Journal of Archaeological Science (2000), **27,** 439–448
doi:10.1006/jasc.1999.0473, available online at http://www.idealibrary.com on IDEAL®

Seasonal Dating Using Fish Otoliths: Results from the Shag River Mouth Site, New Zealand

T. F. G. Higham*

Radiocarbon Dating Laboratory, School of Science and Technology, University of Waikato, Private Bag 3105, Hamilton, New Zealand

P. L. Horn

National Institute of Water and Atmospheric Research (NIWA), P.O Box 893, Nelson, New Zealand

(*Received 7 August 1998, revised manuscript accepted 31 May 1999*)

Fish otoliths of *Pseudophycis bachus* (red cod) have been excavated from cultural deposits at the site of Shag River Mouth in North Otago, New Zealand. We sectioned the otoliths and examined the annual and seasonal growth rings formed during the fishes' life and compared them with an extensive number of modern examples to determine the season in which they were caught in prehistory. Using this method we estimated the seasons of prehistoric occupation of specific cultural layers. Otoliths from the uppermost layer of the site (layer 2) yielded a seasonal estimate of December–February whilst the majority of those from the main layer 4 shell midden yielded a series of September–November estimates. The results confirm earlier seasonal results determined from oxygen isotope analysis of blue mussel (*Mytilus edulis aoteanus*). The seasonal data obtained from the prehistoric otoliths also match the seasonality of the modern fishery. Red cod are common between November and May from Banks Peninsula to Timaru. The implications of the results for prehistoric seasonality in southern New Zealand are explored.

Keywords: OTOLITHS, SEASONALITY, SHAG RIVER MOUTH, OXYGEN ISOTOPE ANALYSIS, PREHISTORIC FISHING.

Introduction

The earliest cultural layers in archaeological sites in the southern South Island of New Zealand (*Murihiku*) disclose an economic adaptation centred upon "big game" hunting of moa (Aves: Dinornithiformes) and seal. Because of the temperate climate south of Banks Peninsula, the traditional Polynesian cultigens were unable to be introduced with success, so the earliest inhabitants, in the region from about 1250–1300 AD, exploited a wide faunal spectrum. The ethnographic record suggests that during the 19th century, Maori settlements comprised base camps, or villages, occupied by a transient population which spent much of the year dispersed in family (*whanau*) groups involved in seasonal gathering and hunting (Shortland, 1851). The areas of concentrated resources varied spatially as well as seasonally. The most optimal subsistence strategy revolved around the preservation of summer-procured foods in preparation for winter, a degree of mobility and the division of *hapu* (extended family/subtribe groups) into sub-groups for different seasonal gathering activities through the summer months (Shortland, 1851; Leach, 1969). The group probably coalesced during winter for trade and exchange, and feasting. Population numbers in base camps, then, fluctuated through the months. Parallels have been noted between this lifestyle and that of the earliest groups in the region during the 13th and 14th centuries (Anderson & Smith, 1996*b*, *c*). The underlying difference seems to be that in the early phase, permanent settlement depended more upon local big game resources (Anderson & Smith, 1996*b*, *c*) with little emphasis on importing food or on preserving seasonally available foods. While big game resources remained, settlement was sustained. Once they declined, people simply moved to other areas. The subsistence pattern, while based upon big game, probably revolved around a seasonal round of activities as it did in later times. There is considerable evidence for specialised activity camps in the interior and along the coasts which were probably contemporaneous in the 13th and 14th centuries. Different seasonally abundant resources were probably procured at certain times of the year from temporary camps such as this.

Elucidating seasonality in southern prehistory has been a problem squarely before the prehistorian since

* For correspondence. Email: T. Higham@Waikato.ac.nz

0305–4403/00/050439+10 $35.00/0

the 1960s, when an increasing emphasis on economic prehistory resulted in the development of a number of practical methods designed to determine the nature of prehistoric seasonality in southern New Zealand. Coutts (1970, 1974), Coutts & Higham (1971), Coutts & Jurisich (1972), Coutts & Jones (1974), Teal (1975), Leach & Leach (1978), Anderson (1981*a*), Till (1984), Smith (1985, 1989), Till & Blattner (1986), Higham (1990, 1996) and Samson (1996) have made seasonality an emphasis in their research. Leach (1969) and Anderson (1980, 1982, 1988, 1989) have attempted to integrate some of these results together with a rich ethnographic record, in developing regional syntheses of settlement patterns and seasonality.

Despite some significant developments, the inflexible nature of the region's faunal spectrum has meant that determining site seasonality with precision has been problematic. Much of the flora and fauna exploited by southern Maori were available all year round. Some which were restricted in availability were items which are known to have been traded in prehistory therefore their presence in archaeological contexts is no guaranteed seasonal indicator (e.g. muttonbird, *Puffinus griseus*).

In this paper, the seasonality of an area of the Shag River Mouth site (New Zealand Archaeological Association site number J43/2) is examined. This important site is located at the mouth of the Waihemo, or Shag River, near Palmerston in North Otago (Figure 1). It is over 2 ha in size and has a long history of archaeological investigation beginning with Von Haast (1874) in 1874. In 1988, after a series of smaller test excavations, Anderson and Allingham directed a large research programme at the site (Anderson *et al.*, 1996*a*. The most extensive excavation comprised one large 10 × 10 metre square on the highest part of the dune (SM/C:Dune) and smaller test excavations along it and down onto the lower marsh land (Figure 2) (Anderson *et al*., 1996*a*). The research described in this paper incorporates material excavated from the SM/C:Dune site.

Materials and Methods

Seven cultural layers were identified in the SM/C:Dune excavation (Anderson & Allingham, 1996). The lowest (layers 5, 6, 7, 9 and 11) were dominated by remains of extinct moa species whilst the uppermost (4 & 2) were dominated by shell and fish remains. Layers 8 and 10 contained some patchy cultural material. They might indicate abandonment of this area of the site, but it is equally likely that a brief period is represented because of the rapid buildup of sand that can eventuate in this environment. The most important of the upper layers in terms of subsistence remains and artefacts was layer 4. This layer was the focus of seasonal analyses which are the subject of this paper. The lower sections of this layer were almost solely comprised of a dense *Austrovenus stutchburyi* (common cockle) shell midden. The upper margins of layer 4 comprised a series of lenses of fish and shell remains (see below).

