

**Title**

Inferring human behaviors from isotopic analyses of rat diet: A critical review and historical application

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**Abstract**

Rat (*Rattus* spp.) bone collagen stable isotope values are often assumed to reflect an average of food stuffs that were available to archaeological populations. This paper considers the feasibility of using stable isotope evidence from rat remains as a source of proxy information for human food-related social, economic, and sensorial behaviors. First, a literature review of archaeological and modern ecological rat isotope work reveals that, while rat dietary signatures are often a reasonable proxy for human food waste, they will not always record an unbiased average of foods which are available in a given environment. Second, an overview of ethological, biological, and environmental factors that can influence rat diets is given from the perspective of archaeological bone chemistry, to help identify factors that require explicit and critical consideration when rat stable isotope data is taken as a proxy for human food-related behaviors. Finally, rat stable isotope values are considered to provide new evidence about the social and economic responses of an important historical English fishing community at Ferryland (CgAf-02) to conflict and political turmoil at the turn of the eighteenth century. These results also highlight how information on rat diets can provide a counterpoint to other common faunal isotope approaches that focus on dogs and pigs as a proxy for human dietary behaviors.

**Keywords**

Stable isotope, diet, human behavior, rat, historical archaeology, fishery, smell.

## 1 Introduction

In recent centuries, rats (*Rattus* spp.) have traveled, lived, and colonized alongside humans and, for this reason, rats are an excellent proxy for human activity. As intelligent and behaviorally flexible omnivores, these animals are well-suited to exploit a commensal relationship with humans for food. However, unlike other omnivores that have a culturally sanctioned food-sharing relationship with humans (i.e., dogs and pigs), rats obtain their food with comparatively little human supervision or control. From this perspective, rat stable isotope dietary information can have significant potential to provide an alternative window into human food-related behaviors, particularly when analyzed in conjunction with domestic animals. In the context of increasing concern about the treatment of human remains among scientific and indigenous communities (Hublin et al. 2008; Katzenberg 2001), exploration of rat stable isotope data as a proxy for assessing human dietary behaviors could provide an important alternative to the application of the destructive process of direct stable isotope analyses to human bone.

This paper explores the archaeological potential of dietary information from commensal rats and is presented in three sections. First, a review is given of previous work in which stable isotope information from rats has been used to draw inferences about past human behaviors. Also considered are modern ecological field studies that have isotopically analyzed rat diets. From these reviews, it is apparent that archaeological rat stable isotope values could be prone to misinterpretation if contextual factors are not taken into account. The second section provides a review of relevant literature on rat ethology and ecology with the aim of systematically identifying which behavioral and environmental factors could influence rat diets. The third section provides a stable isotope study of rats showing a shift in the nature of edible food wastes at Ferryland (CgAf-02), coincident with the turn of the eighteenth century. These findings are interpreted within the framework of documentary and archaeological data from the site to uncover new evidence for social and economic change.

## 2. Stable isotope theory

Stable isotope values of archaeological human and animal bone can provide information about past diet. Isotopic analyses are based on two premises: first, that ‘you are what you eat’, and second, that different foods have distinctive isotopic compositions. This study focuses primarily on stable carbon and nitrogen isotope analyses of rat bone collagen.

Isotopic signatures from biological tissues will reflect an average of dietary intake, focused mainly on protein, over the period of time in which the tissue was formed (Ambrose and Norr 1993; Tieszen and Fagre 1993). The length of time represented depends on how quickly a particular tissue remodels, or ‘turns over’. Some tissues, for instance, muscle (about 4 weeks; Dalerum and Angerbjörn 2005) and liver (about 1 week; Hobson and Clark 1992 a, b; Tieszen et al. 1983), have a faster turnover rate and their stable isotope values reflect diet over a short time period. Bone collagen, on the other hand, turns over slowly and can reflect dietary intake over several years or even decades for larger mammals (Hedges et al. 2007; Wild et al. 2000).

Stable carbon isotopes ( $\delta^{13}\text{C}$ ) can be used to distinguish between a dietary reliance on plants with different photosynthetic pathways. Diets based on  $\text{C}_3$  and  $\text{C}_4$  plants will produce lower and higher  $\delta^{13}\text{C}$  values, respectively (DeNiro and Epstein 1978). Carbon sources in marine environments are usually enriched in  $^{13}\text{C}$  (by  $\sim 7\text{‰}$ ) over

terrestrial ecosystems and, for this reason,  $\delta^{13}\text{C}$  values are also a useful indicator of marine-oriented diets (Chisholm et al. 1982). This is particularly the case in environments, such as Ferryland, where no  $\text{C}_4$  plants were known to have been economically important. Stable nitrogen isotope values ( $\delta^{15}\text{N}$ ) increase by about 3-5‰ between each trophic level and can be used to distinguish between herbivorous, omnivorous, and carnivorous diets within a particular ecosystem (DeNiro and Epstein 1981; Hedges and Reynard 2007). In archaeological contexts baseline  $\delta^{15}\text{N}$  values can vary based on a variety of factors (Szpak 2014). In marine habitats, food chains are extended significantly and can create very high and distinctive  $\delta^{15}\text{N}$  values in the tissues of upper trophic level marine animals such as piscivorous fish and the animals that feed on them (Schoeninger et al. 1983).

### 3.1 Rats in archaeological stable isotope bone chemistry

Archaeologists and historical ecologists have mainly been interested in rat isotopic data for two reasons (Drake and Hunt 2009): 1) as a commensal animal, rats have been used as a signifier of the arrival of humans or certain human activities (e.g. Prebbel and Wilmhurst 2008), and 2) to look at the environmental implications of rat introductions in sensitive ecosystems (Athens 2009; Atkinson 1985; Diamond 1985; Hunt 2007; Jones et al. 2008).

A handful of archaeological stable isotope studies have included analyses of rat remains explicitly for other reasons (e.g., Commendador et al. 2013; Richards et al. 2009). Most have analyzed rats as a minor component of a faunal stable isotope baseline intended to aid in the interpretation of corresponding human data (e.g., Atahan et al. 2011; Choy and Richards 2009). Nonetheless, nearly all of these studies have obtained notable results from rats.

In Asia, for instance, Atahan et al. (2011) analyzed rats ( $n=4$ ; *Rattus* sp.) from two Bronze Age sites (2200-1700 BC), Huoshiliang and Gangangwa, in the Hexi corridor of north central China, as part of a standalone faunal stable isotope baseline to help understand animal husbandry practices and reliance on  $\text{C}_3$  versus  $\text{C}_4$  crops in the area. The authors note that rats as well as other omnivore data show a relatively high reliance on  $\text{C}_4$  cultigens, indicating that millet agriculture was an important subsistence focus for humans occupying the site. In another study, Choy and Richards (2009) analyzed a single rat (*Rattus* sp.) from Nukdo, a Neolithic shell midden site in South Korea (ca. 550 BC to 1AD), also as part of a faunal stable isotope baseline for interpreting human stable isotope values. Here, the authors compared the rat's values to those of a number of *Sus* bones with divergent values and argued based on stable isotope similarities between rat and specific *Sus* bones, that some of the latter specimens likely derive from husbanded pigs that (like rats) fed on food waste around a human settlement, while *Sus* specimens with divergent dietary signatures probably represent wild boars.

More work has been done with archaeological rat remains in Polynesia. Richards et al. (2009) analyzed twelve rats (*Rattus exulans*) along with omnivorous domesticates (pigs and dogs) and humans from the Hanamiai site (1025-1850AD) in the Marquesas Islands, French Polynesia, to provide an early reconstruction of diet, animal husbandry practices, and ecological adaptations. Separated by archaeological time period, rat and other terrestrial omnivore data appeared to show a decline in the availability or use of marine resources over time. The broad variability in rat data is also thought to reflect hunting of rats in multiple habitats as food items for pig and possibly human consumption. Commendador et al. (2013) also analyzed a large number of rats (*Rattus* sp.) from the Anakena Beach site (1200-1400AD) on Easter Island ( $n=29$ ) as part of a faunal stable isotope baseline to help interpret human

values. These rats also produced a wide range of isotope values but mainly clustered around their human counterparts. The authors use these data to argue that rats formed a dietary staple for early inhabitants of Rapa Nui.

