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Research Article

An application of the variable-r method to subpopulation growth rates in a 19th century agricultural population

Corey S. Sparks

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Corey S. Sparks[1]

Abstract

This paper presents an analysis of the differential growth rates of the farming and non-farming segments of a rural Scottish community during the 19th and early 20th centuries using the variable-r method allowing for net migration. Using this method, I find that the farming population of Orkney, Scotland, showed less variability in their reproduction and growth rates than the non-farming population during a period of net population decline. I conclude by suggesting that the variable-r method can be used in general cases where the relative growth of subpopulations or subpopulation reproduction is of interest.

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1. Introduction

In many areas of the world, the population involved in agriculture is in decline, mainly due to the movement of people to cities and the reorganization of national economies away from agricultural production (Firebaugh 1984; Rhoda 1983; Stambuk 1991; Wenxian and Xiaorong 1989; White 2008). While these changes document macro-level population trends, the micro-level implications of these shifts are that, especially in areas with high concentrations of the population in agricultural production, many farms face failure due to the out-migration of family members to urban areas, financial constraints, or inadequate labor resources (Goldschmidt 1978; Harris and Gilbert 1982; Lobao and Meyer 1995; Meert 2000; Meert et al. 2005; Meyer and Lobao 1997). For farming households to remain sustainable, they must walk a tight demographic line between persistence and failure. This suggests, at least for smallholder agriculture (Netting 1993), that individual families must balance their current and future economic interests by managing fertility and the household consumer/worker ratio, while ensuring an adequate labor supply (Chayanov 1966; Durrenberger 1984; Durrenberger and Tannenbaum 2002; Hammel 2005a, 2005b, 2005c; Van Bavel 2004). This assumes that the family provides much of the household's agricultural labor, an assumption which generally holds for smallholder agriculture, and is especially true in the current setting of the northern islands of Scotland. This pressure is coupled with the need to maintain a household size that is small enough to avoid the negative effects that come with having a high density of persons in the household (Curtis et al. 1993; Desai 1992; Gupta 1997; Hagen et al. 2006; Hagen et al. 2001). For larger commercial farms, this balance is less important because of the reliance on hired labor, and because bigger farms often have a larger capital base that provides a buffer against seasonal hardship. Meanwhile, the non-farming segment of most national populations has tended to grow, especially in urban areas (Bradshaw and Schafer 2000; Firebaugh 1984; Kasarda and Crenshaw 1991), because of the movement of the locus of production away from agriculture to manufacturing and service industries.

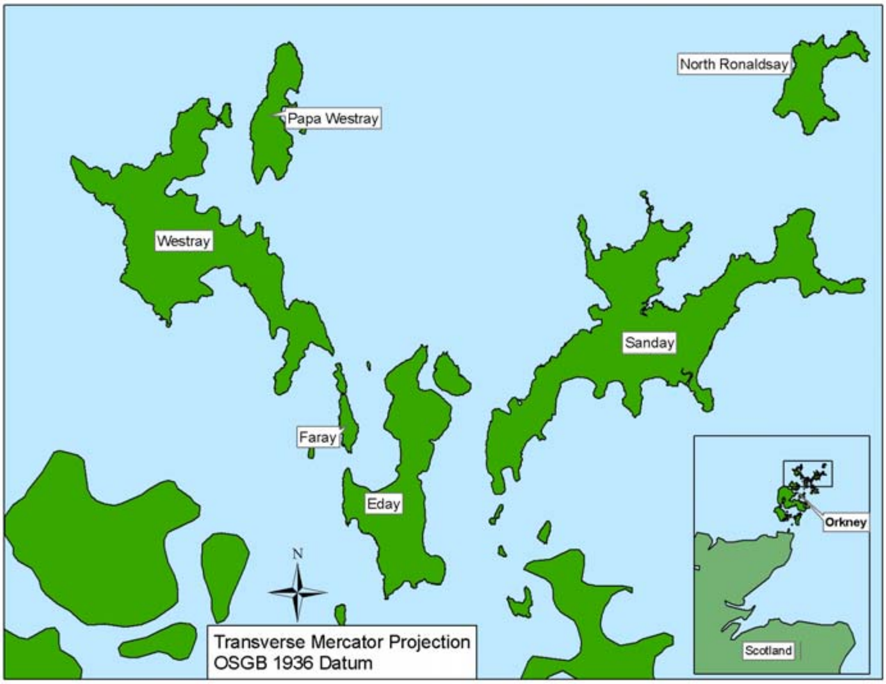
In the Orkney archipelago, which lies off the northern coast of Scotland, the 19th and 20th centuries witnessed a major restructuring of the population and the agricultural workforce, with the population in agriculture declining from around 60% in the mid-19th century to just over 10% in 2000 (GROS 2001). The purpose of this paper is to illustrate an application of the variable-r method (Preston and Coale 1982) for comparing subpopulation age-specific growth rates and net reproductive rates, with an example from the Orkney islands of Scotland during the 19th century. The goal of the analysis is to determine how the farming and non-farming segments of the population grew in relation to one another during a period of economic downturn and population decline. I begin by providing a description of the geographic and cultural setting for the population under consideration, and follow with the application of the variable-r method.

2. Geographic and cultural background

This paper deals with the population decline and the shift away from the agricultural sector of the economy that took place on the Orkney archipelago in northeast Scotland during the mid- to late-19th century. These changes may be attributed in large part to the geographic, temporal, and cultural setting of the islands. Figure 1 shows the geographic position of the archipelago. Located at roughly 59˚N 3˚W (the meeting ground of the North Sea and the North Atlantic), the Orkney island group is composed of 20 inhabited islands, as well as many other uninhabited small islands referred to as holms or calves. These 20 islands correspond to a land area of approximately 1,000 square kilometers. The current study focuses on the northern Orkney islands. The total surface area of the northern islands is 177.92 square kilometers, with the six islands of the study area representing less than 20% of the total land area of Orkney proper. The six islands included in the study area are Eday, North Ronaldsay, Papa Westray, Pharay, Sanday, and Westray. These islands were selected from the Orkney archipelago as part of a large multi-year interdisciplinary study of demographic and family history, archaeological settlement patterns, and environmental variation (Jennings et al. 2008; Johnson et al. 2005; Murtha et al. 2008; Sparks 2006; Sparks et al. 2005).

Settlement within the islands is extremely discontinuous, with individual settlements called farmsteads scattered widely across the landscape, and only weakly clustered into higher-order settlements – traditionally called townships, but purely rural in character. Higher-order settlement is extremely restricted, and there are only two “villages” in the entire Northern Isles. The whole of Orkney itself today only has two towns (Kirkwall and Stromness) on the island of Mainland, where the majority of the archipelago's population lives today. Like most areas outside of the two towns of Orkney, the Northern Isles today are characterized by sparsely occupied agricultural communities, which are similar to other areas of the Scottish Highlands and Islands. The maximum population size of the islands was 6,062 people in 1861, and it has since diminished to 1,297 in 2001.

