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– ARTICLE –

An Exploratory and Integrative Study of Māori Kurī (*Canis familiaris*) at the NRD Archaeological Site in Aotearoa New Zealand

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ABSTRACT

This multidisciplinary study analyzes kurī skeletal remains from the Northern Runway Development (NRD) archaeological site (AD 1400–1800) to develop an 'osteo-history' and help us better understand 1) human-dog interactions; 2) the role kurī played in early Māori societies; and 3) to potentially use kurī as a proxy for human behavior at the site. We combine dental analysis with stable isotope analyses of bone and tooth dentine to investigate the kurī diet. Additionally, we use strontium isotope and mitogenomic analyses to explore the migration histories of the kurī and, by proxy, the humans they lived among at the NRD site during the late pre-contact period in Aotearoa. Through our exploratory investigation of the kurī skeletal remains, we found evidence of extensive interaction spheres with nearby and potentially distant communities. Furthermore, the kurī were healthy, demonstrated minimal tooth wear, and they subsisted heavily on a protein-rich, marine diet. This study demonstrates that variability is present in the origins, diet, health, and treatment of kurī at a single locality.

INTRODUCTION

Dogs (*Canis familiaris*) are the earliest known domesticated animal, appearing in the archeological record 15,000 years ago or more (Ovodov *et al.* 2012; Perri 2016). In Asia, archeological evidence shows that dogs have lived among humans since at least 8,000 BCE (Newsome *et al.* 2001; Chowning 1991; Greig *et al.* 2015). Dogs were introduced to island groups throughout Island Southeast Asia and the Pacific Ocean, including the remote islands of Eastern Polynesia, although processes of dispersal are complex and not well resolved (Cramb 2021; Greig *et al.* 2018). Dogs had various social and economic uses. Historical records from Polynesia show they were exchanged as ceremonial gifts, eaten as everyday food items, and sometimes associated with higher status individuals (Luomala 1960). In New Zealand (Aotearoa), dogs (kurī in Māori) have been recovered at many pre-European sites. Kurī appear in many forms of material culture: their skins and hair were used to make chiefly cloaks (kahu kurī); their bones and teeth were used to make fishhooks, awls, pendants, and necklaces (Davidson 1984); they were used as watch dogs, hunting dogs, kept as pets; as a meat source; and consumed on ceremonial occasions (Greig & Walter 2021). Kurī also feature in rock art and oral traditions throughout Aotearoa (Anderson 1981; Ihimaera 2020).

The objective of this study is a multidisciplinary analysis of kurī skeletal remains from a late period pre-

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European Māori site (the NRD site) to develop an 'osteohistory' to help us better understand human-dog interactions, the role kurī played in early Māori societies and the potential of kurī as a proxy for aspects of human behavior. Furthermore, we explore the differences between kurī buried formally and those recovered from midden contexts. We combine macroscopic analysis of tooth wear, tooth fractures, oral health, and stable isotope analysis of bone and tooth dentine to investigate kurī diet. Additionally, we use strontium isotope and mitochondrial genomic (aDNA) analyses to explore the migration histories of kurī and, by proxy, the humans they lived among at the NRD site during the late pre-contact period (Table 1).

In this exploratory study, the kurī results are interpreted within two theoretical frameworks: the 'osteobiography approach' (Losey *et al.* 2011) and the 'canine surrogacy approach' (Guiry 2012). An osteobiography uses evidence from the remaining osteological materials (*i.e.*, bones and teeth) to gain an understanding of diet, residency, genetic variation, health, and the individual lived experience of a person or animal (Hill 2013; Hull 2020; Losey *et al.* 2011; Tourigny *et al.* 2016). The canine surrogacy approach (CSA) relies on the assumption that domesticated dogs were likely fed by people or scavenged human-derived food scraps (Guiry 2012, 2013). The CSA posits that dog dietary isotope values should resemble the associated human dietary isotope values. Cultural, behavioral, and environmental contexts should be considered when implementing the CSA since these constituents influence how and which foods were being eaten by humans and dogs (Glencross *et al.* 2020; Guiry 2012, 2013). Importantly, while we cannot fully understand the lived experience of people in the past by studying dogs, analyzing kurī remains circumvents the need to perform destructive analysis (required for isotope and DNA analysis) on kōiwi (human skeletal remains).

THE NRD SITE

The Auckland International Airport Northern Runway Development (NRD) site (R11/859) on the shores of the Manukau Harbour was excavated in 2008–2009 and the archaeologists recovered a rich assemblage of material cultural and faunal remains typical of late (*c.* AD 1500–1800) period Māori sites (Figure 1). Of the nine excavation areas, Areas A and B contained kōiwi, which were analyzed non-destructively on site and returned to tangata whenua (Māori groups with traditional ties to the land) for reburial. Area A was the larger of the two, with an earlier date (a combined date of cal AD 1620–1690 at 95 percent confidence interval) and a more complex set of burial practices, including the use of distinctive round burial pits ~1 m diameter × 1 m deep, as well as burials in more conventional grave cuts. Area B (with a combined date of cal AD 1650–1870 at 95 percent confidence interval) was 30 m south of Area A and was probably used by a descendant population who knew of, and deliberately avoided, the earlier burials.

Because the shell midden overlying the burials had been plowed, disturbing and redistributing the kōiwi, it was sieved through 3 mm or 6 mm screens. Consequently, all vertebrate bone, as well as all artifacts, were retained alongside the kōiwi. This included both articulated and disarticulated kurī bones from Areas A (NISP = 963) and B (NISP = 621), as well as kurī bone that had been used as industrial material. Four kurī had been deliberately buried; two from Area A (from features 918 and 2837) appeared

Table 1. *Aotearoa Time Periods and General Trends*

Early Period	**Middle Period**	**Late Period**	**Post-Contact Period**
~1250–1450 AD	**1450–1650 AD**	**1650–1770 AD**	**1770–present**
Kurī introduced to Aotearoa by human settlers (Greig 2015; Matisoo-Smith 2015).	Climatic change (Little Ice Age); Populations move North as cold climate in South make gardens unproductive (Anderson 2016).	Concentrated, large scale gardening (Anderson 2016).	Kurī breed with European canines (Greig & Walter 2021).
Big game hunting: moa and seal (Anderson 2016). Kurī were used as hunting companions (Anderson 1981).	Over-hunting & extinction of moa and other species (Anderson 2016).	Increase in intertribal conflict – defended settlements, *pa*, appear (Anderson 2016).	European populations start to immigrate to Aotearoa and introduce non-native species of animals and flora (Matisoo-Smith 2015).
Kurī & Human Interaction (Greig & Walter 2021). • Managed kurī populations served as reliable source (food and tools) • Free-ranging dog populations: not actively managed by humans.			Feral dog populations: live independently from humans (Greig & Walter 2021).
Wairau Bar evidence that kurī were consumed at large-scale public feasting events (Greig & Walter 2021).	Dog assemblages and abundances are poorly represented at archaeological sites (Pillay *et al.* 2022).	Kurī population rebound possibly due to husbandry practices (Pillay *et al.* 2022).	Accounts of kurī consumption say it was socially restricted – used for special occasions and by high status individuals, such as chiefs (Greig & Walter 2021).

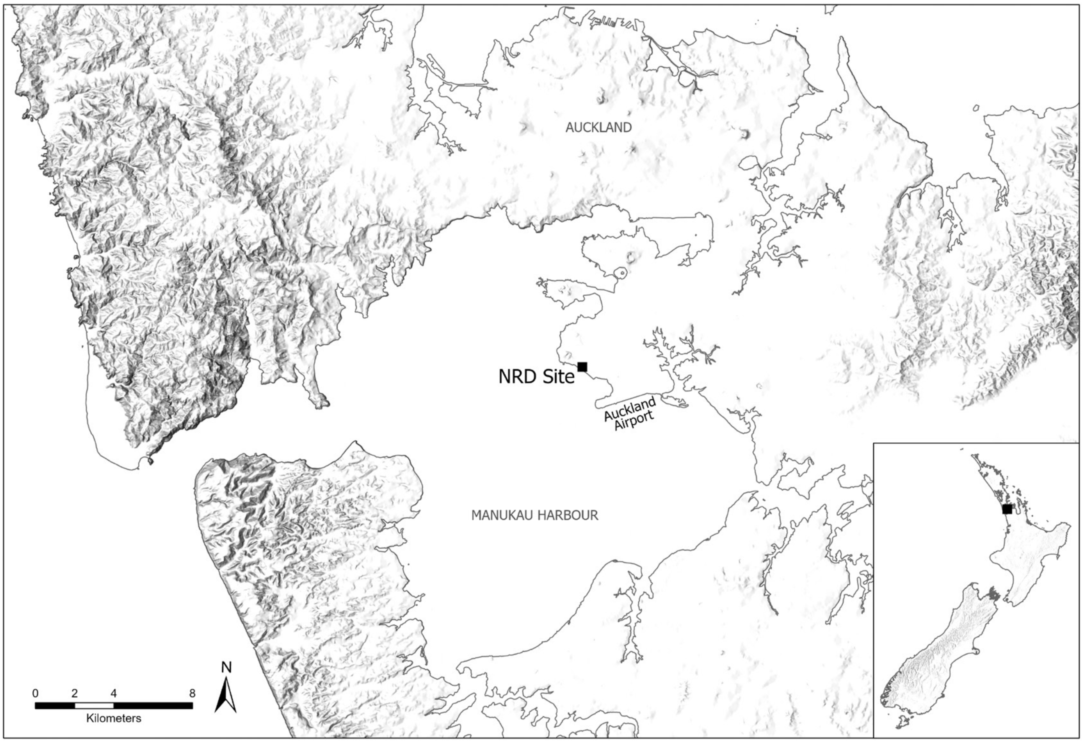

Figure 1. NRD (R11/859) archeological site located northwest of the Auckland Airport on the shore of Manukau Harbor. Figure created in ArcGIS Pro with a coastlines vector (made with Natural Earth) and a hillshade layer created using 8m DEM raster (GNS Science 2021).

to have been buried in the same manner as humans, or in place of absent humans, often in the round pits that were otherwise typically used for human burial (Figure 2). Some burials at the site had been revisited to inter new burials. Others, particularly round pits, had whale bones or non-local scoria basalt rocks in them (most likely from the Auckland volcanic field) buried with or without accompanying kōiwi. In two instances, valves of toheroa (*Pahphies ventricosa*, an indigenous surf clam) were associated with buried kōiwi. These were the only valves recovered from the site and the nearest source for toheroa is at least 40 km away. Some round pits had neither kōiwi nor grave goods, although it is possible that wooden or woven objects may have been present but have since decayed. This burial practice implies a wider resource procurement area or interaction sphere for the people buried at the site than just the local Manukau lowlands (Campbell & Hudson 2011).

