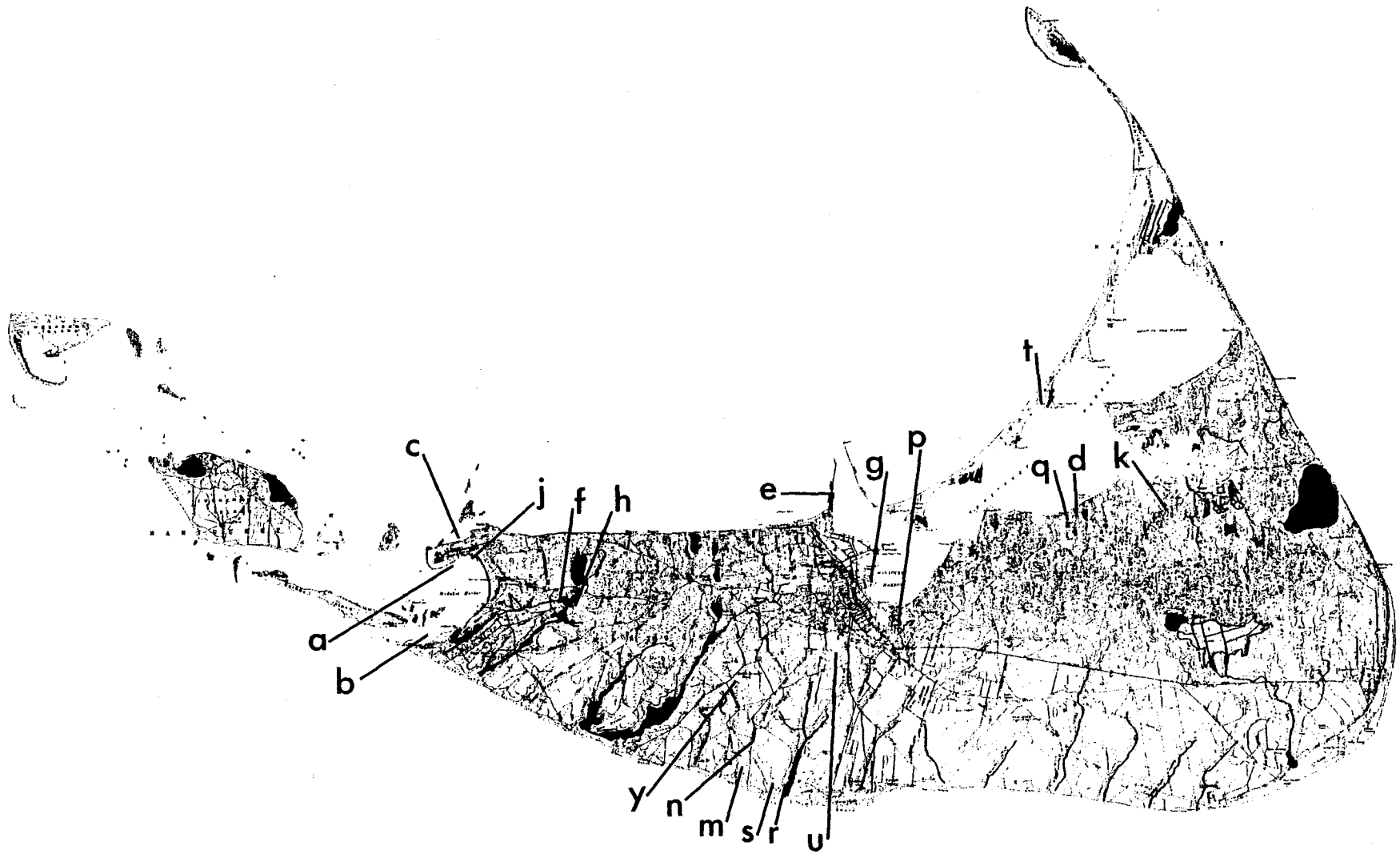

Figure 15. Nantucket Island locations of samples of plants and seafood collected for this study, prepared with the help of J.C. Andrews (see Appendix II).

APPENDIX 4. INTER-LABORATORY COMPARISON OF ISOTOPE MEASUREMENTS.