A shell-bearing site dominated by a sandy matrix presents the excavator with difficulties owing to collapse of walls and influx of sand. The relatively deep stratigraphy ($\sim$2 m) for a southern New Zealand site was able to be more carefully investigated by leaving a 2 × 1 m baulk comprising the upper layer 4 midden. Within the baulk, detailed lensing and microstrata could be identified (Figure 2). Claassen (1991) has suggested that one of the most important variables in determining seasonality and prehistoric shell-bearing site formation more accurately is in emphasising finer stratigraphic resolution and more rigorous attention to retrieving midden components. Within the baulk, seven sub-layers, or spits, were identified. These spits were treated as separate stratigraphic components in this study and investigated independently for seasonality. This approach refined the precision of subsequent seasonal analyses.

The spits are shown in section in Figure 3. Spit 1, the uppermost lens, was thin ($\sim$5–8 cm) and consisted of broken and fractured shell and few fish remains in a black matrix. Spit 2 was dominated by a dense *Austrovenus* assemblage, lenses and a large number of fishhooks. In spit 3, the matrix was ashy and incorporated shell of a variety of species and broken and charred moa bone. Spit 4 was dominated by fishbone remains while spit 5 was composed principally of a thin shell layer intermixed with dark sand. Spit 6 mirrored the components noted above in Spit 2 while the lowest spit, 7, was composed almost exclusively by *Austrovenus* (Higham, 1990). In general, the layer 4 occupation was dominated by *Austrovenus* shellfish and fish remains, predominantly barracouta (*Thyrsites atun*), in addition to bones of dog, sea mammal, small bird and moa. Interspersed within the layer were blackened and fire-cracked oven stones (Anderson & Allingham, 1996).

Nine blue mussel (*M. edulis aoteanus*) shells from layer 4 were analysed using oxygen isotope techniques to determine the season or seasons of occupation (Higham, 1990, 1996). The oxygen isotopes ^{18}O and ^{16}O archived in deposited marine shell calcium carbonate vary in their ratio in relation to temperature change in their immediate environment (Epstein *et al.*, 1951). Shackleton (1973) has identified prerequisites for shellfish suitable for oxygen isotope analysis and blue mussel shell fulfils each of them (Till, 1984; Till & Blattner, 1986; Higham, 1990, 1996). Mussel shell carbonate was sampled from the margins of the shell at 1 mm intervals along the growth axis towards the hinge. The δ^{18}O values were used to develop palaeotemperature profiles and estimate the season of death of each shell. The results of the research were hampered by the small numbers of acceptable, well preserved shells and some of the palaeotemperature profiles comprised too few samples. A rejection criteria

