# 14C Dating of Modern Marine and Estuarine Shellfish

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# $^{14}$C DATING OF MODERN MARINE AND ESTUARINE SHELLFISH

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**ABSTRACT.** We measured the $^{14}$C content of 36 living marine molluscs from Tairua Harbour and the rocky coast on the Coromandel Peninsula of New Zealand. We identified species suitable for radiocarbon dating and show that the open marine intertidal zone is enriched in $^{14}$C compared to the open marine subtidal zone or estuary. We also found a uniform $^{14}$C distribution in the Tairua Harbour, by analyzing samples of the estuarine bivalve *Austrovenus stutchburyi* collected up to 5 km from the harbor entrance.

## INTRODUCTION

Marine shell is commonly used for dating New Zealand archaeological sites and geological deposits because it is ubiquitous, dates the event closely and rarely suffers postdepositional contamination, including recrystallization. However, the species utilized as food sources in prehistoric times and those forming geological deposits derive from a variety of marine reservoirs, including open beaches, rocky coasts, intertidal rock pools and estuaries, often many kilometers in extent. Accurate radiocarbon dating of samples from these habitats is possible only if the $^{14}$C concentration is uniform. Anderson (1991) has suggested that variation between the $^{14}$C results of two different prehistoric estuarine shellfish species may indicate a wider problem in dating organisms from this type of environment. The distribution of $^{14}$C in these various environments needs to be investigated to shed more light upon the reliability of this important dating material, now that higher levels of precision (*ca.* ±20 yr) are available by High Precision Liquid Scintillation spectrometry.

The aims of our research were threefold: 1) to examine the extent of any differences between the mean $\Delta^{14}$C concentrations from estuary and open coast environments; 2) to determine the spatial variation of $^{14}$C within an extensive estuarine system such as Tairua Harbour, by analysis of a single, widely distributed species (*Austrovenus stutchburyi*); 3) to identify species suitable for $^{14}$C dating.

To accomplish this, we measured $\Delta^{14}$C in 13 different species of living coastal and estuarine shellfish collected from Tairua Harbour, on the Coromandel Peninsula in New Zealand. The shellfish were collected over a 2-yr period from an open coast environment (in both the intertidal (rock pool) and subtidal zones (*ca.* 5 m depth below low tide)) and estuary, with samples from the latter ranging up to 5 km from harbor mouth to upper tidal reaches. Tairua Harbour and its associated rocky coast were chosen for the study because the estuary is extensive, it contains an abundance of Mollusca typically found in archaeological and geological deposits and the catchment area of the Tairua River is free of calcareous materials.

### Geographic Setting

Tairua Harbour is located on the east coast of the Coromandel Peninsula in the North Island of New Zealand (Fig. 1). The Tairua River flows into the harbor from a total catchment area of 280 km$^2$. The catchment is dominated by Late Miocene rhyolitic lava and ignimbrite, and andesite lava forming the eastern side of the Coromandel Ranges. The relatively elongated estuary is 13.5 km long and enclosed by sandy barrier dune complexes: the Tairua Ocean Beach tombolo to the north of the

