RADIOCARBON AGE CALIBRATION AT ARCHAEOLOGICAL SITES
OF NANTUCKET AND OTHER NORTHEASTERN COASTS

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RADIOCARBON AGE CALIBRATION AT ARCHAEOLOGICAL SITES
OF COASTAL MASSACHUSETTS AND VICINITY

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Abstract

Radiocarbon ages of fifteen paired marine and terrestrial archaeological samples, along with ten marine samples of known historic age from Massachusetts, Maine, Connecticut and New York, provide data for studying the reservoir effect on these coasts. The marine calibration method of Stuiver, Pearson and Braziunas (1986) proves effective at correcting the ages of shells from Boston Harbor, Cape Cod and Nantucket Island, Massachusetts, and several samples from Maine and Long Island Sound. However, some shells from Long Island Sound and the lower Hudson and Merrimack rivers exhibit very large reservoir ages. Fluvial discharges carrying old terrestrial carbon can explain these large variations, although oceanic upwelling cannot be ruled out.

KEYWORDS: RADIOCARBON AGE CALIBRATION, RESERVOIR EFFECT, PAIRED MARINE AND TERRESTRIAL SAMPLES, NEW ENGLAND COAST.
INTRODUCTION

Marine samples have a reputation for introducing variability into radiocarbon dating. As a result, archaeologists have preferred to analyze ages using charcoal. Recently, Stuiver, Pearson and Braziunas (1986) have provided a method for calibrating marine radiocarbon dates that is based upon the carbon reservoir effect on marine samples. Their model accounts for differences in marine $^{14}C$ between oceanic water masses and variations in marine $^{14}C$ due to atmospheric changes in $^{14}C$. The goals of the present paper are (1) to report regional reservoir effect values and (2) to test marine calibration methods. The data for the study consist of 25 radiocarbon ages of marine samples from archaeological sites or museums, each paired with a radiocarbon age from associated terrestrial material or the calendar date of gathering. Six pairs come from the Gulf of Maine, five from Cape Cod and Nantucket Island, six from Connecticut and eight from New York. The sources are: Barber (1982); Borstel (1984); Brennan (1977); Stuiver et al. (1986); Ceci (1990); Little (1984); Luedtke (1990 personal communication); D. Schell (1990 personal communication); Tanaka et al. (1990). The close agreement between the calibrated ages of pairs from the outer coast of Massachusetts suggests that we can deal with variation over time in these oceanic reservoir ages. However, in order to understand the variation in reservoir effect near river mouths, archaeologists will need to report additional pairs of ages from those locations.

In preparation for the analysis, I shall give a brief background for radiocarbon aging. An element consists of atoms with a characteristic number of protons and varying numbers of neutrons in their nuclei. These different atoms, called isotopes, vary slightly in atomic mass. The element carbon, with six protons in each of its atoms, exists in three isotopic forms, as indicated by the superscript before its symbol C. $^{12}C$ (6 protons, 6 neutrons) is stable and is by far the most common isotope of carbon; $^{13}C$ (6 protons, 7 neutrons) is also stable; only the heaviest isotope, $^{14}C$ (6 protons, 8 neutrons), is radioactive. By releasing an electron and a neutrino, it decays into $^{14}N$ (7 protons, 7 neutrons).
The idea behind radiocarbon dating is that upon the death of an organism, the incorporation of 
$^{14}$C ceases. Thereafter, the radioactive emission of electrons will decrease with time as the number of 
$^{14}$C atoms in its tissues decreases through radioactive decay. By measurement of the ratio of the activity 
of the sample in counts per minute to that of a standard representing atmospheric activity, one may derive 
the number of years since the death of the sample. Several corrections must be applied, and I shall 
discuss two of the most important ones, isotopic fractionation and the reservoir effect, drawing largely 