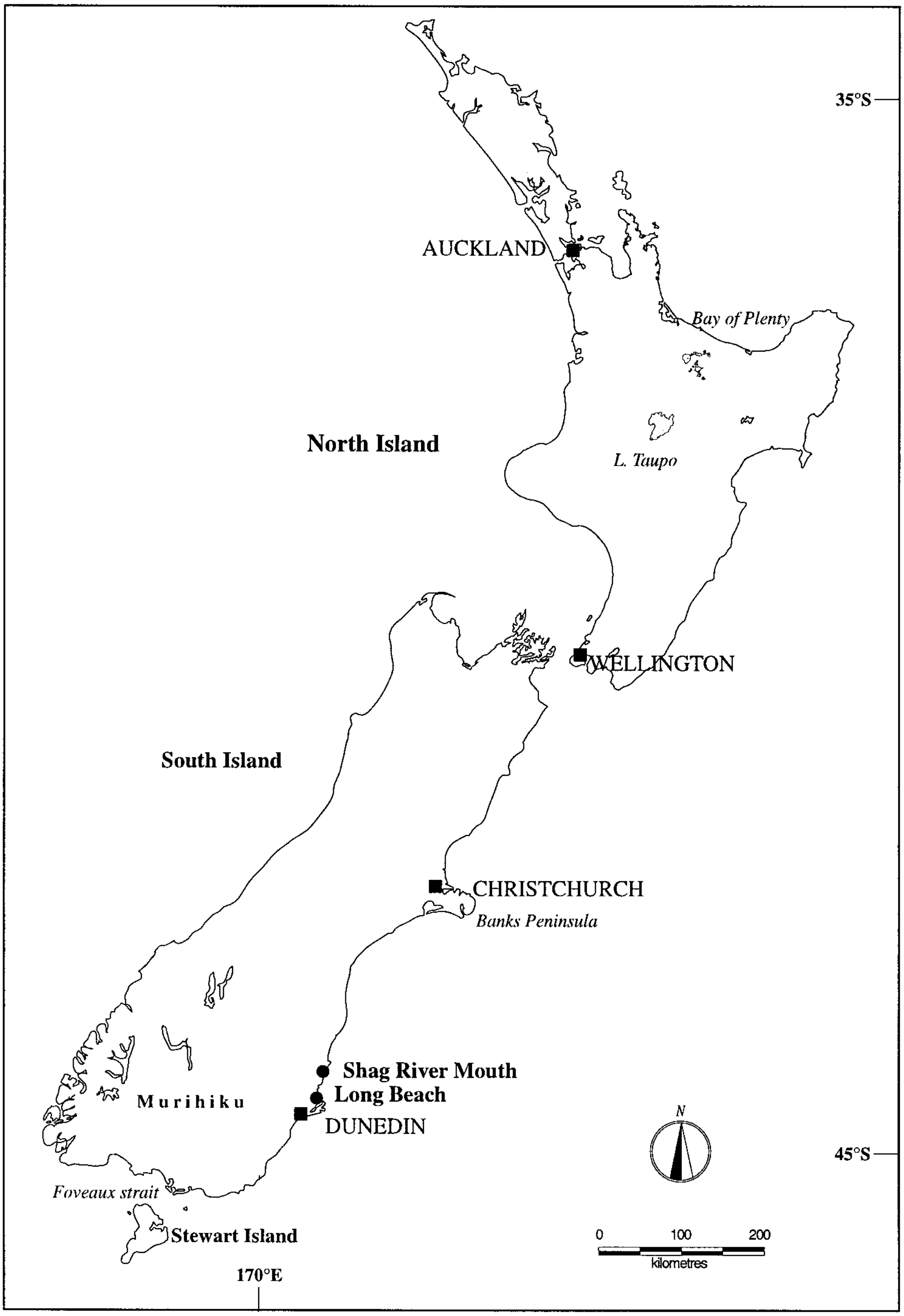

Figure 1. Location of Shag River Mouth and other sites mentioned in the text.

was established to set aside certain profiles from seasonal analysis or assign them tentative estimates (Higham, 1990, 1996). The acceptable profiles suggested that the layer 4 shell-bearing site represented a winter occupation at the lower levels, extending into spring, with summer represented at the uppermost layer (Higham, 1990, 1996). Some of the results were anomalous stratigraphically but Higham (1996) argued that these might be accounted for by post-depositional movement of certain shells in the site.

We decided to examine other faunal remains from the Shag River Mouth site to test the conclusions of the oxygen isotope research and also to investigate further the seasonality of fishing in southern New Zealand. The oxygen isotope results suggested that fishing was an activity practised in the same seasons as shellfishing

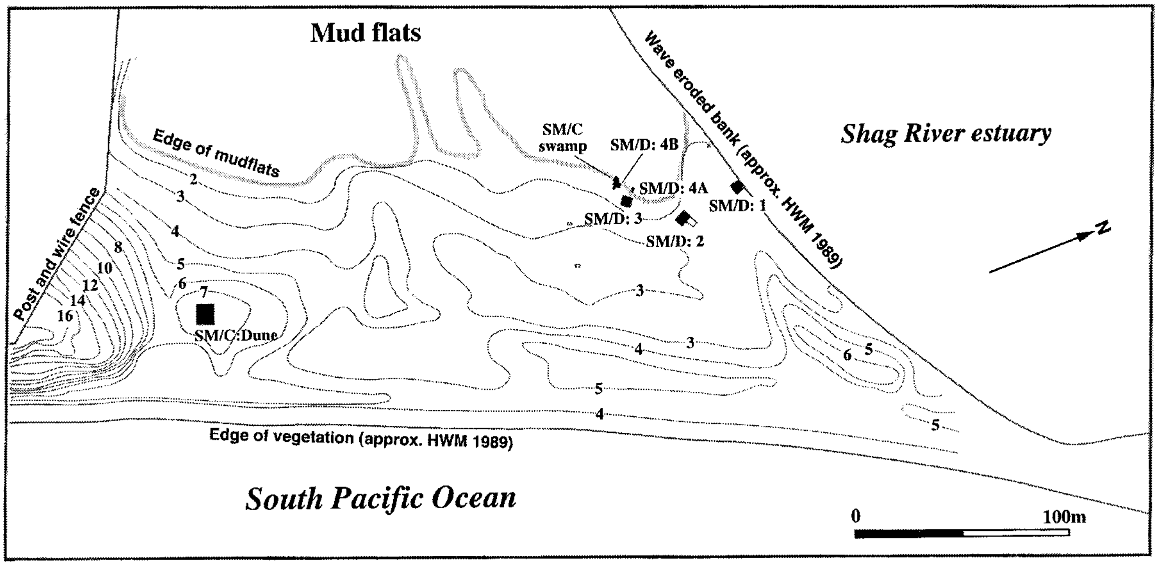

Figure 2. Location of SM/C:Dune excavation, Shag Mouth, New Zealand (after Anderson *et al*., 1996*a*: 8).

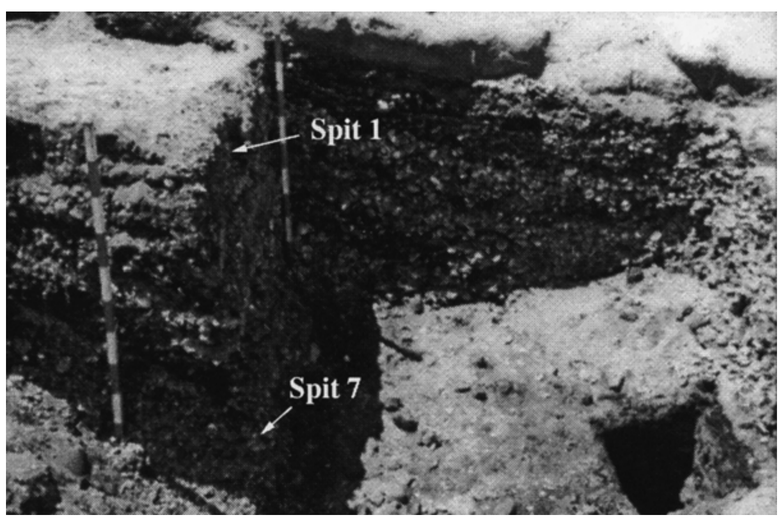

Figure 3. Stratigraphy of baulk squares G8 and H8, Layer 4, SM/C:Dune, Shag River Mouth, New Zealand showing lenses and excavated spits running from spit 1 at the top to spit 7 at the bottom. Scale, staff measures 1 m.

at Shag River Mouth because lenses of fish bone were found within the layer 4 midden. Ethnographic evidence, coupled with studies of the movements of modern fish species, however, has suggested that fishing was probably a summer activity in prehistory (Leach, 1969; Anderson, 1981*a*). Till (1984) and Till & Blattner (1986) challenged this when they obtained a winter estimate using oxygen isotope analysis for a cultural layer dominated by fish at the Long Beach site near Dunedin (Figure 1). They concluded that the seasonality of fishing in the region may need to be modified. Without unequivocal seasonal evidence for fish remains at sites such as Long Beach and Shag River Mouth, however, these conclusions remain tentative because of the possibility fish were cured and preserved in anticipation of periods of resource dearth (Monks, 1981). Fish may have been caught in summer and preserved for winter for example, and indeed this has been documented ethnographically (see Anderson 1981*b*: 148 for example).