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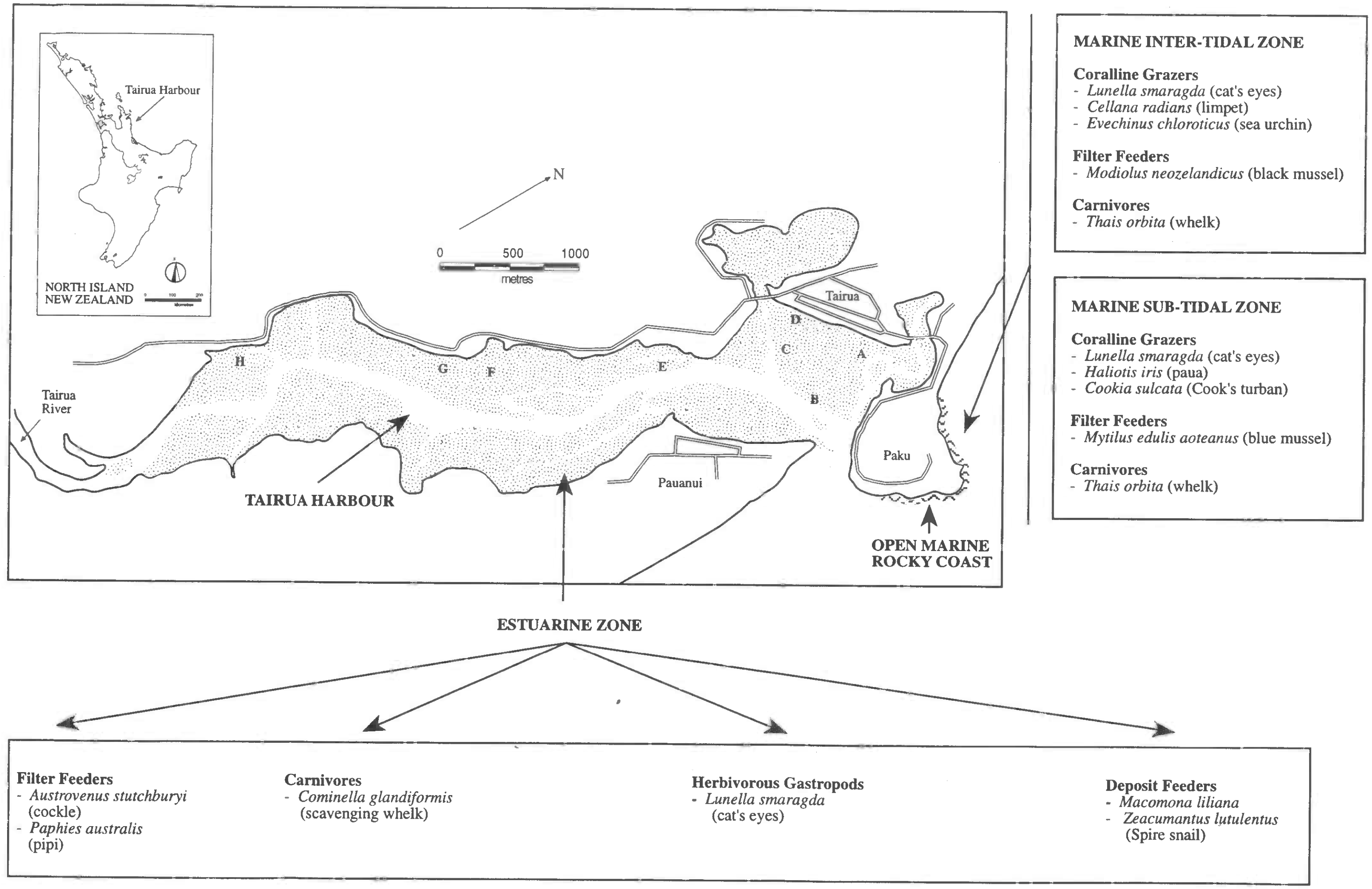

**Fig. 1.** Tairua Harbour and environs, including species studied in both estuarine and marine environments

entrance and the Pauanui Spit to the south. The rhyolitic dome "Paku" forms the eastern end of the tombolo (Fig. 1).

Although the Tairua River can have significant river flows (360–1200 $m^3 s^{-1}$) during major floods, the proportion of fresh water coming from it into the harbor is minor compared to the water exchanged each tide. As such, the estuary is normally tidally dominated. The neap and spring tidal ranges are 1.22 and 1.63 m, respectively, at the Tairua wharf, and the tidal prism (volume exchanged each half tidal cycle) is about $4 \times 10^6$ $m^3$. The total area of the estuary is 6.1 $km^2$ at high tide, with *ca.* 75–80% of this area being intertidal—resulting in significant tidal flushing, with the tidal prism equal to *ca.* 80% of the total high tide harbor compartment.

The harbor sediments are primarily fine sands, though coarser materials occur in lower reaches and in the shell-lagged areas of the main tidal channel. Some muddy sediments also occur toward the harbor margins and in embayments.

We have deliberately chosen a carbonate-free environment to investigate the $\Delta^{14}C$ distribution in a relatively simple system, so that generalizations can be drawn for these types of environments. Marine systems influenced by hard-water input are extremely complex and studies of them may be relevant only to isolated geographic areas.

## METHODS

We collected live shellfish for our analyses from three marine environments: the intertidal and subtidal zones from the open coast north of Paku ("open marine" samples) and the Tairua Harbour estuary (Fig. 1). Samples were collected during four field excursions over a 2-yr period, between 20 August 1993 and 1 August 1995, to assess temporal as well as geographic variation.

### Collection from Open Marine Rocky Coast Environment

The subtidal zone, although influenced by tidal currents, is permanently covered by seawater and is characterized by an abundance of macroalgae. Samples of *Cookia sulcata* (Cook's turban), *Lunella smaragda* (cat's eyes), *Haliotis iris* (paua, or abalone), *Mytilus edulis aoteanus* (blue mussel) and the carnivorous gastropod *Thais orbita* were collected live from this environment. The only suspension feeder from this environment is the bivalve *Mytilus*, the remainder being grazing gastropods that browse predominantly on kelp and algae.