Figure 1: Map showing the location and names of the northern Orkney Islands, Scotland



The traditional system of production in northern Orkney was geared primarily to meeting household subsistence needs, and secondarily to paying rents, mostly in kind (Schrank 1995; Wenham 2001). Agriculture was based on a delicate balance of arable grain production (black oats and bere, a primitive form of barley) and the raising of livestock (cattle, sheep, pigs, and chickens) – a balance that was critical to long-term demographic homeostasis (Dodgshon 1993; Fenton 1978; Firth 1974). This is because livestock grazing both competed with arable land itself, and provided essential inputs into arable land in the form of animal manures (Dodgshon 1994; Fenton 1978; Firth 1974). Archaeological and historical evidence suggests that this traditional system of agricultural production had not changed in any fundamental way since the early medieval period (Fenton 1978; Marwick 1952), but Orkney need not be considered necessarily unique in these traits, as many areas of the North Atlantic and the islands of

Scotland displayed similar settlement patterns as Orkney (Dodgshon 1993; Gunnlaugsson 1988).

Beginning in the late 18th century, several major economic changes occurred to the traditional agrarian system that are known to have had dramatic effects on Orkney, even though the demographic details are not yet clear. The first of these periods of change was the 50-year kelp boom, which began around 1780. During this period, several species of seaweed were collected and burned on a commercial scale to make kelp, which provided alkali to the British glass-, soap-, and dye-making industries (Thomson 2001).[2] In response to the increased demand for labor in kelp harvesting and processing, the Northern Isles and Orkney as a whole appear to have experienced a near doubling of population within a few decades—a remarkable expansion for what had been up to that time a near-subsistence-level agrarian system with low population levels (Barclay 1965; Thomson 1983). Although part of this population increase was attributable to net immigration, there is evidence that increases in the population may also have involved changes in fertility and mortality patterns for local residents (Anderson and Morse 1993a, 1993b; Bowers 1983; Brennan 1979; Brennan 1983; Brennan et al. 1982; Brennan and Relethford 1983; Thomson 2001). Regrettably, standardized demographic data for this period are rare for the Northern Isles, and for Orkney in general. Thus many of the "facts" of the demography of this period are derived from conjectural accounts, such as the Old Statistical Accounts of Scotland (Barclay 1965; Sinclair 1796).

The kelp boom persisted until 1830, when the British government repealed restrictive tariffs on the importation of high quality alkali from other countries (Thomson 1983). As a result, the price of Orkney kelp collapsed, and the islands entered a period of agricultural stagnation largely reflecting the disincentives to agricultural innovation that had been associated with the kelp boom itself. Little is known about the effects of this sudden economic downturn on the population of Orkney; it is clear, however, that the collapse of the kelp market was followed by some 20 to 30 years of low returns on labor caused primarily by poor land management and a dearth of marketable exports. The modern agricultural improvement movement finally reached the Northern Isles in the mid-19th century, ushering in a period of farm reorganization, enclosure of common pasture, construction of new field drainage systems, and general intensification of agricultural production (Schrank 1995; Thomson 2001). This period was again accompanied by population increases, although growth was nowhere near as rapid as during the early stages of the kelp boom. The period of agricultural expansion continued until about 1880, when the prices of Orkney cattle and grain exports experienced another sudden downturn owing to competition from overseas, mainly North America and Australia (Thomson 2001). Because of the ensuing

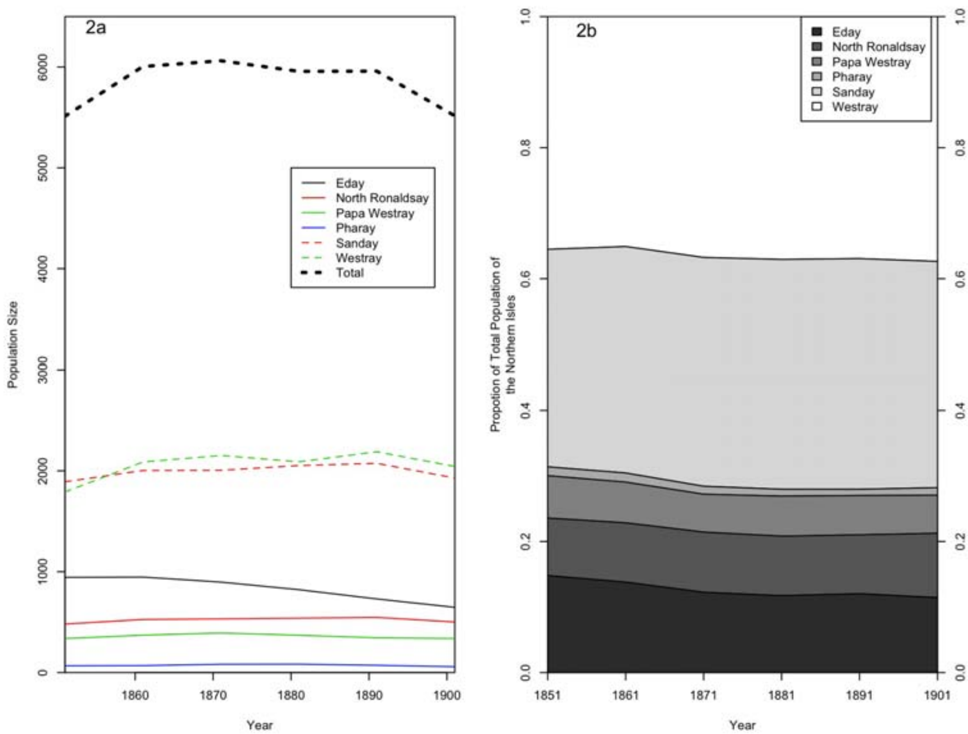
[2] In British usage, *kelp* is the marketable material produced by burning seaweed, as well as the seaweed itself.

agricultural depression, Orkney entered a prolonged period of population decline caused by increased out-migration to mainland Scotland, Canada, the United States, Australia, and New Zealand. The increase in migration associated with this same agricultural depression in other parts of the British Isles has been the subject of some research (Pooley and Turnbull 1998), but detailed information on the north of Scotland in general (Anderson and Morse 1993a, 1993b; Flinn 1977; Lumb 1980; Stockdale et al. 2000), and Orkney in particular (Barclay 1965; Forsythe 1980; Lee 2007), is often sparse. We know that migration in Orkney was both a demographic fact and a life course decision faced by many young men and women. Owing to early steam liner access to the Northern Isles and the fishing and sailing traditions of the Orcadians, many unmarried men (and women) sought paid work away from the farms on which they had been born and raised (Lumb 1980; Miller 1999; Thomson 2001). Migration was seasonal, temporary, or permanent; and while the net effects of migration show up as additions or subtractions of people between censuses, the intricacies of the migration experience often cannot be estimated. Seasonal migration would have been a way of life for the Orcadians, as they have often been described as “farmers with boats” who would have been prepared to travel long distances to participate in whaling and herring fishing (Miller 1999).

Temporary migration was regularly practiced in the Orkney archipelago, as census records for the various islands of Orkney indicate relatively high fractions of residents that were born on other islands in Orkney, but were living away from home for work reasons. For example, between 1851 and 1901 an average of 9% of residents of the Northern Isles of Orkney were from another one of the Northern Isles, and another 8% were from somewhere outside of Orkney. Permanent migration out of Orkney was common, but just how common is unknown.