Higham (1996) suggested that one method to investigate the seasonality of fishing further would be to examine the growth annuli of sagittal fish otoliths found in stratigraphic association with the blue mussel shells in the layer 2 and 4 middens. This would also enable the testing of the accuracy of the seasonal estimates based on oxygen isotope analysis of blue mussel shell.

Sagittal otoliths are paired structures composed primarily of aragonite, which occur in the heads of all teleost species. The otoliths recovered from the upper layer 4 midden at Shag River Mouth were all of

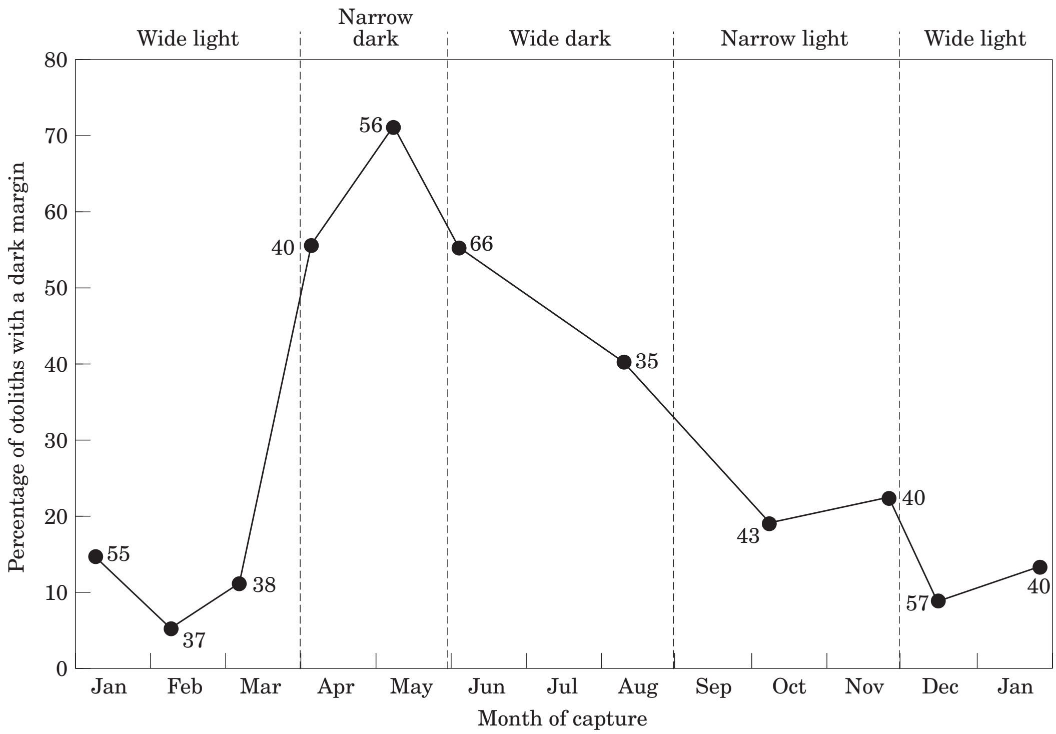

Figure 4. The percentage of otoliths of modern *Pseudophycis bachus* which possessed dark margins plotted against month of capture from January to January. Marginal classifications are shown as vertical lines in the figure. Numbers adjacent to points represent sample sizes.

Pseudophycis bachus (red cod). Nine well-preserved specimens were obtained from bulk midden samples collected from the site (Higham, 1990). Because of this, the provenance of some of the otoliths from within the layer 4 spits is not as precise as that of the blue mussel shells (Table 2).

In most species of fish, otoliths exhibit alternating opaque and translucent bands which together comprise annual increments. These bands have been used to determine the ages of fish since early this century (Paul, 1992). It is important to establish for each species that the banding pattern is annual and to determine the characteristics of zone formation in otoliths (Beckman & Wilson, 1995). A number of methods have been developed to do this (Beamish & McFarlane, 1983). One is to use modern fish to determine the timing of a check ring and identify whether it is winter related or not. Brinkhuizen (1997), for instance, found recently in an analysis of the otoliths of the European eel (*Anguilla anguilla*) that only 50% of his capture-recapture eels yielded an expected winter check ring, which called into question the reliability of seasonal estimates using this species. We utilized a different method. Otolith samples from modern *Pseudophycis bachus* individuals have been collected over a twelve month period and the otolith margins classified as either dark (translucent) or light (opaque) (Horn, 1996). If the bands are formed annually, then the percentage of otoliths in each sample with a dark margin should exhibit one maximum and one minimum during the year as the margin changes from light to dark and back to light again. Horn (1996) showed from an examination of the otolith marginal state in modern examples that there was an annual banding pattern in otoliths of red cod in New Zealand. He has shown that material forming the dark bands is deposited from about April to August, and that the majority of otoliths have light margins from September to March (Horn, 1996) (Figure 4); Table 1). We have applied this method to the prehistoric otoliths collected from the Shag River Mouth site and compared the banding within the prehistoric

Table 1. Data from modern otoliths of Pseudophycis bachus *showing the percentage of otoliths which possessed a dark marginal state from January to January*

Day of collection	Month	Percentage of otoliths with a dark margin
10	0·3	14·5
40	1·3	5·0
67	2·2	12·0
96	3·1	56·5
129	4·2	71·0
156	5·1	56·0
222	7·3	40·0
285	9·3	19·0
331	10·8	23·5
350	11·5	9·0
391	12·8	13·0

Table 2: Shag River Mouth otolith data from Layers 2 and 4. The Layer 4 results are from bulk midden samples and their precise provenance is not known with the exception of otolith 696 from the top of the midden