The intertidal zone is a more diverse environment, ranging from rock pools that are isolated from wave action during low tides, to rocky channels that are partially or completely submerged during low tide. We collected a variety of species including *Thais orbita* and *Lunella smaragda*, *Cellana radians* (limpet) and another coralline grazer, *Evechinus chloroticus* (the sea urchin). *Modiolus neozelandicus* (black mussel) was the only filter-feeding mollusc obtained from this environment.

### Collection from Estuary Environment

Shellfish beds are common on the tidal flats and are dominated by the filter-feeding bivalve *Austrovenus stutchburyi* (common cockle) and the deposit feeder *Macomona liliana*. There are also extensive beds of the bivalve *Paphies australis* (pipi) along the margins of the main tidal channel. Large areas of *Zostera* grasses occur on the extensive tidal flats and a variety of gastropod species are common in these areas and in shallow tidal margins. These include *Lunella smaragda*, the scavenging whelk *Cominella glandiformis* and the deposit-feeding spire snail *Zeacumantus lutulentus*. All of these species were collected for analysis.

## Radiocarbon Method

All samples were converted to benzene and $\Delta^{14}C$ was measured in Waikato synthetic silica liquid scintillation vials (Hogg 1992) in Wallac 1220 Quantulus™ spectrometers. Many analyses were duplicated, to improve precision and to provide a measure of internal reproducibility. All data is expressed as pMC (percent modern carbon) with 1 $\sigma$ standard errors, after Stuiver and Polach (1977).

## RESULTS AND DISCUSSION

Data are summarized in Table 1 and Figure 2.

Two critical sources of variation must be considered in the study and interpretation of marine and estuarine shell $\Delta^{14}C$: the extent of decline in bomb carbon in the immediate region under examination, and how this decline may be archived in shellfish that may span several years of growth. In conventional $^{14}C$ dating, larger samples are required than for the AMS method; therefore, growth and shellfish age become important factors for selecting dateable carbonate.

