FROM THE SAND EEL TO THE GREAT AUK: POTENTIAL PREHISTORIC COASTAL DIETS FOR ISOTOPE ANALYSIS

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ABSTRACT

Many coastal human diets include foods of both the C_3 and C_4 terrestrial and the C_3- and C_4-like marine foodwebs. This presents problems for dietary analysis by carbon-13 and nitrogen-15 isotopes, which appear to provide too little data to unravel the many possible diets. However, a study of Late Woodland diet at Nantucket Island, Massachusetts, demonstrates that a knowledge of food webs and trophic levels can help establish a workable framework for selecting and grouping foods for isotopic study. The environmental and ecological information also provides a basis for the interpretation of potential diets.

INTRODUCTION

Studies have shown that the isotope ratios of diets are reflected in consumers' bone tissues (DeNiro and Epstein 1978,1981), so that stable isotopes hold great promise as indicators of the proportions of various kinds of foods in human diets. Isotope analysis has been able to distinguish between diets that include maize or no maize, and between marine and terrestrial diets. However, problems have arisen in the application of these techniques to the reconstruction of diets created by mixtures of terrestrial C_3 plants and animals with marine foods and maize, for example. These problems have impeded stable isotope studies on the eastern coast of the United States. In this paper I demonstrate that ecological data can augment isotope data and, therefore, reduce the range of possible diets at Nantucket Island, Massachusetts.

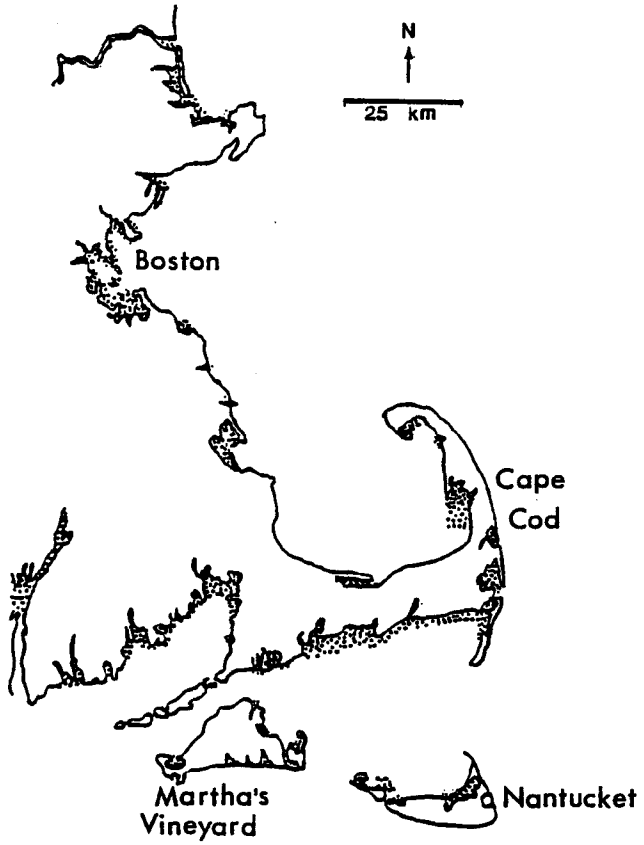

Figure 1. The coast of Massachusetts, showing the location of Nantucket Island. The distribution of shellfish beds (in 1909), shown by dots, indicates harbors, estuaries, and other sheltered waters (Little 1988).