Investigating Diet: Dental Analysis

Macroscopic analyses of kurī teeth were undertaken to assess diet and evidence of nutritional and/or physiological stress. The use of dental markers as indicators of dog diets is well established in Aotearoa (Allo 1971; Clark 1997a, 1997b, 1997c; Pillay *et al.* 2022) and internationally (Littleton *et al.* 2015; Losey *et al.* 2014). Enamel hypoplasia, an indicator of growth disturbance, is useful as a signature of physiological or nutritional stressors, which may arise from, or be ameliorated by, local environmental variation or management practices (Hillson 2005; Kierdorf *et al.* 2009; Littleton *et al.* 2020).

Dental attributes considered for the NRD kurī were tooth wear, tooth fracture, periodontal disease, antemortem tooth loss, caries, calculus, and enamel hypoplasia. Tooth wear is an outcome of both diet content and local conditions. Wear results from the consistency of foods, chewing fibrous materials, and the nature of the local substrate (Littleton *et al.* 2015; Pillay *et al.* 2022). Tooth wear influences function and extreme wear can cause adverse health effects such as the exposure of the pulp cavity to infection (Kieser *et al.* 2001).

Variations in the expression of dental caries and calculus are foremost an outcome of individual diets and the resulting oral environments but may be affected by local environmental conditions (nature of sediments) and husbandry practices (free-ranging or restrained). Carious lesions are typically associated with diets high in carbohydrates (Svihla 1957). The presence of periodontal disease is often a reflection of poor diet, severe dental attrition from consuming resistant matter, calculus deposits, or irritation from damaged teeth (Janssens *et al.* 2018). Antemortem tooth fracture (AMTF) can arise from consumption or mastication of excessively hard materials such as bone or shell. It can also result from physical trauma. AMTF may

Figure 2. Typical kurī burial in a round burial pit (feature 2837) comparable to those that kōiwi were interred within. Image provided by Matthew Campbell.

ultimately lead to antemortem tooth loss (AMTL), that is, the loss of teeth during the lifetime of an individual. Other factors that can result in AMTL include periodontal disease, caries, trauma, and deliberate tooth extraction (Losey *et al.* 2014; Sauer *et al.* 2018).

The expression of enamel hypoplasia (EH) often relates to dental developmental stages, the timing of which can vary between species (Littleton *et al.* 2015: 279). Dogs experience rapid developmental growth compared to other mammals (Dobney & Ervynck 2000; Valentin *et al.* 2006), thus the presence of EH often relates to short-term periods of stress of an individual *in utero* or during the first months of life when dental crowns are developing (Littleton *et al.* 2015; McMillan 2017). Notably, EH is common in contemporary dogs (Hale 1998; Mannerfelt *et al.* 2009). In prehistoric dog populations, linear EH lesions (linear grooves) and pit type defects are commonly observed (Losey *et al.* 2014). Recent histological research on hypoplastic teeth suggests that pit type defects represent more acute stresses (*e.g.*, illness) relative to linear defects (Witzel *et al.* 2006: 412).

Dental variants, historically referred to as abnormalities or anomalies (Allo 1970, 1971) were also considered. These are non-metric morphological features that may be inherited genetically (Ansorge 2001; Saunders & Rainey 2008). Allo (1971: 43) suggested that kurī dental variants might be used to track relationships between dog occupants from different archeological sites—a possibility considered herein (refer to Supplemental Information 1 for further detail).

Investigating Diet: Carbon and Nitrogen Stable Isotope Analysis

Dietary isotope analysis was undertaken to construct a site-specific food web and understand where the kurī were positioned within their environmental niche. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes provide information concerning the plant and animal contributions to the diet of an organism, including the ecosystem where the food item originated (*i.e.*, marine, terrestrial, or freshwater) (DeNiro & Epstein 1978; DeNiro & Epstein 1981; Lee-Thorp 2008).

Teeth form during childhood and do not remodel over time, therefore the isotopic values of teeth are a permanent record of childhood diet (Lee-Thorp 2008). Bone constantly remodels and so the isotopic values of bone reflect the average diet during the last months or years of life (Fahy *et al.* 2017; Matsubayashi & Tayasu 2019). Kurī, like all canines, have a much higher bone turnover and growth rates than humans (Martin *et al.* 2015; Guiry 2012). Specifically, human cortical bone has a turnover rate of approximately 4% per year and 28% per year for trabecular bone (Parfitt 2002). The average annual turnover rate for a young adult female beagle is 140% for trabecular bone (Kimmel & Jee 1982) and 51% to 72% per year for cortical bone (Huja & Beck 2007). Faster bone turnover rates and shorter lifespans mean that the dog isotope data is expected to show greater variability than that of humans (Guiry 2012: 363). Turnover rates for canines vary by skeletal element, structure (cortical versus trabecular), physiology (size, weight, breed, etc.) and age of the canine (Martin *et al.* 2015).

Nitrogen stable isotope values only inform about dietary protein because other macronutrients (*i.e.*, carbohydrates and lipids) do not contain nitrogen (DeNiro & Epstein 1981; Ambrose & Norr 1993). There is a stepwise enrichment in ^{15}N (~3–5‰) with every trophic step and therefore the δ^{15}N values of an organism are an indicator of its trophic position in the local food web (DeNiro & Epstein 1981; Ambrose & Norr 1993). δ^{15}N values of marine and freshwater ecosystems are higher and more variable than terrestrial systems because aquatic food chains are much longer than terrestrial food chains (Lee-Thorp 2008). δ^{15}N values are sensitive to climate and tend to be elevated in hot and arid, inland regions and lower in colder and wetter, coastal regions. As a result, it is important to account for possible environmental variation, such as fertilization and land use practices, when interpreting isotopic results (Ambrose 1991; Chesson *et al.* 2018; Szpak 2014; Swift *et al.* 2021).

In bone and tooth collagen, δ^{13}C values are elevated by 5‰ compared to the diet and experience trophic level shifts with a stepwise increase by approximately 0–2‰ between each trophic level (DeNiro & Epstein 1978; Froehle *et al.* 2010). δ^{13}C values provide information about the photosynthetic pathways of plants (C_3, C_4, and CAM plants) and, when used in conjunction with δ^{15}N values, the relative proportion of protein from marine or terrestrial ecosystems (DeNiro & Epstein 1978; Ambrose & Norr 1993; Chesson *et al.* 2018). Marine ecosystems display higher δ^{13}C values compared to terrestrial systems and freshwater ecosystems are more variable, but generally display lower δ^{13}C values than marine systems (DeNiro & Epstein 1978; Lee-Thorp 1989; Lee-Thorp 2008). Dietary baselines of δ^{13}C and δ^{15}N values from faunal material and, if possible, modern plants and animals are important for the correct interpretation of human and animal diets from an archaeological site.

Investigating Migration: Strontium Isotopes and Isoscapes

The analysis of strontium isotope ratios, ^{87}Sr/^{86}Sr, from bone and tooth bioapatite is a well-established method to assess mobility in the past (Bentley 2006) and the method has been used successfully in Pacific Island contexts (Kinaston *et al.* 2013a, 2013b, 2014a, 2014b, 2016; Kinaston & Buckley 2013, 2017; Kramer *et al.* 2020; Shaw *et al.* 2009, 2010, 2011; Stantis *et al.* 2015, 2016). Strontium isotopes naturally occur in the environment and can be used as 'geological tracers' to predict the origin of unknown materials (Bataille *et al.* 2020; Hartman & Richards 2014; Holt *et al.* 2021). ^{87}Sr/^{86}Sr signatures vary predictably based on the underlying bedrock age, composition, and weathering attributes (Bataille *et al.* 2020). The ^{87}Sr/^{86}Sr in bedrock weathers and leaches into nearby soils and water sources and is then incorporated into the biological systems of organisms as they consume water and plants in the local environment (Bentley 2006; Faure & Powell 1972). Amalgamated ^{87}Sr/^{86}Sr is colloquially referred to as biologically available or 'bioavailable' ^{87}Sr/^{86}Sr and represents the averaged values of ^{87}Sr/^{86}Sr uptake from water and dietary resources (Bentley 2006; Fry 2006). ^{87}Sr/^{86}Sr from the diet is amalgamated into tooth enamel bioapatite while the tooth forms during the first months of an organism's life and can, therefore, be used as a marker for childhood residency (Bentley 2006; Lee-Thorp 2008).