Otolith No.	Provenance	Age	Margin width	Inferred season of death
690	Layer 2 Sq.F7	3·3	Medium-wide light	Nov-Dec (early summer)
691	Layer 2 Sq.G7	4·3	Medium-wide light	Nov-Dec (early summer)
696	Layer 4 spit 1	2·3	Medium-wide light	Nov-Dec (early summer)
692	Layer 4 Sq.F8	4·1	Narrow light	Sept-Nov (spring)
693	Layer 4 Sq. 16	—	—	—
694	Layer 4 upper	3·1	Narrow light	Sept-Nov (spring)
695	Layer 4 Sq. H7	3·1	Narrow light	Sept-Nov (spring)
346·1	Layer 4 Sq. J7	3·1	Narrow light	Sept-Nov (spring)
346·2	Layer 4 Sq. J7	3·1	Narrow light	Sept-Nov (spring)
346·3	Layer 4 Sq. J7	3·0	Wide Dark	Jun-Aug (winter)

† The seasons and months used in interpretation in this paper are September–October–November (Spring); December–January–February (Summer); March–April–May (Autumn); June–July–August (Winter).

otoliths with over 500 modern control samples to estimate the season of capture of the fish in prehistory.

The prehistoric otoliths were prepared and examined in a manner similar to that described by Horn (1996). The technique generally involves breaking the otolith transversely, heating it until it darkens (which enhances the internal banding pattern) and counting the number of dark bands on the broken surface. Otoliths were broken transversely at mid length to expose the nucleus, then placed broken surface down in moulds containing an epoxy resin (Araldite K142). Fresh otoliths are normally baked at *c.* 275°C for a few minutes to enhance the banding pattern. However, bands in the prehistoric otoliths were already apparent after fracturing, presumably due to heating when the fish were cooked, so the baking process was not considered necessary. After the resin had set, the mould surface with the broken otolith ends was polished on a grinding wheel using coarse and then fine grades of sandpaper to produce a smooth, flat otolith surface. The smoothed otolith cross-sections were then coated with paraffin oil and examined under a binocular microscope (× 25) using reflected light. Patterns of dark and light bands were apparent on the polished surface of the otolith. The margins of the cross-sections were classified as being either light or dark, and the relative width of the last band was estimated. Each seasonal estimate was determined by comparison with modern widths. The age of the fish at the time of death was also determined (Table 2).

Results

Most of the otoliths examined had clear banding patterns, so the margins could be classified with confidence. This was fortunate because modern red cod otoliths tend to have quite diffuse bands, making it hard to define precisely the point where a dark band changes to a light band (Horn, 1996). Assuming size-at-age is comparable to red cod caught today, all but one of the otoliths examined were from relatively large fish (about 50–70 cm total length). Red cod are a fast-growing, short-lived species, with few individuals exceeding four years of life. They occur in inshore waters to depths of about 550 m, but are most abundant in the 100–300 m depth range.

The otolith margin classification, fish ages and seasonal estimates are shown in Table 2. The marginal states of eight of the ten otoliths were relatively clear, one was interpreted with some doubt (otolith 346·1) and one could not be interpreted (693). Two otolith thin sections are shown in Figures 5 and 6. As mentioned above, red cod otoliths generally have dark margins from April to August, and light margins from September to March (Horn, 1996). Otoliths with a narrow light margin probably came from fish caught in spring (September–November), while those with medium-wide light margins were probably caught in early summer (November–December). The one otolith with a dark wide margin was probably from a fish caught in winter (June–August).†

The seasonal results from the layer 4 otoliths are dominated by spring estimates. There are two exceptions. The first is a winter estimate (Table 2) and the second an early summer result from the very top of layer 4 in spit 1.

Layer 2 was separated from layer 4 by a sterile dune sand layer (Anderson *et al.* 1996*a*).

The otoliths analysed from layer 2 both yielded an early summer estimate. We think that layer 2 may represent a continuation of the summer occupation identified at the top of layer 4. There is additional evidence in support of this. A broken adze was found at the top of the Layer 2 occupation and the other half of it was recovered from the Layer 4 midden. This suggests either that there had been significant post-depositional movement in the upper margins of the site, or that the two were not separated by a significant period of time. We prefer the latter explanation.

Although only a small number of otoliths were obtained from the site for this study, they provide

