Feeding environments of New Zealand's extinct merganser revealed by stable isotope analyses

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Abstract

The likely feeding environments of individuals from each of the three populations of New Zealand's extinct merganser *Mergus australis* were interpreted from stable isotope ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in fossil bones and tissue from preserved skins. Analyses of feather and claws from 10 specimens from Auckland Islands indicated the birds fed predominantly on marine prey but that some freshwater-sourced foods may also have been consumed. Stable isotope values from three bones of mergansers from Chatham Island strongly suggest a marine feeding habit while those from two mainland New Zealand bones indicated the birds fed mostly in fresh water. Merganser bones found at a New Zealand lake (Poukawa) suggest this species occupied mainland New Zealand's fresh waters at the time of first human settlement.

Key words: feeding, feeding environment, *Mergus australis*, New Zealand Merganser, stable isotope analysis.

The now-extinct New Zealand Merganser *Mergus australis* once occurred on New Zealand's three main islands (North, South, and Stewart Islands) and on two distant archipelagos, Chatham Islands *c.* 800 km to New Zealand's east and Auckland Islands *c.* 450km to its south (Holdaway *et al.* 2001; Worthy & Holdaway 2002). Early Polynesian settlers extirpated the New Zealand and Chatham Island populations and the last sighting from the Auckland Islands was in 1902 (Kear & Scarlett 1970; Williams 2012). Today this enigmatic waterfowl is represented by just 27 skins from Auckland Islands and small numbers of bones of the other two populations derived from Polynesian's middens and natural deposits.

Deposits containing bones from New Zealand's merganser population are few and, with but one exception, have all been at coastal locations (Kear & Scarlett 1970; Worthy & Holdaway 2002). This

distribution prompted Worthy (2004) to regard four merganser bones retrieved from an extensive natural deposit at North Island's Lake Poukawa as being from "vagrants" rather than being indicative of the merganser's possible wider distribution. Collection localities specified for Auckland Islands' specimens generally refer to the heads of sheltered bays or inlets, locations at which the island's short and steep watercourses debouch (Kear & Scarlett 1970; Williams 2012). On Chatham Island, merganser bones have been retrieved from coastal dune deposits and, most abundantly, from a cave alongside the island's extensive saltwater Te Whanga Lagoon (Millener 1999; Worthy & Holdaway 2002).

Mergansers (Family Anatidae, Tribe Mergini) are specialist fish-eating waterfowl. Five of the six extant species have Holarctic distributions and primarily or exclusively inhabit lakes and rivers whereas the sixth, the now very rare Brazilian Merganser *Mergus octosetaceus*, once occurred more widely on Brazilian and Argentine rivers (Callaghan 2005). The coastal and marine habitat ascribed to mergansers of the New Zealand region (Worthy & Holdaway 2002; Worthy 2004) contrasts with that of other mergansers notwithstanding the Red-breasted Merganser's *Mergus serrator* use of sheltered coastal bays, coves and estuaries (Cramp & Simmons 1977).

In this study we sought to identify the primary feeding environments of individuals from all three New Zealand Merganser populations. We have attempted this by interpreting carbon and nitrogen stable isotopes values obtained from New Zealand and Chatham Island fossil bones and from feathers and claws from 10 Auckland Island specimen skins. Stable isotope ratios of carbon ($^{13}C/^{12}C$) are used to indicate the primary feeding environment (marine or fresh water) (Bearhop *et al.* 1999; Fry 2006) and of nitrogen ($^{15}N/^{14}N$) to indicate comparative trophic levels at which birds within each population fed. The results are compared with carbon and nitrogen isotope values obtained from feather and bones of other merganser species.