Variation in bioavailable ^{87}Sr/^{86}Sr values coincide with the underlying geology which allows scientists to track the migration of human and animals over isotopically distinct geological formations (Bentley 2006; West 2010). The ^{87}Sr/^{86}Sr value of a sampled material, such as animal teeth, can be compared to an established bioavailable ^{87}Sr/^{86}Sr baseline for a region to predict where the ^{87}Sr/^{86}Sr values of the teeth were most likely derived. The ^{87}Sr/^{86}Sr isoscape used for our study applied the machine learning method developed by Bataille *et al.* (2018) and considered plant and soil ^{87}Sr/^{86}Sr values and the best available geomatic data to model bioavailable ^{87}Sr/^{86}Sr variation across Aotearoa (Kramer *et al.* 2022). Using the ^{87}Sr/^{86}Sr isoscape, we predict the region of origin for the kurī recovered at the NRD site to better understand where these canids were living and obtaining their dietary resources while their permanent teeth were forming (*i.e.*, between the ages of two to seven months old) (Muylle 2018).

Investigating Migration: aDNA Analysis

Ancient DNA (aDNA) has been used to investigate the human-mediated dispersal histories of commensal animal and plant species throughout Island Southeast Asia and across the Pacific Ocean (Gosling and Matisoo-Smith 2018). In Aotearoa, aDNA analysis of kurī mitogenomes has focused on the human arrival era to investigate the initial introduction and dispersal of dogs throughout the country

(Greig *et al.* 2015, 2018). The limited mitogenomic diversity observed suggests that only a few dogs were initially introduced by the first human settlers in Aotearoa or, if more numerous than suggested, the dogs were very closely related. In this study, ancient mitogenome analysis provides an opportunity to situate the NRD kurī, which date from a later time period (*c.* AD 1500–1800), within this wider framework and may allow us to gain a better understanding of how the people and dogs at the site interacted with those from nearby regions.

MATERIALS AND METHODS

Sample Description

Thirty individual kurī specimens were analyzed for this study, from kurī burials and disarticulated remains. Seventeen were sampled for strontium isotope analysis, 12 were sampled for nitrogen and carbon isotope analysis, 12 were sampled for aDNA analysis, and 9 were used for the dental analysis (Table 2; Supplemental Information 2). Four kurī appear to have been intentionally buried and were differentiated by Campbell and Hudson (2011) from the other kurī remains recovered in midden deposits. Three of these (Kurī 1, 16, and 17) were sampled and analyzed for this study. For this research, we obtained consent and permission to perform destructive analysis on kurī remains from from Te Ākitai Waiohua. During all stages of analysis, all kurī were treated with respect and were stored safely away from other samples and hazardous chemicals. Results from this research were reported to Te Ākitai Waiohua before writing this manuscript.

Dietary Isotopes

To construct the site-specific food web, $\delta^{13}C$ and $\delta^{15}N$ analysis was performed on 53 faunal bone collagen samples and nine tooth dentine collagen samples (total $n = 62$) representing five species (Supplemental Information 3). Approximately 0.1–1.3 g of bone or dentine was sampled de-

Table 2. NRD *Kurī Samples*

Sample ID	Bag ID	Context	Deposition Type	Area	Analysis Performed
Kurī 1	1419	F. 3768	Pit Kurī Burial	B	Sr, C, N, aDNA, Da
Kurī 2	1269	Sq. R117	Midden	A	Sr, C, N, aDNA, Da
Kurī 3	1424	Sq. C35	Midden	B	Sr, C, N
Kurī 4	4105	F. 3490	Grave cut – contained secondary human burial	B	Sr
Kurī 5	1387	F. 5002	Midden	B	Sr, C, N
Kurī 6	1330	F. 2105	Midden fill in burial pit	A	Sr
Kurī 7	4371	Sq. P109	Midden	A	Sr
Kurī 8	689	F. 885	Earth Oven	A	Sr
Kurī 9	1267	Sq. H38	Midden	B	Sr
Kurī 10	1128	F. 2227	Midden fill in burial pit	A	Sr
Kurī 11	595	F. 923	Midden fill in burial pit	A	Sr
Kurī 12	1152	Sq. Z125	Midden	A	Sr, Da
Kurī 13	1420	Sq. C36	Midden	B	Sr, Da
Kurī 14	247	F. 535	Midden	F	Sr, C, N
Kurī 15	4450	Sq. Z120	Midden	A	Sr, Da
Kurī 16	666 & 747	F. 918	Pit Kurī Burial	A	Sr, C, N, aDNA, Da
Kurī 17	1423	F. 3494	Pit Kurī Burial	B	Sr, C, N, aDNA, Da
Kurī 18	1381	Sq. W110	Midden	A	aDNA
Kurī 19	1138	Sq. X118	Midden	A	aDNA
Kurī 20	1195	N/A	Midden	A	aDNA, Da
Kurī 21	1226	F. 2291	Midden fill in burial pit	A	aDNA
Kurī 22	1360	Sq. X113	Midden	A	aDNA
Kurī 23	4100	Sq. S113	Midden	A	aDNA
Kurī 24	4109	Sq. 120	Midden	A	aDNA
Kurī 25	4195	Unit 7, 170	Midden	A	aDNA
Kurī 26	1321	F. 2454	Midden fill in burial pit	A	C, N
Kurī 27	1296	F. 2867	Midden fill in burial pit	A	C, N, Da
Kurī 28	1357	F. 2931	Post Hole	A	C, N
Kurī 29	806	F. 583	Midden	A	C, N
Kurī 30	1361	F. 2097	Burial pit – cut by secondary human burial	A	C, N

Sr = strontium isotope analysis, C = carbon isotope analysis, N = nitrogen isotope analysis, aDNA = mitogenomic analysis, Da = dental analysis pending on species. A modified Longin method was used to extract the collagen from the samples at the University of Otago Stable Isotope Prep Laboratory (described in full in Kinaston *et al.* 2013). Purified 'collagen' was analyzed by EA-IRMS at IsoTrace, Dunedin. Analytical error was routinely ± 0.1 percent for $\delta^{13}C$ values and ± 0.2 percent for $\delta^{15}N$ values. Stable isotope ratios are expressed relative to international standards (VPDB for carbon and AIR for nitrogen) by means of the delta (δ) notation in parts per thousand, or per mil (‰). All samples were run in duplicate. An internal standard, IA-R042, was used as reference material to ensure the analytical precision of the measurements for the sample analyses. IA-R042, a mixture of IA-R005 and IA-R045 and a mixture of IA-R006 and IA-R046 were analyzed for quality control of the samples. Samples that did not fall within the collagen quality criteria of a C/N ratio of 2.9–3.6 (Ambrose & Norr 1993) were removed from statistical analyses and interpretations.

Migratory Isotopes

Kurī dental enamel samples ($n = 17$) were recorded and photographed before being prepared for strontium isotope analysis following standard procedures provided by the Centre for Trace Element Analysis, University of Otago. Contaminants were removed from tooth surfaces via abrasion using a sonicated Dremel® rotary tungsten carbide drill bit. Then, a 10–20 mg section of enamel was cut from each tooth using a Dremel® reinforced diamond cutting wheel. Samples were then transferred into clean Perfluoroalkoxy alkanes vials (Savillex, Eden Prairie, Minnesota, USA) and weighed in the clean lab prior to digestion in 2 mL of 3M HNO_3 solution at 110°C overnight. Once fully digested, samples were evaporated for four hours at 110°C. Strontium was manually separated utilizing a micro-chromatographic exchange column, Eichrom® Sr-SPEC resin, and the established method of column chemistry (Deniel & Pin 2001; Pin & Bassin 1992). Only a single elution was necessary for the kurī samples which were then evaporated and dissolved in a 2 percent HNO_3 solution for mass spectrometric analysis. The $^{87}Sr/^{86}Sr$ values were measured using a Nu Plasma-HR MC-ICP-MS instrument (Nu Instruments Ltd., UK). $^{87}Sr/^{86}Sr$ data were normalized using repeated measurement of the NIST-SRM 987 standard ($n = 7$, average $^{87}Sr/^{86}Sr = 0.7102441 \pm 0.000021$ 2SD) and verified with an in-house HPS standard ($n = 7$, average $^{87}Sr/^{86}Sr = 0.707615 \pm 0.000019$ 2SD), and another in-house sample of a giant clam (tridacna) (ANU) carbonate control ($n = 4$, average $^{87}Sr/^{86}Sr = 0.709165 \pm 0.000019$ 2SD) which is consistent with expected seawater $^{87}Sr/^{86}Sr$ value of 0.709174 (Hodell *et al.* 1990). Total procedural blanks for the chemical separation process were 60 ng which is negligible relative to the amount of Sr in the tooth enamel samples.