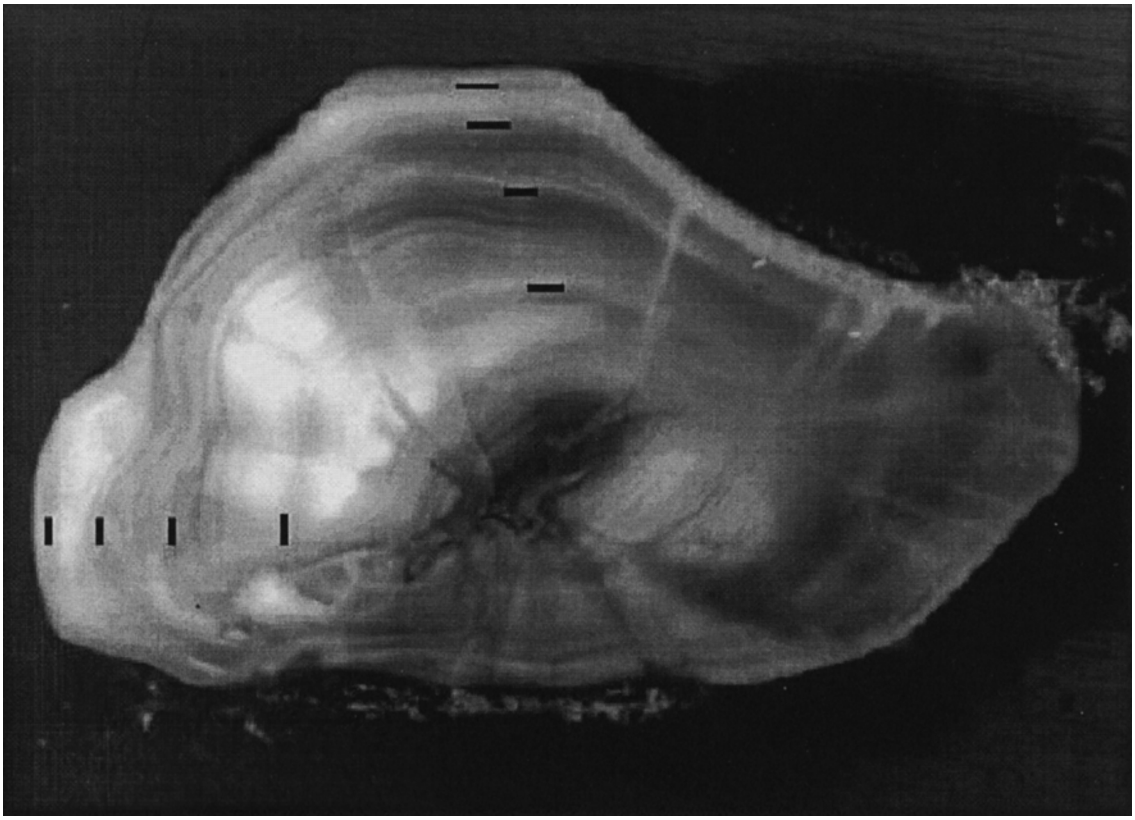

Figure 5. Light micrograph of otolith 691, layer 2, square G7 SMC:Dune. Black marks in the picture show the margins between light (September to March) and dark (April to August) periods of growth. The distance from left to right on this otolith measures *c*. 5 mm. This otolith is estimated to have been caught during early summer because the margin at the periphery of the cross section is a medium-wide light margin.

results which are stratigraphically consistent and similar to the previous seasonal results on mussel shells from similar provenance. The majority of the shellfish sampled using oxygen isotope techniques yielded palaeotemperatures either at, or near a winter low or showed climbing post-winter temperatures which were interpreted as spring deaths. Higham (1990; 1996) therefore suggested that the occupation of layer 4 was predominantly during winter and spring. Two blue mussel shells from the top of layer 4 in squares F8 and H8 were interpreted as summer deaths because of a pronounced peak towards the top of an annual cycle in temperature. Higham (1990; 1996) concluded therefore that the majority of layer 4 was occupied during winter and spring, extending to summer at the upper part of the deposit. The otolith results confirm these estimates.

Discussion

The prehistoric red cod seasonality matches the period of seasonal abundance identified in the modern fishery. Anderson & Smith (1996*a*) have suggested, based upon the work of Graham (1956), that red cod are abundant from early to mid-winter (May, June, July) and tend to disappear offshore by the end of July. More recent research suggests that red cod are available (and support a modern commercial fishery) between Banks Peninsula and Dunedin from November to May (late spring to late autumn) (Beentjes, 1992; Horn, 1996). Although it is possible that the period of availability has changed during the past few centuries, it is unlikely to have changed to this extent. The contemporary period of abundance therefore matches broadly the estimated season and capture of the fish in prehistory (spring to summer) and the ethnographic record (Shortland, 1851; Leach, 1969).

Barracouta were the most common fish found in layer 4 (c. 70% of total fish MNI) and in the site as a whole (Anderson & Smith, 1996*a*). Hurst & Bagley (1989) have investigated the modern seasonal availability of this species. In March 1984 and January 1987 they tagged fish from the Bay of Plenty to Stewart Island at times when barracouta formed surface feeding shoals and could be caught on lures, that is during late spring and summer months. Sampling in winter and spring was limited, but only in the Bay of Plenty, because barracouta are not so easily caught on lures then. The main barracouta fishing season off the east coasts of the South Island takes place between October and May and the fish move out of the area over autumn and winter. Anderson (1981*b*) has suggested