Methods

Specimens and tissue analysed

We were permitted to sample undertail covert feathers, entire hind claws and a rib bone from 10 museum skins of Auckland Island's mergansers and bone from New Zealand and Chatham Island-sourced mergansers (Appendix 1). From one Auckland Island specimen (NHM 1904.8.4.1; 1904.8.4.2) we obtained feather, claw and bone and from four others, feather and claw (Appendix 1) which allowed us to present isotope ratios from different tissues of an individual. Two specimens providing feather and claw samples (NHM 1904.8.4.1; samples 9, 10 and NHM 1901.10.21.58; samples 13, 14, Appendix 1) were initially preserved in formalin (Ogilvie-Grant 1905). Two feather (7, 25) and one claw (8) samples came from young birds in juvenile plumage whereas all others samples were from adult birds (see Appendix 1 in Williams 2012).

The two fossil New Zealand-sourced limb bones were from Polynesian middens on Old Neck, Stewart Island and at Marfells Beach, Lake Grassmere, South Island

(Worthy 1998a,b). The three Chatham Island bones were fragments of sterna retrieved from the natural deposit in Te Ana a Moe cave near Te Whanga Lagoon (Millener 1999; Appendix 1).

Feather and bone samples from other merganser species were obtained from specimens in the collections of the Natural History Museum, Tring, UK (Appendix 2) and mean isotope values from feathers of living Scaly-sided Merganser *Mergus squamatus* were provided by Diana Solovieva and Tony Fox (pers. comm.).

Analytical techniques

Feather and claw samples were prepared at the Stable Isotope Laboratory, GNS Science, New Zealand. They were cleaned in 2:1 chloroform/methanol v/v and air dried for 48 h to remove surface oils (Wassenaar & Hobson 2006) and any residual museum conservation treatments, and then finely ground. The five fossil bones (samples 27–31; Appendix 1) were prepared and analysed by IsoTrace New Zealand Ltd (Dunedin, New Zealand) and the remainder by the Stable Isotope Laboratory, GNS Science, New Zealand. Extraction of bone collagen at both laboratories followed the procedure described by Holdaway & Beavan (1999). The cleaned bones were ground and demineralised in 1N HCl for 24 h to remove carbonates and all organic traces, then neutralised and rinsed with deionised water. The collagen extract was gelatinised, ultra-filtered and freeze-dried. Ground feather and claw subsamples (1.5 ± 0.1 mg near their tip) and dried bone powders (1.5 mg) were weighed into tin capsules for isotopic analysis.

The samples were combusted in an ANCA SL elemental analyser (Europa Scientific, Crewe, UK) and measured in a GEO 20–20 isotope ratio mass spectrometer (Europa Scientific, Crewe, UK). Results are reported as %C and %N by dry mass and as $\delta^{13}C$ or $\delta^{15}N$ (‰) = $(R_{SAMPLE}/R_{STANDARD} - 1)*1{,}000$ with R = $^{13}C/^{12}C$ or $^{15}N/^{14}N$ relative to VPDB (Vienna PeeDee Belemnite) and N_2 gas in air standards (Rogers 2003; Sharp 2007).

Results

New Zealand Merganser

Auckland Islands

Carbon ($\delta^{13}C$) isotope values of feathers extended from –10.6‰ to –18.0‰ (n = 10), claw values from –11.6‰ to –19.8‰ (n = 5) and the single bone value was –11.6‰ (Appendix 1, Fig. 1).

The $\delta^{13}C$ values for two of the five claws sampled (Appendix 1, Fig 1) were *c.* 2‰ more negative than corresponding feather values from the same specimens (samples 9–10, 13–14), there was little difference for another two (samples 2–3, 5–6) whereas the difference for the fifth, a newly-fledged bird, was *c.* 5‰ (samples 7–8). From the single specimen providing bone (11), feather (10) and claw (9) samples, the $\delta^{13}C$ values of feather and bone were similar (Fig. 1).

