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# Investigating the influence of regional climate and oceanography on marine radiocarbon reservoir ages in southwest New Zealand

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ABSTRACT

The New Zealand fjords are located at a latitude where distinct oceanic and atmospheric fronts separate carbon reservoirs of varying residence time. The marine radiocarbon reservoir age in this region is likely to deviate from the global average reservoir age over space and time as frontal boundaries migrate north and south. Here we present new estimates of modern radiocarbon reservoir age using the radiocarbon content of bivalve shells collected live before 1950. Multiple measurements from hydrographically distinct sites support the use of a ΔR, defined as the regional offset between measured and modeled marine radiocarbon reservoir age, of 59 ± 35 years for the New Zealand fjords. We also assess the radiocarbon content of bulk surface sediments throughout the fjord region. Sediment with a higher proportion of marine organic carbon has relatively less radiocarbon than more terrestrial sediment, suggesting a short residence time of organic carbon on land before deposition in the fjords. Additionally, we constrain reservoir age variability throughout the Holocene using coeval terrestrial and marine macrofossils. Although our modern results suggest spatial consistency in ΔR throughout the fjords, large deviations from the global average marine radiocarbon reservoir age exist in the paleo record. We find four ancient ΔR values, extending back to ~10.2 cal kyr BP, to be negative or near zero. A likely cause of younger radiocarbon reservoir ages at select intervals throughout the Holocene is the increased influence of the Southern Hemisphere westerly winds, which cause extreme precipitation in the region that delivers terrestrial carbon, enriched in radiocarbon, to fjord basins. However, bivalve depth habitat may also influence radiocarbon content due to a stratified water column containing distinct carbon pools. This work highlights the need for thorough assessment of local radiocarbon cycling in similar regions of dynamic ocean/atmosphere frontal zones, especially fjords and other semi-restricted estuaries.



## 1. Introduction

Radiocarbon ($^{14}C$) is a natural radionuclide produced in the upper troposphere and stratosphere. Incoming cosmic rays influence molecular interactions, leading to the production of neutrons, which then interact with $^{14}N$ to produce $^{14}C$. As incoming radiation fluctuates over time, so does the production rate of $^{14}C$, leading to secular variability in $^{14}C$ levels. Once produced, $^{14}C$ decays at a constant rate with a half-life of 5730 ± 40 years (Godwin, 1962), such that older carbon-bearing materials will have less $^{14}C$ than younger ones. On Earth, the atmosphere and the ocean are two major $^{14}C$ reservoirs. Independently dated tree-ring measurements, plant macrofossil data, and speleothem data provide a relatively well constrained record of atmospheric $^{14}C$ concentration over the last 50,000 years (Reimer et al., 2013). However, the robust reconstruction of marine $^{14}C$ variations is more complicated. In part, this difficulty arises from less abundant marine archives that can be dated by other independent methods (e.g., fossil coral U/Th dating or varve counting). The slow equilibration time between the ocean and the atmosphere and upwelling of $^{14}C$-depleted

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deepwaters adds an additional complication by creating an offset in $^{14}C$ levels between contemporaneous marine and terrestrial carbon reservoirs (Stuiver and Braziunas, 1993). Due to lower concentrations of $^{14}C$, the marine reservoir appears older than its terrestrial counterpart.

The offset between $^{14}C$ content in contemporaneous marine and terrestrial organic matter ($OM_{mar}$ and $OM_{terr}$, respectively) reservoirs is known as the marine reservoir age, R(t). A global average R(t) can be derived by incorporating the atmospheric $^{14}C$ calibration curve (IntCal13) (Reimer et al., 2013) into an ocean-atmosphere diffusion box model (Stuiver et al., 1986), which results in a modeled global average R(t) of ~400 years for surface waters (Stuiver and Braziunas, 1993). However, significant spatial and temporal deviations can occur from the global average R(t). The difference between a measured marine $^{14}C$ age of a known year and the modeled mixed layer $^{14}C$ age for that year is defined as ΔR (Stuiver et al., 1986). When a body of water has lower $^{14}C$ activity (i.e., an older age) than the model predicts, it has a positive ΔR. A good knowledge of past and present ΔR values is necessary to precisely date marine sediments and can also be used to understand ocean circulation. This is particularly important in restricted marine zones, such as fjords and other estuaries, where circulation may be sluggish. Yet the global dataset of marine reservoir ages is limited, requiring large extrapolations to understudied regions.

In particular, there is a paucity of data from the waters surrounding southwest New Zealand (Table 1) and no constraints for the fjords of Fiordland National Park, despite the potentially valuable paleoclimate archives that can be obtained by coring the underlying sedimentary deposits found in restricted sub-basins. The current practice to apply the nearest ΔR values is problematic for several reasons. First, the closest ΔR estimates, from the northwest and southeast coasts of the South Island (Collingwood and Pounawea, Table 1), are in different oceanographic settings from the southwest coast. Specifically, the southwest coast of New Zealand's South Island deflects the Subtropical Front (STF), which has migrated on glacial/interglacial timescales (Carter et al., 2004). The STF serves as a boundary between the distinct subantarctic and subtropical water masses, which each carry unique water mass properties and reservoir ages (Chiswell et al., 2015; Petchey et al., 2008). Thus, movement of the STF may cause variable ΔR values on multi-millennial timescales along the southwest coast of New Zealand's South Island. For this reason, applying the nearest ΔR values from oceanographically distinct regions to southwest New Zealand may lead to incorrect age reconstructions.