FRACTIONATION

Rates of chemical and metabolic reactions involving an element depend upon its atomic mass 
(Olsson, 1983, pp. 280). Generally, in photosynthesis a plant incorporates the lighter carbon isotope, $^{12}$C, 
more readily than the heavier, $^{13}$C. This process, called fractionation, decreases the plant's ratio of 
$^{13}$C/$^{12}$C relative to that of the atmosphere. Fractionation also takes place in animal metabolism whereby 
an animal's bones are enriched in $^{13}$C/$^{12}$C compared to its diet. To study $^{13}$C/$^{12}$C values, we measure 
the following quantity, which is conventionally denoted as $\delta^{13}$C o/oo (delta carbon thirteen per mil): 

$$\delta^{13}$C = \left[\frac{(^{13}$C/$^{12}$C)_{sample}/(^{13}$C/$^{12}$C)_{PDB}}{1} - 1\right] \times 1000.$$

The standard, PeeDee Belemnite (PDB), is an ancient marine carbonate.

Since the difference in atomic weight between $^{12}$C and $^{14}$C is twice as large (two neutrons) as 
that between $^{12}$C and $^{13}$C (one neutron), a material such as shell, enriched in $\delta^{13}$C by fractionation, will 
be enriched approximately twice as much in $^{14}$C. Unless a correction is made, this increased 
radioactivity would be interpreted as a reduced radiocarbon age, because higher radioactivity ordinarily 
means less time spent decaying. Therefore, in order to make radiocarbon ages from different materials
comparable, contemporary practice is to measure fractionation of each by means of $\delta^{13}C$ and adjust
(normalize) the $^{14}C$ activity to the value that would be obtained with a standard enrichment of $\delta^{13}C = -25$
$\text{o/oo}$. (If $\delta^{13}C$ has not been measured, approximate values for a variety of materials may be obtained
from Stuiver & Polach [1977, pp. 358]). Since the enrichment in $^{14}C$ activity by fractionation is
approximately $2 \times (\delta^{13}C_{\text{sample}} + 25) \text{o/oo}$, the enrichment in $^{14}C$ activity for shell ($\delta^{13}C \sim 0 \text{o/oo}$)
would be 50 $\text{o/oo}$. The age correction for each $\text{o/oo}$ enrichment equals approximately $+8^{14}C$ years.
Thus, $+400$ years represents the age correction in $^{14}C$ yrs for marine shell (see Taylor, 1987).

The resulting age adjusted for fractionation, called the conventional radiocarbon age, $t$, can be
expressed in the following formula (Stuiver and Polach, 1977:360). Let $A_{SN} = A_S \left[1 - 2(25 + \delta^{13}C) \times 10^{-3}\right]$, and $A_{ON} = 0.95A_{Ox} \left[1 - 2(19 + \delta^{13}C) \times 10^{-3}\right]$, where $A_S$ is the net activity of the sample in
counts per minute, $A_{Ox}$ is the net activity of the oxalic acid standard. From this, $t = -8033 \ln A_{SN}(in$
1950)/$A_{ON}(in 1950)$. $A_{SN}/A_{ON}$ is a ratio independent of time, and therefore $t$ (years before 1950) is
independent of the year of measurement. Its use implies the assumption of constancy of atmospheric $^{14}C$
during the past, the use of the Libby 5568 yr half-life, oxalic acid as a standard, $\delta^{13}C$ normalization of
all sample activities, and the year 1950 as the base year (Stuiver & Polach, 1977).

Conventional terrestrial radiocarbon ages are not equivalent to calendar years for a number of
reasons, chiefly the changing $^{14}C$ in the atmosphere attributed to solar activity and earth’s geomagnetic
dipole field, the burning of fossil fuels and atomic bomb testing (Taylor, 1987). However, the counting
and radiocarbon dating of tree rings (dendrochronology) provides calibration tables or graphs (Stuiver
& Pearson, 1986; Klein et al., 1982) that convert conventional radiocarbon ages ($^{14}C$ yrs) to calendar
years, for samples that incorporate atmospheric carbon.
RESERVOIR EFFECT

If the $^{14}$C activity of the source or reservoir from which an organism obtains its carbon differs from that of the atmosphere, an additional correction is needed before calibration. For marine shells the significant reservoir is usually dissolved inorganic carbon. Radioactive carbon, produced in the atmosphere, diffuses into the ocean where it can be stored in deep water for long periods of time before reaching the surface by upwelling (Mangerud, 1972). Because of the reservoir effect, radiocarbon ages of marine shell samples appear older than the shells really are. Ancient limestone and plant matter depleted in $^{14}$C, as well as modern plant detritus, is often introduced into estuaries by fluvial or coastal runoff, and can also affect the reservoir age of shells (Fry & Sherr, 1984; Keith et al., 1963, 1964; Krantz et al., 1987; Mook & Vogel, 1968; Schell, 1983; Spiker, 1980; Strain & Tan, 1979).