A number of similar, smaller-scale studies have also been conducted in Oceania. Kinaston et al. (2013) analyzed six rats (*Rattus exulans*) as part of an extensive faunal stable isotope baseline aimed at contextualizing early inhabitants of New Zealand (ca. 1200-1300 AD) at the Wairau Bar site. These data are interpreted to reflect a diet based on human food scraps discarded at the site and, in the context of human values, suggest that rats may have been a food species for later inhabitants. Guiry et al. (2014) analyzed five rats (*Rattus* sp.) from the Commonwealth Block, a historical (1850-1890 AD) urban archaeological site in Melbourne, Australia, as part of a stable isotope-based reconstruction of local animal husbandry and meat trade. They use rat data as an averaged measure of the stable isotope values for human food waste in the area which, in turn, provided a reference point for considering the frequency of consumption of imported meat products. Valentin et al. (2010) analyzed two rats (*Rattus exulans*) from an early Lapita village midden (ca. 2800-2500BP) as part of a faunal baseline to help reconstruct the dietary practices of humans buried in an underlying cemetery (ca. 3100-3000BP) at the Teoumka site in Vanuatu. While human data from this site suggest a broadly marine-oriented subsistence focus, rats produced terrestrial dietary signatures. The authors discuss the possibility that the diets of these rats could reflect human control and husbandry of commensal mammal diets.

In sum, though none of these archaeological analyses has taken rats as a primary object of study, they have all found rat diets to be of particular interest and, therefore, share common interpretive threads. Similar assumptions are made about the nature of rat behavior and rats' relationship with humans and human settlements. Rats are assumed to originate from an adjacent region or the site itself and, for this reason, their diets are taken to reflect local foods. Also, following the assumption that human intentionality has not interfered with rat dietary choices, rat data has been considered suitable as a kind of 'control' value for human-associated foods when interpreting data from domestic omnivores.

From an ecological perspective, however, the central notion that rat diets will passively reflect an isotopic average of foods in their environment could be problematic. A number of key issues require consideration such as the potential for variation in *Rattus* and related species' biology and behavior to influence how different populations would be expected to feed in a given situation. The potential importance of these issues has been demonstrated by a growing body of stable isotope-based field studies of modern rat populations.

### **3.2 Observations from modern stable isotope based field studies of rat diets**

The idea that rat isotopic signatures will passively reflect a dietary average of foods available in the rats' surroundings has, at a basic level, been supported by a number of field studies of modern populations (e.g., Hobson et al. 1999; Major et al. 2007). Hobson et al. (1999) conducted the first field study using stable isotope analysis to interpret how rat diets reflect food resources available at various habitats on Langara Island, Canada. Their study demonstrated that  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from rat liver and muscle tissues corresponded with expected locally available foods in three different habitats spaced along a ~8 km transect. Following this work, similar experiments have focused mainly on the impact of rats near insular sea bird populations (e.g., Stapp 2002). These studies have

been based on the working hypothesis that commensal rat species are “generalist predators and will change diet with location to whatever the most readily available and highest nutritional quality prey may be” (Major et al. 2007:463-464). In each of these cases, the premise that rat diets will, more or less, passively reflect foods which are suitable and expediently available has been supported in both spatial (Cassaing et al. 2007; Drever et al. 2000; Major et al. 2007; Quillfeldt et al. 2008; Stapp 2002) and temporal dimensions (Caut et al. 2008; Ruffino et al. 2011).

These studies have focused on feral rats in relatively simple natural ecosystems in which only one *Rattus* species is present and, for this reason, the relative straightforwardness of their findings may not be readily transferable to archaeological contexts. In particular, rat remains from archaeological sites derive from animals that may have lived through different intra- and inter-annual time scales and thus probably experience a greater variability in the kinds of foods available. Moreover, the living conditions for rats recovered from archaeological sites could have been much more complex, potentially involving, for instance, different predator relationships (e.g., cats and humans), greater habitat complexity, and, most importantly, interspecific competition. These factors can encourage a given population of rats to adopt a less-generalized dietary niche (see Section 4.3 for discussion), which will not passively integrate an average of all foods that are available in a given habitat. A small number of stable isotope studies have begun to investigate how rat diets respond to niche partitioning (e.g., Harper 2006; Shiels et al. 2013) and provide a cautionary counterpoint to the *de facto* assumption that rat diets will isotopically reflect an average of appropriate foods in their surroundings.

Harper (2006) was the first to conduct stable isotope analyses on different but sympatric species of rats. He analyzed muscle tissue from *R. rattus*, *R. norvegicus*, and *R. exulans* individuals coexisting in different habitats on Pearl Island, New Zealand, and found significant differences between the respective dietary signatures of different species caught in the same area. For instance, in a coastal habitat, he found that *R. rattus* produced stable isotope values indicative of a mix of marine and terrestrial foods, whereas *R. norvegicus* showed evidence of a much stronger reliance on the former. Conversely, a comparison of *R. rattus* and *R. exulans* inhabiting a nearby forested area produced nearly identical stable isotope values. A similar comparison of stable isotope values (on bone collagen) from forest-dwelling *R. rattus* and *R. exulans* in Hawaii was also undertaken by Shiels et al. (2013), but with results suggesting differing relative consumption of C<sub>3</sub> versus C<sub>4</sub> plant species. A trophic level separation was also noted in which *R. exulans* (and house mice *Mus musculus*) were more carnivorous than *R. rattus*.

In short, when ecosystem complexity is higher, rat dietary behavior may be less straightforward. Factors which can influence the observed dietary-niche partitioning among different sympatric species vary and are discussed below. The important point is that potential for the dietary-niche specialization of rats should be made explicit in archaeological bone chemistry work and, insofar as is possible, critically assessed before using rat diets as a source of proxy information for human and other animal behaviors.

#### **4.1 Rats and diet: An overview for archaeological bone chemistry**

Substantial rat ethology and field ecology literatures demonstrate that a wide variety of factors beyond food availability and abundance can influence rat diet. Some of these factors are reviewed here with particular emphasis on *R. rattus*, the species that is dealt with extensively in Section 5. First, however, it may be helpful to describe the

species which are commonly encountered in archaeological sites and briefly review variation in *Rattus* spp. dietary behavior.

#### **4.2 Rats in archaeology**

Three species of rat have benefited most from commensal relations with humans – the Ship rat (*R. rattus*), the Norway rat (*R. norvegicus*), and the Pacific rat (*R. exulans*) and it is these species which are expected to turn up more commonly in archaeological deposits (e.g., Armitage 1994; Ervynck 2002). There are a number of issues that may reduce the frequency with which rats are identified in the archaeological record. For instance, poor preservation conditions may have a stronger impact on smaller mammal bones (see Ervynck 2002). Coarser sampling and recovery procedures may also reduce the number of small bones collected during excavations. Another issue is that *Rattus* spp. bones are sometimes assumed to reflect from later intrusive burrowing activities and are consequently ignored.

It can also be very difficult to determine which species are represented in an assemblage of rodent bones (Pagès et al. 2010). While each species has slightly different physical qualities (see Table 1; Dieterlen 1999; King 2005:159-221; Nowak 1999:1517-1522), morphological overlap can occur (especially *R. Rattus* and *R. norvegicus*) making it difficult or impossible to distinguish between taxa based on osteological analyses alone. In some cases, however, it might be possible to infer *Rattus* sp. identity and/or presence of multiple *Rattus* spp. based on historical and archaeological context relative to the known migration histories of each species (e.g., see Section 5.2; Aplin et al. 2011; Armitage 1993, 1994; Ervynck 2002; Savinetskey and Krylovinch 2010; Twigg 1992).