The recent history of Orkney may be summarized as having undergone both population growth and decline. The period of population growth generally peaked in the mid- to late-19th century, followed by a sustained decline that continued into the 20th century. For the 19th century, these trends are illustrated by the population sizes of the various Northern Isles given in Figure 2a. Figure 2b is provided to show more accurately the proportion of the total population of the Northern Isles that each of the individual islands represents.

Figure 2a-b: Population size of the northern Orkney islands, Scotland, 1851 to 1901, and proportionate distribution of population size for each island in the area



The population as a whole has declined substantially since the 19th century, though Westray and Sanday were and continue to be the largest communities within the Northern Isles. The questions asked in the current analysis are as follows: First, did the farming segment of the population manage to sustain itself demographically during the period of population growth and initial decline? Second, is the decline primarily attributable to the loss of landless households that were never able to secure their livelihoods as farmers?

First, a distinction between the "farming" and "non-farming" segments of the population must be made. By "farming" population, I explicitly mean households whose members are working in agriculture the majority of the time for their personal livelihood. These households may own or rent land which is used for their personal production, or as a partial means of covering rent to a larger land owner. In contrast, I assume the “non-farming” segment of the population is employed by and large in activities not related to household agricultural production. This includes more professional occupations, such as teachers, merchants, smiths, and clergy; but also general and agricultural laborers. The latter occupation is assumed not to be working toward the household’s account, but instead toward the account of another household or large landowner. This distinction between the farming and non-farming segments of the population is made for two reasons. First, the farming population is assumed to be more “native,” or to have deeper ties to the area, and to have a stronger need to retain the sustainability of their families so that land (or access to land) may be passed down from generation to generation. This, I argue, is key to the need to maintain a balanced pace of reproduction and child survival for this segment of the population (see below). Second, the non-farming segment of the population is composed of households whose members are less likely to share the deep community connections that the farming population does. Given this detachment from the community, they are more likely to be influenced in their behaviors by swings in the labor market, less likely to be interested in maintaining a favorable ratio of household producers to consumers, and more likely to emigrate when market conditions are unfavorable.

Based on a preliminary analysis of infant and childhood mortality data generated from a record linkage procedure from Orkney that employed a hazard analysis framework, we find that the farming segment of the population of the northern Orkney islands faced an apparent, although small, advantage in terms of child survival and the timing of reproduction. For example, the hazard analysis of childhood mortality shows that children in farming families had a higher probability of surviving past age one and age 15 than children born into non-farm families, after controlling for characteristics of the child, the mother, and the household. Additionally, farm families had significantly longer first birth intervals compared to non-farm families, indicating a delay in the onset of childbearing. Also related to this delay in first births is the delay in marriage for farm families: the average age at marriage is two years later among males from farm families (farm mean age at marriage= 27.1, non-farm =25.1), with a smaller difference seen among females (farm mean age at marriage =23.1, non-farm=22.8). This trend is consistent with the system of land inheritance, in which the sons typically had to wait until they were old enough to purchase or take over the family farm. Based on these analyses, it would appear that, at the individual family level, there may have been a balancing act occurring in farm households whereby the households were seeking to balance their current and future reproduction in order to maximize the well-being of themselves and their children (Hagen et al. 2006; Hagen et al. 2001; LeGrand et al. 2003; Strulik 2004; Van Bavel 2004). This balancing act suggests that farm families could have postponed childbearing and invested more time/resources in their children in an effort to ensure their survival to adulthood. In turn, by increasing the likelihood that each child would live to adulthood, they improved the odds of keeping the land they had, and increased the chances that they would be able to acquire more. On the reproductive side of the equation, it appears that the families chose not to have a large number of children, as they were aware that having too many offspring would consume resources that could decrease the potential income they could use to rent and eventually purchase more land. At this point, direct evidence of intentional spacing of births is lacking—a general lament of scientists studying historical populations. However, recent work has shown theoretically how and why such spacing could occur in such populations (Van Bavel 2004, 2007; Van Bavel and Kok 2004).

A preliminary analysis based on record linkage procedures using vital registration information on marriages, births, and deaths has suggested there were some problems in the data. One apparent problem of concern is the reliability of the vital registration data, especially concerning infant deaths and incomplete linkage due to out-migration prior to death or marriage. Specifically under-enumeration of infant deaths was suspected, as mortality rates under age one were very low, and estimates of life expectancy at birth were in the mid-sixties in the mid-19th century. The fact remains that, as is the case with any study using historical vital registration data, one has to cope with the possibility that both birth and death registration may be flawed, especially in remote areas such as Orkney. In hopes of avoiding some of these data problems, I employ the variable-r method. This method is selected because it was originally derived for use in estimating demographic parameters in situations where the ideal data do not exist (Cai 2008; Preston and Coale 1982; Preston and Wang 2007) from "more reliable" sources, such as census enumerations and fertility surveys. Still, some doubt must exist when historical data are used, as many factors may combine to introduce discrepancies in the data. However, based on facts I have stated above, I believe that the census enumerations in this case provide good "snap shots" of the population of the Northern Isles. As for the reliability of the birth registration, there is some doubt that there was 100% registration of births. But because the communities in this analysis are rather small in area, and because each community in the study area had its own local registrar of vital events, I suspect that the birth records may be representative of the actual number of births. I have constructed a database of census enumerations, marriage records, and birth registrations for Orkney with the goal of providing the necessary data to use the variable-r method, while avoiding the problematic data (notably, enumerations of infant deaths).

More conceptually speaking, this paper represents an attempt to link the small, family-level advantages of the farm segment of the population to a population level measure of net reproduction, the NRR. Theoretically, the NRR captures both contributions of mortality and fertility to the overall net reproductivity of the two segments of the population: the population in farming households and those involved in other forms of work. I hypothesize that, because of the previously observed advantage in terms of child survival and birth spacing in farm families, the farm population should display a more stable pattern of reproduction and survivorship (as measured in a net fashion by the NRR) than the non-farm segment of the population. I also hypothesize that the non-farm segment of the population will display a higher degree of variability in its reproductive pattern because of that population's tendency to follow cycles in the local labor market. At the same time, however, I also have to account for the possibility that not everyone within a farm household would have been directly involved in agricultural labor, and that those in non-farm households would not have participated in agriculture. Based upon my fieldwork in this area, I can confirm that it is very much the case that members of families who are actively farming tend to be devoted to agricultural production, while younger members of non-farm families are much more flexible in their activities, and generally only participate in agriculture directly if a close relative is in need of temporary labor. Moreover, it has been the rule rather than the exception that farming families also extensively engage in non-farm work in order to maximize potential income: one of the primary sources of income in the early 20th century for farm families and non-farm families alike was the production of eggs, which often brought in enough cash income to allow families to purchase more farm land (Thomson 2001). Additionally, as in many areas where smallholder agriculture dominates small farms, family members in Orkney often participate in off-farm labor to earn cash income. Indeed, it is difficult to find a smallholder economy in which farmers are agricultural purists (Netting 1993). But, as is also the case in other societies in which smallholding dominates agricultural production, those families who are able to gain access to agricultural land tend to pass it down through inheritance, rather than sell the land to non-family members or outsiders. It is the latter situation that I believe is operating in Orkney. In the analysis that follows, I attempt to determine if the farming population showed signs of demographic sustainability during a dynamic portion of the area’s history.