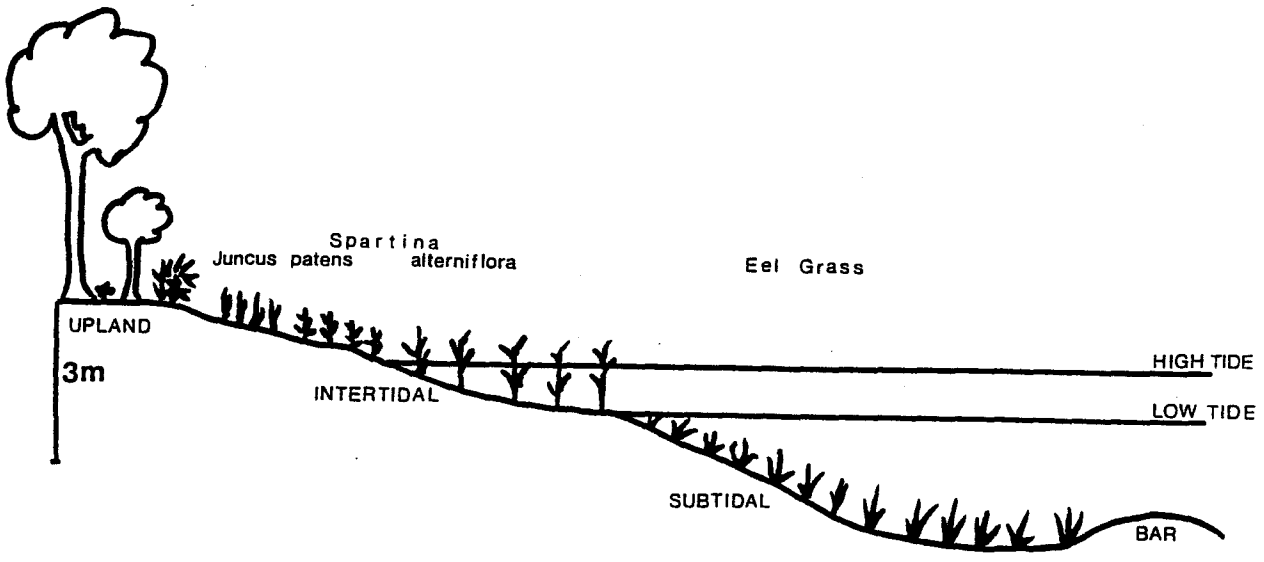

Figure 2. Schematic transect from upland through Spartina marsh and eelgrass at Nantucket.

On the coast of Massachusetts both prehistoric and modern settlements cluster around harbors and estuaries where shellfish beds are found (Figure 1). Nantucket Island provides good examples of these near-shore environments that we examine in some detail. Nantucket, 42 kilometers south of Cape Cod at 41° N, consists of sand, gravel and clay deposited by the Wisconsinan ice about 20,000 years ago, and has shrunk considerably in size with rising sea level and coastal erosion (Oldale 1985). A schematic transect (Figure 2) that starts from a spring or brook in the upland and follows a tidal creek to the harbor, shows the location of upland plants, Spartina saltmarsh and eelgrass meadows in relation to the mean tidal range ($\pm$0.5 m). The tidal creek and harbor constitute an estuarine-like environment, but because of the small amount of freshwater input (there are no rivers), is not an estuary as usually defined (W. N. Tiffney, Jr., 1990 personal communication). In 1991 saltmarsh can be found close to shores in sheltered embayments and eelgrass meadows are located in the harbors as far as a bar just off the north shore (Figure 3). Wave energy from Nantucket Sound and the Atlantic Ocean does not allow estuarine plants to gain a foothold on the unprotected shores.

Although storms change both the shoreline and underwater landscapes, shellfish habitat, adjacent prehistoric shell middens and radiocarbon dated burials correlate highly with the modern eelgrass and Spartina beds (Figure 4). Some reasons for settlement around saltmarsh are: access to freshwater, shellfish and fishing, canoe launching sites, and protection from winter winds. Alternative shore sites, lacking these assets, usually consist of eroding sandy bluffs.

Isotopic compositions are expressed as $\delta X = [(R_{sample}/R_{standard}) - 1] \times 10^3$ per mil, where X is ^{13}C or ^{15}N, and R is the corresponding ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$ (Peterson et al. 1985). Botanists have found that most plants use one of two metabolic pathways, the C_3 and C_4, which