In the past, values for reservoir age have been derived with the assumption that $^{14}$C production is constant and that calendar years = radiocarbon years, and the results have been interpreted as providing a constant reservoir effect (Stuiver et al., 1986). For samples gathered between 1850 and 1950, a fossil fuel correction has also been applied that reduces the average measured reservoir age in the mixed layer of the ocean by about 100 years as of 1950 (Mangerud & Gulliksen, 1975).

Stuiver et al. (1986, p. 980) define the reservoir age, $R(T)$, where $T$ is a calendar year, as the difference between the conventional $^{14}$C ages, defined here as $P_{at}(T)$ and $P_{ma}(T)$, of samples grown contemporaneously in the atmosphere and in the marine reservoir. This procedure eliminates fossil fuel effects. Thus, $R(T) = P_{ma}(T) - P_{at}(T)$. For example, a shell gathered from a live shellfish in 1954 at Port Jefferson, L.I., N.Y. had in 1954 a conventional radiocarbon age, $P_{ma}(1954) = 407 \pm 73$ years (Stuiver et al., 1986, pp. 1019). Using the definition, we can calculate $R(1954)$ by subtracting the conventional radiocarbon age for wood grown in 1954, $P_{at}(1954) = 200$ $^{14}$C yrs (Stuiver & Pearson, 1986), from $P_{ma}(1954)$, to obtain $R(1954) = +207 \pm 73$ $^{14}$C years. $R(T)$ varies with temporal
fluctuations in atmospheric $^{14}$C production (Figure 1) and with regional variations ($\Delta R$) in oceanic mixing between various water masses, etc. (Figure 2). For convenience in calibrating marine samples, Stuiver et al. (1986) have developed a generalized reservoir age, $Q(T)$ in $^{14}$C yrs, where $T$ is the calendar year, for the upper 75 m mixed layer of the ocean. $Q(T) = P_{ma}(T) - \Delta R \pm \sigma$, where $P_{ma}$ is the conventional radiocarbon age of a sample, $\Delta R$ is a regional correction factor (Figure 2), and the standard deviation, 

$$\sigma = \sqrt{\sigma_p^2 + \sigma_{\Delta R}^2}.$$ 

If you know $P_{ma}$ and $\Delta R$ for your sample, graphs, tables and computer programs show the calibrated $T$ in calendar years (Stuiver et al., 1986; Stuiver & Reimer, 1986).

Because the age corrections for fractionation and the marine reservoir effect are opposite in sign and almost equal in magnitude on the New England coast, a number of radiocarbon dating labs have reported ages for shell of this region with neither correction, under the assumption that they would cancel (Stuiver & Borns, 1975; Stuiver & Polach, 1977). This is a regional coincidence (Mangerud, 1972; Tauber, 1983) that we test in this paper. It would be helpful for future work if radiocarbon lab directors would report the correction protocols they have used for samples dated in the past.