The $\delta^{13}C$ values from all tissues combined were not distributed evenly throughout their range (–10.6‰ to –19.8‰) but appear distributed as two groupings (Fig. 1): –10.6‰ to –15.2‰ and from –16.5‰ to –19.8‰. Notwithstanding that different fractionation rates will apply

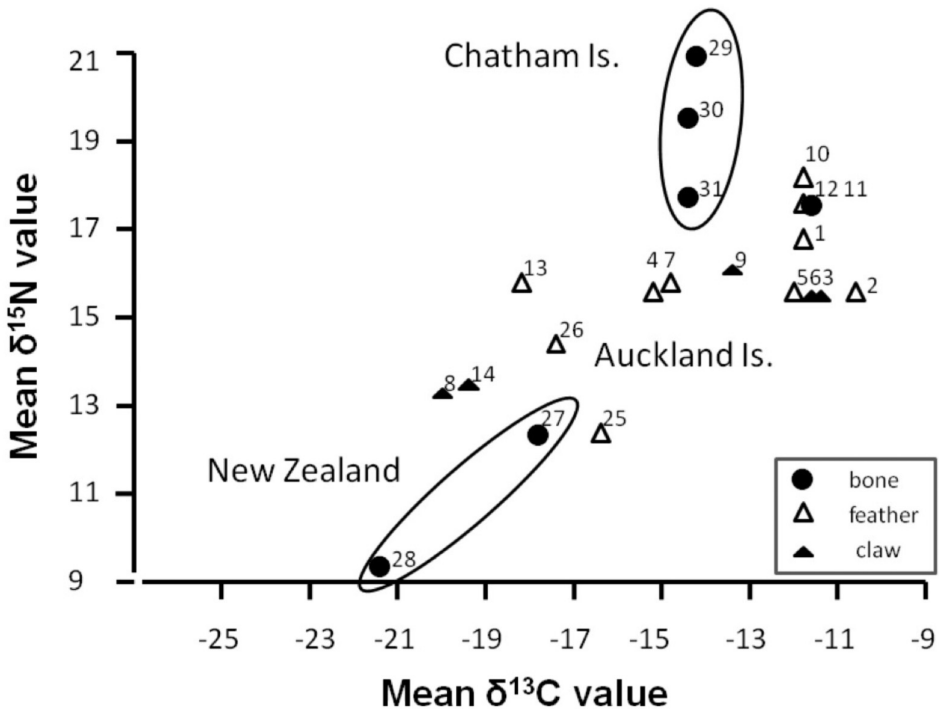

Figure 1. Distribution of $\delta^{15}N$ and $\delta^{15}C$ isotope values of *Mergus australis* bone, feather and claw samples sourced from Auckland Islands, Chatham Island (encircled) and New Zealand (encircled). Sample numbers are those indicated in Appendix 1.

between prey and the tissues sampled, and the large difference between feather and claw values from one specimen (1904.559.1; samples 7, 8), this distribution is suggestive of two different feeding strategies among these individuals.

Most (12 of 16) nitrogen ($\delta^{15}N$) isotope values were within the range 15‰–18‰. The four samples providing lowest $\delta^{15}N$ values were also those with the lowest $\delta^{13}C$ values. The $\delta^{15}N$ values from three of the five claws sampled (Appendix 1, Fig 1) were *c.* 2‰ lower than corresponding feather values from the same specimens (samples 7–8, 9–10, 13–14) but there was little difference for the other two (samples 2–3, 5–6). From the single specimen providing bone (11), feather (10) and claw (9) samples, the $\delta^{15}N$ values of feather and bone were similar (Fig. 1) but almost 2‰ higher than for its claw. These results suggest all mergansers were feeding on similar prey.

New Zealand

Bones from the two New Zealand specimens (samples 27, 28; Fig. 1), both derived from middens, had considerably lower $\delta^{15}N$ and $\delta^{13}C$ values than the Auckland Island and Chatham Island birds.

Chatham Islands

Three Chatham Island merganser bones (samples 29, 30, 31; Fig. 1), all sampled from the same natural site, had similar $\delta^{13}C$ values and these were similar to some of the Auckland Island-sourced specimens. As a group their $\delta^{15}N$ values were higher than those obtained from all other *M. australis* specimens.

