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Determination of geographic origin of unprovenanced Aboriginal skeletal remains in South Australia employing stable carbon and nitrogen isotope analysis

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Abstract

Bone collagen stable carbon and nitrogen isotope analysis of prehistoric human remains recovered from various known localities in southeastern South Australia provide isotopic signatures that distinguish the following geographic regions: the coastal Coorong, the coastal Murray River Mouth, Swanport (Lower Murray River), and Roonka (Upper Murray River). These regional isotopic signatures are employed to determine geographic origin of unprovenanced Aboriginal skeletal remains curated by the South Australian Museum. Nearly 85% of the unprovenanced sample (77/91) could be assigned to a particular geographic zone on the basis of isotopic values, and a further 13% (12/91) were assigned to areas intermediate between two geographic zones. Only two of the 91 individuals possessed anomalous isotopic values in relation to the standard values derived from known geographic localities. Isotopic analysis provides an independent means to address geographic origin of skeletal remains that can supplement other methods, e.g. metric, non-metric, and DNA analysis.

Introduction

Stable carbon and nitrogen isotope analyses of prehistoric human and faunal bone and fossil emu eggshell have been employed in Australia to address Aboriginal landscape use and environmental change during the late Pleistocene and Holocene (Collier and Hobson 1987; Pate 1995, 1998a, 1998b; Grocke 1997; Johnson et al. 1999; Roberts et al. 1999).

Stable isotope analysis of bone collagen from modern marine and terrestrial mammals in South Australia (Pate and Schoeninger 1993; Pate et al. 1998; Pate and Noble 2000; Anson 1997; Grocke et al. 1997) demonstrates that there are significant variations in isotopic values correlated with geographic locality. Variations in stable carbon isotope values ($\delta^{13}C$) are related predominantly to relative proportions of marine vs. terrestrial foods and C_3 vs. C_4 plant foods included in diets, whereas variations in nitrogen isotopes ($\delta^{15}N$) may relate to marine vs. terrestrial dietary intake, trophic level, nutritional stress, water restriction, and synchronic and diachronic changes in rainfall patterns (Ambrose 1991; Pate 1994; Pate et al. 1998; Schwarcz et al. 1999). Oxygen, strontium and lead isotopes in bones and teeth have also been used to address migration and geographic origin in prehistoric populations (cf. Carlson 1996; Ezzo et al. 1997; White et al. 1998; Montgomery et al. 2000; Price et al. 2000; Müller et al. 2002). Ayliffe and Chivas (1990) address variability in oxygen isotope values in the bone phosphate of kangaroos in relation to different environmental zones in Australia.

Thus, in some cases stable isotope values will provide a record of long-term use of various environmental zones by animals and humans. The use of teeth in addition to bone provides information about childhood diet that can be employed to address migration between different environmental zones.

This research provides a novel application of bone collagen stable carbon and nitrogen isotopes as a means to determine geographic locality for museum skeletal collections that lack specific provenance. Archival information and biographical research on collectors continue to provide the primary means for establishing provenance for prehistoric skeletal remains in Australia. However, large numbers of unprovenanced Aboriginal remains occur in museum and research collections throughout Australia and cannot be assigned to a specific locality without the aid of biological anthropology or chemical analyses. Furthermore, returning human remains to the correct Aboriginal community is an issue of great importance to repatriation programs across Australia. Many indigenous people do not wish to rebury human remains in their country if the provenance of the remains is uncertain. There are a number of ethnohistoric sources that discuss the importance to Aboriginal people of burying persons in their own country (Taplin; 1879; Dawson 1881; Meehan 1971).

Aboriginal human remains held by the South Australian Museum that are provenanced to the Adelaide region of South Australia or simply to the state of South Australia were submitted for stable carbon and nitrogen isotope analysis to address the utility of this method in relation to determining geographic origin.

Materials and Methods

The unprovenanced human skeletal sample consisted of 91 individuals collected in the state of South Australia during the 19th and 20th centuries. It is assumed that the majority of these individuals were recovered from unstable Holocene dunes (Pardoe 1988, 1995) within the vicinity of the population centre of Adelaide. Natural erosion of coastal and riverine dune systems combined with urban development would have exposed prehistoric human burials in these sandy sediments.