**CALIBRATION FOR ARCHAEOLOGICAL AND HISTORIC SAMPLES**

In coastal Massachusetts and the adjoining coasts of Maine, Connecticut and New York, archaeologists have occasionally radiocarbon aged marine samples without much analysis or confidence in the results. Their confidence could be increased by the development of reliable $\Delta R$’s. An increasing number of published paired radiocarbon ages, usually one on shell and the other on charcoal, from single features at coastal archaeological sites has made it possible to explore the reservoir effect, $R$ and $\Delta R$, over time and space in this region.
The Data. I have collected radiocarbon ages for 15 archaeologically paired marine and terrestrial samples and ten marine samples of known historic ages for 16 known sites (Figure 3; Table 1), numbered in approximate geographical order from Maine to the Hudson River, NY. Pairs of conventional ages from single archaeological features, three from Nauset harbor, Cape Cod, one from the lower Merrimack River, three from outer Boston Harbor, and seven from coastal New York sites, represent reliable archaeological data. Nine shells from New York, Connecticut and Maine have known calendar years of gathering, but generally their locations are reported only to the town or body of water. A right whale bone from Long Island calibrated by a TL age on pottery and baleen of a fin whale that stranded in 1875 at Cape Cod are included for the record.

Table 1 shows each site name, known or estimated δ13C values (col. 1), lab numbers (col. 2) and the conventional (i.e., δ13C corrected) radiocarbon ages, P (col. 3). For shells gathered live in a known year, T, radiocarbon activities reported as Δ values (Tanaka et al., 1990) have been converted to conventional radiocarbon ages by use of the equation: P_{ma} = -8033 \ln (Δ \times 10^3 + 1) + 0.97(1950-T), where T is the year of gathering (following Stuiver & Polach, 1977, with t = P and x = T). Calibration charts (Stuiver & Pearson, 1986) provide P_{at} ages of (virtual) fragments of wood of given historic years.

For shells from Maine, shells from archaeological features on the Merrimack and Hudson Rivers, and shell and deer bone from Nantucket, no δ13C corrections were made (Brennan et al., 1990; Tanaka et al., 1990; H. Kreuger, 1989, personal communication; J. Bulkley, 1982, personal communication; M. Tamers, 1990, personal communication). Although δ13C = 0 o/oo can be estimated for most shells, at Nantucket and the Ossining site, I opt for more likely assumptions (see Table 1) and strongly recommend measurements of δ13C for shell in the future. As an example of retroactive corrections, the pair of samples from Nantucket consisted of shell and deer bone four meters distant in a continuous shell midden, i.e., possibly but not necessarily deposited within a few years of each other (Little, 1984). The two radiocarbon ages reported were 1575 ± 160 yrs (no δ13C correction; GX-4528) for deer bone apatite and
1680 ± 80 yrs (no reservoir or δ¹³C correction; I-9734) for oyster shell (Little, 1984). The δ¹³C value for deer bone apatite can be estimated at -13 o/oo (Kreuger, 1989, personal communication), and δ¹³C averages +1.2 o/oo for three Nantucket shells (Little files). Thus, the conventional radiocarbon ages for the Quidnet deer bone and oyster shell are 1770 ± 160 yrs bp and 2060 ± 80 yrs bp, respectively.

By subtracting the conventional terrestrial ¹⁴C age from the conventional marine ¹⁴C age of each pair (Table 1, col. 3), we determine the reservoir age, R(T) in ¹⁴C years ± σ, where σ = √σ² + σ² terrestrial (Table 1, col. 4). For regional groupings (Table 1), the average R(T) (over the region and over time), or R* ± average σ (Stuiver et al. 1986; see Long & Rippeteau, 1974), decreases from 453 ± 44 ¹⁴C yrs in the Gulf of Maine to 320 ± 90 at the Cape and Islands, and then increases to 424 ± 50 at Eastern Long Island Sound, 579 ± 60 at Western Long Island Sound, 630 ± 100 at Staten Island and 1780 ± 350 at Ossining, the last two sites located on the Hudson River.

Calibration. Calibration, or conversion to calendar years by dendrochronology, corrects for the modern value of the half-life of ¹⁴C, fossil fuel burning and variations in ¹⁴C production in the atmosphere. Calibration of terrestrial materials from conventional ¹⁴C ages (Table 1, col. 3) is usually straightforward (Stuiver & Pearson, 1986; Table 1, col. 6). 'Cal AD' or simply 'AD' indicates that the date is calibrated. The year in parentheses is the central value, and the first and last years represent a ±σ error range. The marine materials can be corrected by one of two possible routes. By Method 1, one subtracts the average regional R* from each marine ¹⁴C conventional age, and calibrates the results using a terrestrial calibration method. Method 2, explored in this paper, uses the marine model of Stuiver et al. (1986) with a time dependent reservoir age. For the calendar year, T, of death of the terrestrial partner (col.6), the model graphs provide Q(T). From Q(T) and P ma(T) of the marine partner (col. 3) one derives ΔR (Table 1, col. 5), using the equation, ΔR = P ma(T) - Q(T) ± σ, where σ = √σ² + σ² marine.