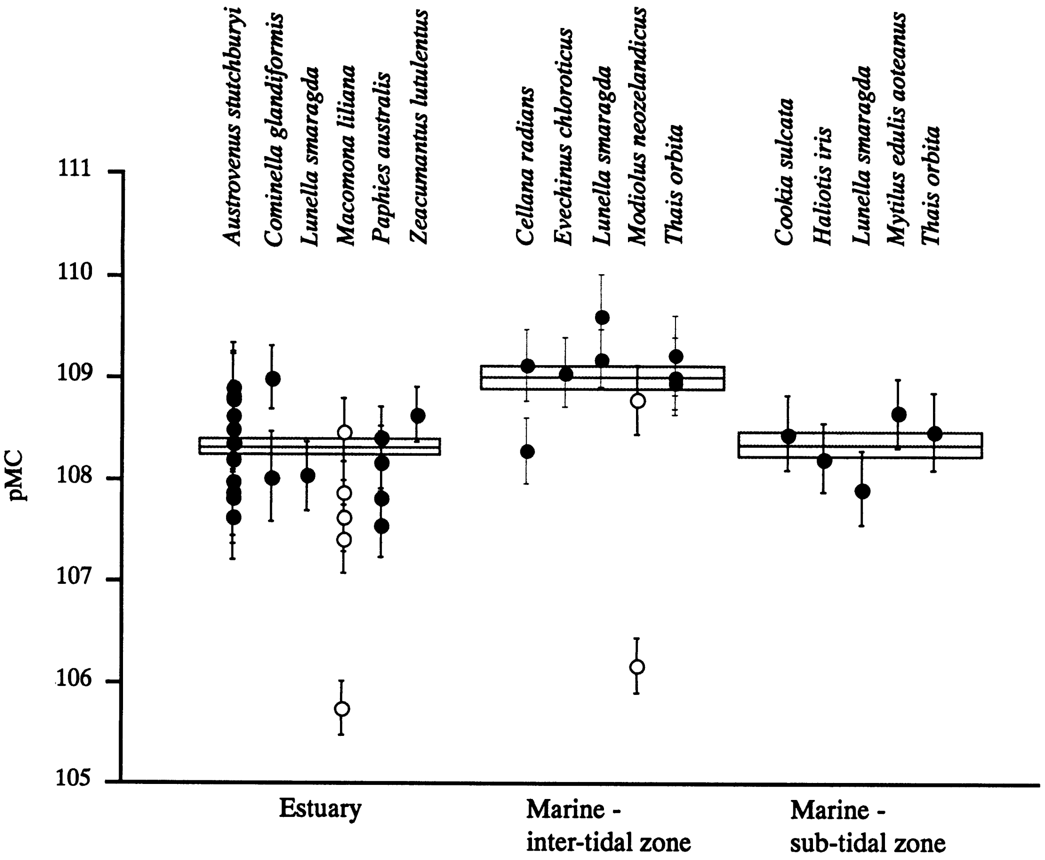

Fig. 2. $^{14}C$ concentration (pMC) in living molluscs from Tairua Harbour and environs. Data points shown as open circles are omitted from calculation of mean $^{14}C$ concentration, shown by lined boxes (± 1$\sigma$).

TABLE 1. $^{14}$C Concentration (pMC) in Living Marine Molluscs from Tairua Harbour and Environs

| Lab code (Wk-) | Species | Part dated | pMC | $\delta^{13}$C (‰) |
|---|---|---|---|---|
| *A. Estuary environment* | | | | |
| 3010 | *Austrovenus stutchburyi* | Whole shell | 108.34 ± 0.27 | 1.28 |
| 3172 | *Austrovenus stutchburyi* | Whole shell [**B**]* | 107.63 ± 0.45 | −0.28 |
| 3173 | *Austrovenus stutchburyi* | Whole shell [**A**] | 107.96 ± 0.41 | −0.05 |
| 3174 | *Austrovenus stutchburyi* | Whole shell [**C**] | 108.89 ± 0.42 | 0.14 |
| 3175 | *Austrovenus stutchburyi* | Whole shell [**D**] | 108.34 ± 0.44 | −1.09 |
| 3176 | *Austrovenus stutchburyi* | Whole shell [**E**] from Wk-3176 | 107.80 ± 0.45 | −0.22 |
| 3216 | *Austrovenus stutchburyi* | Inner rings from Wk-3176 [**E**] | 108.63 ± 0.32 | 0.35 |
| 3177 | *Austrovenus stutchburyi* | Whole shell [**F**] | 108.78 ± 0.43 | −0.12 |
| 3179 | *Austrovenus stutchburyi* | Whole shell [**G**] | 107.87 ± 0.44 | −0.13 |
| 3180 | *Austrovenus stutchburyi* | Whole shell [**H**] | 108.48 ± 0.43 | −0.82 |
| 3370 | *Austrovenus stutchburyi* | Outer rings from Wk-3370 | 108.80 ± 0.40 | −0.61 |
| 3407 | *Austrovenus stutchburyi* | Whole shells from Wk-3370 | 108.90 ± 0.35 | 0.12 |
| 3988 | *Austrovenus stutchburyi* | Outer rings | 108.20 ± 0.37 | 0.10 |
| 3007 | *Cominella glandiformis* | Whole shell | 108.98 ± 0.30 | 1.56 |
| 3020 | *Cominella glandiformis* | Whole shell | 108.01 ± 0.44 | 2.48 |
| 3004 | *Lunella smaragda* | Whole shell | 108.02 ± 0.33 | 2.15 |
| 3017 | *Macomona liliana* | Whole shell | 108.47 ± 0.30 | −0.30 |
| 3018 | *Macomona liliana* | Whole shell | 105.74 ± 0.27 | −2.06 |
| 3374 | *Macomona liliana* | Outer rings from Wk-3374 | 107.62 ± 0.35 | −0.31 |
| 3375 | *Macomona liliana* | Flesh from Wk-3374 | 107.40 ± 0.33 | −13.88 |
| 3376 | *Macomona liliana* | Outer rings | 107.86 ± 0.31 | −0.03 |
| 3016 | *Paphies australis* | Whole shell from Wk-3016 | 108.17 ± 0.29 | 0.96 |
| 3217 | *Paphies australis* | Inner rings from Wk-3016 | 108.39 ± 0.32 | 0.69 |
| 3218 | *Paphies australis* | Outer rings from Wk-3016 | 107.81 ± 0.34 | 0.48 |
| 3372 | *Paphies australis* | Outer rings from Wk-3372 | 107.54 ± 0.32 | 0.86 |
| 3377 | *Paphies australis* | Inner rings from Wk-3372 | 108.17 ± 0.35 | 0.78 |
| 3006 | *Zeacumantus lutulentus* | Whole shell | 108.62 ± 0.28 | 1.50 |
| *B. Marine mid-tidal environment* | | | | |
| 3014 | *Cellana radians* | Whole shell | 109.10 ± 0.35 | 0.63 |
| 3990 | *Cellana radians* | Outer rings | 108.26 ± 0.32 | −0.04 |
| 3011 | *Evechinus chloroticus* | Whole shell | 109.03 ± 0.34 | −1.39 |
| 3015 | *Lunella smaragda* | Whole shell | 109.16 ± 0.28 | 0.93 |
| 3379 | *Lunella smaragda* | Outer rings | 109.60 ± 0.40 | 0.20 |
| 3021 | *Modiolus neozelandicus* | Whole shell | 106.18 ± 0.29 | −0.26 |
| 3404 | *Modiolus neozelandicus* | Flesh from Wk- 3378 | 108.79 ± 0.34 | −18.50 |
| 3012 | *Thais orbita* | Whole shell | 108.94 ± 0.28 | 1.08 |
| 3380 | *Thais orbita* | Outer rings | 109.20 ± 0.40 | 0.65 |
| 3991 | *Thais orbita* | Outer rings | 108.99 ± 0.37 | 1.11 |
| *C. Marine sub-tidal environment* | | | | |
| 4418 | *Cookia sulcata* | Outer rings | 108.44 ± 0.37 | 0.29 |
| 3992 | *Haliotis iris* | Whole shell | 108.20 ± 0.34 | 0.93 |
| 4419 | *Lunella smaragda* | Outer rings | 107.90 ± 0.37 | 0.91 |
| 3989 | *Mytilus edulis aoteanus* | Outer rings | 108.64 ± 0.34 | 0.75 |
| 4420 | *Thais orbita* | Outer rings | 108.46 ± 0.37 | 1.18 |