3. Data and methods

The variable-r method (Bennett and Horiuchi 1981; Preston 1983; Preston and Coale 1982; Preston et al. 2000) was initially described as an extension of stable population theory that made the relations within a stable population generalizable to any population, without necessarily having to meet the assumption of having a closed population. The method has found popularity in areas in which demographic data are incomplete (Cachinero-Sanchez 1985; Cai 2008; Coale 1984; Gage 1985; Gage et al.

1986; Preston and Wang 2007), and for estimation of more informative quantities from less-than-ideal data sources. The variable-r method allows for the estimation of the NRR, typically given as

$$NRR = \int_{\alpha}^{\beta} p(a)m(a)da \tag{1}$$

with *p(a)* being the probability that a woman survives to age *a*, *m(a)* being the rate at which women age *a* have daughters, and the integral being over all ages of childbearing, typically 15 to 45. Preston and Coale (1982) show how to estimate the NRR from two successive age distributions and the distribution of mother's ages at childbirth, referred to as *v(a)*. They proceed to show the NRR can be calculated as:

$$NRR = \int_{\alpha}^{\beta} v(a)e^{\int_0^a r(x)dx} da \tag{2}$$

where *r(x)* is the age-specific growth rate at each age *x*. The age-specific growth rates act effectively to capture all the effects of mortality and fertility over the time interval (Horiuchi and Preston 1988).

In the present analysis, I apply the modified procedure outlined in Preston and Wang (2007) to estimate the NRR in the presence of migration. This quantity, referred to as NRR*, is the NRR in the presence of migration. As Preston and Wang (2007) show, migration can substantially increase or decrease the NRR, depending on whether the area is a migrant receiving or sending area. They go on to show that NRR* is calculated as

$$\text{NRR*} = \int_{\alpha}^{\beta} p(a)p^*(a)m(a)da \tag{3}$$

where *p*(a)* is the proportionate increase or decrease in a cohort as the result of age-specific migration. The net effect of migration is then represented in the same way as the effects of fertility and mortality. Using their methodology, my equation (2), is then modified to be:

$$NRR^* = \int_{\alpha}^{\beta} v(a)e^{\int_0^a r(x)dx} da \tag{4}$$

because, as Preston and Wang show, the term inside the integral in (3) represents the terms inside the integral in (4):

$$p^*(a)p(a)m(a) = v(a)e^{\int_0^a r(x)dx} \qquad (5)$$

which can be interpreted as the proportion of births to women age *a*, times the relative size of the population at age *a* (Preston and Wang 2007).

In practice, I approximate equation (4) by discrete summations over five-year age categories, centered on the midpoint of the interval (Coale 1984; Preston 1983; Preston and Coale 1982; Preston and Wang 2007). As the variable-r method has been shown to be sensitive to errors in age misreporting, I use five-year intervals in hopes of avoiding some of these prospective errors. In this analysis I am primarily concerned with the relative values of the NRR* for the two subpopulations in the analysis. Additional errors from under-reporting are known to cause problems for the variable-r method. Given the small scale of the populations under consideration in this analysis, variation in geographic coverage is less of a concern than seasonal migration away from the islands in the study. Emigration from Orkney is known to have been relatively steady beginning in the mid-19th century, but we do not know the exact volume of the out-migration over this period. However, previous work suggests that the Northern Isles, and other similar areas of rural Scotland, lost a large proportion of their populations between 1851 and 2001 (Lumb, 1980; Thomson 2001). I use the modification in (4) primarily because I expect age-specific migration to affect the NRR*, but also in order to vary between the farming and non-farming segments of the population.

The recent applications of the variable-r method by new generations of demographers has shown a renewed interest in its utility in a variety of different settings (Cai 2008; Preston and Wang 2007), but the method is mostly used where more precise data are unavailable. Such is the case in this example. The primary data sources for this paper are the individual-level census returns for the Northern Isles of Orkney, Scotland, over the period 1851 to 1901. These data represent the entire population (100% of the population present on the date of the census enumeration, typically in early spring) in households, not samples. These data were obtained by the author through the Orkney Family History Society's office in Kirkwall, Orkney, Scotland. The censuses provide standard information on every person at home on the day of the census enumerations each year, including address, age, sex, conjugal condition, occupation, place of birth, and, in some years, the amount of land held by the household. From these returns, occupations of household heads were reclassified based on standardized codes from the IPUMS project (Ruggles et al. 2008), and those households whose heads were listed as farmers or crofters were classified as being farm families. Households with heads listed as having any other occupation category were classified as being non-farm families. I present the distribution of the IPUMS codes for household head occupations in Table 1 to show the variety of occupations present in the non-farm segment of the population. While in general the farm/non-farm occupation classification seems restrictive, especially for Orkney, this classification is necessary to estimate the age-specific growth rates and the NRR* for the two segments of the population described above.

Table 1: Distribution of household head occupations by farming and non-farming household definitions

Occupation Class	Year					
	1851	1861	1871	1881	1891	1901
Farming Households						
Farmers/Crofters/Farm Managers	581	627	649	643	589	634
Total % of Households	51.3	53.6	57.1	58.0	57.9	63.8
Non-farming Households						
Laborers	150	110	114	101	114	75
Agricultural Laborers	182	168	153	146	105	89
Service Workers (non-household)	5	8	2	6	4	11
Service Workers (household)	7	9	3	8	12	9
Operatives	74	72	68	54	34	29
Craftsmen	89	128	102	91	97	93
Sales Workers	15	14	19	21	26	17
Clerical and Kindred Workers		1		4	1	4
Managers, Officials, Proprietors	3	4	2	4	8	6
Professional/ Technical	27	28	25	30	27	26
Total % of Households	48.7	46.4	42.9	42.0	42.1	36.2

There are several issues concerning the nature of the census data that deserve some discussion. As mentioned above, it appears that seasonal migration of males was not a problem in this setting, since a very small fraction of households were headed by married women, and, on average, 85% of the households in the Northern Isles had male household heads. Many times when the household head was listed as an unmarried female, the enumerator also provided an occupation, so I believe that a substantial undercount of household occupations in this case is unlikely. Additionally, less than 1%

of households were listed as having married female household heads, suggesting seasonal migration will not be a major factor in the analysis.