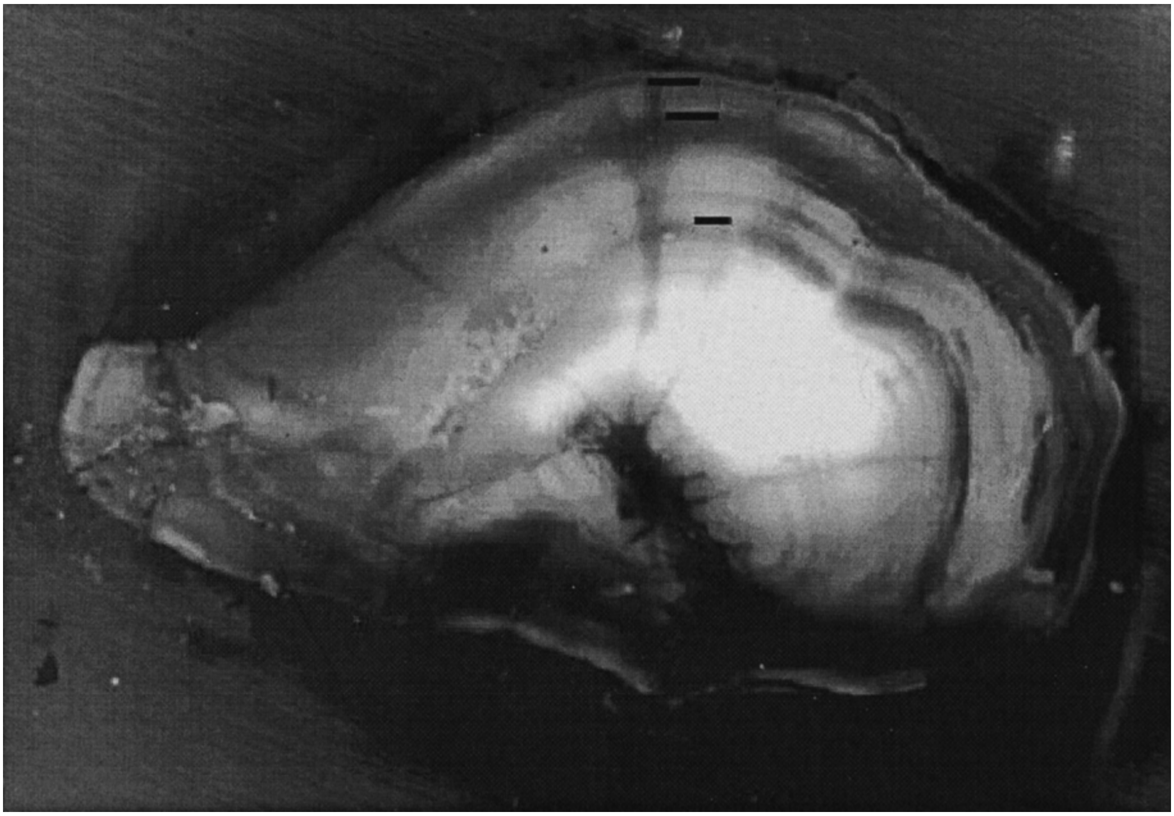

Figure 6. Light micrograph of otolith 694, layer 4 (upper), SMC:Dune. The distance from left to right on this otolith measures *c*. 5 mm. This fish was probably caught in spring because of the narrow light margin visible at the periphery of the otolith.

on the basis of traditional and historical accounts that the barracouta season peaked in March and extended from November to April. The seasons of occupation inferred at the layer 4 midden at Shag River Mouth midden, then, are similar to the seasonal presence of barracouta because they suggest that they were caught from spring onwards. Again, the problem with deriving precise seasonal information from most faunal indicators such as these is that their presence is not restricted to single seasons only.

Conclusion

The seasonal investigations at Shag River Mouth have been hampered by a small number of suitably well-preserved remains of species of fish and shellfish which are restricted in their seasonal availability. Several different strands of evidence, however, suggest that layer 4 of the SM/C:Dune site represents a prehistoric occupation which spanned the winter, spring and summer months. Given the lack of hiatuses through the site, it seems likely that the entire sequence of nine cultural layers at SM/C:Dune represents an occupation of short duration, though one which was apparently permanent, and year round. A brief occupation here is also attested to by the pattern of oven use throughout the entire sequence. The same ovens were continually re-used throughout the sequence from the lower to the upper layers. In addition, the radiocarbon dates obtained from the site are indistinguishable from one another (Anderson *et al*., 1996*b*). All of these factors suggest that the site at SM:C/Dune, and indeed the remainder of the site, was occupied briefly (Anderson & Smith, 1996*c*).

If, as Anderson & Smith (1996*c*) have suggested, the sequence at SM/C:Dune represents a simple progression of resource degeneration incorporating a transformation from a big game economy to a marine based economy, then this transformation must have been extremely rapid. The similarity of the radiocarbon determinations and the spreading of calibrated age ranges makes it difficult to ascertain exactly how brief. While the analysis of otoliths from the Shag River Mouth site has provided an important glimpse into the seasonal round of activities in the Archaic phase of prehistory in Murihiku, there may be equally important benefits for analyses such as these as chronological indicators, especially within the brief span of prehistory in New Zealand. Many Archaic sites in New Zealand are beginning to fall into a pattern of short-term occupation, involving a sustained onslaught upon the local fauna, followed by abandonment. The precise length of occupation of such sites in the light of indistinguishable radiocarbon determinations is likely to be a difficult problem to overcome. The careful spit excavation of the components of the layer 4 midden and the subsequent seasonal analyses refine the chronology beyond the resolution obtainable by high precision radiocarbon dating.

Acknowledgements

The Skinner Fund for Prehistory of the Royal Society of New Zealand funded this research. We are grateful to Professor A. J. Anderson (Division of Archaeology and Natural History, The Australian National University, Canberra, Australia), Mr L. Paul (NIWA, Greta Point, Wellington) and Dr B. F. Leach (Archaeozoology Laboratory, Museum of New Zealand, Wellington). Dr I. W. G. Smith (Department of Anthropology, University of Otago, Dunedin) provided the otolith samples. Dr B. O'Brien (Department of Biological Sciences, University of Waikato) photographed the otolith sections.

References

Anderson, A. J. (1980). Towards an explanation of protohistoric social organisation and settlement patterns amongst the Ngai Tahu. *New Zealand Journal of Archaeology* **2,** 3–25.

Anderson, A. J. (1981*a*). A fourteenth-century fishing camp at Purakanui inlet, Otago. *Journal of the Royal Society of New Zealand* **11,** 201–221.

Anderson, A. J. (1981b). Barracouta fishing in prehistoric and early New Zealand. *Journal de la Societe des Oceanistes* **72–73,** 145–158.

Anderson, A. J. (1982). A review of economic patterns during the Archaic phase in southern New Zealand. *New Zealand Journal of Archaeology* **4,** 45–75.

Anderson, A. J. (1988). Coastal subsistence economies in prehistoric southern New Zealand. In (J. Parkington & G. Bailey, Eds). *The Archaeology of Prehistoric Coastlines*. Cambridge: Cambridge University Press.

Anderson, A. J. (1989). *Prodigious Birds. Moas and Moa-hunting in Prehistoric New Zealand*. Cambridge: Cambridge University Press.

Anderson, A. J. & Allingham, B. J., (1996). The high dune and swamp excavations. In (A. J. Anderson, B. J. Allingham & I. W. G. Smith, Eds) *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History, **27,** pp. 39–50.

Anderson, A. J. & Smith, I. W. G. (1996*a*). Analysis of Fish remains. In (A. J. Anderson, B. J. Allingham & I. W. G. Smith, Eds) *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History, **27,** pp 237–244.

Anderson, A. J. & Smith, I. W. G. (1996*b*). Shag River Mouth as an early Maori Village. In (A. J. Anderson, B J Allingham & I. W. G. Smith, Eds) *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History **27,** pp. 276–291.

Anderson, A. J. & Smith, I. W. G. (1996c). The transient village in southern New Zealand. *World Archaeology* **27,** 359–371.