#### **4.3 A brief overview of rat dietary behavior**

A capacity for individual and social learning is at the heart of the extraordinary behavioral dexterity that allows commensal rat species to adapt to and fill a wide variety of ecological and dietary niches (e.g., Galef 2003). From an ethological perspective, rats can be pickier eaters than is sometimes assumed and usually exhibit a strong aversion to experimenting with unfamiliar objects and foods (Barnett 1958). While individual learning about which things are edible and which are not plays an important role in rat food preferences (Garcia and Koelling 1966), rats have a significant advantage in also being able to learn from one another (Galef 1996; see also Galef and Whiskin 2008). Such socially transmitted food preference information moves between individuals via observation and olfaction and can pertain not only to which foods are most palatable (for review see Galef 1996; see also Galef et al. 2006) or nutritious (Beck and Galef 1989) and where they can be found (Galef and Buckley 1996), but also to specialized techniques for obtaining food (Terkel 1996). For instance, specialized skill sets observed include dive-foraging (Galef 1980; Parisi and Gandolfi 1974), shoreline-based fishing (Cottam 1948), and terrestrial hunting and stalking of prey (Caut et al. 2008; Steiniger 1950).

From a dietary perspective, interspecific competition is thought to be a key factor in encouraging dietary specialization (e.g., Harper and Veitch 2006). Though all species are anatomically equipped to thrive on generalist diets in diverse habitats, the presence of multiple species can allow slight differences between them to influence the ways in which they feed in a particular environment. Relative differences include basic biological and behavioral

qualities, such as body size, thermoregulation, aggressiveness, agility, and average lifespan, but also more variable contextual factors such as the distances that members of a particular group of rats will typically travel and the strategies they employ while foraging, the methods by which they avoid predators, and how they interact with environments of differing structural complexity (see below). It is also amongst the comparative studies of sympatric rat species where the relative differences between each kind of rat are thrown into the sharpest relief (e.g., Harper and Veitch 2006; Kimura et al. 2013; Shiels et al. 2013).

Niche separation among sympatric rat species is partly managed through geographical and/or temporal specialization (Bramley 2014a). This process is encouraged by habitat diversity (Bramley 2014b), as well as the slight differences in the behavioral and physical qualities of each species (King et al. 2011). For instance, a study of sympatric rats in different environments found that *R. norvegicus* dominated in damp environments and *R. exulans* preferred areas with greater amounts of ground cover (Harper et al. 2005). Fitzgerald (1991) found that *R. exulans* was more frequently preyed upon than *R. norvegicus*. Harper and Vietch (2006) found strong evidence for interference competition between *R. norvegicus* and *R. exulans*.

The outcome of niche separation and the relative success of different sympatric species of rat is also dependent on environmental parameters. While the larger size and more aggressive behavior of the *R. norvegicus* may have a significant advantage in the form of interference competition, factors such as food distribution, habitat complexity, and climate can shift the competitive advantage in favor of *R. rattus* and *R. exulans* (King et al. 2011). The opposing outcomes of the introduction of *R. norvegicus* and *R. rattus* to Britain and New Zealand provides an excellent example. In Britain, *R. rattus* was replaced by *R. norvegicus* after its introduction in the eighteenth century, most likely due to the latter's larger size, capacity for aggressive competition, and more temperate adaptations. In many parts of New Zealand, on the other hand, *R. norvegicus* was displaced by a later introduction of *R. rattus*, whose smaller size, greater agility, more versatile foraging strategy, and superior capacity for arboreal activity have allowed it to outcompete its larger cousin (Foster et al. 2011; King et al. 2011).

In sum, it is well established that *Rattus* and related species may adapt differently to their environments in response to factors such as predation (e.g. Childs 1986; Moller and Tilley 1986; Norrdahl and Korpimäki 1993; Taylor 1978), climate, habitat, and interspecies interactions (e.g. Harper et al. 2005; Harris et al. 2006; Russell and Clout 2004; Tobin and Sugihara 1992; Yom-Tov et al. 1999), and that different adaptations can result in dietary variations (e.g. Cheng et al 2005; Fall et al. 1971; Harper et al. 2006; Sugihara 1997; Yabe 1979). These observations, of course, speak most strongly to the potential for rat dietary biases in archaeological contexts within which interspecific rat relationships may have occurred. At the same time, they serve to illustrate the potential for a variety of ecological factors to impact rat diets. From an archaeological perspective, it is critical to assess these factors and the responses that could be exhibited by a given *Rattus* sp. in order to establish the degree to which rat diets can be taken as passively reflecting an average of local food sources.

#### **4.4 The Ship rat (*R. rattus*)**

The Ship rat (hereafter *R. rattus*) is thought to have been the only species present at Ferryland during the time periods relevant to the case study presented below (see Section 5.2). The food and habitat preferences, as well

as ranging behaviors and average lifespan, of *R. rattus* could influence the diet and isotopic signatures of a particular population. It is therefore important to consider how each of these factors influences the foods that are available to individuals in a given environment.

The typical *R. rattus* individual is nocturnal, can reproduce prolifically, and possesses well-developed senses of touch, smell, and hearing (e.g., Innes 2005; Shiels et al. 2014). *R. rattus* are also highly agile (King et al. 2011), adept climbers and jumpers (Foster et al. 2011), accomplished contortionists (Pitt et al. 2011), and capable swimmers (Innes 2005).

#### **4.4.1 Food preference and diet**

The potential for differential food preferences has obvious implications for rat diet. On the whole, *R. rattus* food habits are omnivorous, generalized, and compositionally versatile – probably even more so than other *Rattus* spp. (Fall et al. 1971; King et al. 2011). Clark (1982), for instance, found that *R. rattus* maintain high within-meal diversity, particularly when population density is high. *R. rattus* are also capable of existing at either end of the continuum of omnivory. Miller and Miller (1995) and Gales (1982), for instance, found that some populations of *R. rattus* in New Zealand were mainly carnivorous (see also Stapp 2002). On the other hand, studies on other Pacific islands have found that plant-based foods (mainly seeds) dominated *R. rattus* diets (e.g., Norman 1970; Sweetapple and Nugent 2007; Tobin et al. 1994; Yabe 1979; for recent thematic reviews see Grant-Hoffman and Barboza 2010; Jones et al. 2008; Shiels et al. 2014). In the same region, Daniel (1973) found that *R. rattus* diets seasonally oscillated between relative carnivory and herbivory as the natural abundance of different foods fluctuated in an annual cycle (see also Caut et al. 2008; Quillfeldt et al. 2008). In sum, where dietary behavior has not been circumscribed by external influences (e.g., interspecific competition), *R. rattus* food preferences should not have any impact on the suitability of this species' diet as a proxy for food wastes at archaeological sites.

#### **4.4.2 Habitat**

The potential array of habitats available to rats living near human settlements means that habitat preferences could have an impact on archaeological rat diet. *R. rattus* can thrive in diverse ecological settings including open (savanna and grassland), sheltered, and urban environments (e.g. Cavia et al. 2009; Clark 1981). As with food preference, this behavior is highly flexible. For instance, some forest-dwelling populations exploit more complex arboreal habitat (Innes et al. 1992), while others forage mainly on the ground (Dowding and Murphy 1994). When cover from predators is needed, ground-dwelling *R. rattus* give preference to habitats areas with more abundant leaf litter (Cox et al. 2000). *R. rattus* are also well suited to foraging at the shoreline (Navarrete and Castilla 1993; Pye and Bonner 1980; Drummond 1960; McDonald et al. 1997). This habitat flexibility also extends to den sites as *R. rattus* have been observed to den both on and below ground (e.g., Pye et al. 1999; Rutherford et al. 2009; Shiels 2010) and arboreally (e.g. Hooker and Innes 1995; Lindsey et al. 1999). Overall, the habitat flexibility exhibited by *R. rattus* suggests that, barring external influences from predators or interspecific competition, habitat preference will not impact the dietary signatures of archaeological rats.