To estimate the *v(a)* quantity in (2), I use vital registration data collected from the General Registrar's Office of Scotland on births that were subsequently linked to the marriages that produced them using standard record linkage criteria (Fure 2000; Hautaniemi et al. 2000; Wrigley 1973). This linkage procedure produced a linkage rate of 76%; i.e., 76% of births between 1855 and 1901 could be linked to the correct marriage. The primary reason why births could not in some cases be linked to a marriage was that the marriage took place outside of Orkney, and the record could not be located. This of course produces an interesting situation in which there could be missing births to non-farm or farming migrants, and the linkage process would miss these. For each birth, the age of the mother was calculated as the year of the child’s birth minus the year of the mother’s birth, which was obtained from her marriage registration. Mother’s ages were then lumped into five-year intervals to match the same ages as the census data. Finally, since the vital registration of births did not begin until 1855, the period 1851 to 1854 has no data for this analysis; instead, I use the distribution of births between 1855 and 1861 to calculate the *v(a)* function for this time period. This produced fewer births to use in the calculation of *v(a)* for the 1851 to 1861 period, and the ages of the mothers were found to be lower on average than the ages of mothers in the other decades. While this may be a data bias problem, it may also be a representation of younger mean ages at childbearing at this time.

The farm/non-farm classifications for each birth (and subsequently for each mother at the time of the birth) were generated in the same way as the census classifications. If the child's father's occupation on the birth record was listed as farmer or crofter, the birth was classified as belonging to the farm segment of the population; otherwise, the birth was classified as a non-farm birth. While most families maintained the same occupational classification throughout their childbearing history, it was possible for a family to change classifications; thus a family could contribute births to both the farm and non-farm segments. Based on the subdivision of the population into two categories, the resulting age and subpopulation specific growth rates are calculated as:

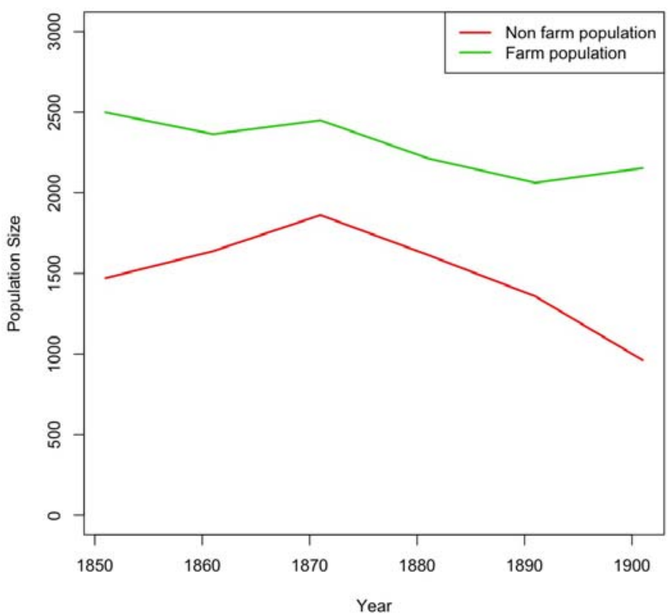
$$r_i(a) = \ln\left(\frac{N_i(a,t+h)}{N_i(a,t)}\right) * \frac{1}{h} \qquad (6)$$

with *h* being the inter-census period (10 years), and where the index *i*, indicates the farm and non-farm segments of the population. To clarify, the age-specific growth rate represents the relative size of the same age class at two different time periods; for example, the number of people aged 25 to 29 in 1851 compared to the number of people age 25 to 29 in 1861. The NRR* calculations will take the form of equation (4), which is essentially the same as the methodology in Preston and Wang (2007), with the only difference being that I use five-year age intervals and 10-year census intervals, while those authors used five-year intervals for both age and time.

4. Results

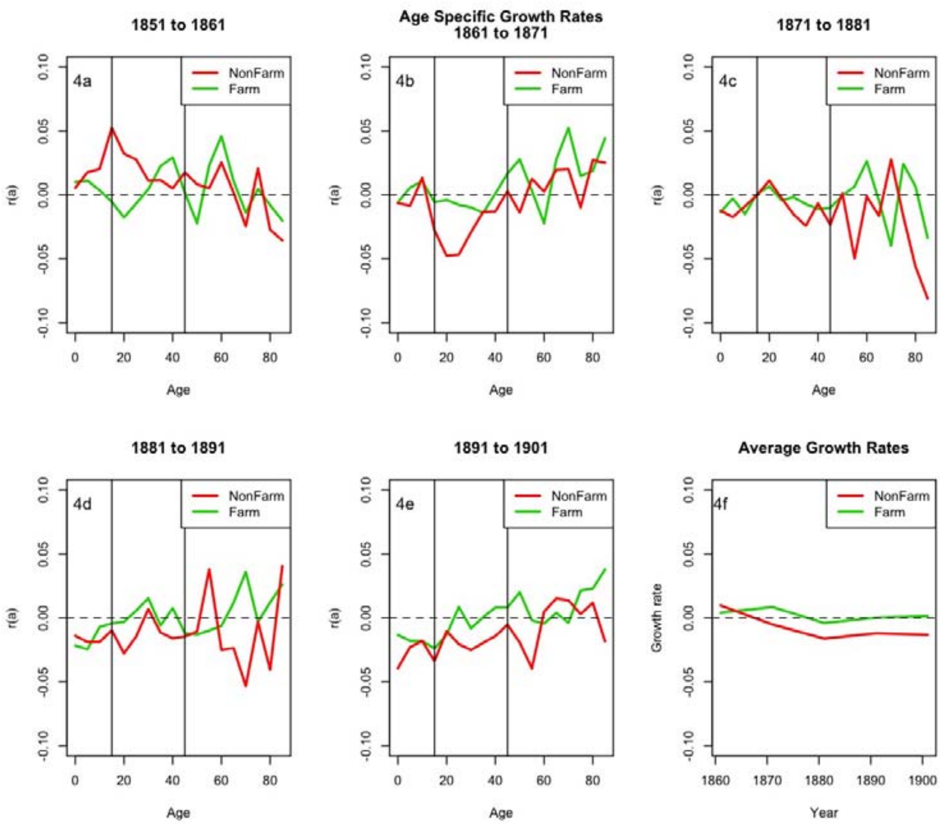
Figure 3 provides the population sizes over the period 1851 to 1901 for the northern Orkney isles. In terms of total size, both segments of the population declined over the period 1851 to 1901, with the non-farm population first increasing then decreasing, and the farm population showing a bit more of a cyclical fluctuation. Based on estimates of the crude birth and death rates for this period, the population of the archipelago would have grown on average by 1.23% if we were to consider the population closed. However, as seen in Figure 2a, it is obvious that emigration led to general decline in both segments of the population.

Figure 3: Size of the farm and non-farm population of the northern Orkney islands, Scotland, 1851 to 1901



Farm and non-farm age-specific growth rates and total annual growth rates are presented in Figures 4a-f. These figures provide the estimated age-specific growth rates for the farm and non-farm segments of the total population, as estimated via equation (6). To aid in the interpretation of the figures, I include a baseline for 0% annual growth and vertical lines showing the childbearing segments of the population.