Anderson, A. J., Allingham, B. J & Smith, I. W. G. (Eds) (1996*a*). *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History **27.**

Anderson, A. J., Smith, I. W. G. & Higham, T. F. G. (1996*b*). Radiocarbon Chronology. In (A. J. Anderson, B. J. Allingham & I. W. G. Smith, Eds) *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History **27,** pp 237–244.

Beamish, R. J. & McFarlane, G. A. (1983). The forgotten requirement for age validation in fisheries biology. *Transactions of the American Fisheries Society* **112,** 735–743.

Beckman, D. W. & Wilson, C. A. (1995). Seasonal timing of opaque zone formation in fish otoliths. In (D. H. Secor, J. M. Dean & S. E. Campana, Eds) *Recent Developments in Fish Otolith Research* Columbia, S.C: The Belle W. Baruch Library in Marine Science **19,** pp 27–43.

Beentjes, M. (1992). Assessment of red cod based on recent trawl survey and catch sampling data. *New Zealand Fisheries Assessment Research Document* **92/16.** 40 pp.

Brinkhuizen, D. C. (1997). Some remarks on seasonal dating of fish remains by means of growth ring analysis. *Internet Archaeology* **3,** (http://intarch.york.ac.uk/journal/issue3/brink/index.html)

Claassen, C. (1991). Normative thinking and shell-bearing sites. *Archaeological Method and Theory* **3,** 249–298.

Coutts, P. J. F. (1970). Bivalve-growth patterning as a method for seasonal dating in archaeology. *Nature* **226,** 874.

Coutts, P. J. F. (1974). Growth characteristics of the bivalve. *Chione stutchburyi. New Zealand Journal of Marine and Freshwater Research* **8,** 333–339.

Coutts, P. J. F. & Higham, C. F. W. (1971). The seasonal factor in prehistoric New Zealand. *World Archaeology* **2,** 226–278.

Coutts, P. J. F & Jurisich, M. (1972). Results of an Archaeological Survey of Ruapuke Island. *Otago University Monographs in Prehistoric Anthropology* **5**. Anthropology Department, University of Otago, Dunedin.

Coutts, P. J. F. & Jones, K. L. (1974). A proposed method for deriving seasonal data from the Echinoid (*Evechinus chloroticus* (Val)), in archaeological deposits. *American Antiquity* **39,** 98–102.

Epstein, S., Buchsbaum, R., Lowenstam, H. A. & Urey, H. C. (1951). Carbonate-water isotopic temperature scale. *Bulletin of the Geological Society of America* **62,** 417–426.

Graham, D. H. (1956). *A Treasury of New Zealand Fishes*. Wellington: A. H and A. W Reed.

Higham, T. F. G. (1990). *The seasonal factor at Shag Mouth*. M.A. Thesis. University of Otago, Dunedin, New Zealand.

Higham, T. F. G. (1996). Shellfish and seasonality. In (A. J. Anderson, B. J. Allingham & I. W. G. Smith, Eds) *Shag River Mouth: the Archaeology of an Early Southern Maori Village*. Canberra: Australian National University Research Papers in Archaeology and Natural History **27,** pp 245–253.

Horn, P. L. (1996). Age and growth of red cod (*Pseudophycis bachus*) off the south-east coast of the South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **30,** 151–160.

Hurst, R. J. & Bagley, N. W. (1989). Movements and possible stock relationships of the New Zealand Barracouta. *Thyrsites atun*, from tag returns. *New Zealand Journal of Marine and Freshwater Research* **23,** 105–11.

Leach, H. M., (1969). *Subsistence patterns in Prehistoric New Zealand*. Studies in Prehistoric Anthropology **2**: University of Otago, Dunedin.

Leach, H. M. & Leach, B. F. (1978). The Riverton site: an archaic adze manufactory in western Southland, New Zealand. *New Zealand Journal of Archaeology* **8,** 107–139.

Monks, G. G. (1981). Seasonality studies. *Advances in Archaeological Method and Theory* **4,** 177–240.

Paul, L. J. (1992). Age and growth studies of New Zealand marine fishes, 1921–90: a review and bibliography. *Australian Journal of Marine and Freshwater Research* **43,** 879–912.

Samson, J. (1996). *Seasonal Studies from the mouth of the Pleasant River*. M.A Thesis, University of Otago, Dunedin.

Shackleton, N. J. (1973). Oxygen isotope analysis as a means of determining season of occupation of prehistoric midden sites. *Archaeometry* **15,** 158–187.

Shortland, E. (1851). *The Southern Districts of New Zealand*. Christchurch: Capper Press.
Smith, I. W. G. (1985). *Sea Mammal Hunting and Prehistoric Subsistence in New Zealand*. Ph.D. Thesis. Anthropology Department, University of Otago.
Smith, I. W. G. (1989). Maori Impact on the Marine Megafauna: Pre-European Distributions of New Zealand Sea Mammals. In (D. G. Sutton, Ed.) *Saying so Doesn't Make it So, Papers in Honour of B. Foss Leach*. New Zealand Archaeological Association Monograph **17**, pp. 76–108.
Teal, F. J. (1975). Pleasant River Excavations. P.G.D. Thesis, University of Otago, Dunedin, New Zealand.
Till, M. (1984). *Seasonality in Murihiku: The evidence from Oxygen Isotope ratios*. M.A. Thesis, University of Otago, Dunedin, New Zealand.
Till, M. & Blattner, P. (1986). The seasonality of fishing and shellfishing in prehistoric Otago: The evidence from Oxygen Isotope ratios. In (A. J. Anderson, ed) Report 11, *Traditional Fishing in the Pacific. Ethnographical and Archaeological Papers from the 15th Pacific Science Congress*, Pacific Anthropological Records. **37,** Honolulu: Bernice P. Bishop Museum.
Von Haast, J. (1874). Notes on the Moa-hunter encampment at Shag Point, Otago. *Transactions of the New Zealand Institute* **7,** 91–8.