Strontium Isoscape and Geographic Origin Prediction

This study utilizes a recently constructed bioavailable $^{87}Sr/^{86}Sr$ isoscape (Figure 3a) that improved upon an existing random forest regression framework (Bataille *et al.* 2020) and uses the best available geospatial data to build a regional model for Aotearoa (Kramer *et al.* 2022). The isoscape predicts the spatial distribution of bioavailable $^{87}Sr/^{86}Sr$ within Aotearoa by considering various atmospheric, geological, and climatic variables that contribute to the bioavailable $^{87}Sr/^{86}Sr$ pool (Figure 3a) and is calibrated using 417 bioavailable plant, soil, and local animal $^{87}Sr/^{86}Sr$ data (Kramer *et al.* 2022). To create the uncertainty raster required to perform region-of-origin predictions, the log-transformed $^{87}Sr/^{86}Sr$ values of the bioavailable data were used to construct quartile-1 and quartile-3 regression models that were then subtracted from one another (Q3–Q1) to create an interquartile range raster (Figure 3b) with values ranging from 0.0001 to 0.002. The $^{87}Sr/^{86}Sr$ isoscape ($R^2 = 0.53$, RMSE = 0.00098) and accompanying uncertainty raster were validated for use in region-of-origin predictions using the top 33 percent by area probability quantile threshold and successfully provenanced food products (cow milk) obtained from known locations (Kramer *et al.* 2022; Wijenayake 2021).

We assessed the most likely region-of-origin for the NRD kurī using assignR (Chao & Bowen 2019) (described in full in Kramer *et al.* 2022). The assignR package provides a Bayesian tool to generate spatial probability maps by comparing the isotope values of a given substrate with that of an isoscape. In our case, we compare the $^{87}Sr/^{86}Sr$ of each kurī tooth with that of the regional isoscape of Aotearoa (Kramer *et al.* 2022). For each kurī, we obtain a prediction map displaying probability that the individual comes from each 1 km × 1 km pixel of the map based on its isotope values. We then extracted the top 33 percent probability using the 'qtlraster' function in assignR and only displayed these results (relative probability maps are provided in the Supplemental Information 4). The probabilities highlight regions within Aotearoa that have similar $^{87}Sr/^{86}Sr$ values with the kurī tooth. Though there are many distinct lithologies throughout Aotearoa, there are also many similarly aged and composed geological formations that are expected to display similar $^{87}Sr/^{86}Sr$ values. These regions with similar $^{87}Sr/^{86}Sr$ values would also display similar probabilities of origin when compared to the $^{87}Sr/^{86}Sr$ values of the kurī tooth. Additionally, the prediction maps do not depict movement of the kurī across the predicted areas, but instead shows the probable region of residence for the kurī while their tooth was forming. Due to these limitations, it is important to consider archaeological context and interpret probability maps with existing scientific understanding and traditional knowledge in mind.

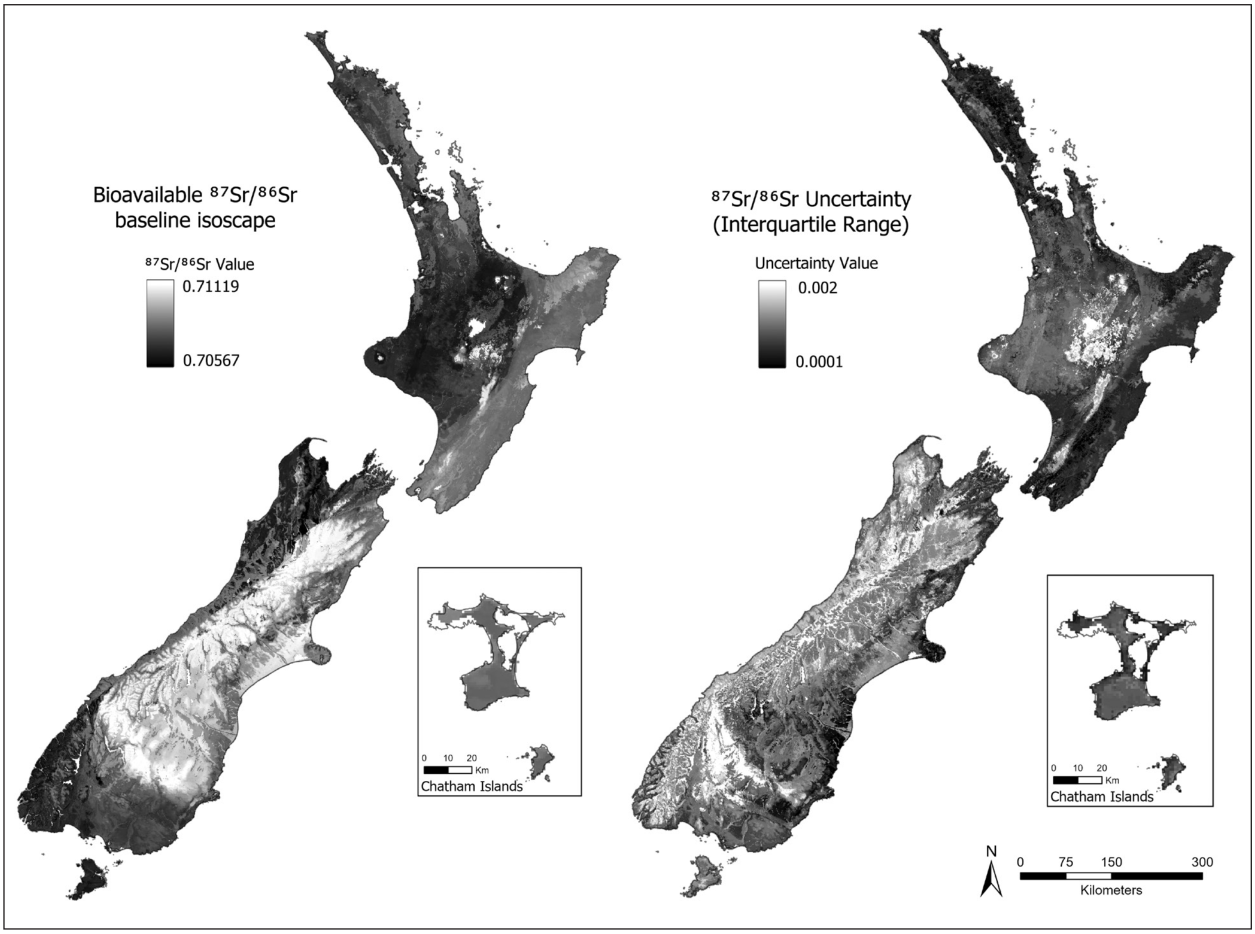

Figure 3. Bioavailable $^{87}Sr/^{86}Sr$ baseline isoscape and uncertainty (interquartile range) raster for Aotearoa and Wharekauri. The bioavailable $^{87}Sr/^{86}Sr$ isoscape (a) ($R^2 = 0.53$, RMSE = 0.00098), demonstrates the predicted $^{87}Sr/^{86}Sr$ values, ranging from 0.70567 to 0.71118, for Aotearoa and Wharekauri (Chatham Islands). Log-transformed $^{87}Sr/^{86}Sr$ values of the bioavailable data were used to construct quartile-1 and quartile-3 regression models that were then subtracted from one another (Q3–Q1) to create the final interquartile range raster (b) with values ranging from 0.0001 to 0.002.

aDNA Analysis

Twelve tooth specimens (n = 12) were selected for aDNA analysis from three burials (Kurī 1, 16, and 17) and midden remains (Table 2). Where possible, the same element (left mandibular M1) was used to avoid sampling the same dog more than once. Ancient DNA extraction and analysis were carried out in the dedicated Ancient DNA Laboratory at the University of Otago, following strict procedures to avoid contamination (Knapp *et al.* 2012a). Extraction and library preparation were carried out as described in Greig *et al.* (2015). We carried out silica-based extractions (Rohland & Hofreiter 2007b), sequencing libraries were then prepared as described by Knapp and colleagues (2012b) for Illumina sequencing, with slight modifications. To enrich for target mtDNA we included an in-solution hybridization capture step (Maricic *et al.* 2010) with slight modifications. We used a purpose-built in-house pipeline to process raw sequence reads with alignment performed against the dog mitochondrial reference sequence (NC_002008, Kim *et al.* 1998). Consensus sequences passing quality control measures have been deposited in GenBank. To investigate the genetic history of the NRD kurī we combined these mitochondrial genomes with published sequences obtained from earlier work on dogs from Aotearoa and the Cook Islands (Greig *et al.* 2015, 2018). We used this dataset to construct a median-joining network using Popart (http:popart.otago.ac.nz, v1.7.1) (Leigh & Bryant 2015) with default settings.

Dental Analysis

The seven dental attributes described above were used to assess kurī diet and oral health (Table 2). Three burials (Kurī 1, 16, 17) provided a total of 47 teeth, including 38 *in situ* mandibular teeth and nine *in situ* maxillary teeth (Table 2). Additionally, midden contexts provided another 22 *in situ* mandibular teeth, 17 *in situ* maxillary teeth, and 5 loose teeth, representing a minimum of six individuals. Overall, 91 teeth were analyzed in this study, from a minimum of nine individuals, derived from Areas A and B (Table 2; Supplemental Information 1).

Where age could be determined, subadults or juveniles were indicated, with the latter dominating. Details of the dental observations are summarized in Supplemental Information 1 (and additional samples are in Pillay 2020). Kurī osteological age estimates were adapted from Clark (1995) and materials were compared to reference specimens of known ages in the University of Auckland Zooarchaeological collection. Four age classes were distinguished: juvenile (less than 7 months), sub-adult (7–18 months), adult, and mature adults (18+ months) (Pillay *et al.* 2022). The methods for the analysis of tooth wear, periodontal disease, calculus, AMFT, AMTL caries, and EH are detailed in Pillay *et al.* (2022). Dental variants were also recorded when present following criteria outlined by Allo (1970, 1971).