Other mergansers

Feathers from two Brazilian Mergansers (samples 15, 16; Appendix 2) had $\delta^{13}C$ values that were 1–3‰ lower than any of the Auckland Island specimens. However, they were in turn 1–2‰ higher than the Smew *Mergellus albellus* feather (sample 19), and considerably higher than the range recorded for Scaly-sided Merganser (Appendix 2). The single feather (sample 17) of Goosander *Mergus merganser* had similar isotopic values to those of two Auckland Island birds (samples 25, 26). The Red-breasted Merganser feather (sample 21; Appendix 2) had higher $\delta^{15}N$ and $\delta^{13}C$ values than any of the other merganser samples, perhaps emphasising this species' considerable use of marine environments (Cramp & Simmons 1977).

Discussion

Observations of merganser food and feeding at Auckland Islands

There are two records of merganser foods at Auckland Islands. A specimen shot in 1901 (NHM 1901.21.57) at McLennan Inlet had a 90 mm ("3.5 in") Koaro *Galaxias brevipinnis*, a fresh water fish, in its bill (Hutton 1901). Kear and Scarlett (1970) reported the gut contents of a preserved partial cadaver (NHM A/1999.1.124) whose collection details are unknown comprised "macerated fish bones, mandibles of an errant polychaete and an unidentified gastropod". They added that "the presence of the polychaete tends to suggest a brackish water environment".

There are no recorded observations of mergansers feeding at the Auckland Islands and few from which their habitat can be discerned with certainty. Reischek (1889) refers to a group of six mergansers (probably adults and fledglings) among rocks on the shoreline of Waterfall Inlet. Waite (1909) quotes Captain J. Bollons (master of the government ships regularly visiting the subantarctic islands) as not having seen the bird on the coasts, but having found them at the heads of estuaries and especially on the island's watercourses "picking about in the creeks". Falla (1970) reports R.A Wilson, the collector of two specimens in 1891 (sample 26 is from one), as having "encountered his quarry up the stream bed some distance from the coast and in a deep pool where the stream was partly dammed on a rocky terrace."

Despite streams on Auckland and Adams Islands being short and mostly very steep, *G. brevipinnis* is common along their lengths and especially so where the stream gradients ease prior to reaching the sea (M. Williams pers. obs.). Human access up streams from the coastline is extremely difficult so it is not surprising that mergansers were seen only on the sea at the heads of bays and inlets (see Williams 2012).

Interpreting isotope values

Influence of formalin preservation and midden effects

All *M. australis* specimens sampled from Natural History Museum (NHM), Tring (samples 9–14, Appendix 1) had been transported to England in formalin (Ogilvie-Grant 1905) and possibly the Dublin Museum specimen also (samples 7, 8; see Williams 2012). Formalin lowers $\delta^{13}C$ values by up to 2‰ but has little effect on $\delta^{15}N$ (Barrow *et al.* 2008 and references therein). From three specimens we obtained both feather and claw samples (7–8, 9–10, 13–14; Appendix 1, Fig 1); claw $\delta^{15}N$ and $\delta^{13}C$ values were *c.* 2‰ lower than feather values from all which suggests a possible differential effect even though both tissues are keratin. There was little difference between feather and claw measurements from the other two specimens (2–3, 5–6) which are thought to have been transported as dry skins (Kear & Scarlett 1970). In our interpretation of merganser feeding environments at Auckland Island we assume a formalin effect of lowering $\delta^{13}C$ values by *c.* 2‰.

The two New Zealand fossil bones (samples 27, 28; Appendix 1) were from middens (Worthy 1998a,b). Temperatures at which Polynesians cooked birds in ground ovens appear not have been high enough to have altered the carbon and nitrogen isotopic ratios in the bone collagen (see de Niro *et al.* 1985) and biomolecules have been extracted from some midden eggshell fragments (*e.g.* Oskam *et al.* 2011).

Isotope turnover and fractionation

The tissues analysed accumulate and retain dietary carbon and nitrogen over different time periods. Feathers capture dietary carbon and nitrogen during their short period (2–4 weeks) of growth. Claws, however, grow continuously; Bearhop *et al.* (2003) found that claws have similar isotope values to feathers and in some passerines the whole claw contained a record of the bird's diet over the *c.* 3–5 months of its growth. The growth rate of merganser claws is unknown. Bone collagen retains a dietary isotope record for considerably longer, with perhaps a dietary carbon turnover of 50% after about 6 months (Hobson & Clark 1992).