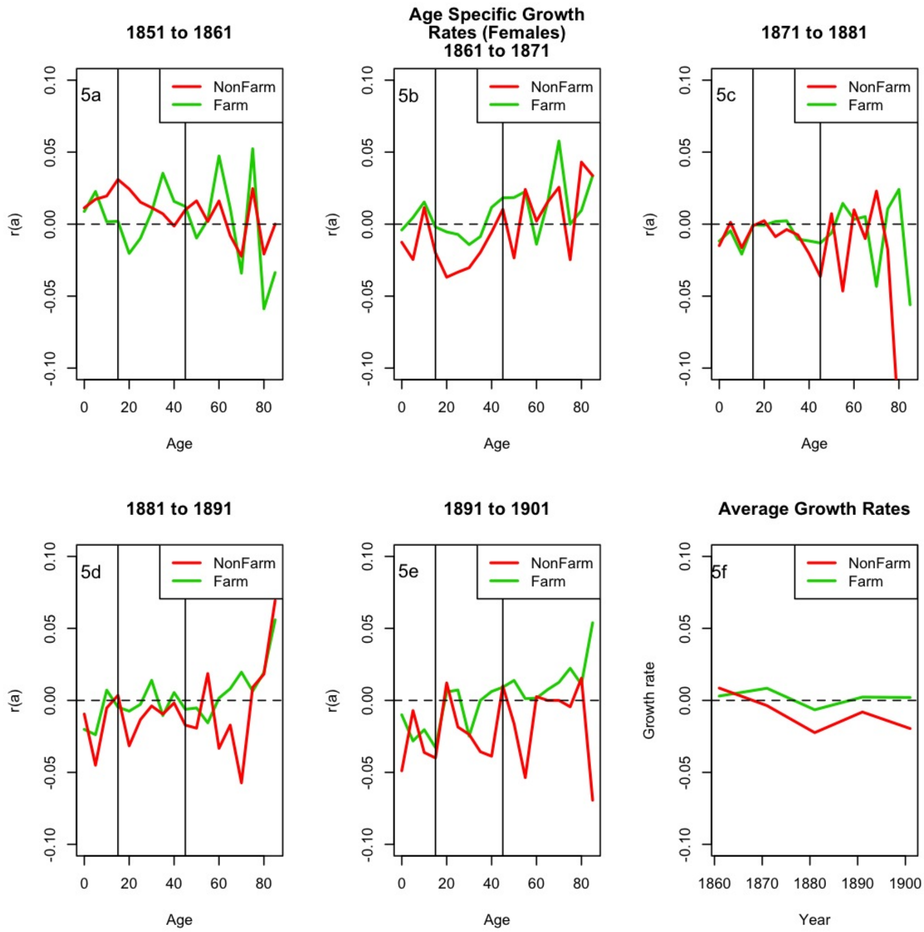
Figure 4a-f: Age-specific growth rates, $r_i(x)$, and total annual growth rates, r, for the farm and non-farm segments of the northern Orkney islands, Scotland population, 1851 to 1901



Between 1851 and 1861, the non-farm segment of the population grew in all age categories except the 70+ age ranges, but grew most noticeably in the early reproductive years (15 to 35). In comparison, the farm segment of the population exhibited growth in the <15, the 40 to 49, and the 60 to 69 age intervals; which suggests a much more inconsistent growth pattern than among the non-farm population. This pattern is somewhat reversed in the 1861 to 1871 period, with the non-farm population exhibiting negative growth in the reproductive years, and positive growth in the 10 to 15 and 55+ age intervals. On the other hand, the farm segment of the population exhibited growth in the 10 to 15 and 50+ age ranges. The decade spanning 1861 to 1871 is the period when the majority of agricultural re-organization is thought to have occurred in Orkney; an effort that roughly doubled available farm land in many areas of Orkney, including the Northern Isles (Schrank 1995; Thomson 2001; Wenham 2001). The 1871 to 1881 period shows near 0% growth rates for the farm population, and overall negative growth is observed for the non-farm population. Historical sources suggest that this was a relatively calm period in the Orkney economy, when agriculture was being gradually reorganized to focus more on animal husbandry and cattle production (Thomson 2001). The 1881 to 1891 period shows a re-emergence of the farm population, with positive growth rates in the childbearing years and in the seventies. However the non-farm segment of the population exhibits population declines for nearly all age ranges. This pattern corresponds to the historical period when there was a general decline in agricultural prices in Orkney (Thomson 2001). During the final period of 1891 to 1901, the non-farm segment of the population declined at all age ranges, except among the 60 to 70 age interval. Meanwhile, the farm segment of the population exhibited positive growth in all but the youngest age ranges. The average growth rate for both segments of the population is presented in Figure 4f, which summarizes the net growth of both segments of the population between 1851 and 1901. The major finding of this analysis is that the growth rates fluctuated for both the farm and non-farm segments of the population, and the youngest segments of the population were declining steadily over the period 1851-1901. In contrast, the largest growth rate occurred in the 50+ age ranges, indicating the general emergence of population aging in the Northern Isles. While the non-farm segment of the population was growing during the initial time period, this portion of the population was dominated by population loss after this period. In comparison, the farming population, while showing a slight negative growth rate around 1881, had positive net growth in all other time periods. In addition, the specific upturns and downturns in age-specific growth rates coincided with historically noted trends in the economic setting of Orkney. Our knowledge of these trends suggest that we are indeed capturing real trends in population change, and not just a statistical aberration. If the variances in the age-specific growth patterns of the farm and non-farm populations are compared using a standard F ratio, the farm population shows significantly less variability (F ratio = 0.558, p=.006) than the non-farm population.

The age-specific growth rates for the female segment of the population are shown in Figures 5a-f.

Figure 5a-f: Age-specific growth rates, $r_i(x)$, and total annual growth rates, r, for the female farm and non-farm segments of the northern Orkney islands, Scotland population, 1851 to 1901



Generally, the patterns of age-specific growth for the female population mirror those of the total population, with an overall trend of slightly more variable patterns of growth as seen in Figure 5f. If the variance in the female age-specific growth patterns of the farm and non-farm populations are compared using a standard F ratio, the farm population shows significantly less variability in the patterns of growth (F ratio = 0.498, p=.001).

Details of the NRR* calculations are provided in Tables 2 through 6, with the first table providing calculations for the period 1851 to 1861, and each subsequent table offering the calculations for the next decade, ending with the calculations for 1891-1901 in Table 5. The columns in these tables correspond to the steps taken in the calculation. Column 1 is the observed female age distribution of each segment of the population at the beginning of the interval (in Table 1, $N(1)$ is the population in 1851). Column 2 is the observed female age distribution at the end of the interval (in Table 1, $N(2)$ is the observed age distribution in 1861). Column 3 is the distribution of births by age of mother, $v(a)$, and is calculated from the observed distribution of births by age of mother between the periods given in the first line of the table (e.g., 1851 to 1861). Column 4 is the age-specific growth rate for age a calculated using equation (6). To approximate the integral in equation (4), I employ the same approximation as others (Cai 2008; Preston and Wang 2007), using discrete intervals and "locating" the observation of the current interval at the midpoint of the interval. This is done using the equation

$$\sum_{a=0}^{a-5} {}_5r_a \cdot 5 + 2.5 \cdot {}_5r_a \qquad (7)$$

Column 5 represents the first term of the summation, column 6 the second term, and column 7 the resulting summation. Column 8 is the exponent of the result of column 7, which is the approximated integral of the age-specific growth rate from equation (6). Finally, column 8 is the product of column 7 and column 3. Column 8 is summed over the ages of reproduction, and represents the estimate of the NRR reported in the tables.