*Bold letter in brackets (*e.g.*, [A]) identifies samples shown in Fig. 4.

A number of workers have shown declining levels of oceanic $^{14}C$ over the past two decades in both hemispheres as the marine reservoir re-equilibrates after the bomb carbon pulse (Kalish 1993; Weidman and Jones 1993; Druffel and Griffin 1995). We investigated the significance of this phenomenon in this region by repeat measurement of the $\Delta^{14}C$ activity of the estuarine bivalve *Austrovenus stutchburyi* and the marine gastropod *Thais orbita* over two years. Both yielded statistically indistinguishable $^{14}C$ values over the duration of the study, suggesting minimal change in $\Delta^{14}C$ over that time. In contrast, the estuarine bivalve *Macomona liliana* collected from the Upper Harbour did show variation. Its $^{14}C$ content ranged from 105.74 ± 0.27 pMC (Wk-3018, collected August 1993) to 107.62 ± 0.35 pMC (Wk-3374, collected September 1994). However, values for *Macomona* collected in the Lower Harbour at the same time showed indistinguishable $^{14}C$ levels (108.47 ± 0.30 from Wk-3017, collected August 1993; 107.86 ± 0.31 from Wk-3376, collected September 1994). Research into the physiognomy of molluscs has demonstrated that the carbon utilized in shell carbonate formation is derived from both dissolved inorganic carbon (DIC) and metabolic carbon (Tanaka *et al.* 1986). For instance, *Macomona* is a deposit-feeding telenid that processes organic detritus contained within fine silts in estuarine sediments. Experience with similar organisms, such as *Amphibola crenata* (the mudsnail), has suggested that deposit-feeders may ingest organic detritus containing $^{14}C$ of variable age, affecting the $^{14}C$ concentration from both archaeological and living specimens (Higham 1993; Higham and Hogg 1995). Filter-feeders like *Austrovenus* that inhabit the same environment do not display this effect, because their carbonate is derived principally from seawater, either by uptake of DIC or from their diet, consisting largely of suspended phytoplankton. In addition, the changes in $^{14}C$ levels in *Macomona* over the two-year study are contrary to the current trend in marine $\Delta^{14}C$, which is declining. This suggests that *Macomona* is producing aberrant results.