#### **4.4.3 Mobility**

The distance that rats travel to forage will affect the types of food available to them. This is particularly so for rats that cohabit human settlements, where different locations might provide significantly different types of foods. Some researchers have found that rats occupy relatively small ranges, as little as 0.2 ha (Tobin et al. 1996; Weinbren et al. 1970), while others have observed rats that routinely range over areas as large as 10 ha (Pryde et al. 2005; Shiels 2010). Variation in ranging behavior has been linked with seasonal food abundance (e.g., Dowding and Murphy 1994), habitat complexity (Shiels 2010:70), population density (Gomez 1960; Innes et al. 2011), mating cycles, and sex (Hooker and Innes 1995; Innes et al. 1992; Lindsey et al. 1999). Unfortunately, factors that might have influenced ranging behavior for an archaeological population of rats may be difficult to predict.

#### **4.4.4 Lifespan**

The duration of dietary intake represented by *R. rattus* bone collagen stable isotope values will depend mainly on lifespan. In captivity, rats can survive up to 4 years of age (Bently and Taylor 1965). For wild rats, average life expectancy is about one year (and usually not more than two) and can be influenced by a variety of factors such as season of birth or habitat (e.g., Daniel 1972; Ecke 1955; Gomez 1960; Shiels 2010; Watson 1951; Wienbren et al. 1970). This period of dietary intake is relatively small on the time scale of human subsistence and economic behaviors and will not necessarily average inter-annual variation in related food availability. For this reason, a greater degree of variation in the stable isotope signatures of archaeological rats can be expected relative to other omnivorous animals.

#### **4.4.5 Suitability of *R. rattus* as a dietary proxy for human behaviors**

Most of these studies have focused on ‘wild’ *R. rattus* colonies and thus the behavioral information drawn from them may not necessarily be representative of the dietary habits of *R. rattus* living in a direct commensal relationship with humans. Nonetheless, for our purposes, the variation demonstrated in these studies suffices to show the broad range and potential plasticity in factors that relating to *R. rattus* diets.

A rounded diversity in food and habitat preferences provides no *a priori* reason to anticipate that archaeological *R. rattus* populations would, in general, have discriminated against certain foods and habitats. However, a number of caveats are necessary. This assumes a scenario in which rat diet, habitat, and range choices are not meaningfully restricted by interspecific competition, pressure from predators, or other factors. It is also important to note that some factors may not be ascertainable, such as ranging behavior and age at death, and thus may contribute to a greater range of isotopic variability.

### **5.1 Rats diets as a proxy for human behavior at Ferryland**

From the sixteenth century onwards, fishermen from various European nations seasonally visited the shores of Newfoundland to produce salted fish products for export back to European markets (Pope 2004). In the early seventeenth century, English fishing plantations established a permanent presence on the Avalon Peninsula (Figure 1). The Colony of Avalon, a plantation founded at Ferryland in 1621, and later renamed the Pool Planation (the

latter term is used hereafter), was a major commercial fishing port and important seat of power in the region (Gaulton 2013; Pope 2004; Tuck and Gaulton 2003; Tuck 2013). Conflict during the Anglo-French wars (1689-1713) changed the physical, social, and economic infrastructure of the settlement (Hranka 2007; Lesovec 2007; Pope 2004). Extensive archaeological investigations in the area have identified the remains of the Pool Plantation as the administrative hub of the region during the seventeenth century (e.g. Carter 1997; Clausnitzer and Gaulton 2012; Crompton 2000; Gaulton 1997, 2006; Mathias 2009; Nixon 1999; Tuck 1993; for review see Tuck and Gaulton 2003, 2013; Tuck 1996, 2013). Excavations have also documented continued eighteenth-century occupation in the same location (Gaulton and Hawkins 2014; Hranka 2007; Lesovec 2007) but provide comparatively limited information to help interpret how the broader use of this key area changed in response to the repeated attacks and economic turmoil at the turn of the eighteenth century (Hranka 2007; Pope 2004).

To gain new insights into this latter time period, rat diets (as measured from  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from bone collagen) are considered here as a potential window into patterns in human food storage and waste management during the seventeenth and eighteenth centuries at the Pool Plantation. Fish offal is expected to be the dominant food waste at historical fishing settlements; however, with some effort and for a number of social, economic, and/or sensorial reasons, inhabitants of the Pool Plantation could have prevented such accumulations of fisheries waste within the confines of the settlement proper. For that reason, identifying trends in where and how fisheries waste was disposed of can provide evidence for changing human behaviors which may not otherwise be documented by written and archaeological records.

As outlined in Sections 3 and 4, there are a number of environmental factors that need to be considered before rat dietary information can be used as a proxy for human behavior and these are first contextualized within documentary and archaeological information about historic Ferryland.

## **5.2 Historical and environmental context**

### *The Pool Plantation: settlement history*

Archaeological investigations indicate that the area immediately around the Pool (Figure 2), a small sheltered harbor situated within the larger harbor of Ferryland, was prime real estate and had been a center of infrastructure development, commerce, fishing, and other human activity since the settlement was first constructed in the early 1620s (Pope 2004; Tuck and Gaulton 2003). The Kirke family expropriated the colony in the 1630s and held significant power over commerce in the area throughout the seventeenth century (Gaulton 2013; Gaulton and Hawkins 2014; Tuck and Gaulton 2003). Major settlement disruptions occurred in 1696 and 1705 when Ferryland was sacked by French attacks and its inhabitants deported (Lesovec 2007; Norris 1698). Resettled once more, residents survived to become firmly reestablished with a stable population for the remainder of the eighteenth century (Lesovec 2007).

### *Rat habitat and food availability*

For rats inhabiting the Pool Plantation, human structures and associated fishing and agricultural activities could have provided a bountiful habitat. In particular, the domestic habitations, stages, and other structures such as a

brewhouse and bakery that have been excavated in areas B, C, F, and G (Figure 2) could have provided ideal year-round shelter.

Large provision stores, domestic food stuffs, and agricultural activities around the settlement certainly would have been excellent targets for rat pillaging. However, the most abundantly available food during the spring, summer, and early fall months would have been cod (*Gadus morhua*) procured by the associated fishery. Period observers, for instance, note that the waters and shoreline around fishing stages were usually a quagmire of rotting fish offal which attracted and supported a variety of scavenging fauna such as birds and other fish (e.g., Cadigan 1995:133; Lysaught 1971:137). In such a scenario, it is easy and perhaps unpleasant to imagine, as for instance Hodgetts (2006; 2009) has, that rats would be a common sight along the waterfront at the Pool Plantation where they would be found exploiting a bounty of floating or washed-up fish.

The other main access point for unwanted fish parts would be on land. From time to time, unwanted cod parts were dumped on beaches or land areas adjacent to fishing stations (e.g. Betts et al. 2014; Lysaught 1971:47; Prowse 2002:559). Historical documents and archaeology also indicate that some cod offal was saved intentionally for agricultural use as feed for livestock (Pope 2004) and as a materials for manureing fields (e.g., Cadigan 1995:60, 133; Prowse 2002:99, 400).

### *Species Assemblage*

Due to the potential impact of interspecific competition on rat dietary behavior, it is important to establish the composition of the *Rattus* species present during the seventeenth and eighteenth centuries at Ferryland. Zooarchaeologically, rodent bones from Ferryland have been identified to the genus level (Tourigny 2009). The first species of rat to arrive in Newfoundland was *R. rattus* and according to naturalist Joseph Banks' 1766 assay of Newfoundland's fauna, *R. rattus* remained the only species until at least some time after the mid eighteenth century. During the late-eighteenth or early-nineteenth century *R. norvegicus* was introduced to the island (Stewart 1985; Tourigny 2009:123). While it is possible that some rat remains from later eighteenth century deposits could derive from *R. norvegicus* individuals, it is practical to expect that all rat specimens from the seventeenth and early-mid eighteenth centuries analyzed here derive from *R. rattus* only and that the dietary behavior of these individuals was not influenced by interspecific competition between different *Rattus* spp. (see Section 4.3). The House mouse (*Mus musculus*) was also occasionally present at Ferryland but does not appear to have established a population (Tourigny 2009:156-157).