Table 1 shows that measured ΔR varies somewhat with location and with time, although with less
range than $R(T)$. To find $\Delta R^*$, an average $\Delta R$ for a region over time, we may average the $\Delta R$'s, or we could subtract the average $R(T)$ value of the model for the period AD 200 to 1800 (394 $^{14}\text{C}$ yrs [M. Stuiver, 1990, personal communication]) from the regional $R^*$ value. $\Delta R^*$ decreases slightly from the Gulf of Maine (+36±37) to the Cape and Islands (-95±50) and then increases through eastern L.I. Sound (+46±37), western L.I. Sound (+190±40), to the two Hudson River sites (+230±70 and +1405±350) (Table 1, col. 5).

Table 1, column 6 shows the calendar dates of marine materials calibrated by $\Delta R^*$'s and marine Method 2. In most cases the paired terrestrial and marine dates are significantly closer than before calibration, but in ten (starred) instances out of 25, the calibrated marine dates differ by a large amount from the terrestrial ones, a point to be explored further.

For a selected region of Massachusetts consisting of Nantucket, Cape Cod and Boston Harbor (Figure 4), the variation in $\Delta R$ is small. $R^* = 320±62$ $^{14}\text{C}$ yrs and $\Delta R^* = -95 ±43$, close to the -85 ±75 of Fig. 2. Here the calibrated terrestrial dates (Table 2, col. 1) compare very well with the marine dates calibrated by marine Method 2 with a $\Delta R^*$ correction (Table 2, col. 3) or by terrestrial Method 1 with an $R^*$ correction (Table 2, col. 2). For comparison, Table 2, col. 4 gives dates for which no $\delta^{13}\text{C}$ or reservoir correction was made; they are not as accurate as dates given by Methods 1 and 2.

ANALYSIS

Most calibrated marine dates of shells are considerably closer to their terrestrial partners' dates than they were before a reservoir effect correction. For example, the pair of Nantucket conventional ages 290±179 $^{14}\text{C}$ years apart, are close enough after calibration to be nearly indistinguishable, Cal AD 70 (244) 420 and Cal AD 105 (221) 337. This suggests that the midden material may have been deposited,
if not the same year, at least during a relatively short period of time, a reasonable conjecture. The close calibrations of paired marine and terrestrial dates from Port Jefferson, Cape Cod, Boston and Maine are similarly striking. To understand the large reservoir effects in shell from Ossining, Tottenville, Port Washington, West Haven, New Haven, Stonington, Sebonac and the Merrimack River, will require further analysis and data than are presently available.

Some observations can be made, however, for the 25 data points assembled here. Are the variations in $\Delta R$ primarily dependent upon geography or time? Among the possible geographic influences would be differences in fluvial input and marine flushing between estuaries, Long Island Sound and the oceanic promontory formed by Cape Cod and the Islands. Figure 4, with a strictly geographical ranking, shows that $\Delta R^*$ is higher in Long Island Sound than in the Gulf of Maine. Boston, the Cape and Nantucket Island, with seven pairs of dates, show no high $\Delta R$'s at present, in contrast to sites near the mouths of large rivers such as the Hudson, Quinnipiac (New Haven), Mystic (Stonington) and Merrimack rivers, which show very high $\Delta R$'s. The high $\Delta R$ at Sebonac is puzzling in the absence of a river. The habitat differences between the two species of shells from one feature at Calf Island, Boston, may account for their difference in $\Delta R$.