Marine and estuarine shellfish deposit calcium carbonate throughout their lifetime. A $^{14}C$ measurement of the entire shell will therefore produce an average measurement of $^{14}C$ uptake during that time. Erlenkeuser *et al.* (1975) have shown significant differences between the $\Delta^{14}C$ contents of different portions of incrementally deposited shell. We investigated this effect by dating inner and outer increments of different species of the shellfish we collected and by examining their life expectancy. In general, we found that any difference in $^{14}C$ between the inner and outer shell growth rings was masked by counting errors (Fig. 3). However, the tendency for inner growth rings to have higher $\Delta^{14}C$ levels is apparent and for this reason either small (*i.e.* <10 mm diameter), young individuals or outer growth rings of larger individuals (*ca.* 5 mm from the edge of the shell mantle) were chosen for analysis. In the case of *Austrovenus stutchburyi*, Morton and Miller (1968) have suggested that small individuals (<10 mm) are < 2 yr old, with larger individuals (>10 mm) being 5–6 yr old. In the case of this shellfish, we dated complete, small individuals. This was an identical approach to Higham (1993), who selected only juvenile shellfish for $\Delta^{14}C$ analysis. Our results show that for larger shellfish, significant errors may arise if edges are not sub-sampled for dating.

## Spatial Variation within Tairua Harbour

We measured the spatial distribution of $\Delta^{14}C$ within the harbor to determine the influence of the freshwater input from the Tairua River. As mentioned earlier, the harbor is normally tidally dominated, with river inflows making up a relatively small proportion of the water exchanged each tide. We sampled a single species (*Austrovenus stutchburyi*) in one day (9 March 1994) to eliminate species differences and temporal variation. We collected 9 samples from 8 sampling locations (Fig. 1), ranging between *ca.* 0.3 and *ca.* 4.5 km from the harbor entrance.

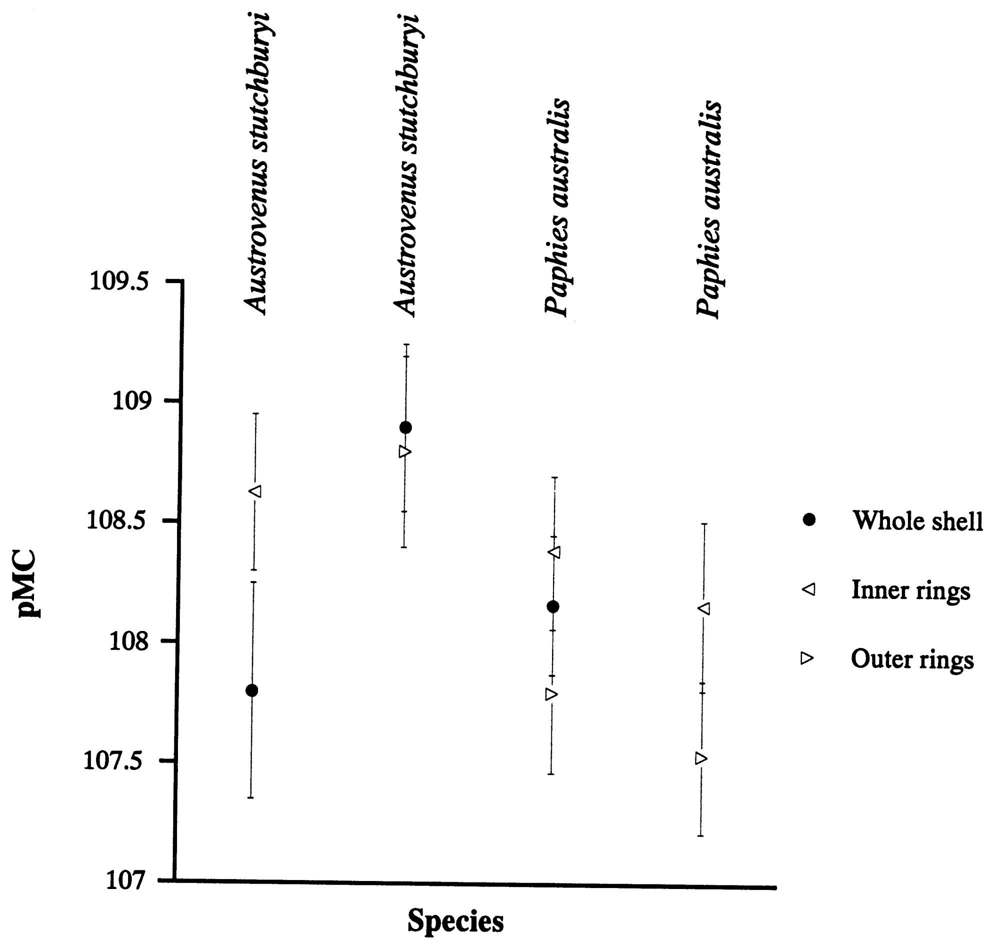

Fig. 3. $^{14}C$ variation between inner and outer growth rings and whole shells for two samples of two bivalve species (*Austrovenus stutchburyi* and *Paphies australis*).