### **5.3 Methods**

Use of 1mm mesh wet sieving during excavations at Ferryland has resulted in the recovery of a large number of rat remains. Thirty-one new *R. rattus* and one *M. musculus* specimens were selected for analyses based on the element which gave the largest minimum number of individuals per archaeologically distinct context. Rat specimens analyzed here were excavated from domestic structures in areas B, C, F, and G. These locations occur within an area of ~0.5.ha along roughly 50 m of the Pool's shoreline. All rat bones were collected within 40 m from the water's edge, a distance that would have provided foraging rats with mutually easy access to shore-washed and

other fish offal as well as foods and other provisions of terrestrial origin in domestic and commercial structures and gardens. For this reason, it is probable that rats from both seventeenth- and eighteenth-century deposits had access to similar types of foods, of both marine and terrestrial origins. To mitigate the potential for age-induced variability in rat stable isotope data, bones from small or obviously young individuals were avoided during sampling. All remains were excavated from secure contexts and do not appear to have resulted from later intrusive burrowing activities. For this reason we are confident that specimens are contemporaneous with their respective archaeological deposits.

Bone collagen was extracted at the Archaeology Isotope Lab at the University of British Columbia (Canada) based on established procedures (Brown et al. 1988; Richards and Hedges 1999). Bone chunks were soaked in 0.5M hydrochloric acid at 4°C until demineralized. Resulting collagen pseudomorphs were gelatinized in a pH3 solution at 75°C over a 48-hour period. Collagen gelatins were then filtered (5-8µm mesh Eze filters followed by 30kd ultrafilters), frozen, and lyophilized for 48 hours. Isotope ratios were measured from collagen samples weighing approximately 0.5 mg at the Max Planck Institute, Department of Human Evolution, using a Carlo Erba elemental analyzer coupled to a Thermo Delta V continuous-flow isotope ratio mass spectrometer. Based on replicate measurements ( $n=7$ ) of a known standard (methionine) instrumental error ( $1\sigma$ ) for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements was  $\pm 0.09\text{‰}$  and  $\pm 0.04\text{‰}$ , respectively. Collagen quality was assessed using atomic carbon to nitrogen ratios (C:N) as well as carbon and nitrogen concentration data. Criteria for acceptable stable isotope measurements are C:N values between 2.9 and 3.6 and carbon and nitrogen concentrations above 16 % and 8 %, respectively (DeNiro 1985; Van Klinken 1999). Statistical analyses were performed using SPSS 17.0. Differences between group means were compared using a Oneway ANOVA. Homogeneity was assessed using a Levene's test. If variances were equal a Post Hoc Tukey HSD test was performed. If variances were not equal a Dunnett's T3 test was used.

## 5.4 Results

Collagen quality data indicate variable preservation. Two *R. rattus* and one *M. musculus* samples produced C:N values outside of the acceptable range and are not discussed further. Stable carbon and nitrogen isotope data for Ferryland rats (Table 2 and Figure 3) were highly variable with mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of  $-18.3 \pm 1.7\text{‰}$  (range  $= 7.6\text{‰}$ ) and  $11.5 \pm 3.9\text{‰}$  (range  $= 16.3\text{‰}$ ), respectively. In the context of other wild and domestic animals analyzed from Ferryland (Guiry et al. 2012) these new rat data provide evidence for relatively terrestrial-, marine-, and mixed-terrestrial/marine-oriented diets (Figure 4).

When temporal context is considered, a trend emerges (Figure 3). Individuals from the seventeenth century have stable isotope values that are significantly different from their eighteenth-century counterparts ( $p < 0.05$ ). In particular, relatively few rats from before the French attack of 1696 appear to have obtained a significant portion of their dietary protein from marine-derived foods such as cod, whereas rats from contexts which postdate this period consistently did receive their dietary protein from this source. These latter rats are, in fact, not significantly isotopically different from animals such as pigs, dogs, and cats that were raised by residents at the Pool Plantation on a diet of fish offal (Figure 4; Guiry et al. 2012).

## 5.5 Discussion

While the marine-oriented dietary signatures of eighteenth-century rats are anticipated for scavengers inhabiting a fishing settlement, it is surprising that their counterparts inhabiting the same space during the previous century generally exhibit terrestrial diets. The simple explanation for this phenomenon is that there probably was relatively less fish around for them to eat.

Before exploring this explanation, it is important to critically consider its major assumptions. Rats are assumed to have lived, foraged, and died near the area where they were excavated. The observed dietary pattern probably does not reflect spatial or temporal biases because rats were sampled from diverse archaeological contexts (domestic, commercial, and fishery related) excavated from within a relatively small area (allowing all rats equal access to different resources). Also, given the much later arrival of the other rat species in Newfoundland, it is reasonable to assume that interspecific competition has not influenced seventeenth-century or early-mid eighteenth-century rat diets. In this context, the most parsimonious explanation for the observed shift between seventeenth- and eighteenth-century rat diets appears to be that a genuine change occurred in the relative abundance of different types of foods that were available to rats.

Two related hypotheses are discussed below to explain this phenomenon: 1) that the scale of fish processing relative to other economic activities near the habitation areas of the Pool Plantation differed between the seventeenth and eighteenth centuries; and, 2) that the denser seventeenth-century population of the Pool Plantation, took greater care to reduce the amount of fish offal that lay about their settlement.

The first explanation posits that the availability and abundance of terrestrial foods was relatively high during the seventeenth century and then declined during the eighteenth century. This hypothesis is supported by the presence of a large seventeenth-century commercial storehouse at the waterfront that does not appear to have had a local eighteenth-century counterpart. This storehouse was likely used as a stockpile depot for provisions intended for local consumption as well as for sale (or resale) to other fishing operations (Gaulton 2013). Other nearby seventeenth-century buildings such as a tavern, a brewhouse and bakery, and a cowhouse could also have been a target for rats. While such structures could obviously have provided significant access to terrestrial foods (e.g., grain and barreled salt meats), the hypothesis that these formed a basis for most rats' diets (regardless of which archaeological deposit they are collected from) does not fully account for the observed dietary patterns. For instance, the single rat analyzed from the storehouse provided isotope values falling at the marine end of seventeenth-century sample (SUBC 1724;  $\delta^{13}\text{C} = -17.4\text{‰}$ ,  $\delta^{15}\text{N} = 14.1\text{‰}$ ) suggesting access to these structure would not necessarily entice rats to disproportionately consume terrestrial food stuffs. This hypothesis also overlooks the opposing terrestrial and marine isotope values from seventeenth- and eighteenth-century rats excavated from similar (if smaller-scale) access points to terrestrial foods, such as domestic kitchens and associated midden deposits which are dominated by terrestrial fauna (Tourigny 2009). Also, there is no reason (based on ethological and ecological considerations – see Section 4) to expect that, given equal access, rats would preferentially exploit terrestrial resources from these structures more intensively relative to the marine foods that abounded in their immediate surroundings. For these reason, while the disappearance of a provisions storehouse and other commercial structures at the waterfront at the beginning of the eighteenth century is probably a contributing factor, the lack of a stronger

marine emphasis in seventeenth-century rat diets most likely also reflects a difference in the relative abundance of marine-derived foods. In other words, these rat data suggest that the relative abundance of cod offal increased at the turn of the eighteenth century.

This second explanation, that relatively less fish offal was available to rats during the seventeenth century, would seem at odds with evidence suggesting that the Pool has always been an excellent base for fishing activities (Tuck and Gaulton 2003:189). Underwater investigations of the Pool itself, for instance, have identified a stratified deposit containing fisheries waste dating as far back as 400 years, which appears to provide a record of extensive cod processing and periodic fish offal dumping directly into the harbor (Skanes and Deichmann 1985).

During the seventeenth century, the Pool Plantation was home to a much denser population than it would achieve in later years (Gaulton 2013; Lesovec 2007), and given this centralized organization it is possible that residents of the area had compelling reasons to reduce the disposal of fish-processing waste from around the land and waters closest to the settlement's waterfront and domestic structures. A pragmatic reason for this reduction could have been to avoid attracting scavengers. Early letters, for example, document a preoccupation of settlers with dangerous beasts such as wolves and bears (Hoskins 1622; Powell 1622; Wynn 1622b). Preventing a buildup of fisheries waste could also help control the rat population and preserve the harbor's depth and the stone seawall's capacity to moor ships with larger drafts.