Prehistoric human controls derived from four distinct environmental zones located within a 200km radius of Adelaide (Fig. 1) were employed to provide standard stable carbon and nitrogen isotope values for these regions. The four geographic zones consisted of 1) the coastal Coorong, 2) the coastal Murray River mouth, 3) the Adelaide plains-

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Lower Murray River, and 4) inland Blanchetown-Upper Murray River. Prehistoric human control samples included 3 individuals from the Coorong, 12 from Lake Alexandrina at the mouth of the Murray River, 110 from the inland Swanport site near Murray Bridge (lower Murray River), and 32 from the Roonka site near Blanchetown (Pate 1998a, 1998b). The inland sites of Swanport and Roonka are located approximately 20 km and 120 km north of the Murray River mouth, respectively (Stirling 1911; Pretty 1977, 1986).

A 1 - 1.5 g cortical bone specimen was taken from each individual for stable isotope analysis. These whole bone specimens generally equated to the size of an adult thumb nail. Sample preparation involved ultrasonic cleaning of whole bone specimens, demineralization, and sodium hydroxide treatment. Whole bone chunks were demineralized in dilute HCl according to the methods of Sealy (1986). Humic acids and other base-soluble contaminants were removed using a 0.125 M NaOH solution. Extracts were soaked and washed thoroughly following acid and base treatments in order to remove dissolved contaminants. The remaining organic component was oven dried at 35 C and carbon and nitrogen concentrations were determined using an ANCA SL elemental analyzer. Stable carbon and nitrogen isotope values were determined by mass spectrometry. Analytical precision was better than ± 0.1‰ for carbon and ± 0.3‰ for nitrogen.

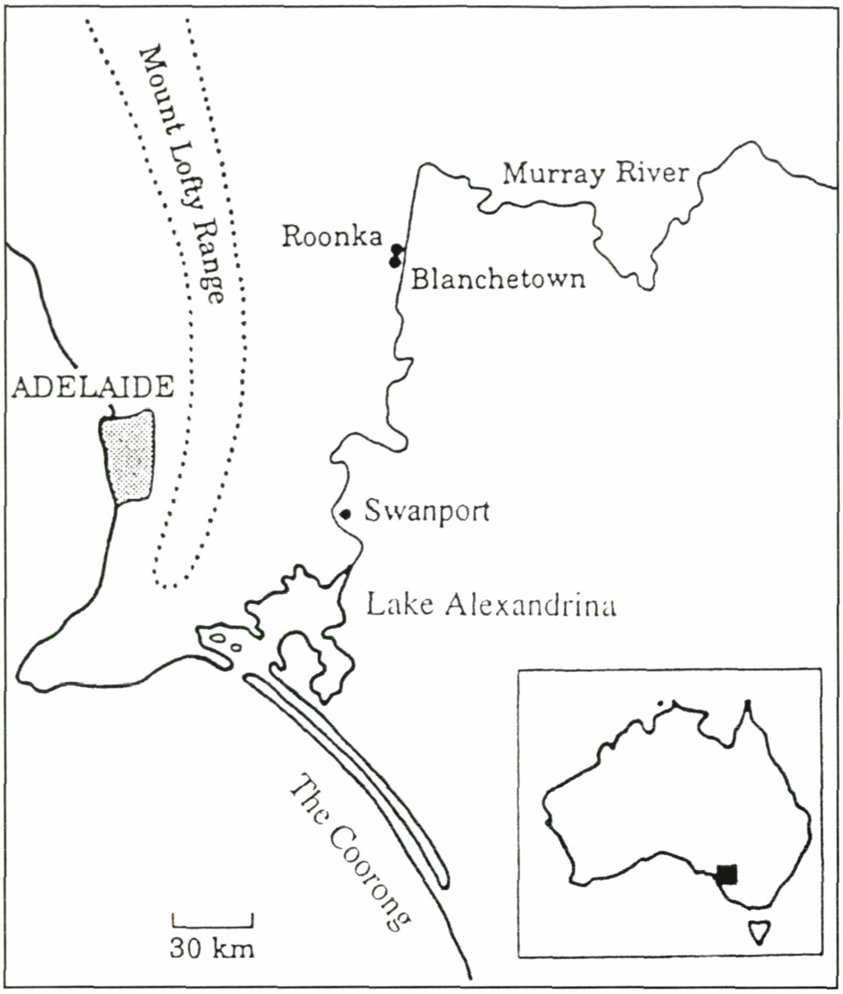

Figure 1 Map showing location of regions and sites in South Australia.