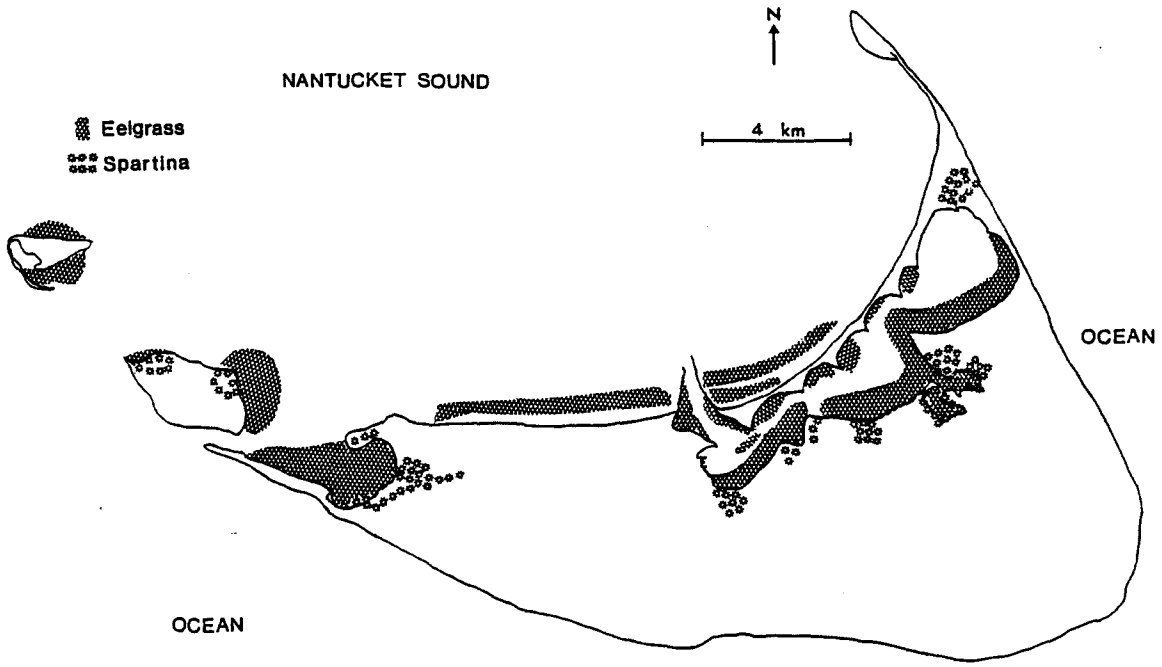

Figure 3. Nantucket Island, Harbors, Sound and Ocean, showing area of eelgrass and Spartina in 1991 (J. C. Andrews, 1991 personal communication).

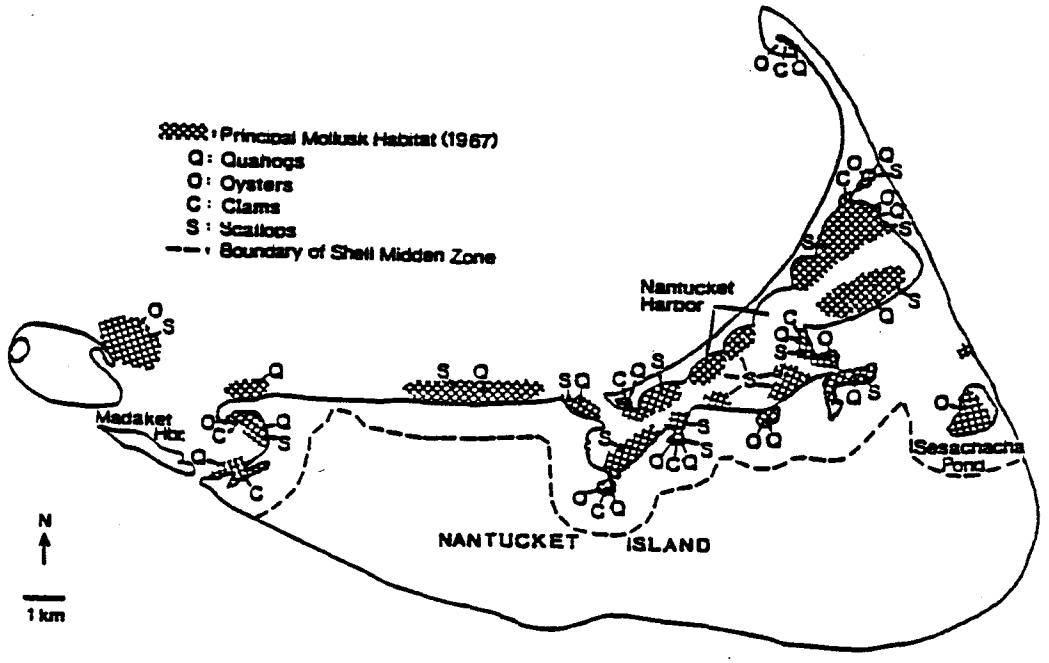

Figure 4. The principal shellfish habitat at Nantucket (hatched) and the adjacent prehistoric shell midden zone (north of dashed line) (Little 1986; Little and Andrews 1986).