	Harvard/Wisconsin Laboratories		Geochron Laboratories	
	$\delta^{13}C$ o/oo	$\delta^{15}N$ o/oo	$\delta^{13}C$ o/oo	$\delta^{15}N$ o/oo
MS3197 (TCM)	-10.4	15.5	-10.2	14.9
MS3738 (Q-1916)	-10.6	15.1	-10.3	15.9
MS3736 (T#3)	-10.4	16.7	-9.6	15.9
MS3735 (T#1)	- 9.6	15.3	-10.0	16.0
Avg (N=4):	-10.25	15.7	-10.0	15.7
MS3198 (Wau)	-11.0	14.1		
MS3199 (Pol)	-10.3	15.3		
Tuck.#5			-10.5	15.8
Abrams Pt.			-10.3	16.8
Tuck.#1-A			-10.7	15.4
Hughes			-10.7	15.9

Average to use for Linear Equations $\pm$ the range of variation:

-10.4$\pm$0.8 (N=10) 15.6$\pm$1.5 (N=10)

APPENDIX 5. COMPARISON OF CONCLUSIONS ABOUT THE LATE WOODLAND NANTUCKET DIET FROM VARIATIONS IN THE LINEAR EQUATIONS FOR $\delta^{13}N$ AND $\delta^{15}N$.

TYPE OF ANALYSIS	PERCENTAGES OF THE DIFFERENT FOOD GROUPS IN THE KILOCALORIE DIET					
	$D_{1,2}$	D_3	D_4	D_5	$D_{6,7}$	D_8
NO FAT ADDED:						
1. basic equations 1, 2 & 3, $\delta_{diet}{}^{13}C$ = coll. −5 o/oo, $\delta_{diet}{}^{15}N$ = coll. −2.5 o/oo:						
	0–1	37–43	0–4	53–62	0–2	0–4
1′. basic equations, with $\delta_{diet}{}^{13}C$ = collagen − 6 o/oo:						
	0–7	37–72	0–36	0–50	0–16	0–25
2. basic equations, with protein weighted $\delta^{15}N$:						
	0–13	35–50	0–34	0–63	0–19	0–46
2′. D_8=0:	0–2	35–37	0–8	58–63	0–4	0
3. basic equations, with protein weighted $\delta^{13}C$ & $\delta^{15}N$:						
	0–1	34–35	0–3	49–65	0–2	0–17
FAT ADDED TO GROUP 3.						
4. protein weighted $\delta^{15}N$, $\delta_{diet}{}^{13}C$ = collagen − 5 o/oo:						
	0–5	50–60	0–15	0–35	0–7	15–40
4′. protein weighted $\delta^{15}N$, $\delta_{diet}{}^{13}C$ = collagen − 6 o/oo:						
	0–10	52–67	0–27	0–45	0–13	0–32
4′. D_8=0:	0–3	52–57	0–13	35–45	0–6	0
5. protein weighted $\delta^{15}N$ & $\delta^{13}C$, $\delta_{diet}{}^{13}C$ = collagen − 5 o/oo:						
	0–1	50–52	0–3	35–48	0–2	0–15
5′. D_8=0:	0–1	51–52	0–3	47–48	0–2	0
5". Energy Equation added, with Eqs. 1,2,3 from #5:						
	0–0.4	50.4–50.9	0–1.1	39.2–40	0–0.6	9–9.4
5"′. protein wtd $\delta^{15}N$ & $\delta^{13}C$, $\delta_{diet}{}^{13}C$ = col. −5.3 o/oo, $\delta_{diet}{}^{15}N$ = coll. −3.0 o/oo:						
	0–8	42–59	0–23	0–50	0–12	0–40
5"". D_8=0:	0–6	42–52	0–18	39–50	0– 9	0
5""′P=250g:	0–7	45–53	0–21	13–37	0–10	6–20
6. protein wtd $\delta^{15}N$ & $\delta^{13}C$, with estimated values of $\delta^{13}C_{pi}$ for each food group						
6′. $\delta_{protein\ diet}{}^{13}C$ = collagen − 1.3 o/oo: no solution						
6′′. $\delta_{protein\ diet}{}^{13}C$ = collagen −2.5 o/oo:						
	0–5	52–60	0–10	0–42	0–8	0–42
6"′. D_8=0:	0–5	52–60	0–10	32–42	0–8	0.
6"". $\delta_{protein\ diet}{}^{13}C$ = collagen − 5 o/oo:						
	13–21	64–75	0–23	0–14	0–11	0–19