Conversion of prey tissue to body tissue is accompanied by change in isotope ratios. In general there is a stepwise increase of approximately 4‰ in $\delta^{15}N$ and ≈1‰ for $\delta^{13}C$ (*e.g.* de Niro & Epstein 1978; McCutchan *et al.* 2003). However Bearhop *et al.* 1999 identified a consistent $\delta^{13}C$ fractionation from fish prey to Cormorant *Phalacrocorax carbo* and Goosander feather of 2.3‰, Mitzutani *et al.* (1992) recorded an average $\delta^{13}C$ fractionation from prey to feather for fish-eating birds of 3.3‰ in an experimental study, and Becker *et al.* (2007) reported fractionation of $\delta^{13}C$ was 2.5‰ ± 0.2‰ from delipidated fish muscle to breast feather of the marine-feeding Common Murres *Uria aalge*. Furthermore, Mitzutani *et al.* (1991) demonstrated considerable variation in $\delta^{13}C$ fractionation from fish prey to different Cormorant tissues and Hobson & Clark (1992) reported a diet to bone collagen $\delta^{13}C$ fractionation of 2.6 ± 1.1‰ for gulls fed solely on fish.

To assist our interpretations of merganser feeding environments we assume a $\delta^{13}C$ fractionation of 2.5‰ from prey to each of the merganser tissues sampled.

Carbon isotope values indicative of marine and fresh water feeding

No isotope measurements of likely marine and fresh water prey of *M. australis* at Auckland and Chatham Islands are known to us. From the literature (*e.g.* Bearhop *et al.* 1999 and references therein; Bushula *et al.* 2005; Crow *et al.* 2010) we derived an approximate $\delta^{13}C$ isotope value for merganser tissue which, taking into account the fractionation estimate above, could indicate mixed marine–fresh water feeding (–17‰) and predominantly fresh water feeding (–21‰).

Feeding environment of Auckland Islands' mergansers

Mergansers at the Auckland Islands undoubtedly fed in fresh water; Bollons and Wilson (*loc. cit.*) saw them there, Wilson shot one there (sample 26; Williams 2012) and Hutton (1901) prised an exclusively freshwater fish from a cadaver's bill. However, the $\delta^{13}C$ isotope values, most of which exceed –16‰, do not indicate fresh water having been a significant feeding habitat. The range of $\delta^{13}C$ values lies within the range of values recorded for many marine birds, including piscivorous (*e.g.* Bearhop *et al.* 1999; Hobson *et al.* 1994) and squid-eating species (*e.g.* Phillips *et al.* 2009).

Sample 26 (Appendix 1), a feather of the bird collected "up the stream bed some distance from the coast and in a deep pool where the stream was partly dammed on a rocky terrace" (Falla 1970) had a $\delta^{13}C$ value of –17.5‰. Allowing 2.5‰ fractionation from prey to predator suggests that, during feather growth, the merganser consumed prey with an average $\delta^{13}C$ value of *c.* –20‰. This is consistent with feeding in both fresh water and marine environments (see Fig. 3 in Bearhop *et al.* 1999). There are three other samples (8, 13, 14) which returned similar $\delta^{13}C$ values; these samples were obtained from two specimens initially preserved in formalin. If applying a +2‰ correction to their $\delta^{13}C$ values (Barrow *et al.* 2008) is appropriate, then they too indicate mixed fresh water and marine feeding.

The $\delta^{15}N$ values from feathers of all but one of the mergansers lie within a narrow 4‰ range, indicative of the mergansers feeding on similar prey at the time of feather growth. The most likely nearshore marine prey for mergansers would have been the abundant small omnivorous and predatory Nototheniidae fishes (Williams 1988; Paulin & Roberts 1992), while fresh water streams contained *Galaxias brevipinnis,* an invertebrate predator.