Table 2: Details of the NRR* calculation for the period 1851 to 1861.†

1851 to 1861 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	Exp(Col 7)	Contribution to NRR*
0 to 5	206	225	0.000	0.009	0.000	0.022	0.022	1.022	0.000
5 to 10	169	212	0.000	0.023	0.044	0.057	0.101	1.106	0.000
10 to 15	184	187	0.000	0.002	0.157	0.004	0.161	1.175	0.000
15 to 20	200	204	0.053	0.002	0.166	0.005	0.170	1.186	0.063
20 to 25	163	133	0.291	-0.020	0.175	-0.051	0.125	1.133	0.330
25 to 30	128	116	0.280	-0.010	0.074	-0.025	0.049	1.050	0.295
30 to 35	90	98	0.185	0.009	0.025	0.021	0.046	1.047	0.194
35 to 40	85	121	0.143	0.035	0.067	0.088	0.155	1.168	0.167
40 to 45	76	89	0.048	0.016	0.244	0.039	0.283	1.327	0.063
45 to 50	84	95	0.000	0.012	0.323	0.031	0.353	1.424	0.000
50 to 55	76	69	0.000	-0.010	0.384	-0.024	0.360	1.433	0.000
55 to 60	65	67	0.000	0.003	0.336	0.008	0.343	1.410	0.000
60 to 65	43	69	0.000	0.047	0.351	0.118	0.469	1.599	0.000
65 to 70	43	48	0.000	0.011	0.587	0.028	0.615	1.850	0.000
70 to 75	45	32	0.000	-0.034	0.642	-0.085	0.557	1.746	0.000
75 to 80	16	27	0.000	0.052	0.472	0.131	0.603	1.827	0.000
80+	27	18	0.000	-0.041	0.734	-0.101	0.632	1.882	0.000
			#Births 115					NRR	1.111

Table 2: (Continued)

1851 to 1861 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	Exp(Col 7)	Contribution to NRR*
0 to 5	234	262	0.000	0.011	0.000	0.028	0.028		0.000
5 to 10	170	202	0.000	0.017	0.057	0.043	0.100	1.105	0.000
10 to 15	102	124	0.000	0.020	0.143	0.049	0.192	1.211	0.000
15 to 20	77	105	0.077	0.031	0.240	0.078	0.318	1.374	0.106
20 to 25	94	120	0.259	0.024	0.395	0.061	0.457	1.579	0.409
25 to 30	115	134	0.318	0.015	0.518	0.038	0.556	1.743	0.555
30 to 35	99	111	0.186	0.011	0.594	0.029	0.623	1.864	0.347
35 to 40	94	101	0.127	0.007	0.651	0.018	0.669	1.953	0.249
40 to 45	75	74	0.032	-0.001	0.687	-0.003	0.684	1.981	0.063
45 to 50	67	74	0.000	0.010	0.680	0.025	0.705	2.024	0.000
50 to 55	57	67	0.000	0.016	0.730	0.040	0.771	2.161	0.000
55 to 60	54	55	0.007	0.002	0.811	0.005	0.816	2.260	0.015
60 to 65	40	47	0.000	0.016	0.820	0.040	0.860	2.364	0.000
65 to 70	39	36	0.000	-0.008	0.901	-0.020	0.881	2.413	0.000
70 to 75	30	24	0.000	-0.022	0.861	-0.056	0.805	2.237	0.000
75 to 80	25	32	0.000	0.025	0.749	0.062	0.811	2.250	0.000
80+	16	13	0.000	-0.021	0.873	-0.052	0.821	2.272	0.000
			#Births						
			150					NRR	1.744

†The births for the *v(a)* calculations in this table were from 1855 to 1861, not 1851 to 1861, since vital registration did not begin until 1855.

**If *v(a)* from 1891 – 1901 is used instead of 1855-1861, farm NRR* increases to 1.123, and non-farm NRR* increases to 1.768.

B=# of births.

Table 3: Details of the NRR* calculation for the period 1861 to 1871

1861 to 1871 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	225	216	0.000	-0.004	0.000	-0.010	-0.010		0.000
5 to 10	212	222	0.000	0.005	-0.020	0.012	-0.009	0.991	0.000
10 to 15	187	218	0.000	0.015	0.003	0.038	0.041	1.042	0.000
15 to 20	204	200	0.053	-0.002	0.079	-0.005	0.074	1.077	0.057
20 to 25	133	126	0.291	-0.005	0.069	-0.014	0.056	1.058	0.308
25 to 30	116	108	0.280	-0.007	0.042	-0.018	0.025	1.025	0.287
30 to 35	98	85	0.185	-0.014	0.007	-0.036	-0.029	0.971	0.180
35 to 40	121	111	0.143	-0.009	-0.064	-0.022	-0.086	0.918	0.131
40 to 45	89	100	0.048	0.012	-0.108	0.029	-0.078	0.925	0.044
45 to 50	95	114	0.000	0.018	-0.049	0.046	-0.004	0.996	0.000
50 to 55	69	83	0.000	0.018	0.042	0.046	0.088	1.092	0.000
55 to 60	67	84	0.000	0.023	0.134	0.057	0.191	1.210	0.000
60 to 65	69	60	0.000	-0.014	0.247	-0.035	0.212	1.237	0.000
65 to 70	48	56	0.000	0.015	0.177	0.039	0.216	1.241	0.000
70 to 75	32	57	0.000	0.058	0.254	0.144	0.399	1.490	0.000
75 to 80	27	27	0.000	0.000	0.543	0.000	0.543	1.721	0.000
80+	18	19	0.000	0.005	0.543	0.014	0.557	1.745	0.000
			#Births 189					NRR	1.007

Table 3: (Continued)

1861 to 1871 NonFarm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	262	231	0.000	-0.013	0.000	-0.031	-0.031		0.000
5 to 10	202	158	0.000	-0.025	-0.063	-0.061	-0.124	0.883	0.000
10 to 15	124	139	0.000	0.011	-0.186	0.029	-0.157	0.854	0.000
15 to 20	105	86	0.077	-0.020	-0.129	-0.050	-0.179	0.836	0.065
20 to 25	120	83	0.259	-0.037	-0.229	-0.092	-0.321	0.726	0.188
25 to 30	134	96	0.318	-0.033	-0.413	-0.083	-0.496	0.609	0.194
30 to 35	111	82	0.186	-0.030	-0.580	-0.076	-0.655	0.519	0.097
35 to 40	101	83	0.127	-0.020	-0.731	-0.049	-0.780	0.458	0.058
40 to 45	74	70	0.032	-0.006	-0.829	-0.014	-0.843	0.430	0.014
45 to 50	74	82	0.000	0.010	-0.857	0.026	-0.831	0.436	0.000
50 to 55	67	53	0.000	-0.023	-0.806	-0.059	-0.864	0.421	0.000
55 to 60	55	70	0.000	0.024	-0.923	0.060	-0.862	0.422	0.000
60 to 65	47	48	0.000	0.002	-0.802	0.005	-0.797	0.451	0.000
65 to 70	36	42	0.000	0.015	-0.792	0.039	-0.753	0.471	0.000
70 to 75	24	31	0.000	0.026	-0.715	0.064	-0.651	0.522	0.000
75 to 80	32	25	0.000	-0.025	-0.587	-0.062	-0.648	0.523	0.000
80+	18	27	0.000	0.041	-0.710	0.101	-0.609	0.544	0.000
			#Births						
			220					NRR	0.615

B=# of births.