Controls for postmortem organic decomposition were implemented by excluding samples with 1) less than 5% collagen yield from whole bone, or 2) less than 5% carbon yield from collagen, or 3) less than 0.5% nitrogen yield from collagen (Schoeninger et al. 1989; Ambrose 1990; Pate 1997). When collagen yields were less than 5% upon initial demineralization, additional whole bone samples were taken and demineralized until a specimen with adequate collagen yield was obtained.

Standard bone collagen stable carbon and nitrogen isotope ranges for the four geographic zones were calculated using the 2σ ranges around the mean values of prehistoric human samples derived from the known localities. The probable geographic origin of unprovenanced individuals was then determined by comparing their carbon and nitrogen isotope values with the standard isotopic ranges for each known locality.

Results

Stable carbon and nitrogen isotope values for the known human samples from each geographic zone in southeastern South Australia are reported in Table 1 and Figures 2- 3. The Coorong has the most positive $\delta^{13}C$ and $\delta^{15}N$ values in relation to high levels of seafood intake. The Murray Mouth (Lake Alexandrina) shows intermediate $\delta^{13}C$ and $\delta^{15}N$ values due to consumption of marine and terrestrial foods. The Swanport (Lower Murray River) and Roonka (Upper Murray River) regions have the most negative $\delta^{13}C$ values reflecting a predominantly terrestrial diet based on C_3 plant foods and animals that fed on C_3 plants. However, $\delta^{15}N$ values are more positive in the inland semi-arid Roonka population than they are in the temperate Swanport region. Thus, the observed isotopic variations between the known human samples suggest that a combination of carbon and nitrogen isotope values will provide the best indicator of geographic origin for the unprovenanced human samples.

Figure 4 shows individual data points for each of the unprovenanced skeletons. Table 2 reports the most likely provenance or geographic origin for the unprovenanced human samples on the basis of bone collagen stable carbon and nitrogen isotope values. A majority of the unprovenanced samples (77/91) could be reliably assigned to a particular geographic zone on the basis of isotopic values. These included Coorong (24), Murray Mouth (27) and Swanport, Lower Murray (26). Three individuals had isotopic values suggesting use of both the Coorong and