Feeding environments of New Zealand's and Chatham Islands' mergansers

The isotope values of sample 28 (Appendix 1, Fig. 1), from a midden on Stewart Island, suggests that this merganser fed primarily in fresh water. The midden is at the mouth of Paterson Inlet, a large sheltered coastal inlet into which two major rivers (Rakeahua, Freshwater), and many smaller streams, flow. These waterways drain extensive, low relief, peat-filled basins and although their waters are typically stained brown by tannins they support an abundant fish fauna, including diadromous and non-diadromous *Galaxias* species (McDowall & Chadderton 1999). The $\delta^{15}N$ value of sample 28 (9.0‰) is low relative to that for other *M. australis*

samples but consistent with a diet of non-diadromous *Galaxias* sp. with isotope values similar to those of *G. gollumoides* from streams in nearby Southland streams ($\delta^{15}N$ = 5.15 to 6.59‰; $\delta^{13}C$ = –21.63 to –26.76‰; Crow *et al.* 2010).

We interpret the $\delta^{13}C$ isotope from sample 27 (Appendix 1, Fig. 1) as indicative of a diet of mixed fresh water and salt water prey. This bone is from a midden at Marfells Beach, a natural gravel and sand bar separating Lake Grassmere from the sea: natural fossil deposits in the dunes also contain many merganser bones (Worthy 1998a). The compositions of those deposits clearly indicate a rich freshwater avifauna at Lake Grassmere after it was separated from the sea *c.* 1800 years ago (Ota *et al.* 1995, Worthy 1998a). As with other barrier-bar lakes such as Ellesmere and Wainono (eastern South Island) and Onoke (southern North Island) Grassmere would have been connected to the sea periodically, its water then becoming increasingly saline and allowing a variety of estuarine fish (*e.g.* Flounder *Rhombosolea plebeia*, Mullet *Aldrichetta forsteri)* as well as diadromous galaxiids to enter and thrive. We consider this bone was from a bird that fed predominantly in Lake Grassmere, not in the adjacent marine environment.

Chatham Island mergansers had access to a distinctive feeding environment, a large saltwater lagoon. The high $\delta^{15}N$ values of the three Chatham Island samples probably reflects a prey fauna consisting largely of piscivorous fishes with $\delta^{15}N$ enrichments similar to or higher than those reported in other seabird trophic studies (Hobson *et al.* 1994; Thompson & Furness 1995; Bearhop 1999). That the Chatham Islands' mergansers were primarily marine is emphasised by the presence of conspicuous salt gland impressions on the skulls of all 44 merganser crania examined at the Museum of New Zealand (see Fig. 7.2 in Worthy & Holdaway 2002). Impressions of salt glands are barely discernible on three crania of mergansers from Auckland Island examined at the Natural History Museum, Tring, UK. (M. Williams unpubl. data).

Comparing *Mergus australis* with other mergansers

The $\delta^{15}N$ and $\delta^{13}C$ values of tissues of mergansers from the Auckland Islands were higher than those of samples from almost all other merganser species. Isotope values of Auckland Islands' mergansers indicate they fed in the marine environment more than other mergansers, except Red-breasted Merganser. More negative $\delta^{13}C$ values for Goosander (Bearhop *et al.* 1999; Morrissey *et al.* 2004) confirm their strong freshwater isotopic signatures. The $\delta^{13}C$ values for the two mergansers from mainland New Zealand, however, are close to or within the range reported from other freshwater mergansers (Appendix 2).

Could New Zealand's merganser have been more widespread than existing bone deposits suggest?

With the exception of the Red-breasted Merganser, all extant mergansers occupy primarily or exclusively freshwater habitats. Brazilian Mergansers are year-round inhabitants, and Scaly-sided Mergansers seasonal inhabitants, of mountain foothill rivers whose physical characteristics are

similar to those of many New Zealand rivers. Could New Zealand's mergansers also have lived in rivers or lakes beyond the coastal fringe?