Shells from Pelham Bay, Cape Cod and Boston Harbor at different times show different $\Delta R$'s, which is evidence that time as well as geography is involved. In Figure 5, a plot of $\Delta R \pm \sigma$ against calibrated years shows a scatter of data points clustering about $\Delta R = -70 \, ^{14}C$ yrs. Very high $\Delta R$'s appear at about A.D. 230, 1270, 1410, 1880 and 1930. The ages of the ten shells from non-riverine sites at Port Jefferson, Boston, Cape Cod, Nantucket and Maine show no high $\Delta R$'s, but may not correspond in time to very high $\Delta R$ events. Aging of pairs for a range of T's from the same sites will be required to distinguish a normal riverine reservoir effect from transient fluvial or oceanic processes.

The seasonal migration of whales in the North Atlantic and the geographical variation of $\Delta R$ values in their feeding grounds probably determine whale $\Delta R$'s (Fig. 2; Schell et al., 1988). Therefore,
although the ΔR's for the Sebonac right whale bone and the 1875 Cape Cod fin whale baleen are consistent with ΔR values of the region (Figure 5), the whales should be handled separately. Another extraneous source of high R's can lie in errors in the pairing of the archaeological samples; they may not have been deposited at the same time. However, this potential error cannot explain the existence of high R's, many of which were measured on museum shells gathered in known years.

Possible Factors in the Variability of ΔR. Mixing equations for shell δ¹³C and Δ¹⁴C studies demonstrate that marine shells contain carbon partly derived from dissolved inorganic carbon in ocean water and partly from metabolic carbon (Keith et al., 1963, 1964; Tanaka et al., 1986, 1990:76). Variation in the relative amounts of water introduced by the Gulf Stream (prebomb estimated reservoir age, R*: 330 yrs) and the Gulf of Maine (prebomb est. R*: 502 yrs) (estimates from shells, Table 1), and in the amounts and sources of metabolic carbon in the shellfish diet could account for the variation in ΔR reported here.

Shellfish can derive metabolic carbon from modern or ancient marine or terrestrial plant detritus, including peat or humus that is introduced into estuaries by rivers (Fry & Sherr, 1984; Keith et al., 1964; Krantz et al., 1987; Schell, 1983; Tanaka et al., 1986). Dissolved, particulate or metabolized organic carbon from terrestrial sources with low δ¹³C (~-26 o/oo), can reduce shell δ¹³C substantially and raise R as high as 2300 years (Spiker, 1980; Keith & Anderson, 1963), or lower it, depending upon the age of the plant carbon. Alternatively, Tanaka et al. (1990) suggest that transient upwelling of Antarctic Intermediate Water into the Mid-Atlantic Bight could explain the large variations in ΔR in Long Island Sound shells (see also Kashgarian & Tanaka, 1991). An input from this source, with a pre-bomb and pre-industrial R of about 760 years and a δ¹³C of about +0.5 o/oo (Tanaka et al., 1990) would, like dissolved limestone, tend to lower δ¹³C only slightly and raise ΔR values in marine shells. These hypotheses can be tested with a study of the relation between shell δ¹³C and ΔR, which eliminates the
effects of varying atmospheric $^{14}$C input.

Three data sets suggest that in L. I. Sound the $\Delta R$ of shells is increased and their $\delta^{13}$C decreased, compared to oceanic values, by the addition of old light carbon with a fluvial source. In a transect going west through Long Island Sound, the salinity decreases (Tanaka et al., 1990), indicating an increasing freshwater contribution toward the west end of the Sound. For shells (Figure 6), the average $\Delta R$ increases and the $\delta^{13}$C decreases from Boston Harbor through L.I. Sound to Staten Island, where the shell reflects the low $\delta^{13}$C ($\sim -12$ o/oo) values of a river (Mook & Vogel, 1968; Spiker, 1980; Strain & Tan, 1979). Probably Ossining (Hudson River) and Merrimack River shells have similarly low riverine $\delta^{13}$C values to match their high $\Delta R$ values. In summary, $\delta^{13}$C- and $\Delta^{14}$C-depleted waters from rivers emptying into the confines of L. I. Sound can account for increases in $\Delta R$ and decreases in $\delta^{13}$C values in the Sound more easily than can oceanic upwelling.