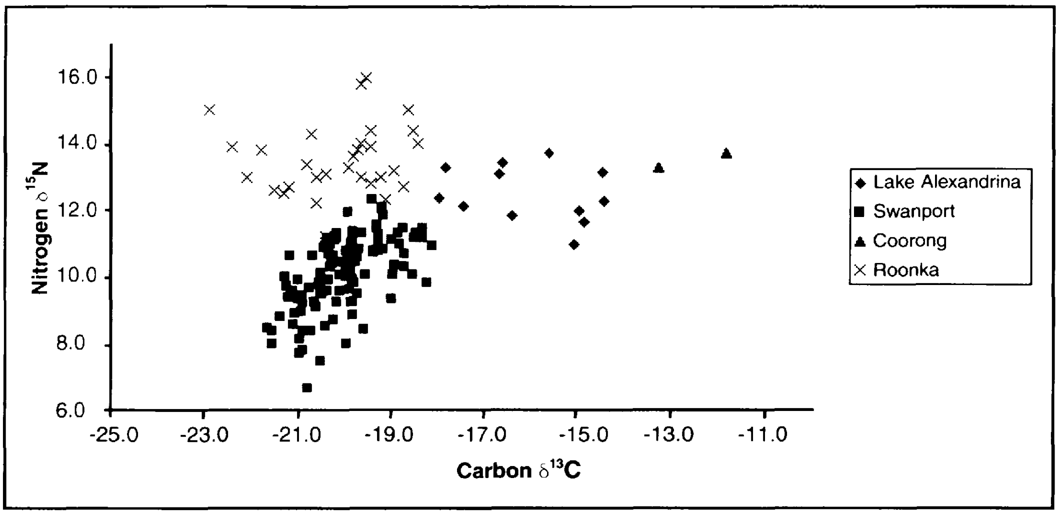

Figure 2 Diagram showing stable carbon and nitrogen isotope data points for individual prehistoric Aboriginal skeletons associated with the four areas of known geographic locality in southeastern South Australia.

Murray Mouth regions, whereas 9 individuals showed values intermediate between the Swanport (Lower Murray) and Roonka (Upper Murray) zones. None of the unprovenanced individuals could be placed in the Upper Murray region on the basis of $\delta^{13}C$ and $\delta^{15}N$ values. Finally, two individuals presented anomalously negative $\delta^{15}N$ values that did not correlate with any of the known human standards.

Raw data for the unprovenanced sample are presented in Appendix 1.

Discussion

Bone collagen stable carbon and nitrogen isotope values provide a reliable means to determine geographic origin of unprovenanced prehistoric skeletal remains in southeastern South Australia. Unprovenanced human remains can be assigned to general geographic zones on the basis of this method. The use of standard stable carbon and nitrogen isotope values for prehistoric human populations from known geographic localities was essential for the successful application of this technique in South Australia. Although baseline isotopic values derived from marine and terrestrial mammals with known diets are useful in determining general differences in diet and landscape use in prehistoric populations, they do not provide the detailed information necessary for repatriation studies because there are significant differences in the ranges of $\delta^{13}C$ and $\delta^{15}N$ values for animals and humans (cf. human values in this study with faunal values in Pate 1998a, 1998b; Brodie 2000).

Observed differences between animal and human stable isotope values in similar South Australian habitats are most likely explained by 1) metabolic differences between humans and fauna and 2) restrictions of access to various marine and terrestrial foods in humans related to territoriality and other cultural factors. Thus, carbon and nitrogen isotopic variability in prehistoric human populations results from a combination of environmental and cultural variables.

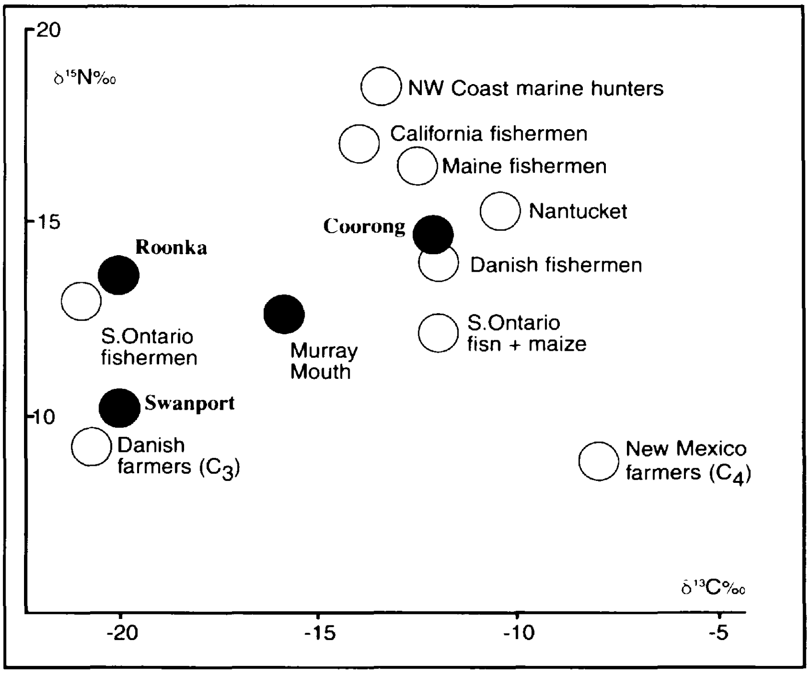

Figure 3. Diagram showing mean stable carbon and nitrogen isotope values for prehistoric Aboriginal skeletal samples from southeastern South Australia with known geographic locality in comparison to isotopic results for prehistoric human samples from other regions of the world.