fractionate carbon isotopes differently (O'Leary 1988). Most temperate North American plants are C_3 plants, but the tropical plant maize is a C_4 plant with $\delta^{13}C$ values up to 18 o/oo higher than those of C_3 plants (van der Merwe 1982). $\delta^{13}C$ values for plankton-based marine resources are about 8.0 o/oo higher than those for terrestrial C_3 foods (Chisholm et al. 1982; Schoeninger and DeNiro 1984). Similar studies show that $\delta^{15}N$ is enriched in marine phytoplankton (plants), in some fresh water plants, and in meat and fish, and depleted in nitrogen-fixing coral reefs and salt marshes (Peterson et al. 1985; Schoeninger et al. 1983). With these studies as a guide, a dramatic increase in $\delta^{13}C$ found in humans of Ohio and Illinois around A.D. 900-1000 has been interpreted to reflect the addition of maize (C_4) to foods of the C_3-foodweb (van der Merwe and Vogel 1978), and a sharp decrease in $\delta^{13}C$ in Danish diets between the Mesolithic and Neolithic to reflect a change in diet from marine resources to the terrestrial C_3-foods of farmers (Tauber 1981).

Unfortunately, the simple model of a diet with only two possible isotopic components does not hold for all peoples, and, particularly, does not apply on the southern coast of New England. At Nantucket during the Late Woodland and Contact Periods, available foods included: C_3 plants and their consumers; C_4 plants (maize); and marine animals with food webs that include C_3 and C_4 terrestrial and C_3-like and C_4-like marine plants. Although these dietary components are extremely varied isotopically, an understanding of the food webs can provide a framework to disaggregate the human diet into environmentally distinct component parts.

ISOTOPE MEASUREMENTS

A stable isotope study explored the diet of three Late Woodland Nantucket burials, radiocarbon dated between cal A.D. 990 and 1414 (no r.e. correction; span includes $\pm\sigma$; Stuiver and Pearson 1986). A study of floral and faunal remains in archaeological deposits and 17th century historic reports of the Cape and Islands suggested the following foods to sample: fish, both freshwater and saltwater; mammals, both terrestrial and marine; shellfish and crustaceans (bivalves, gastropods, lobsters); waterfowl; terrestrial plant roots, nuts, fruits, seeds and maize. Knowledgable islanders collected at Nantucket representative samples of most of these foods and local fishermen caught the marine fish purchased at an island fishmarket. In addition to these contemporary foods, we were able to obtain samples of an antique strain of 8-rowed northern flint maize from mainland Massachusetts (courtesy of Tonya Largy).

Samples of the edible parts of a number of foods and of bone collagen for three Nantucket burials were analyzed in the lab of Professor Margaret J. Schoeninger at Harvard University and in Professor John Hays' lab at Indiana University (see Medaglia, Little and Schoeninger 1990). J. Clinton Andrews has provided local ecological data for this analysis.

ANALYSIS

In order to relate human diet to constituent foods by means of isotope analysis, we need to define groups of foods with similar isotope values that can be mixed together to form the diet.

In the process of forming these groups, it became apparent that the measured isotope values of individual foods depend strongly on the bases of the food chains in the habitat from which the food was obtained, and on the fractionation of the isotopes by trophic level. With an understanding of these two phenomena, seven different food groups can be described and compared with isotope values of human bone samples to shed light on possible human diets.