Social and sensorial hypotheses are also worth exploring. One possibility could be that efforts were made to reduce the frequency of fish offal dumping in the immediate vicinity of the settlement in order to maintain general cleanliness and/or avoid the odors that accompany intensive fish processing activities. It is, perhaps telling that a number of early letters written from Ferryland pause briefly to dwell on the 'sweetness' or relative 'healthfulness' of the air there (e.g. Hoskins 1622; Kirke 1639; Wynn 1622a). On one hand, it may be ethnocentric or presentist to assume that seventeenth-century inhabitants of Ferryland valued an environment that was not contaminated by waste from the fishery or by the odors it produced (for a review of contemporary English olfactory sensibilities see Cockayne 2008:206-229). It was certainly the case that seasonal fishermen in this period often used fishing stages as lodgings and quickly became accustomed to living in an atmosphere thick with the stench of fish offal (for a vivid account see Lysaught 1971:135-136). On the other hand, the journals of individuals that seasonally visited Newfoundland show that they were often deeply troubled by the conditions and particularly the smell that permeated fishing stations and settlements (especially during the summer months, see Lysaught 1971:147), not least because of a prevailing belief in the causal relationship between foul smells and disease at the time (e.g. Poynter 1963:59; also see Cockayne 2008:210-214).

In this context it is important to point out that the Pool Plantation served as an early capital, as well as hub of commerce and exchange, and that those who occupied its central mansion complex, the Kirke family, were not servant fishermen but, rather, elites with immense wealth and influence over the region. Archaeological evidence shows that members of this family were keen to display their affluence and elevated social status through the material culture they possessed (e.g., Gaulton and Casimiro 2015; Stoddart 2000; Tuck and Gaulton 2003). Another indication of wealth in seventeenth-century urban England was a capacity to live in, or at least occasionally visit, areas with unpolluted air (Cockayne 2008:206-229). In this social and economic context, the maintenance of a

perimeter of relatively pleasant atmosphere around the Pool Plantation and its environs could be viewed as an additional conduit through which the Kirkes could display their influence.

In 1696 and again in 1705, Ferryland was taken by French attackers and the Pool Plantation razed to the ground. Documentary and archaeological evidence indicate that the settlement was soon repopulated, albeit less densely, but remains hazy about where and how rebuilding took place or who was involved (Hranka 2007). Dietary information from eighteenth-century rats provides new clues about what happened at the Pool Plantation after these turbulent events.

Rat diets consistently show that fish offal was a dietary staple during this time and that it was therefore probably more abundantly available in the area. The straightforward explanation for this shift is that the focus and scale of economic and social activities at the Pool Plantation changed after it was rebuilt. That is, at least for the immediate area around the Pool Plantation, with the reduction in population density and the importance of commercial (storehousing and provisioning) and domestic (elite residence and associated households) activities, came a relative increase in the importance of fishing and cod processing interests. Lacking centralized control and management, as had been the case during the seventeenth century, the careful separation of fishery and non-fishery related activities within the plantation proper were no longer possible. Post 1696 Ferryland was reconfigured, both with respect to the colonial infrastructure and with regards to the reversion of the Pool back to a fishing station as it was prior to 1621. Eighteenth-century maps of Ferryland (Des Barres 1762; Hylton 1752; Sculp 1794), for instance, suggest that the Pool had become congested with numerous structures and fishing stages. Moreover, a decline in the density and variety of non-domestic, commercial, and proto-industrial (e.g., brewhouse and bakery) structures within the settlement could have curtailed sources of non-marine food for rats during the eighteenth century.

This change in economic emphasis at the Pool Plantation shoreline may also have been accompanied by a shift in social context as well. That is, the planters who rebuilt directly upon the ground of the ruined Pool Plantation were of different and/or more heterogeneous social statuses or otherwise did not mind (or lacked the means to control) the adjacent fishery activities. This possibility is supported by the presence of less affluent early eighteenth-century houses built upon and partly from the remains of its wealthier seventeenth-century predecessor (Hranka 2007:206-210).

It is, at any rate, noteworthy that these rat data may provide an archaeologically rare glimpse of one of the most ephemeral and yet elemental aspects of past human experience: smell (e.g., Smith 2007). Because this sense is so rarely evidenced by material culture, it has probably been overlooked as an explanatory tool for past human behavior. But in the context of seventeenth- and eighteenth-century England, smell was certainly a meaningful and even significant aspect of social context (Cockayne 2007:206-229). Regardless of the degree to which historical residents of Ferryland were inured or otherwise indifferent to the smells associated with fishery activities, it is hard to imagine that the sensorium at the Pool Plantation was not noticeably, and probably meaningfully, changed as a result of the increased presence of cod offal during the eighteenth century.

These results also provide a clear case for the utility of stable isotope dietary information from rats to contrast and complement data from other domestic omnivores. Recent discussion has focused on the potential of domesticates such as dogs and pigs as a proxy for human diet and related activities (e.g. Allen and Craig 2009;

Guiry 2012, 2013; Guiry and Grimes 2013). These approaches are a valuable means of partially circumventing issues around the destructive analyses of human remains but rely on animal dietary signatures that are, to some degree, controlled by human husbandry. Because rats are not intentionally fed by humans, their diets can provide a complementary counterpoint. The large offset observed here between seventeenth-century rats and dogs and pigs (the difference in means for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  is 3.3 ‰ and 6.2 ‰, respectively), demonstrates this capacity by showing that Ferryland residents exercised tight control over the diets of their domesticates, a factor that would complicate or preclude attempts to use pigs and dogs as a source of proxy information for human diets.

## 6. Summary and conclusion

This paper has aimed to critically consider and develop a more rigorous methodology for an approach that uses rat stable isotope data as a source of proxy information about human dietary behavior in archaeological contexts. A small but growing archaeological bone chemistry literature has analyzed rat remains, most often as part of faunal stable isotope baselines. A review of several factors related to rat biology and behavior suggests that there is potential for variability in rat diets that has not been considered by this previous archaeological bone chemistry work. For example, factors such as interspecific competition and the likely distribution of food resources around a human settlement can change the diets that are consumed by a given population of rats such that they will *not* passively integrate an average of all foods that are available in a given habitat. An overview of such factors for *R. rattus*, the first species to form an extensive relationship with Europeans in the North Atlantic, is also provided in order to establish the suitability of this species for use as a proxy for the distribution of human food waste and associated activities at the archaeological site of Ferryland. *R. rattus* at Ferryland demonstrate a shift in the relative abundance of cod offal and other food resources that is coincident with a period of conflict and strife and suggests that the social and economic role of the Pool Plantation changed after resettlement in 1697.