The diets of the two individuals with anomalous $\delta^{15}N$ values most likely included a large proportion of low trophic level foods. This is one explanation for the more negative nitrogen isotope values in these individuals in comparison to the majority of the sample (Ambrose 1991). If this is the case, the individual with the $\delta^{13}C$ value of –10.1‰ and $\delta^{15}N$ value of 8.8‰ can be assigned to the Coorong region on the basis of the very positive carbon isotope value, and the individual with values of –15.2‰ and 4.2‰ to the Murray Mouth zone due to the intermediate carbon isotope value.

Because stable isotopic analyses will normally only provide general regional locality for unprovenanced human remains, the association between these broad geographic zones and contemporary Aboriginal territorial boundaries or landscape associations must be determined on a case by case basis. In some cases there will be a correlation between broad geographic zones and Aboriginal community boundaries, e.g. the Coorong and Murray Mouth regions in this study are associated with the

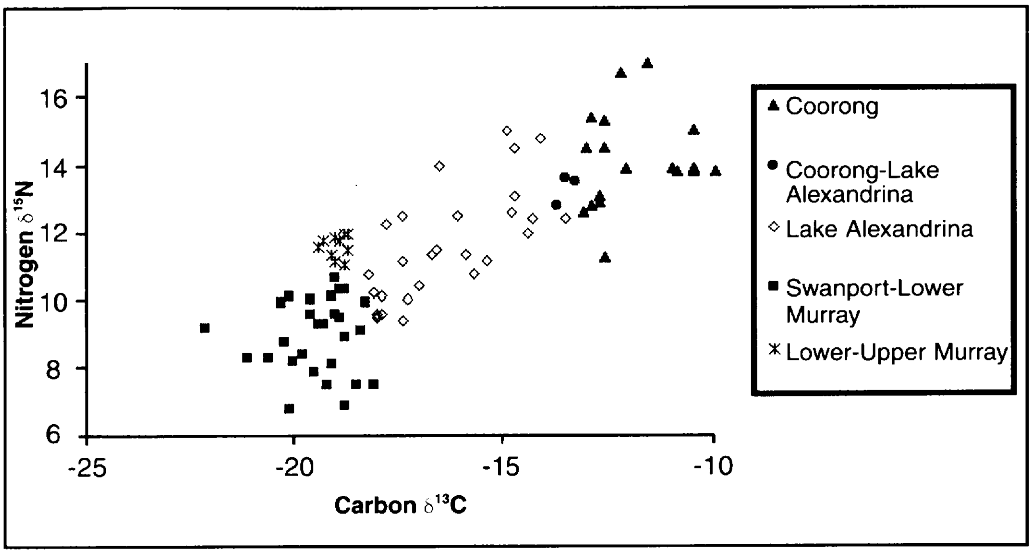

Figure 4 Diagram showing stable carbon and nitrogen isotope data points for individual unprovenanced Aboriginal skeletons that have been assigned to three geographic areas in southeastern South Australia. Outliers are also shown.

Region/Site	n	$\delta^{13}C$ $\bar{X} \pm$ SD (‰)	2σ Range	$\delta^{15}N$ $\bar{X} \pm$ SD(‰)	2σ Range
Coorong	3	-12.3 ± 0.8	-13.9, -10.7	14.6 ± 2.0	12.6, 16.6
Lake Alexandrina (Murray Mouth)	12	-16.0 ± 1.3	-18.6, -13.4	12.5 ± 0.8	10.9, 14.1
Swanport (Lower Murray)	110	-20.0 ± 0.8	-21.6, -18.4	10.1 ± 1.1	7.9, 12.3
Roonka (Upper Murray)	32	-20.1 ± 1.2	-22.5, -17.7	13.4 ± 1.2	11.0, 15.8

Table 1 Bone collagen stable carbon and nitrogen isotope values for prehistoric humans from known localities in southeastern South Australia.