Isotope Values of the Bases of Food Chains in Different Environments. Bivalve diets consist chiefly of suspended particulate organic carbon filtered from the local water. Peterson et al. (1985) have shown that the $\delta^{13}C$ and $\delta^{15}N$ values of filter-feeding bivalves (ribbed mussels) living in a Spartina saltmarsh at Falmouth, Mass., vary considerably with location from near the upland to near the bay, a phenomenon that they interpret to reflect the different isotope values in the mixture of food resources (upland plants, Spartina and plankton) available at the different locations.

Figure 5 shows the $\delta^{13}C$ and $\delta^{15}N$ values of four bases of major food chains that we have found in Nantucket waters. Spartina in the saltmarsh (a C_4 plant) has a high $\delta^{13}C$ value; upland plants along the shores at Nantucket (C_3 plants) have low $\delta^{13}C$ values; and both kinds of plants show the low $\delta^{15}N$ isotope values that reflect terrestrial nitrogen-fixing systems. Phytoplankton (marine plants) of Nantucket Sound have a low $\delta^{13}C$; eelgrass (a marine C_4-like plant) in the harbors shows a high $\delta^{13}C$; and both show a higher $\delta^{15}N$ than do the terrestrial plants. Detritus of both kinds of terrestrial plants carried by runoff and tidal flushing into the harbor, eelgrass detritus, associated epiphytes and plankton provide food to filter-feeders either directly or as metabolized by micro-organisms (Fry and Sherr 1988; Haines and Montague 1979; McConnau-

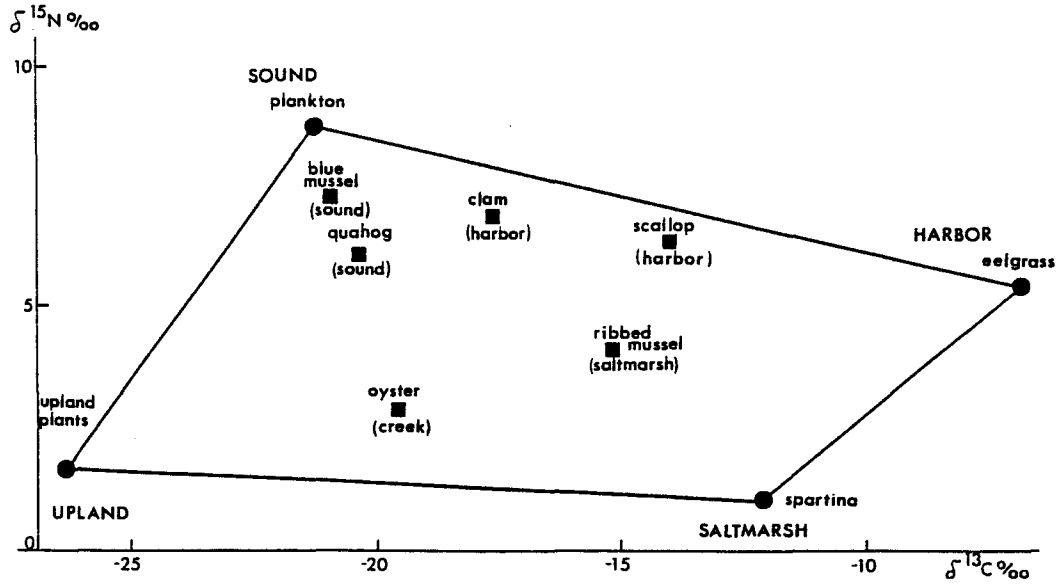

Figure 5. Isotope values of bases of food webs at Nantucket, plankton in Nantucket Sound (Peterson et al. 1985), eel grass near shore, Spartina in saltmarshes and upland detritus in creeks. Isotope values of filter feeding bivalves reflect the mixture of foods in different locations (Medaglia et al. 1990).