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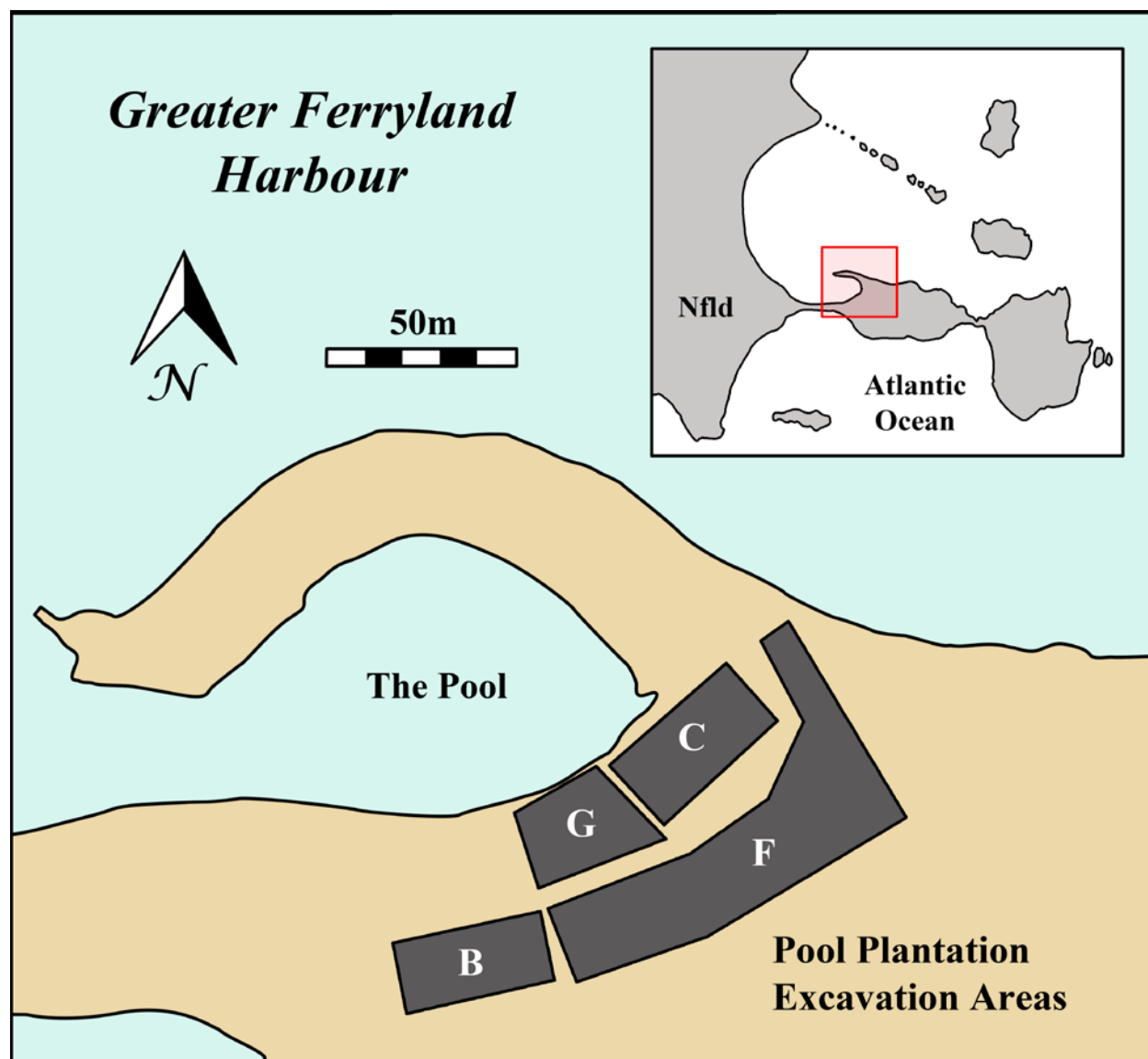


## Figures

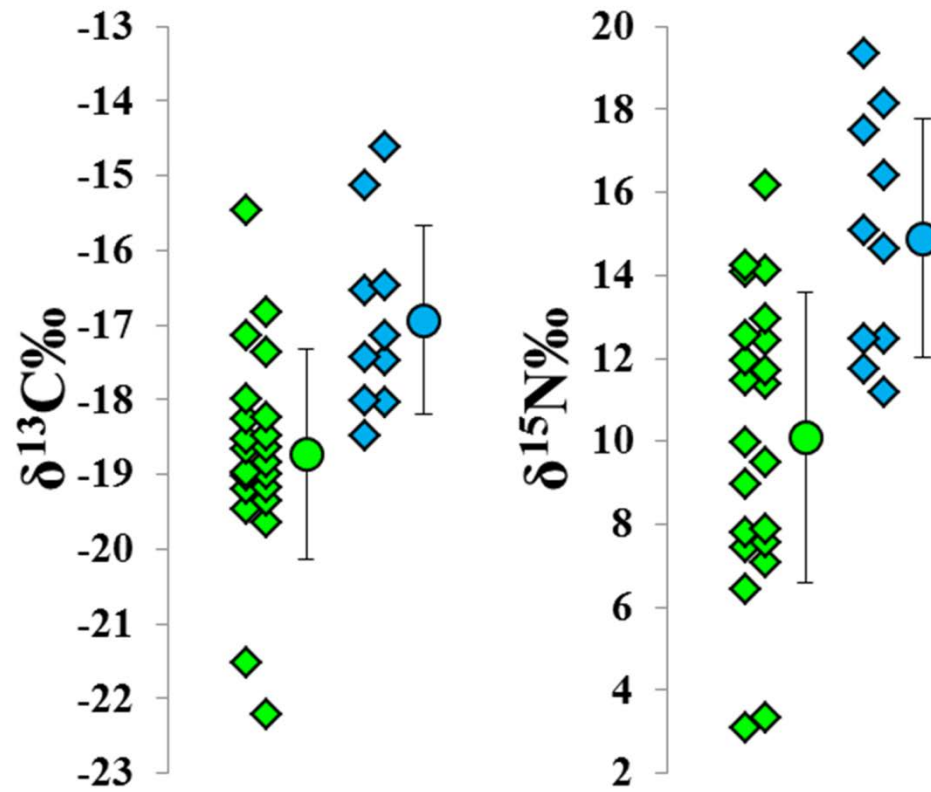
Figure 1. Map showing the location of the Avalon Peninsula in context of the western North Atlantic.



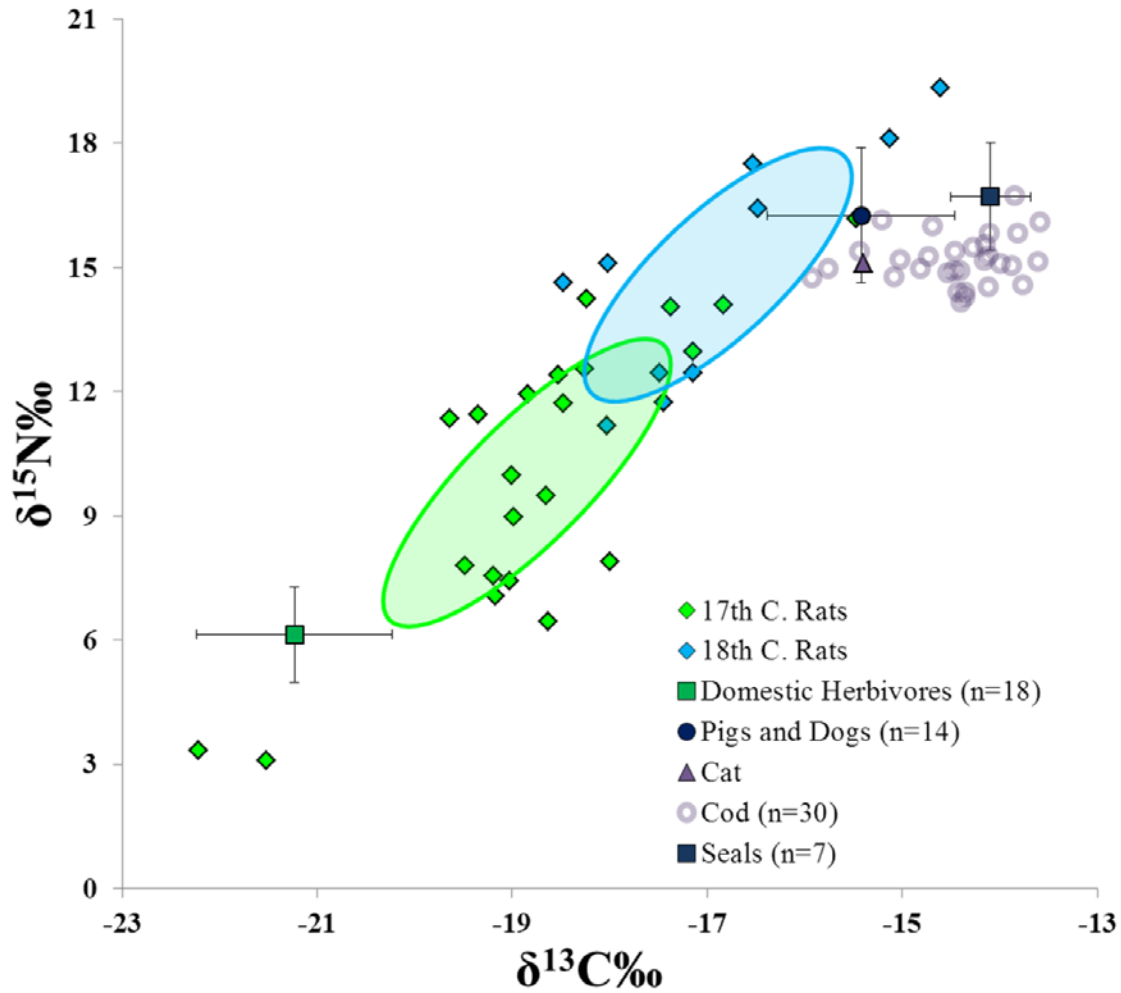
Figure 2. Map of the Pool and Pool Plantation excavation areas at Ferryland (modified from Lesovec 2007).