RESULTS

Bioavailable $^{87}Sr/^{86}Sr$ geographic region-of-origin prediction

Descriptive statistics for the kurī $^{87}Sr/^{86}Sr$ values are provided in Table 3. In total, the region of geographic origin was predicted for 17 kurī (Supplemental Information 2). The *assignR* predictions and top 33 percent by area predictions were exported as rasters and their symbologies edited in ESRI ArcGIS Pro to highlight the probable regions-of-origin for each sample. Four of the kurī (Kurī 2, 9, 12, and 15) predict similar regions-of-origin and highlight areas near the NRD site (Figure 4). In addition to these nearby areas, the prediction maps highlight the northernmost regions and the eastern coast of Te Ika a Maui (North Island), Wharekauri (Chatham Islands), and the north-central coast of Te Wai Pounamu (South Island) as potential regions-

Table 3. *Descriptive statistics for Kurī $^{87}Sr/^{86}Sr$ data.*

$^{87}Sr/^{86}Sr$	N	Mean	2 SE (Standard Error)	1 Standard Deviation	Minimum	Maximum
Kurī burials	3	0.70893	0.00002	0.00005	0.70888	0.70897
Midden kurī	14	0.70868	0.00002	0.00022	0.70822	0.70899
All kurī	17	0.70872	0.00002	0.00022	0.70822	0.70899

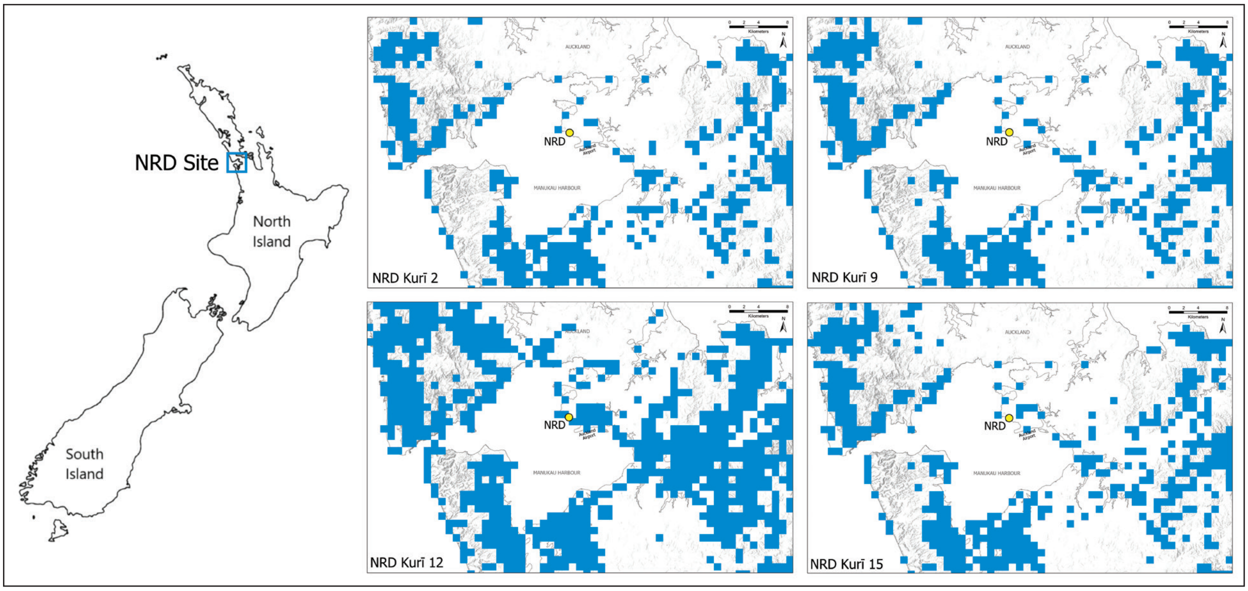

Figure 4. Geographic region-of-origin assignments for the four kurī (2, 9, 12, and 15) that were predicted to be local to the NRD archaeological site based on their teeth $^{87}Sr/^{86}Sr$ values. Areas highlighted in blue represent the top 33 percent of areas predicted as probable regions-of-origin. Prediction probability surface produced by assignR (Chao & Bowen 2019) and the figure was created in ArcGIS Pro with a coastlines vector (made with Natural Earth) and a hillshade layer created using 8m DEM raster (GNS Science 2021).

of-origin for the four kurī. It is important to note that the isoscape did not include any plant and soil samples from Wharekauri, so the $^{87}Sr/^{86}Sr$ values for these islands are not as well-calibrated, though the isoscape is known to extrapolate $^{87}Sr/^{86}Sr$ values well in nearby regions (Bataille *et al.* 2020).

The remaining 13 kurī predictions do not include the NRD site as a probable region-of-origin (Supplemental Information 4). The nonlocal predictions generally highlight areas of the northern peninsula and the eastern coast of the North Island and portions of the central-eastern South Island where the geological compositions are similar and the regions display intermediate $^{87}Sr/^{86}Sr$ values (Figure 3). However, the nonlocal kurī predictions still highlight areas surrounding the Manukau Harbour and areas within the Auckland and Northland regions. As mentioned above, four kurī were formally buried and three of those four (Kurī 1, 16, and 17) were sampled for this study. The geographic assignments for the formally buried kurī all predict areas away from the NRD site meaning the burials may represent non-local kurī. Furthermore, we performed a two-sample t-test of unequal variance between the formally buried kurī (n = 3) and the midden kurī (n = 14) and found that there was a significant difference between their $^{87}Sr/^{86}Sr$ values (t(16) = –3.96, p = 0.001). Figure 5 shows the prediction outputs for each of the formally buried kurī where regions surrounding the Manukau Harbour, Auckland, and Northland are highlighted as potential regions-of-origin.

Dietary Isotope Findings

$\delta^{13}C$ and $\delta^{15}N$ analysis was conducted on archaeological kurī (teeth and bone), kiore (Pacific rat) (bone), and sea mammal (bone) from both areas A and B. Additionally, historic (*i.e.*, species introduced to Aotearoa post-1769) rabbit (*Oryctolagus cuniculus*) and cow (*Bos taurus*) bone from the site's midden and overlying historic fill were analyzed to compare two herbivore species with the kurī and kiore. All but one (a kiore) of the faunal samples yielded good quality collagen with C:N ratios between 2.9 and 3.6 (DeNiro 1985: 807). Both archaeological and historic faunal samples were analyzed to build a site-specific food web and demonstrate the environmental isotopic ranges of potential dietary resources available for the NRD site (Figure 6). Summary statistics are provided for the $\delta^{13}C$ and $\delta^{15}N$ values of all species (Table 4) and burial versus midden kurī (Table 5). All raw data and collagen quality indicators are present in Supplemental Information 3.

For herbivorous consumers, a single cow and three rabbits were analyzed. The $\delta^{13}C$ and $\delta^{15}N$ values of the cow and rabbits can be used as a proxy for a purely terrestrial C_3 plant-based diet. As expected, the rabbits demonstrated the lowest $\delta^{15}N$ values (4.2‰ ± 1.6‰) and the most negative $\delta^{13}C$ values (–21.8‰ ± 0.6‰). The cow produced slightly higher $\delta^{15}N$ and $\delta^{13}C$ values compared to the rabbit, 7.4‰ and –20.3‰, respectively. The average $\delta^{13}C$ and $\delta^{15}N$ values of the sea mammal (*Cetacea sp.*) represents a purely marine carnivore diet (consisting of marine fish).

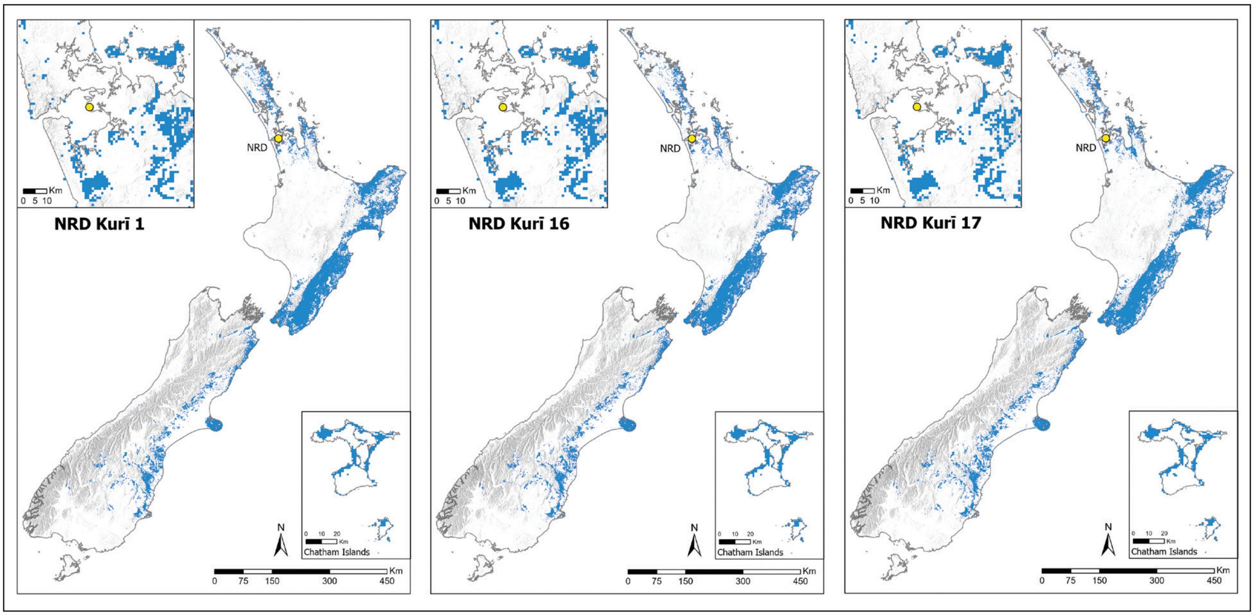

Figure 5. Geographic region-of-origin predictions for the formally buried canids, Kurī 1 16, and 17. Areas highlighted in blue represent the top 33 percent of areas predicted as probable regions-of-origin based on the $^{87}Sr/^{86}Sr$ value of the kurī tooth. Prediction probability surface produced by assignR (Chao & Bowen 2019) and the figure was created in ArcGIS Pro with a coastlines vector (made with Natural Earth) and a hillshade layer created using 8 m DEM raster (GNS Science 2021).