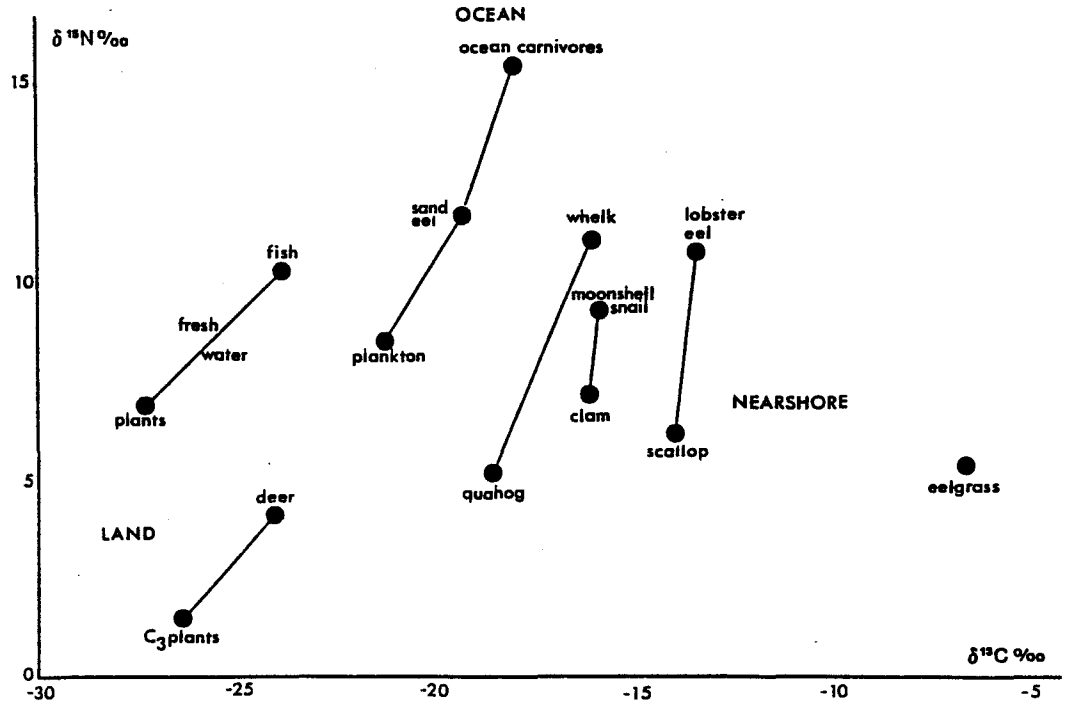

Figure 6. Schematic diagrams of isotopic fractionation (arrows) with increasing trophic level in different environments at Nantucket. Data from Medaglia et al. (1990), Peterson et al. (1985), and sand eel data from Little, Schoeninger and Medaglia (in preparation).

ghey and McRoy 1979). Within the quadrilateral defined by the four food bases, we have plotted the isotope values of the flesh of various bivalves from different locations at Nantucket (Figure 5). These isotope values show the influence of the environment from which the bivalves were harvested. For example, oysters in creeks and ribbed mussels in saltmarshes show lower $\delta^{15}N$ values than scallops living in eelgrass beds, or blue mussels or quahogs at the north shore outside the harbor. Scallops, with an eelgrass habitat, show a high $\delta^{13}C$ value.

Fractionation by Trophic Levels. The usefulness of fractionation in dietary studies lies in the ability of isotopes in foods and consumers to indicate the bases of food chains and the consumers' food webs and trophic levels. Metabolic processes operating on ingested food produce fractionation, an enrichment or depletion of isotope ratios in a consumer's tissues. Estimates from several data sets for the trophic level changes in isotope values from plants to herbivores and herbivores to carnivores show that, to a first approximation, as the trophic level increases one step, $\delta^{13}C$ values of a given tissue increase by about 1.3 o/oo and $\delta^{15}N$ values by about 3 o/oo (Lee-Thorp et al. 1989; Schoeninger and DeNiro 1984; Keegan and DeNiro 1988).

In Figure 6, line segments show measured isotope changes between plant/consumer or prey/predator pairs in several food webs. Deer consume upland C_3 plants, freshwater fish (omnivores) consume foods based on freshwater plants. Plankton constitutes a source of carbon and nitrogen for the sand eel (Ammodytes americanus) that provides food for marine fish and sea mammals on the next higher trophic level in Massachusetts waters. The whelk is a consumer of quahog and the moonshell snail's favorite food is clams (Little and Andrews 1986). Lobsters and eels in eelgrass habitat eat small or dead scallops (J.C. Andrews 1990, personal

Table 1. Isotope Differences (Δ) between Flesh of Prey/Predator Pairs at Nantucket.