In Fig. 4, *Austrovenus* $\Delta^{14}C$ content is plotted against distance from the harbor entrance. We found that all 9 samples were statistically indistinguishable using Ward and Wilson's (1978) Case II method ($T'$=9.55; $\chi^2_{8:0.05}$ = 15.51). There is no evidence that geographic location is a significant factor in determining the reliability of this particular species for dating.

## Variation in $\Delta^{14}C$ between Species within the Estuarine and Open Marine Environments

It is clear from Figure 2 that not all species within a particular marine environment will show similar $^{14}C$ concentrations. We will now look briefly at the variability of $^{14}C$ in the various species in each environment.

### *Estuarine Environment*

We have already discussed the deposit-feeder *Macomona liliana,* which can give significantly depleted $^{14}C$ levels where it inhabits the fine grained organic-rich sediments of the Upper Harbour. When the *Macomona* samples are removed from consideration, statistical analysis of the remaining species indicates a homogeneous population ($T'$ = 29.85; $\chi^2_{21:0.05}$ = 32.67).

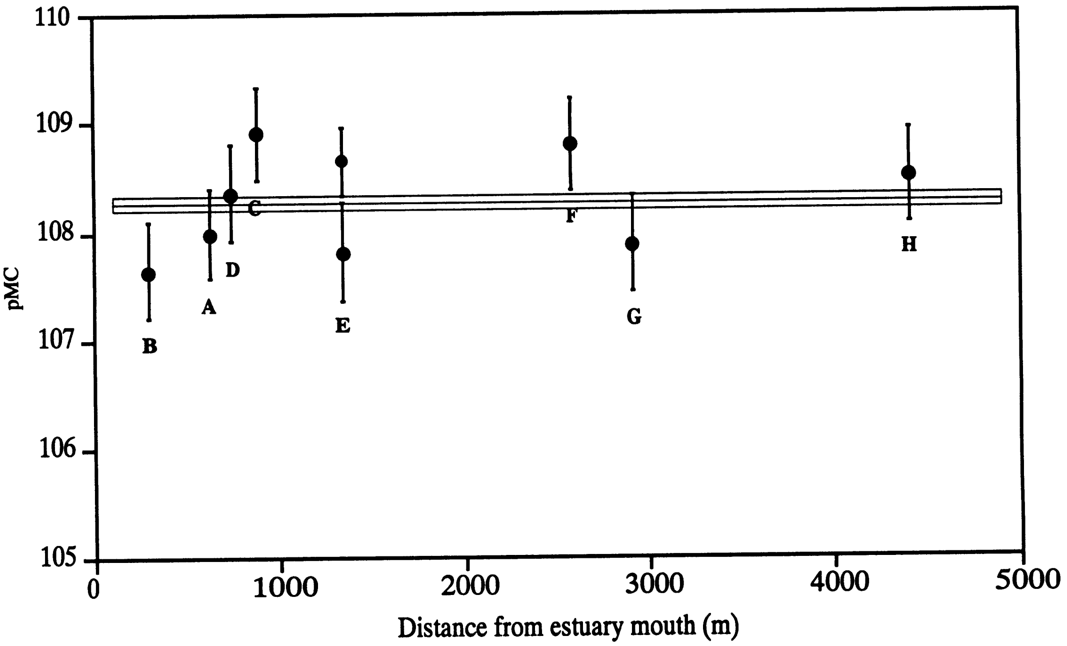

Fig. 4. $^{14}C$ concentration (pMC) variation in living *Austrovenus stutchburyi* from Tairua Harbour (geographic location of sites given in Fig. 1). Mean $^{14}C$ concentration is shown by lined box (± 1σ).

### *Open Marine Intertidal Environment*

*Modiolus neozelandicus* has atypical $^{14}C$ concentrations, ranging from 106.18 ± 0.29 pMC (Wk-3021, shell) to 108.79 ± 0.34 pMC (Wk-3404, flesh). It is unclear why a filter-feeder like *Modiolus* should have depleted shell values when the flesh from a repeat sample showed more typical $^{14}C$ levels. The mussels are 5–10 mm long and form a continuous "blanket" on the strongly weathered rhyolitic and andesitic boulders that litter the intertidal zone. We are continuing to study *Modiolus*, with investigations centering upon the possibility that the boulders may contain localized fissures of calcium carbonate contaminating the shells.

When the *Modiolus* samples are rejected, statistical analysis of the remaining species indicates a homogeneous population ($T' = 8.65$; $\chi^2_{8:0.05} = 15.51$).