Second, the Southern Hemisphere westerly winds (SHWW) impinge upon the southern part of the South Island, and decrease in strength to the north in their modern configuration. The winds cause more vigorous ocean mixing along the coast and extreme precipitation (>6 m $yr^{-1}$) as the Southern Alps mountain range intercepts the SHWW (Salinger and Mullan, 2001). Wind-driven orographic precipitation causes locally variable water bodies moving north–south along the coast. The northeast-flowing,

**Table 1**
Summary of existing ΔR values for waters around New Zealand. Location information found online using the 14CHRONO Marine Reservoir Database (http://calib.qub.ac.uk/marine/).

| Site name | Latitude | Longitude | $^{14}C$ age (yr BP) ± error | Reservoir age (yr BP) ± error | ΔR (yr) ± error | Species | Feeding habit | Reference |
|---|---|---|---|---|---|---|---|---|
| Pounawea[a] | −46.5 | 169 | 427 ± 39 | 250 ± 42 | −42 ± 39 | *Protothaca crassitesta* | N/A | (Rafter et al., 1972) |
| Kairaki[a] | −43.5 | 172.677 | 494 ± 35 | 317 ± 38 | 25 ± 35 | *Pahies subtriangulatum* | Suspension | (Higham and Hogg, 1995) |
| Collingwood | −40.5833 | 172.583 | 432 ± 46 | 273 ± 48 | −36 ± 46 | *Austrovenus stutchburyi* | Suspension | (Higham and Hogg, 1995) |
| Paekakariki | −41.667 | 174 | 410 ± 46 | 268 ± 47 | −40 ± 46 | *Dosinia anus* | Suspension | (Higham and Hogg, 1995) |
| Makara Beach (A)[a] | −41.55 | 174 | 422 ± 62 | 245 ± 64 | −47 ± 62 | *Haliotis* | N/A | (Higham and Hogg, 1995) |
| Makara Beach (B)[a] | −41.55 | 174 | 464 ± 62 | 287 ± 64 | −5 ± 62 | *Cellana* | N/A | (Higham and Hogg, 1995) |
| Makara Beach (C)[a] | −41 | 174.6 | 390 ± 44 | 213 ± 46 | −79 ± 44 | *Austrovenus stutchburyi* | Suspension | (Higham and Hogg, 1995) |
| Pauatahanui Inlet[a] | −41 | 174.6 | 451 ± 32 | 274 ± 35 | −18 ± 32 | *Alcithoe arabica* | Carnivore | (Higham and Hogg, 1995) |
| Turakirae Head (A) | −41.45 | 174.92 | 473 ± 47 | 350 ± 48 | −10 ± 47 | *Haliotis iris* | Browser | (McSaveney et al., 2006) |
| Turakirae Head (B) | −41.45 | 174.92 | 466 ± 41 | 343 ± 42 | −17 ± 41 | *Haliotis iris* | Browser | (McSaveney et al., 2006) |
| Turakirae Head (C) | −41.45 | 174.92 | 518 ± 43 | 395 ± 44 | 35 ± 43 | *Serpulorbis zealandicus* | Suspension | (McSaveney et al., 2006) |
| Turakirae Head (D) | −41.45 | 174.92 | 489 ± 35 | 366 ± 36 | 6 ± 35 | *Haustrum haustorium* | Carnivore | (McSaveney et al., 2006) |
| Turakirae Head (E) | −41.45 | 174.92 | 490 ± 36 | 367 ± 37 | 7 ± 36 | *Diloma nigerrima* | N/A | (McSaveney et al., 2006) |
| Turakirae Head (F) | −41.45 | 174.92 | 474 ± 48 | 351 ± 49 | −9 ± 48 | *Diloma nigerrima* | N/A | (McSaveney et al., 2006) |
| Turakirae Head (G) | −41.45 | 174.92 | 519 ± 44 | 396 ± 45 | 36 ± 44 | *Melagraphia aethiops* | Browser | (McSaveney et al., 2006) |
| Turakirae Head (H) | −41.45 | 174.92 | 509 ± 29 | 386 ± 30 | 26 ± 29 | *Turbo smaragdus* | Browser | (McSaveney et al., 2006) |
| Turakirae Head (I) | −41.45 | 174.92 | 452 ± 45 | 329 ± 46 | −31 ± 45 | *Cellana denticulata* | Browser | (McSaveney et al., 2006) |
| Turakirae Head (J) | −41.45 | 174.92 | 454 ± 50 | 331 ± 51 | −29 ± 50 | *Cellana denticulata* | Browser | (McSaveney et al., 2006) |
| Muriwai Beach[a] | −37 | 174.5 | 506 ± 39 | 329 ± 42 | 37 ± 39 | *Paphies ventricosum* | Suspension | (Higham and Hogg, 1995) |
| East coast | −37.33 | 176 | 429 ± 57 | 299 ± 58 | −20 ± 57 | *Pagrus auratus* | N/A | (Higham and Hogg, 1995) |

[a] Sample collected after 1950.