Prey/Predator	$\Delta^{13}C$ o/oo	$\Delta^{15}N$ o/oo
clam/moonsnail[1]	0.2	2.1
quahog/whelk[1]	2.4	5.8
C_3plants/deer[1]	2.3	2.6
freshwater plants/fish (omnivore)[1]	3.3	3.4
plankton[2]/sand eel[3]	2.0	3.1
sand eel[3]/ocean carnivores[1]	1.3	3.8
scallop/lobster & eel[1]	0.5	4.5
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Average value (N=7)	1.7	3.6

[1] Medaglia et al. 1990

[2] Peterson et al. 1985

[3] Little et al. in preparation

communication). Figure 6 displays considerable consistency for changes in $\delta^{13}C$ and $\delta^{15}N$ with change in trophic level. Although most predators consume additional foods, the average value of the isotope changes between the flesh of seven prey/predator pairs (Table 1) is quite close to the values of the literature, with an average change in $\delta^{13}C$ of 1.7 o/oo and in $\delta^{15}N$ of 3.6 o/oo.

One result of this analysis is that we can estimate that the average bivalve diet has a $\delta^{15}N$ value of 1.8 o/oo. This low $\delta^{15}N$ value, which reflects the terrestrial environment of the harbor, is carried up the nearshore marine food chains to the human diet and creates an alternative to maize for explaining the relatively low $\delta^{15}N$ values of Nantucket human diets (compare marine diets in Schoeninger et al. 1983). Another important result is that the eelgrass community shows high $\delta^{13}C$ values. Thus, we can estimate that the locally nearly extinct eelgrass-grazing Brant goose might have had a $\delta^{13}C$ value of about -5.2 o/oo, and a $\delta^{15}N$ value of about 9.0 o/oo. This would have provided higher $\delta^{13}C$ values than any other food measured and would be of considerable interest. Another missing food conjectured to be of potential importance is the Great Auk, a penguin-like bird that has become extinct. For isotope tests of samples of these and a number of other species that are extinct or nearly so, we shall need to seek museum specimens.

DIETARY ANALYSIS

We may now establish seven isotopically and environmentally distinguishable food groups with reasonably small ranges and no overlap (Figure 7): (1) C_3 terrestrial plants and animals;

(2) C_3 freshwater plants and fish; (3) ocean carnivores, low $\delta^{13}C$; (4) near-shore carnivores, middle $\delta^{13}C$; (5) near-shore carnivores, high $\delta^{13}C$; (6) near-shore omnivores; and (7) C_4 terrestrial plants (maize). Some special cases of terrestrial plants have been omitted for simplicity.

Isotope relations between human bone collagen and human diet have not been reported. Therefore, for studies of human diet, we must use estimates from several data sets of plant, herbivore, carnivore and omnivore measurements, which indicate that the $\delta^{13}C$ of the consumer's diet (plant and/or flesh) is that of the consumer's bone collagen minus about 5 o/oo, and the dietary $\delta^{15}N$ is that of the bone collagen minus about 2.5 o/oo (Keegan and DeNiro 1988; Lee-Thorp et al. 1989; van der Merwe and Vogel 1978). With these estimates, the diet of three Late Woodland Nantucket humans has average values and ranges of $\delta^{13}C = -15.6$ ($\pm$ 0.4) o/oo, and $\delta^{15}N = 12.5$ ($\pm$0.7) o/oo (Medaglia et al. 1990).

By hypothesis, the human diet is a mixture of the seven food groups. We can see from Figure 7 that, in order to achieve the high $\delta^{15}N$ value of the diet, the amount of group (3) must be large. Also, we can see that, in order to achieve the high $\delta^{13}C$ value while also including a large amount of group (3), the amount of food from the combination of group (5) and group (7) must be large.