The isotopic measurements and historic observations suggest that fresh waters were part of, but not the exclusive, feeding environment of mergansers at Auckland Islands, which is unsurprising given the short and steep nature of the islands' watercourses. The Chatham Island birds had isotope values indicating a marine-sourced diet which, too, is unsurprising given the presence of the extensive Te Whaanga Lagoon and the lack of anything other than small slow-flowing streams and peat lakes on the island. However, the isotope values from both New Zealand bones are suggestive of fresh water feeding. The view that New Zealand's merganser was a "coastal species" (Worthy & Holdaway 2002; Worthy 2004) is not disproved, especially if by "coastal" was meant estuaries and coastal dune lakes. However, the Stewart Island bone (sample 28) indicates that some New Zealand mergansers may have fed mostly in fresh waters, and if that was possible on Stewart Island then it could also have been so on North and South Islands where, historically, their numerous rivers and lakes contained an abundant small fish fauna (McDowall 2010).

Lacustrine avian bone deposits in New Zealand are rare (Worthy 2004) so the presence of a *Mergus* bone at two of the three sites excavated is significant. Although the Marfells Beach site is "coastal" it is also on the shore of an extensive lake (Grassmere; Worthy 1998a) while the other, at Lake Poukawa in Hawkes Bay (Worthy 2004), is 25 km inland. Isotopic examination of a Lake Poukawa bone would advance ecological understanding of the New Zealand population, especially if assessed in relation to isotope measurements of other species from the deposit which would have consumed similar prey from the lake's water column (*e.g.* New Zealand Scaup *Aythya novaeseelandiae*, New Zealand Dabchick *Poliocephalus rufopectus,* Great Crested Grebe *Podiceps cristatus,* and shags *Phalacrocorax* sp.). The other major lacustrine site, Pyramid Valley in North Canterbury, is 30 km inland and although it contained the remains of most endemic waterfowl and wetland birds (Holdaway & Worthy 1997) it lacked mergansers and other piscivorous birds.

The general lack of piscivorous birds in New Zealand rivers – perhaps only Black Shag *Phalacrocorax carbo* represents this guild in the present avifauna – suggests that the merganser could have had little direct competition, whereas the estuaries and coasts of New Zealand, as well as at the Auckland and Chatham Islands, would have been occupied, as they still are, by a range of individual and group-feeding species of shags (Family Phalacrocoracidae). Taken together, the evidence that some Auckland Island's mergansers fed in fresh water, that a Stewart Island bird fed mostly or exclusively in fresh water, that the $\delta^{13}C$ value of the Marfells Beach specimen suggests it fed in a brackish lake, that mergansers were present on Lake Poukawa, and that all other merganser species inhabit rivers and lakes, suggests New Zealand's merganser was a hitherto unrecognised occupant of its fresh waters at the time of first human settlement.

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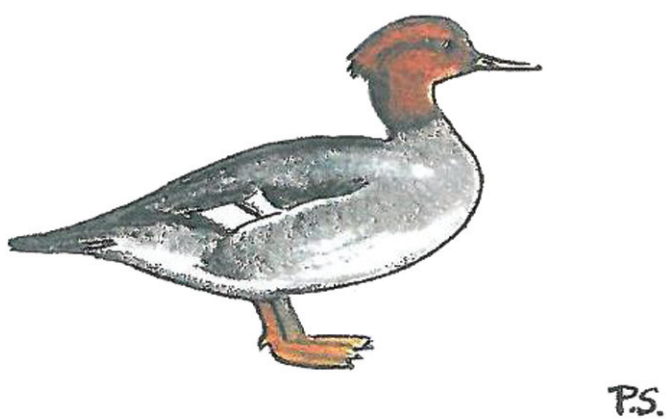

Drawing: Auckland Islands Merganser by Peter Scott.

Appendix 1. New Zealand Merganser specimens and tissues sampled, and their mean (± s.d.) $\delta^{15}N$ and $\delta^{15}C$ isotope values. Bones from Museum of New Zealand (MONZ) are from Chatham Island cave deposits, both bones from Canterbury Museum are from South Island, New Zealand Polynesian midden deposits, all other specimens are from Auckland Island. All feathers were undertail coverts and all claws were entire hind claws.