Figures 3. Stable carbon (left) and nitrogen (right) isotope values from seventeenth- (green diamonds) and eighteenth- (blue diamonds) century rats at Ferryland. Group averages are shown as circles with error bars indicating  $1\sigma$ .



Figures 4. Stable carbon and nitrogen isotope values and standard ellipses for seventeenth- (green diamonds) and eighteenth- (blue diamonds) century rats contextualized within faunal baseline data from Ferryland (Guiry et al. 2012). Error bars indicate  $1\sigma$ .



## Tables

Table 1. Physical attributes of three major commensal *Rattus* species encountered at archaeological sites (adapted from King 2005; based on a survey of data rats inhabiting New Zealand).

Species	<i>Rattus exulans</i>	<i>Rattus rattus</i>	<i>Rattus norvegicus</i>
Adult weight range (g)	60-180	120-225	200-450
Max length (head and body; cm)	180	225	250
Tail length	~head-body length	< head-body length	> head-body length

Table 2. Stable carbon and nitrogen isotope and associated collagen quality data for Ferryland rodents. MARC numbers are from Guiry and colleagues (2012).

Lab No.	Taxon	Element	Event	Context	Time Period	$\delta^{13}\text{C}\%$	$\delta^{15}\text{N}\%$	%col	%C	%N	C
S-UBC 1727	<i>Rattus</i> sp.	Femur	116	Privy deposit	1630s	-19.5	7.8	12.5	41.6	14.7	
S-UBC 1721	<i>Rattus</i> sp.	Maxilla	111	Privy deposit	1640s	-19.0	10.0	14.4	41.2	14.0	
S-UBC 1724	<i>Rattus</i> sp.	Femur	44	Storehouse occupation deposit	1650-1673	-17.4	14.1	13.2	41.5	14.5	
S-UBC 1719	<i>Rattus</i> sp.	Inominate	49	Privy destruction layer	1673	-19.4	11.5	9.5	41.4	14.0	
S-UBC 1730	<i>Rattus</i> sp.	Humerus	644	First house occupation deposit	1622-1696	-15.5	16.2	14.3	41.5	14.9	
S-UBC 1711	<i>Rattus</i> sp.	Tibia	651	Mansion house refuse deposit	1622-1696	-18.2	14.2	13.3	40.0	13.0	
S-UBC 1712	<i>Rattus</i> sp.	Tibia	651	Mansion house refuse deposit	1622-1696	-17.1	13.0	14.8	42.2	14.9	
S-UBC 1723	<i>Rattus</i> sp.	Inominate	NA	Privy deposit	1622-1673	-19.6	11.4	6.1	41.2	13.4	
S-UBC 1728	<i>Rattus</i> sp.	Tibia	481	Fireplace of brew or later kirk house	1622-1696	-18.7	9.5	12.4	41.5	14.5	
S-UBC 1722	<i>Rattus</i> sp.	Maxilla	509	Mansion house refuse deposit	1650-1696	-18.5	12.4	13.5	40.7	13.8	
S-UBC 1713	<i>Rattus</i> sp.	Humerus	627	Mansion house refuse deposit	1622-1696	-18.3	12.5	18.1	41.4	13.8	
S-UBC 1718	<i>Rattus</i> sp.	Humerus	627	Mansion house refuse deposit	1622-1696	-18.8	11.9	18.4	40.9	13.4	
S-UBC 1741	<i>Rattus</i> sp.	Tibia	627	Mansion house refuse deposit	1622-1696	-18.5	11.7	14.9	42.7	15.4	
S-UBC 1714	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-16.8	14.1	14.5	42.2	14.8	
S-UBC 1715	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-19.0	7.4	13.4	41.6	14.7	
S-UBC 1716	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-19.0	9.0	15.0	41.6	14.4	
S-UBC 1734	<i>Rattus</i> sp.	Mandible	634	Mansion house service wing (structure 18)	1622-1696	-21.5	3.1	9.2	43.3	15.0	
S-UBC 1735	<i>Rattus</i> sp. or <i>M. musculus</i>	Mandible	634	Mansion house service wing (structure 18)	1622-1696	-22.2	3.3	11.1	42.1	13.6	
MARC 325	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-19.2	7.6	16.4	43.9	15.7	
MARC 326	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-19.2	7.1	14.6	43.8	15.8	
MARC 327	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-18.6	6.4	16.6	44.3	15.8	
MARC 328	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-18.0	7.9	16.3	44.7	16.0	
S-UBC 1733	<i>Rattus</i> sp.	Ulna	637	House deposit (structure 15)	1697-1720s	-16.5	17.5	17.5	41.9	13.8	
S-UBC 1729	<i>Rattus</i> sp.	Humerus	694	Occupation layer	1750s-1790s	-18.0	11.2	15.2	41.5	14.8	
S-UBC 1731	<i>Rattus</i> sp.	Humerus	847	Kitchen deposit (stucture 19)	1700s	-18.5	14.6	10.3	42.0	13.9	
S-UBC 1732	<i>Rattus</i> sp.	Humerus	847	Kitchen deposit (stucture 19)	1700s	-17.1	12.5	12.8	43.6	15.4	
S-UBC 1736	<i>Rattus</i> sp.	Mandible	873	Kitchen deposit (stucture 19)	1697-1700s	-14.6	19.3	15.1	42.2	14.5	
S-UBC 1737	<i>Rattus</i> sp.	Mandible	873	Kitchen deposit (stucture 19)	1697-1700s	-15.1	18.1	12.8	42.3	14.8	
S-UBC 1738	<i>Rattus</i> sp.	Mandible	873	Kitchen deposit (stucture 19)	1697-1700s	-17.4	11.7	12.6	41.5	14.8	
S-UBC 1739	<i>Rattus</i> sp.	Mandible	873	Kitchen deposit (stucture 19)	1697-1700s	-16.5	16.4	13.5	38.2	13.5	
S-UBC 1740	<i>Rattus</i> sp.	Mandible	873	Kitchen deposit (stucture 19)	1697-1700s	-17.5	12.5	10.3	42.2	15.1	
S-UBC 1725	<i>Rattus</i> sp.	Tibia	306	Plow zone	1700s-1900s	-18.0	15.1	14.8	41.5	14.1	

S-UBC 1726	<i>Rattus</i> sp.	Femur	0	Unknown	Unknown	-17.7	13.0	11.4	40.9	14.0
S-UBC 1717	<i>Rattus</i> sp.	Femur	634	Mansion house service wing (structure 18)	1622-1696	-20.4	8.6	5.9	40.5	12.4
S-UBC 1720	<i>Rattus</i> sp.	Tibia	50	Privy (upper fill)	1650-1673	-16.4	15.5	8.0	41.3	12.8
S-UBC 1710	<i>Mus musculus</i>	Tibia	613	Stable or kitchen refuse	1640-1650s	-21.9	7.5	14.3	39.2	10.7

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