Geographic Region	$\delta^{13}C$ n	$\delta^{15}N$ $\bar{X} \pm$ SD (‰)	Range	$\bar{X} \pm$ SD (‰)	Range
Coorong	24	-11.6 ± 1.2	-13.2, -9.6	14.7 ± 2.7	11.2, 22.2
Coorong-Lake Alexandrina	3	-13.6 ± 0.2	-13.8, -13.4	13.3 ± 0.4	12.8, 13.6
Lake Alexandrina (Murray Mouth)	27	-16.4 ± 1.5	-18.3, -13.6	12.0 ± 1.9	9.5, 17.2
Swanport (Lower Murray)	26	-19.6 ± 0.9	-22.2, -18.2	9.0 ± 1.0	6.9, 10.4
Lower Murray-Upper Murray	9	-19.0 ± 0.2	-19.4, -18.8	11.6 ± 0.3	11.1, 12.0

Table 2 Geographic origin of unprovenanced prehistoric human samples from South Australia as determined by bone collagen stable carbon and nitrogen isotope values.

Narrinjerri community.

The application of this technique in South Australia will be improved by an expansion of stable isotope data for prehistoric Aboriginal populations from known geographic localities. For example, a sample from the Adelaide region may improve differentiation between inhabitants of the Adelaide Plains vs. the nearby lower Murray River region in the vicinity of Swanport and Murray Bridge. Sample sizes for the Murray Mouth and Coorong regions should also be increased to improve differentiation between these two areas.

Stable carbon and nitrogen isotopic analysis provides an independent means to address geographic origin of skeletal remains that can supplement other methods, e.g. metric, non-metric, and DNA analysis (Kirk and Thorne 1976; Brown 1989; Pardoe 1995; Adcock et al. 2001). Greater precision in relation to skeletal assignment to geographic locality via isotopic analysis will be achieved by 1) employing both bone and tooth samples and 2) using a combination of a number of different isotopes (cf. Budd et al. 2002; Müller et al. 2002).

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Appendix 1

SAMPLE No.	LOCATION	C/N	d 15N	d 13C
DP 405	Coorong	2.6	11.2	-9.6
DP 400	Coorong	2.7	12.1	-9.8
DP 460	Coorong	2.6	13.5	-9.8
DP407	Coorong	2.6	13.8	-10.1
DP 404	Coorong	2.6	13.8	-10.6
DP 410	Coorong	2.6	13.9	-10.6
DP478	Coorong	2.7	15	-10.6
DP399	Coorong	2.7	22.2	-10.9
DP402	Coorong	2.6	19.9	-10.9
DP409	Coorong	2.7	13.8	-11
DP484	Coorong	2.7	13.9	-11.1
DP403	Coorong	2.6	19.5	-11.4
DP442	Coorong	2.6	17	-11.7
DP450	Coorong	2.6	13.9	-12.2
DP490	Coorong	2.8	16.7	-12.3
DP395	Coorong	2.6	14.5	-12.7
DP396	Coorong	2.6	15.3	-12.7
DP456	Coorong	2.7	11.3	-12.7
DP408	Coorong	2.6	12.9	-12.8
DP411	Coorong	2.6	13.1	-12.8
DP445	Coorong	2.8	15.4	-13
DP479	Coorong	2.6	12.8	-13
DP480	Coorong	2.6	14.5	-13.1
DP401	Coorong	2.6	12.6	-13.2
DP406	Coorong-L. Alexandrina	2.7	13.5	-13.4
DP397	Coorong-L. Alexandrina	2.6	13.6	-13.6
DP434	Coorong-L. Alexandrina	2.6	12.8	-13.8
DP474	Lake Alexandrina	2.6	12.4	-13.6
DP459	Lake Alexandrina	2.6	14.8	-14.2
DP412	Lake Alexandrina	2.7	12.4	-14.4
DP426	Lake Alexandrina	2.7	12	-14.5
DP419	Lake Alexandrina	2.8	13.1	-14.8
DP462	Lake Alexandrina	2.6	14.5	-14.8
DP394	Lake Alexandrina	2.7	12.6	-14.9
DP420	Lake Alexandrina	2.6	15	-15
DP454	Lake Alexandrina	2.9	11.2	-15.5
DP468	Lake Alexandrina	3.6	10.8	-15.8
DP458	Lake Alexandrina	2.7	11.4	-16
DP461	Lake Alexandrina	2.7	12.5	-16.2
DP413	Lake Alexandrina	3.4	14	-16.6
DP418	Lake Alexandrina	2.7	17.2	-16.6
DP464	Lake Alexandrina	2.6	11.5	-16.7
DP465	Lake Alexandrina	2.6	11.4	-16.8
DP451	Lake Alexandrina	2.6	10.1	-17.4