One alternative, high ocean carnivores/high maize, is quite feasible. But, the other alternative, high ocean carnivores/high lobsters and eels/low maize, would have provided a high protein diet, and required sources of carbohydrate or fat for energy (Speth and Spielmann 1983). Because of its high $\delta^{13}C$ value, the diet cannot include much C_3 plant food, and we have no evidence that C_4 or C_4-like Spartina, eelgrass or other seaweeds were eaten. Thus, a valid low

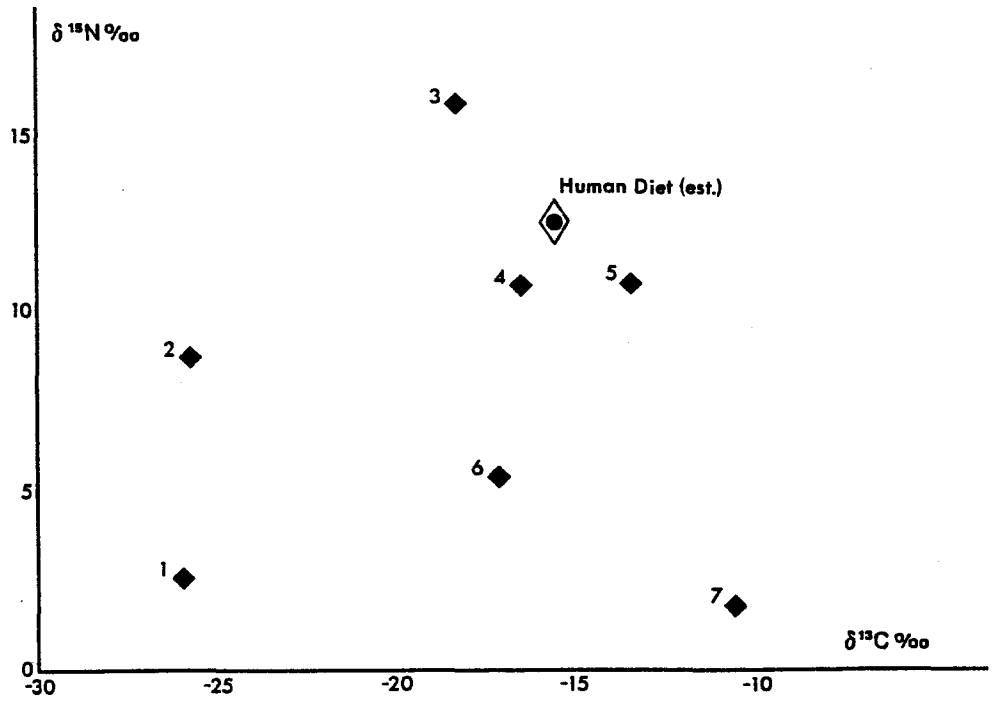

Figure 7. Schematic display of average $\delta^{13}C$ and $\delta^{15}N$ for estimated Late Woodland Nantucket diet and seven food groups (data from Medaglia et al. 1990). (1) elderberry, shadberry, orache, sea rocket and deer; (2) calamus roots, cattail roots and white perch; (3) bluefish, striped bass, halibut; (4) whelk, moonshell snail, scup, flounder, crab; (5) lobster, cunner, eel; (6) quahog, &2clam, scallop, oyster, ribbed mussel and blue mussel; (7) maize.

maize diet must include fat-rich foods such as bluefish, mackerel and eels, geese and ducks, and/or seals and whales, which carry thick layers of fat for insulation. The substantial numbers of whales and seals that seasonally frequent Nantucket and Cape Cod waters would make such an Eskimo-like diet quite possible (J. C. Andrews, 1991 personal communication; Little and Andrews 1982).

CONCLUSIONS

Heretofore, dietary reconstruction by means of isotope studies has not been attempted for maize consumers living in the complex coastal environments known to contain salt marsh and seagrass meadows and therefore, both terrestrial C_3 and C_4 and marine C_3- and C_4-like plants. I argue that, with enough isotopic and environmental data on foods at different trophic levels in the food webs, it is possible to form food groups that analysis can narrow down to a manageable few diets for further testing. As a specific example, we have enough evidence to say that Late Woodland Nantucketers ate a great deal of ocean carnivores (fish and sea mammals) together with a great deal of high $\delta^{13}C$ foods. The latter foods may have been entirely nearshore animals of eelgrass meadows such as lobsters, eels, and Brant geese, or entirely maize, or some mix of these two groups. A distinction between these two groups will require research in additional dietary dimensions, such as carbohydrates, fats and proteins.

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