A fluvial source for the high $\Delta R$'s is further supported by analysis of $\Delta R$ of rivers. Mixing equations (Tanaka et al., 1990) for the $\delta^{13}$C and R of Staten Island shell (-10.3 o/oo; $+630\pm 100$ yrs) compared to those of Cape Cod shell ($+2.0$ o/oo; $+320\pm 62$ yrs), show that Staten Island shells consist of about 44% terrestrial carbon ($\delta^{13}$C = -26 o/oo) and 56% marine carbon ($\delta^{13}$C = +2.0 o/oo), and that the reservoir age of the Hudson River terrestrial carbon at Staten Island would have been about 1040 years in Cal AD 1255-1283. This is entirely consistent with an R of $1780\pm 350$ years for Cal BP 2939-2139 at Ossining, further up the lower Hudson river, and with the roughly 2000 year discrepancy long noted between the $^{14}$C ages of shell and stone tool styles for the lower Hudson river, as well as the Chesapeake and Delaware estuaries (Brennan, 1977,p.131; Custer, 1991,p.28).

Because of the strong tidal flushing and small watersheds with few or no rivers on the outer coasts of Massachusetts (David Folger, 1989, personal communication), fresh water input usually contributes only a small amount to the reservoir effect at Nantucket, Cape Cod and outer Boston Harbor sites. Occasionally, transient events that introduce contemporary terrestrial plant detritus into tidal
marshes may explain the lowest AR values associated with reduced δ13C's (Fig. 6; Tanaka et al., 1990).

Although our seven data points from Massachusetts (see also Druffel [1982] for measurements on coral growth in the Gulf Stream off Florida) do not provide evidence for the Antarctic Intermediate Water upwelling hypothesis, the high AR at Sebonac in eastern Long Island requires clarification.

SUMMARY

The 25 pairs of marine-based/terrestrial based radiocarbon ages for coastal materials from Maine to the Hudson River NY provide data for determining regional coastal reservoir effects and their variability in the northeast. Calibration of seven marine shells from outer Boston Harbor, Cape Cod and Nantucket, Massachusetts, for which AR* = -95 ± 43 14C years, illustrate that the marine method of Stuiver et al. (1986) brings widely disparate conventional 14C marine ages nearly into synchronization with calibrated ages for paired terrestrial samples. However, large values of reservoir ages for estuarine shells from the Hudson river, the Merrimack river, or parts of Long Island Sound, NY, suggest caution in using shell for dating purposes without first establishing the range of variation in AR over time at the site of interest using paired marine/terrestrial materials.

Several calibration methods for marine materials were compared for the Massachusetts sites that, excluding a riverine site, showed small variations in AR. The marine method using a regional ΔR* gives excellent results. The method by which a regional R* is subtracted from the marine radiocarbon age, which is then calibrated by a terrestrial table, give results reasonably close to those of the marine method. Both are superior to the procedure of using no δ13C or reservoir correction for shells in Massachusetts.

Accurate calibration of marine samples in the Northeast requires that we describe the diachronic and geographical characteristics of reservoir ages (see also Arundale, 1981). Because the average R
increases as δ¹³C decreases in a transect from Boston to New York via Long Island Sound, and because R is highest in the Hudson and Merrimack Rivers and δ¹³C at its lowest in the mouth of the Hudson, I argue that old terrestrial carbon such as humus or peat, carried into estuarine waters by rivers, is probably the dominant source of the large magnitudes and wide variation in reservoir ages in this region. Variations in inputs of Gulf Stream, Gulf of Maine and Antarctic Intermediate waters and transient contributions of modern plant detritus and dissolved limestone, are probably of minor importance.

Since humans occupying coastal sites included marine foods in their diets, radiocarbon dates on coastal human bone also need a reservoir correction in order to reflect calendar years (Tauber, 1983). Radiocarbon ages on paired terrestrial material and coastal human bone also deserve the attention of field archaeologists.

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CAPTIONS FOR FIGURES.

Figure 1. Reservoir age in $^{14}$C yrs of mixed layer of the ocean (upper 75 m) as a function of calibrated years BP (before 1950), as modelled by Stuiver et al. (1986,p.992, with permission).