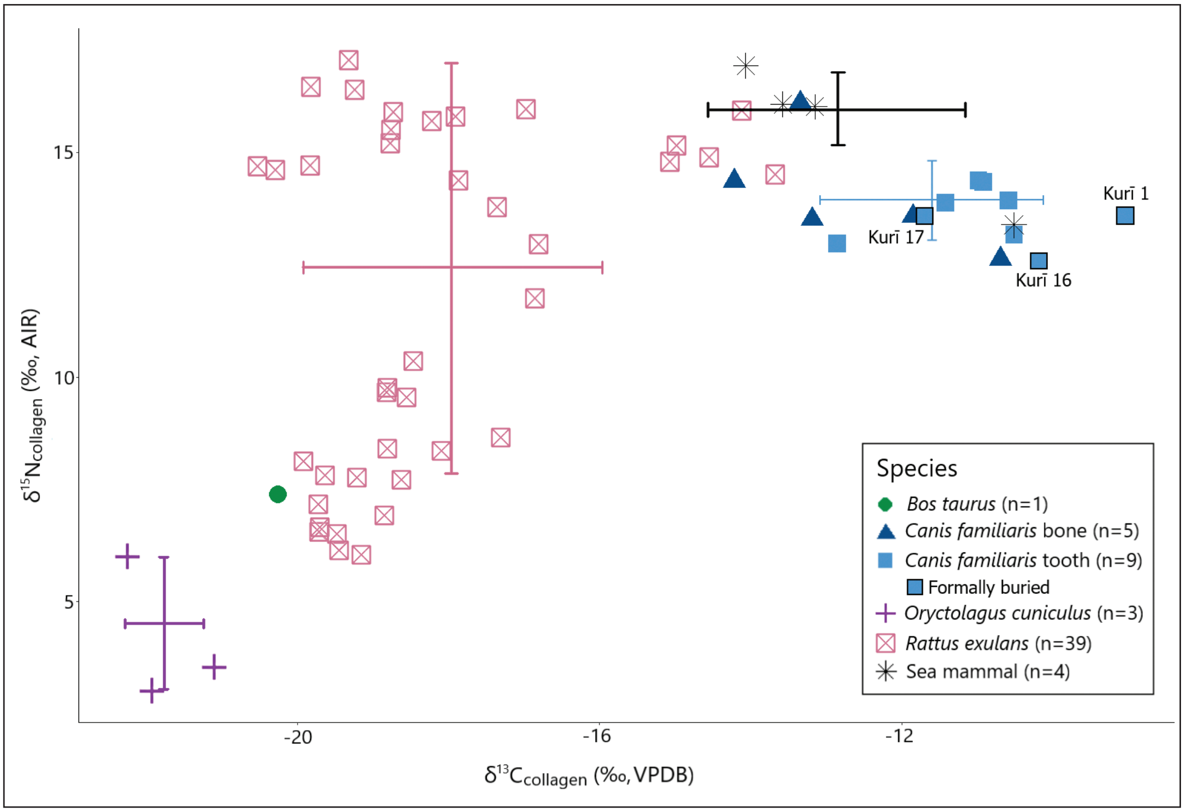

Figure 6. Dietary plot using NRD faunal δ^{13}C (x-axis) and δ^{15}N (y-axis) collagen values of all faunal species at the NRD archaeological site. All δ^{13}C and δ^{15}N were obtained from bone collagen except for nine kurī (*Canis familiaris*) tooth values obtained from dentine collagen and differentiated on the plot as light blue square points. Large crosses with caps represent the average for each species.

Table 4. *Average δ^{13}C and δ^{15}N values of all species analyzed.*

	N	δ^{13}C average	1 SD	δ^{15}N average	1 SD
Kurī	14	−11.54	1.42	13.76	0.90
Kiore	39	−18.26	1.74	11.76	3.82
Rabbit	3	−21.75	0.58	4.20	1.60
Cattle	1	−20.26		7.38	
Cetacea (Whale)	4	−12.83	1.59	15.60	1.53

Table 5. *Average δ^{13}C and δ^{15}N values of burial versus midden kurī*

	Kurī burials	Midden Kurī	All Kurī
N	4 (MNI = 3)	9	13
δ^{13}C	−10.5 ± 1.1 (1 SD)	−11.9 ± 1.4 (1 SD)	−11.5 ± 1.5 (1 SD)
δ^{15}N	13.2 ± 0.5 (1 SD)	14.0 ± 1.0 (1 SD)	13.8 ± 0.9 (1 SD)

The kurī displayed δ^{13}C and δ^{15}N values very similar to the sea mammals, although with slightly lower δ^{15}N values, demonstrating that the kurī mainly consumed protein resources from lower trophic levels, such as inshore species of fish. It is important to note that two of the kurī were juveniles and the increased δ^{15}N values could be higher than expected if they were not yet weaned. The sea mammals have slightly higher δ^{15}N values averaging 15.6‰ ± 1.5‰ compared to the 13.8‰ ± 0.9‰ average for the kurī samples (Figure 6). Sea mammals and kurī both display higher δ^{13}C values averaging −12.8‰ ± 1.6‰ and −11.5‰ ± 1.4‰, respectively, providing further evidence that kurī had access to and consumed marine protein resources, such as fish, shellfish, and possibly sea birds (Figure 6). It is not likely that the higher δ^{13}C values result from the consumption of C4 plants because they were not known to be common in Aotearoa before contact with Europeans. The most prevalent plants cultivated by Māori (noted by early Europeans in the late 18th century) were *Ipomoea batatas* (sweet potato, kūmara*), Dioscorea sp.* (yam), and *Lagenaria siceraria* (bottle gourd), and *Colocasia esculenta* (taro), all of which are C3 plants (Horrocks 2004).

There is some differentiation between kurī bone and tooth collagen δ^{13}C values where isotopes derived from tooth dentine collagen are slightly more enriched in ^{13}C than the bone collagen δ^{13}C values (Figure 6). This may suggest that younger kurī had access to greater quantities of marine resources, specifically shellfish which is enriched in ^{13}C compared to pelagic fishes (Kinaston *et al.* 2014). A principal components analysis was performed for six kurī that had $^{87}Sr/^{86}Sr$, $\delta^{13}C$, and $\delta^{15}N$ data available. No patterns or groupings were apparent for the kurī which was most likely due to the small sample size.

Across all consumers, kiore demonstrated the largest range for both $\delta^{13}C$ (−20.5 to −13.6‰ ± 1.7‰) and $\delta^{15}N$ (6.0 to 17.0‰ ± 3.8‰) values (Figure 6). Most of the kiore displayed more terrestrial $\delta^{13}C$ values compared to the kurī values (Figure 6). However, approximately half of the kiore sampled for $\delta^{15}N$ values were eating higher trophic level foods like the kurī and sea mammals at NRD (Figure 6). The other half of the kiore subsisted on lower trophic level foods that are comparable to the historic cow (*Bos taurus*), but higher than the herbivorous rabbits (*Oryctolagus cuniculus*) (Figure 6). This suggests that the kiore were subsisting on a variable diet of plants and protein-rich sources from both marine and terrestrial environments. Interestingly, the higher $\delta^{15}N$ values of most of the kiore are not accompanied by higher $\delta^{13}C$ values, except for five kiore that plot near the kurī $\delta^{13}C$ values. There was a significant difference between the kurī and kiore $\delta^{13}C$ values ($p<0.001$) and a tendency for a difference between the two species average $\delta^{15}N$ values ($p<0.060$).

Lastly, we compared the dietary isotope values between the kurī recovered from burial versus midden contexts to see if any differences exist between the two groups (Table 5). We performed a two-sample t-test of unequal variances between the kurī burials ($n = 3$) and the midden kurī ($n = 14$) and found that there was no significant difference for the $\delta^{13}C$ ($t(8) = 2.03$, $p = 0.076$) and $\delta^{15}N$ values ($t(11) = -1.89$, $p = 0.085$). Therefore, the kurī from both groups were most likely consuming similar diets to one another.

aDNA Analysis Findings

aDNA preservation, sequence recovery, and authenticity

Complete mitogenomes were generated from three specimens, with a further six specimens having sequences that covered over 97 percent of the reference genome (Table 2; Supplemental Information 2). The remaining three specimens were discarded from further analyses as they failed to generate acceptable consensus sequences (greater than 95 percent of the reference sequence covered by a read depth of greater than two). The median average read depth for the nine specimens was 50×, varying across specimens from between 7.2× and 186× (Supplemental Information 2). Damage patterns such as short fragment lengths and deamination patterns were consistent with those expected from aDNA (Sawyer *et al.* 2012). Throughout DNA extraction and library preparation, blank extractions were processed alongside samples to provide negative controls, and these did not contain any reads mapping to the dog reference genome.