Museum*	Collection no.	Tissue sampled	Sample no.	$\delta^{15}N \pm$ s.d.	$\delta^{13}C \pm$ s.d.
Dresden	3092	Feather	1	16.5 ± 0.08	–11.8 ± 0.03
	3022	Feather	2	15.7 ± 0.04	–10.6 ± 0.20
	3022	Claw	3	15.6 ± 0.01	–11.8 ± 0.27
Vienna	50760	Feather	4	15.5 ± 0.06	–15.2 ± 0.34
Cambridge	12/Ana/38/a/1	Feather	5	15.6 ± 0.08	–11.9 ± 0.08
	12/Ana/38/a/1	Claw	6	15.8 ± 0.20	–11.6 ± 0.08
Dublin	1904.559.1	Feather	7	15.8 ± 0.09	–14.9 ± 0.12
	1904.559.1	Claw	8	13.2 ± 0.11	–19.8 ± 0.06
NHM	1904.8.4.1	Claw	9	16.0 ± 0.74	–13.4 ± 0.38
	1904.8.4.1	Feather	10	18.0 ± 0.04	–11.9 ± 0.01
	1904.8.4.2	Bone (rib)	11	17.7	–11.6
	1902.8.6.1	Feather	12	17.7 ± 0.00	–11.8 ± 0.00
	1901.10.21.58	Feather	13	15.5 ± 0.05	–18.0 ± 0.10
	1901.10.21.58	Claw	14	13.6 ± 0.02	–19.4 ± 0.04
Canterbury	AV1580	Feather	25	12.1	–16.5
	AV1583	Feather	26	14.1	–17.5
	AV37111	Bone (humerus)	27	12.0	–18.0
	AV13512B	Bone (tibiotarsus)	28	9.0	–21.5
MONZ	S/30036/1	Bone (sternum)	29	21.1	–13.8
	S/30046/2	Bone (sternum)	30	19.4	–14.2
	S/30046/3	Bone (sternum)	31	17.3	–14.4

*Museums are: Dresden = Staatliches Museum fur Tierkunde, Dresden, Germany; Vienna = Naturhistorisches Museum, Vienna, Austria; Cambridge = Zoology Museum, Cambridge University, Cambridge, England; Dublin = National Museum of Ireland, Natural History, Dublin, Ireland; NHM = Natural History Museum, Tring, UK; Canterbury = Canterbury Museum, Christchurch, New Zealand; MONZ = National Museum of New Zealand, Wellington, New Zealand.

Appendix 2. Mean (± s.d.) $\delta^{15}N$ and $\delta^{15}C$ isotope values of merganser species and tissues sampled. All tissues were obtained from Natural History Museum, Tring, UK; the Smew, Red-breasted Merganser and Goosander specimens were collected in United Kingdom and Brazilian Merganser from Argentina (15) and Brazil (16). The Scaly-sided Merganser data are from the South Primorye region of eastern Russia (D. Solovieva, unpubl. data and A.D. Fox, unpubl. data).

Species	Collection no.	Tissue sampled	Sample no.	$\delta^{15}N \pm$ s.d.	$\delta^{13}C \pm$ s.d.
Brazilian Merganser	1892.2.1.22	Feather	15	14.8 ± 0.04	–20.4 ± 0.02
	1966.24.2	Feather	16	13.9 ± 0.03	–18.5 ± 0.01
Goosander	1934.1.1.1752	Feather	17	13.4 ± 0.01	–15.8 ± 0.32
	1919.12.10.319	Bone	18	14.8 ± 0.06	–20.1 ± 0.21
Smew	1941.5.30.9241	Feather	19	13.8 ± 0.69	–21.7 ± 0.31
	S/1986.32.1	Bone	20	12.4 ± 0.10	–24.7 ± 0.24
Red-breasted Merganser	1955.3.40	Feather	21	16.8 ± 0.03	–13.3 ± 0.19
	S/1997.78.1	Bone	22	9.9 ± 0.04	–9.6 ± 0.27
Scaly-sided Merganser	D. Solovieva, unpubl. data and A.D. Fox, unpubl. data.	Feather (n = 18)		12.1 ± 1.00	–23.5 ± 1.60