Figure 2. World map of $\Delta R$ values in $^{14}$C years (Stuiver et al. 1986,p.955, with permission).


Figure 4. Values of $\Delta R \pm \sigma$ (solid squares) and regional average $\Delta R^*$'s (open squares) in a transect from the Hudson River, NY, eastward through Long Island Sound to Nantucket, MA, and then north to Casco Bay, ME (Table 1). An arrow adjacent to a location indicates a river.

Figure 5. $\Delta R \pm \sigma$ in $^{14}$C yrs as a function of calibrated (AD) years (for clarity, only cal yrs $-\sigma$ is shown for archaeological samples), from coastal Maine to coastal New York (Table 1). $\Delta R = -68 \pm 28$ years is the average of the low range of $\Delta R$. The Ossining, NY, $\Delta R$ of $1405 \pm 350$ is off the scale at 2672+537/-703 BP.

Figure 6. Mean values of $\Delta R$ (average $\sigma = \pm 100$ yrs) plotted against $\delta^{13}$C for marine shells (Table 1) for sites at Boston Harbor/Cape Cod/ Nantucket, L.I. Sound, and Staten Island NY. Average regional values shown by open circles. A line west of Pt. Jefferson and east of W. Haven divides eastern and western L.I. Sound.
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<td>Quahog Bay, ME&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>SW of Bath</td>
<td>110±5&lt;sup&gt;14&lt;/sup&gt; (1878 wood)</td>
<td>507±56</td>
<td>397±56</td>
<td>+17±56</td>
<td>1878 (known)</td>
<td>1813 (1914) 1955&lt;sup&gt;m&lt;/sup&gt;</td>
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<td>Wheeler's</td>
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<td>* Merrimac River</td>
<td>115±5&lt;sup&gt;14&lt;/sup&gt; (1873 wood)</td>
<td>521±56</td>
<td>406±56</td>
<td>+26±56</td>
<td>1873 (known)</td>
<td>1799 (1887) 1955&lt;sup&gt;m&lt;/sup&gt;</td>
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<td>Calf Island&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-24.9</td>
<td>GX-3652</td>
<td>410±110 (charcoal)</td>
<td>860±115 (M. arenaria)</td>
<td>-25±115</td>
<td>1410 (1453) 1640&lt;sup&gt;t&lt;/sup&gt;</td>
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<tr>
<td>Boston Harbor</td>
<td>+1.8</td>
<td>GX-7456</td>
<td>860±115 (M. arenaria)</td>
<td>450±160</td>
<td>-85±75</td>
<td>1410 (1453) 1640&lt;sup&gt;t&lt;/sup&gt;</td>
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<tr>
<td>World's End&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-25.6</td>
<td>GX-15664</td>
<td>765±70 (charcoal)</td>
<td>1065±70 (M. arenaria)</td>
<td>-85±75</td>
<td>1218 (1264) 1280&lt;sup&gt;t&lt;/sup&gt;</td>
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<td>Boston Harbor</td>
<td>+2.6</td>
<td>GX-15661</td>
<td>1065±70 (M. arenaria)</td>
<td>300±99</td>
<td>1291 (1337) 1420&lt;sup&gt;m&lt;/sup&gt;</td>
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<td>Average, R&lt;sup&gt;c&lt;/sup&gt;, ΔR&lt;sup&gt;c&lt;/sup&gt;:</td>
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<td>Cape Cod&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>GX-9550</td>
<td>1265±130 (charcoal)</td>
<td>1570±120 (M. arenaria)</td>
<td>80±120</td>
<td>650 (720-761) 890&lt;sup&gt;t&lt;/sup&gt;</td>
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<td>305±177</td>
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<td>GX-12928</td>
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<td>(Balaenoptera physalus)</td>
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<td>6. Nantucket&lt;sup&gt;o&lt;/sup&gt; (-13.0)</td>
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Average, R*, ΔR* (excl. whale): 320±90 -95±50

EASTERN LONG ISLAND SOUND: ________________________

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