Genetic population structure

Previous studies of the genetic population structure of kurī have revealed a marked lack of genetic diversity in the founding population (Greig *et al.* 2015, 2018). The median-joining network of the NRD kurī mitogenomes combined with colonization era sequences from Aotearoa and those from the Cook Islands (Figure 7) shows the same star-burst pattern, with a single haplotype forming a central node, surrounded by other nodes that mostly vary by only one or two mutations. Three of the mitogenomes from NRD kurī form separate nodes differing from the central node by one mutation. Another two form a separate node that differs by three mutations, and this node also contains a sequence from Houhora, a colonization-era site from the upper North Island. The Cook Islands sequences make up another separate node with a shared mutation not present in the Aotearoa mitogenomes, but also diverge from each other at multiple positions.

The NRD kurī mitogenomes show continuity with the overall structure of the founding population, but also three new haplotype types not observed in earlier studies. These variations may have been present but not sampled in the colonization era population or possibly have arisen subsequently, although this is less likely given the relatively short chronology. Kurī from the NRD site and Houhora also share a haplotype off the central node, and this may indicate some emerging geographic patterning in the upper North Island, but more data are required to investigate this further.

Dental Analysis Findings

The sample of 91 teeth represented at least nine subadults and juveniles, with the latter predominating. Dental variants were observed on maxillary and mandibular specimens. Kurī 2, a subadult, had the retention of a deciduous tooth in the maxillary dentition and the presence of a supernumerary tooth in the mandible. The juvenile Kurī 17 from a pit burial also had the same type of dental variants present in the maxillary and mandibular dentitions respectively. As noted above, these variants may indicate inherited genetic traits. The only instance of AMTL, where bone resorption indicated loss during the individual's life, was in Kurī 1, a subadult from a burial context. AMTF was also observed on two incisors of this individual, which could indicate trauma or poor health.

Overall, the NRD kurī specimens exhibited low tooth wear. These findings are perhaps not surprising given the relatively young age of the individuals. However, Kurī 1 was an exception to this general pattern, with its permanent mandibular teeth scoring seven on the ten-point wear scale (Supplemental Information 1). Periodontal disease was absent in all kurī specimens from the NRD assemblage. No caries or calculus were observed across the whole of the assemblage, consistent with the earlier findings of Clark (1997c). With respect to enamel hypoplasia, both EH and

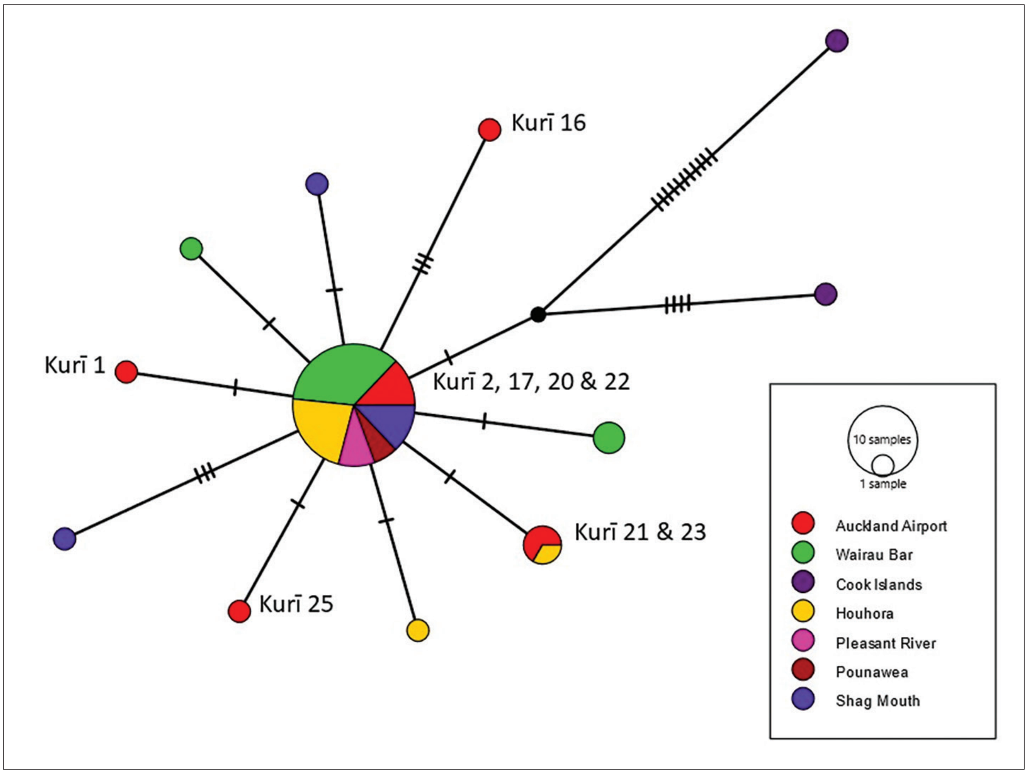

Figure 7. The median-joining network of the NRD kurī mitogenomes combined with colonization era sequences from Aotearoa and those from the Cook Islands. Figure created in PopART (http:popart.otago.ac.nz) by Greig for this study.

pit type defects were infrequent, but observed in three juvenile individuals (Supplemental Information 1).

DISCUSSION

NRD Site (Sample-based) Osteo-history

The osteo-history we constructed using isotopic, genetic, and macroscopic analyses illustrate that the kurī from the NRD site were healthy, had diets high in marine protein, and were likely part of an interaction network across part of the upper North Island of Aotearoa. This is reflected in the strontium isotope analysis and subsequent region-of-origin predictions that suggest four kurī (Kurī 2, 9, 12, and 15) buried at NRD are possibly locals and the other 13 are potentially from areas throughout the whole of Aotearoa. However, it is most likely that the kurī originated from the nearby Auckland and Northland regions, or perhaps the Bay of Plenty or Waikato, based on archaeological and oral history evidence (Campbell & Hudson 2011). Utilizing the bioavailable $^{87}Sr/^{86}Sr$ isoscape and assignR tool enables researchers to go past simple statements of whether a sample is local or nonlocal to a prescribed area and allows for the inference of where the sample may have originated.

The region-of-origin predictions for kurī highlight many potential areas that they may have originated from because all these regions display similar $^{87}Sr/^{86}Sr$ values and share similar geological compositions. Because of this geologic affinity, we must consider other lines of evidence to further narrow down their potential regions-of-origin and interaction spheres for the site. For example, remains of two toheroa (*Paphies ventricosa*) shell valves were recovered from the excavations and both were found associated with kōiwi. The nearest source of toheroa is Muriwai beach where they were formerly abundant (Ross *et al.* 2018), approximately 40 km northwest of the site. This implies that the resource procurement area of the site extended at least as far as Muriwai, and it may imply that the toheroa valves mark these two kōiwi as originating on the open coasts of Muriwau or further north. Analysis of the kurī mitogenomes shows that there may be a shared genetic relation between the NRD kurī and kurī from Houhora, an archaeological site near Ninety Mile beach in the northernmost region of the country where toheroa are also common. However, it is important to acknowledge that the shared kurī mitogenomes may be present at other sites that have not been analyzed at this time.

In addition to the inferred interaction network and resource procurement area, we can deduce that the NRD kurī were healthy based on the macroscopic analysis of their teeth (Pillay 2020, Pillay *et al.* 2022). Of the nine individuals analyzed, represented by 91 teeth, three were from burials, and all were relatively young apart from two where age was indeterminable. In their previous study of kurī in

Aotearoa, Allo (1971: 37) suggested that North Island kurī experienced lower rates of periodontal disease and tooth wear due to their consumption of soft vegetable foods, such as kūmara, in contrast to South Island kurī diets that were comprised of more abrasive foods, which resulted in higher rates of dental attrition. Our isotopic analysis of the NRD kurī, however, demonstrated that this population had protein-rich diets and did not subsist on low trophic resources (see below). Only three NRD kurī exhibited dental defects, specifically enamel hypoplasia and pit defects. Taking into consideration the affected teeth and the location of the defects, these hypoplastic lesions coincide with the weaning period in dogs, a stressful period in their development (Littleton *et al.* 2015). The absence of defects on teeth that formed *in utero* further suggests that the mothers of these individuals were likely in relatively good health.

All the kurī, except for Kurī 1 (which was buried in a round burial pit as shown in Figure 2), had minimal tooth wear and no evidence of periodontal disease the dietary isotopes provide evidence that the kurī had access to a protein-rich diet, so it is also possible that dogs with preferential access to protein were less likely to chew and crack bones, which would lead to dental fractures and wear. The good oral health indicated by the kurī dentition contrasts with the dentition observed in the 88 human burials (Campbell & Hudson 2011), which were severely worn and displayed significant evidence of caries, calculus, and linear enamel hypoplasia. This suggests that local Māori consumed abrasive foods, possibly involving gritty shellfish and fibrous fern, that they did not share with their canine companions.