### *Open Marine Subtidal Environment*

Only 5 shellfish were analyzed in this zone. All measurements were statistically indistinguishable ($T' = 2.53$; $\chi^2_{4:0.05} = 9.49$).

## $\Delta^{14}C$ Variation between Estuarine and Open Marine Environments

One of the principal aims of this study was to compare the $^{14}C$ levels of the estuarine and open marine environments. $^{14}C$ levels can be compared in two ways: 1) by comparison of a single species living in more than one environment; 2) through computation of a mean $\Delta^{14}C$ concentration for all species living in a particular environment.

### *By Analysis of a Species Inhabiting More Than One Environment*

Few species examined in this study were found in more than one environment. Those that were included *Lunella smaragda,* which occupied all three environments, and *Thais orbita,* found in both open marine zones (Table 2).

TABLE 2. Comparison of Two Species Occupying Multiple Environments

| Environment | *Lunella smaragda* (pMC) | *Thais orbita* (pMC) |
|---|---|---|
| Estuarine | 108.02 ± 0.33 | -- |
| Open marine intertidal zone | 109.30 ± 0.23 | 109.02 ± 0.19 |
| Open marine subtidal zone | 107.90 ± 0.37 | 108.64 ± 0.34 |

Statistical analysis of the *Lunella* measurements shows that although the estuarine and open marine subtidal zones are statistically indistinguishable ($T' = 0.06$; $\chi^2_{1:0.05} = 3.84$), the open marine intertidal zone is statistically different ($T' = 15.71$; $\chi^2_{2:0.05} = 5.99$).

The data for *Thais* is inconclusive. Although the two results are statistically indistinguishable at the 95% confidence level, *Thais* also yields a $\Delta^{14}$C maximum in the shellfish measurements obtained from the intertidal zone.

### *By Comparison of Mean $^{14}$C Levels for each Environment*

We have already examined the homogeneity of the three environments identified in the vicinity of Tairua. Error-weighted means for each environment are shown in Table 3. Whereas all three means are statistically different as a group ($T' = 25.59$; $\chi^2_{2:0.05} = 5.99$), the estuarine and open coast subtidal environments are statistically indistinguishable (EW mean = 108.32 ± 0.06 ($T' = 0.01$; $\chi^2_{1:0.05} = 3.84$)).

TABLE 3. Mean $^{14}$C Concentrations for the Three Environments Examined in this Study

| Environment | Error-weighted mean (pMC) | Comments |
|---|---|---|
| Estuarine | 108.31 ± 0.08 | *Macomona* data excluded |
| Open coast intertidal | 108.98 ± 0.11 | *Modiolus* data excluded |
| Open coast subtidal | 108.33 ± 0.16 | |

It is apparent, therefore, that $^{14}$C is not distributed uniformly in all types of coastal marine environment. The significant (75–80%) tidal flushing that occurs in Tairua Harbour is at a high enough level to ensure that $^{14}$C is not only uniformly distributed throughout the harbor (as shown by the *Austrovenus stutchburyi* analyses), but at concentrations similar to those of the shallow-water open sea (represented by the open coast subtidal zone analyses).

The open coast intertidal zone essentially forms a unique marine reservoir. Rock pools in particular are far more complex environments than either the shallow-water open sea or estuaries. The zone is subject to increased wave action and high aeration. This results in an environment slightly enriched in $^{14}$C in comparison to the subtidal and estuarine zones. It is likely that this scenario will be reproduced at other coastal sites.

## CONCLUSION

Several conclusions are apparent from this research:

- The $^{14}$C concentrations in New Zealand estuarine environments that are characterized by significant tidal flushing and an absence of calcareous hinterlands are quite similar to those found in the open marine subtidal zone. Important exceptions include the bivalve *Macomona liliana* and the gastropod *Amphibola crenata*.
- Tidally dominated estuaries (*i.e.,* those which have a large ocean-water flushing component) that have non-calcareous hinterlands should exhibit a uniform distribution of $^{14}$C throughout the estuary.
- The open marine intertidal zone contains higher levels of $^{14}$C compared to estuarine and subtidal zones, and species inhabiting this environment should be avoided for dating by $^{14}$C. This enrichment may be due to increased aeration resulting from more intensive wave action. We are unsure of the magnitude of this error when dating prehistoric samples, and are further studying this in large archaeological midden deposits adjacent to Tairua Harbour containing up to eight different marine species. High-precision analyses of these prehistoric mollusc samples will indicate the magnitude of potential errors highlighted in this paper.

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