Appendix 1 cont.

DP415	Lake Alexandrina	2.8	11.2	-17.5
DP433	Lake Alexandrina	2.6	9.5	-17.5
DP448	Lake Alexandrina	2.7	12.5	-17.5
DP472	Lake Alexandrina	2.7	12.3	-17.9
DP439	Lake Alexandrina	2.7	10.2	-18
DP444	Lake Alexandrina	2.6	9.7	-18
DP443	Lake Alexandrina	2.7	9.7	-18.1
DP496	Lake Alexandrina	2.7	9.6	-18.1
DP438	Lake Alexandrina	2.7	10.3	-18.2
DP482	Lake Alexandrina	2.6	10.8	-18.3
DP 498	Swanport (Lower Murray)	2.6	7.6	-18.2
DP423	Swanport (Lower Murray)	2.7	10	-18.4
DP435	Swanport (Lower Murray)	2.7	9.2	-18.5
DP489	Swanport (Lower Murray)	2.7	7.6	-18.6
DP392	Swanport (Lower Murray)	2.7	10.4	-18.9
DP436	Swanport (Lower Murray)	2.7	9	-18.9
DP440	Swanport (Lower Murray)	2.7	9.6	-19
DP457	Swanport (Lower Murray)	2.6	10.4	-19
DP486	Swanport (Lower Murray)	2.9	9.7	-19.1
DP447	Swanport (Lower Murray)	2.7	10.2	-19.2
DP453	Swanport (Lower Murray)	2.8	8.2	-19.2
DP470	Swanport (Lower Murray)	2.6	7.6	-19.3
DP430	Swanport (Lower Murray)	2.6	9.4	-19.4
DP563	Swanport (Lower Murray)	2.7	9.4	-19.5
DP452	Swanport (Lower Murray)	2.9	8	-19.6
DP428	Swanport (Lower Murray)	2.6	9.7	-19.7
DP432	Swanport (Lower Murray)	2.6	10.1	-19.7
DP437	Swanport (Lower Murray)	2.7	8.5	-19.9
DP429	Swanport (Lower Murray)	2.6	8.3	-20.1
DP422	Swanport (Lower Murray)	2.6	6.9	-20.2
DP492	Swanport (Lower Murray)	2.7	10.2	-20.2
DP449	Swanport (Lower Murray)	2.7	8.9	-20.3
DP427	Swanport (Lower Murray)	2.7	10	-20.4
DP431	Swanport (Lower Murray)	2.6	8.4	-20.7
DP399	Swanport (Lower Murray)	2.7	8.4	-21.2
DP561	Swanport (Lower Murray)	2.6	9.3	-22.2
DP477	Lower-Upper Murray	2.6	11.5	-18.8
DP416	Lower-Upper Murray	2.7	12	-18.8
DP424	Lower-Upper Murray	2.6	11.1	-18.9
DP463	Lower-Upper Murray	2.8	12	-18.9
DP476	Lower-Upper Murray	2.6	11.8	-19
DP485	Lower-Upper Murray	2.8	11.2	-19.1
DP471	Lower-Upper Murray	2.7	11.9	-19.1
DP425	Lower-Upper Murray	2.8	11.4	-19.2
DP466	Lower-Upper Murray	3.2	11.8	-19.4

DP441	Anomalous Coorong, Low Trophic Level Seafood	2.9	8.8	-10.1
DP481	Anomalous Murray Mouth, Low Trophic Level Food	2.6	4.2	-15.2

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