Previous studies of kurī coprolites demonstrate that they consumed a varied diet composed of marine resources and plants (Anderson & Clark 2001; Irwin *et al.* 2004; Pillay 2020; Pillay *et al.* 2022; Wood *et al.* 2016). The kurī dietary isotope values were comparable to the values of the sea mammal recovered at the NRD site suggesting that the two species subsisted heavily on mammal proteins from marine ecosystems that bear similar isotopic variations (Figure 6). The sea mammals have slightly higher $\delta^{15}N$ values ($\delta^{15}N = 13$ to 17‰) than the kurī ($\delta^{15}N = 13$ to 16‰). The kurī were most likely self-provisioning and opportunistically eating whatever was available, much of which may have been fish discarded by humans. Canids are known to be coprophagic (eating of their own and other animal's feces) which could also account for their increased $\delta^{15}N$ values (Butler *et al.* 2018; Guiry 2012, 2013).

Formally Buried Kurī Osteo-histories

Three formally buried kurī (Kurī 1, 16, and 17) recovered at the NRD site provide a unique opportunity to 'flesh out' their osteo-histories. Overall, the genetic diversity for the formally buried kurī (and the entire sample) is lacking (Figure 7). The NRD kurī mitogenomes demonstrate that they all share a single haplotype and vary from one another by one or two mutations at most. Despite the lack of genetic diversity, the formally buried kurī produced non-local region-of-origin predictions and their $^{87}Sr/^{86}Sr$ values were found to be significantly different ($p = 0.001$) from the values of kurī recovered in midden contexts (Figure 5). This contrasts with the kurī recovered from archaeological investigations at Wairau Bar where most appear to be local to the Wairau Bar site (Kinaston *et al.* 2017; Kramer *et al.* 2021). Juxtaposing the two young kurī against the older kurī burial offers evidence that there was differential treatment among the kurī that received formal burials. The osteo-history for each kurī burial is provided below.

Kurī 1 Osteo-history

Kurī 1 was recovered within a pit burial in Area B of the site. Kurī 1 displayed no dental caries, but had evidence of antemortem tooth loss, worn mandibular cusps, and their second and third right incisors were fractured (Supplemental Information 1). These dental attributes suggest that Kurī 1 may have been an older individual. Dietary isotope data indicate that Kurī 1 consumed food that was the most enriched in ^{13}C compared to all other kurī recovered at the site (Figure 6). This variance could provide evidence of differential treatment of dogs, both during life and after death, at the NRD site. Lastly, the $^{87}Sr/^{86}Sr$ region-of-origin predictions for Kurī 1 indicate that they are nonlocal to the NRD site. Furthermore, the prediction suggests that they may have ties to the eastern and northern coasts of Aotearoa (Figure 5; Supplementary Information 4).

Overall, Kurī 1 lived a long life in comparison to others in the NRD sample. During their long life, Kurī 1 had access to food resources outside the options available to other NRD kurī and they participated in chewing activities that led to noticeable dental wear, the antemortem loss of a tooth, and the fracture of two other teeth. Furthermore, Kurī 1 spent time away from the general NRD area while their mandibular molars were forming and integrated in nonlocal $^{87}Sr/^{86}Sr$ values from another region that is geologically distinct from the NRD site. The distinctiveness of Kurī 1's old age, diet, formal burial, and its non-local $^{87}Sr/^{86}Sr$ value suggest that this individual had a unique life-experience compared to the majority of the NRD kurī sample.

Kurī 16 Osteo-history

Kurī 16 was recovered within a round pit burial in Area A of the NRD site. This kurī had little to no wear on their teeth suggesting that the kurī was relatively young at time-of-death and had little time to develop dental pathologies or experience disease and stress that would affect their teeth and other skeletal elements (Supplemental Information 1). Kurī 16 demonstrated the second most ^{13}C enriched diet compared to the other kurī sampled. This trend suggests that formally buried kurī may have been fed different diets or at least had been provided access to ^{13}C enriched foods more often than their counterparts, regardless of their age. Conversely, Kurī 16 also produced the lowest $\delta^{15}N$ value for the sample (Figure 6). The combination of high $\delta^{13}C$ and low $\delta^{15}N$ values (compared to other kurī) suggest that the diet for Kurī 16 has less access to ^{15}N enriched proteins than Kurī 1. The differences in these diets could result from their age differences, access to different quality and quantity of food/foods scraps, or there could be noise associated with the dietary isotopes of the young kurī's mother being integrated into its deciduous mandibular molar during weaning and even in vitro (Guiry 2012; Schurr 1998). However, if weaning was causing noise, the $\delta^{15}N$ values would be expected to be higher than the other kurī in the sample (Schurr 1998). Therefore, we suspect that the most likely cause of the low $\delta^{15}N$ values is differential access to food or food scraps. Lastly and similarly to the first burial, Kurī 16 produced nonlocal $^{87}Sr/^{86}Sr$ region-of-origin predictions and may have originated from the eastern and northern coasts of Aotearoa (Figure 5; Supplementary Information 4).

Overall, Kurī 16 lived a short life and had access to food resources, most likely shellfish and other food scraps, that produced high $\delta^{13}C$ and lower $\delta^{15}N$ values compared to the rest of the kurī at the NRD site. Furthermore, Kurī 16 may have shared a similar migrational history with Kurī 1 and traveled to the NRD site from another geologically distinct region.

Kurī 17 Osteo-history

Kurī 17 was recovered within a round pit burial in Area B of the NRD site. Like Kurī 16, this kurī demonstrated little wear on their teeth suggesting a young age-at-death (Supplemental Information 1). Despite their similarity in age, Kurī 17 demonstrated the most ^{13}C depleted diet compared to the other formally buried kurī. This furthers the evidence that formally buried kurī experienced differential treatment and access to food and food scraps. Furthermore, Kurī 17 shares a closer genetic affinity with three kurī (Kurī 2, 20, and 22) recovered from midden contexts than it does with the other formally buried kurī (Figure 7). Kurī 20 and 22 were not available to be sampled for dietary and migratory isotope analysis so we cannot further compare them with Kurī 17. However, isotope data from Kurī 2 suggest that the individual is local to the NRD site and consumed ^{13}C enriched foods compared to Kurī 17. This suggests that although there is a stronger genetic affinity between Kurī 2 and 17, their life experiences (*i.e.*, migration history and diet) differ significantly from one another. Like the other two formal burials, Kurī 17 predicts a nonlocal region-of-origin and is predicted to originate from similar regions to Kurī 1 and 16 (Figure 5; Supplementary Information 4).

Overall, Kurī 17 lived a short life, was relatively healthy (based on its dental pathological assessment), and had access to different food resources than the other formally buried kurī which led to its lower $\delta^{13}C$ values. Interestingly, Kurī 17 seems to share a similar migrational history with both of the formally buried kurī recovered at the NRD site. This suggests that the kurī and the humans they travelled with from elsewhere may have shared or viewed human-kurī relationships differently from the life-long inhabitants of the NRD site.

CONCLUSION

This multifaceted study produced an 'osteo-history' of the kurī from the NRD site using isotopic, genetic, and macroscopic analyses of their skeletal remains. This exploratory and interdisciplinary approach provides insight into the past through the analysis of kurī bones and teeth and, although they are imperfect proxies, these insights help avoid destructive analysis on human remains. These investigations have also broadened our understanding of the archaeology of the NRD site.

Areas A and B are urupā (cemeteries) and so differ from occupation sites in important ways. We interpret the archaeology to demonstrate that people visited the site to undertake tangihanga (funerary rites), including burial of the dead, and subsequent revisiting of graves for further ritual. Such activities mean the site is tapu (ritually restricted) and this tapu is lifted through, among other things, feasting, which is archaeologically visible in the midden remains (Shepherd and Campbell 2021; Campbell *et al.* 2021). The kurī analysis indicates that the kurī, and hence the people, both living and dead, came from a wide geographic catchment. This is supported by the presence of nonlocal shell species in burial contexts and mitogenomic evidence that the NRD kurī may share genetic relations with kurī in Houhora near the northernmost tip of the North Island.

The kurī appear to have been healthy, based on evidence for good oral health from *in utero* until their death. The dental and dietary isotope analyses show that the kurī have minimal tooth wear and that they subsisted heavily on a protein-rich, marine diet. Because of this, we may infer that the humans also had access to a healthy diet of marine resources. However, the kōiwi teeth showed significantly greater wear than their kurī proxies, which may mean that they consumed foods (most likely higher in sugars and starches) that were not shared with their canine companions. Lastly, the people who used the site as an urupā extended traditional human burial treatments to kurī and cultural materials, like basalt, imported shellfish, and whale bones. We may never know why a particular kurī or object was given a formal burial, but we can say that the kurī and other objects appear to have been buried with intention and this suggests a special relationship existed between Māori and their kurī.

Lastly, it is important to acknowledge that although canids can serve as proxies for humans when reconstructing diets and migrational histories, it is not a direct relationship. This is because canids are not subjected to the same societal factors that produce intra-site human dietary variation, such as unequal access to resources based on a person's sex, gender, wealth, status, and the intersectionality of these social identifiers (Glencross *et al.* 2020; Perri *et al.* 2019). There is also potential interference or noise produced through husbandry practices, differential access to specific resources (some food scraps may be more available than others), and species preference. This study illustrates the richly textured understandings that can emerge from applying a transdisciplinary approach, and that variability is present in the origins, diet and health, and treatment of kurī at a single locality. It is important to include kurī in any future archaeological investigations in Aotearoa to help build our foundational understanding of variability across sites and regions.

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