Table 4: Details of the NRR* calculation for the period 1871 to 1881

1871 to 1881 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	216	192	0.000	-0.012	0.000	-0.029	-0.029		0.000
5 to 10	222	212	0.000	-0.005	-0.059	-0.012	-0.070	0.932	0.000
10 to 15	218	177	0.000	-0.021	-0.082	-0.052	-0.134	0.875	0.000
15 to 20	200	199	0.022	-0.001	-0.186	-0.001	-0.187	0.829	0.018
20 to 25	126	125	0.172	-0.001	-0.189	-0.002	-0.191	0.826	0.142
25 to 30	108	110	0.216	0.002	-0.193	0.005	-0.188	0.829	0.179
30 to 35	85	87	0.269	0.002	-0.183	0.006	-0.178	0.837	0.225
35 to 40	111	100	0.251	-0.010	-0.172	-0.026	-0.198	0.820	0.206
40 to 45	100	89	0.057	-0.012	-0.224	-0.029	-0.253	0.776	0.044
45 to 50	114	100	0.013	-0.013	-0.282	-0.033	-0.315	0.730	0.010
50 to 55	83	78	0.000	-0.006	-0.348	-0.016	-0.363	0.695	0.000
55 to 60	84	97	0.000	0.014	-0.379	0.036	-0.343	0.710	0.000
60 to 65	60	62	0.000	0.003	-0.307	0.008	-0.299	0.742	0.000
65 to 70	56	59	0.000	0.005	-0.290	0.013	-0.277	0.758	0.000
70 to 75	57	37	0.000	-0.043	-0.264	-0.108	-0.372	0.689	0.000
75 to 80	27	30	0.000	0.011	-0.480	0.026	-0.454	0.635	0.000
80+	19	18	0.000	-0.005	-0.428	-0.014	-0.441	0.643	0.000
			#Births						
			227					NRR	0.824

Table 4: (Continued)

1871 to 1881 NonFarm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	231	199	0.000	-0.015	0.000	-0.037	-0.037		0.000
5 to 10	158	160	0.000	0.001	-0.075	0.003	-0.071	0.931	0.000
10 to 15	139	118	0.000	-0.016	-0.068	-0.041	-0.109	0.897	0.000
15 to 20	86	85	0.080	-0.001	-0.150	-0.003	-0.153	0.858	0.068
20 to 25	83	85	0.229	0.002	-0.156	0.006	-0.150	0.861	0.197
25 to 30	96	88	0.276	-0.009	-0.144	-0.022	-0.166	0.847	0.234
30 to 35	82	79	0.236	-0.004	-0.188	-0.009	-0.197	0.821	0.194
35 to 40	83	77	0.120	-0.008	-0.206	-0.019	-0.225	0.799	0.096
40 to 45	70	57	0.056	-0.021	-0.244	-0.051	-0.295	0.744	0.042
45 to 50	82	57	0.003	-0.036	-0.346	-0.091	-0.437	0.646	0.002
50 to 55	53	57	0.000	0.007	-0.528	0.018	-0.510	0.600	0.000
55 to 60	70	44	0.000	-0.046	-0.492	-0.116	-0.608	0.544	0.000
60 to 65	48	53	0.000	0.010	-0.724	0.025	-0.699	0.497	0.000
65 to 70	42	38	0.000	-0.010	-0.675	-0.025	-0.700	0.497	0.000
70 to 75	31	39	0.000	0.023	-0.725	0.057	-0.667	0.513	0.000
75 to 80	25	21	0.000	-0.017	-0.610	-0.044	-0.653	0.520	0.000
80+	27	7	0.000	-0.135	-0.697	-0.337	-1.034	0.355	0.000
			#Births						
			301					NRR	0.833

B=# of births.

Table 5: Details of the NRR* calculation for the period 1881 to 1891.

1881 to 1891 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	192	157	0.000	-0.020	0.000	-0.050	-0.050		0.000
5 to 10	212	167	0.000	-0.024	-0.101	-0.060	-0.160	0.852	0.000
10 to 15	177	190	0.000	0.007	-0.220	0.018	-0.202	0.817	0.000
15 to 20	199	190	0.031	-0.005	-0.184	-0.012	-0.196	0.822	0.026
20 to 25	125	116	0.145	-0.007	-0.208	-0.019	-0.226	0.797	0.115
25 to 30	110	107	0.245	-0.003	-0.245	-0.007	-0.252	0.777	0.191
30 to 35	87	100	0.226	0.014	-0.259	0.035	-0.224	0.799	0.181
35 to 40	100	90	0.176	-0.011	-0.189	-0.026	-0.216	0.806	0.142
40 to 45	89	94	0.151	0.005	-0.242	0.014	-0.228	0.796	0.120
45 to 50	100	94	0.025	-0.006	-0.215	-0.015	-0.230	0.795	0.020
50 to 55	78	74	0.000	-0.005	-0.245	-0.013	-0.259	0.772	0.000
55 to 60	97	83	0.000	-0.016	-0.272	-0.039	-0.311	0.733	0.000
60 to 65	62	63	0.000	0.002	-0.350	0.004	-0.346	0.708	0.000
65 to 70	59	64	0.000	0.008	-0.342	0.020	-0.321	0.725	0.000
70 to 75	37	45	0.000	0.020	-0.301	0.049	-0.252	0.777	0.000
75 to 80	30	32	0.000	0.006	-0.203	0.016	-0.187	0.829	0.000
80+	18	26	0.000	0.037	-0.171	0.092	-0.079	0.924	0.000
			#Births						
			159					NRR	0.795

Table 5: (Continued)

1881 to 1891 NonFarm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	199	181	0.000	-0.009	0.000	-0.024	-0.024		0.000
5 to 10	160	102	0.000	-0.045	-0.047	-0.113	-0.160	0.852	0.000
10 to 15	118	112	0.000	-0.005	-0.273	-0.013	-0.286	0.752	0.000
15 to 20	85	88	0.070	0.003	-0.299	0.009	-0.290	0.748	0.053
20 to 25	85	62	0.238	-0.032	-0.281	-0.079	-0.360	0.698	0.166
25 to 30	88	77	0.256	-0.013	-0.439	-0.033	-0.472	0.624	0.159
30 to 35	79	76	0.225	-0.004	-0.506	-0.010	-0.515	0.597	0.134
35 to 40	77	70	0.154	-0.010	-0.525	-0.024	-0.549	0.578	0.089
40 to 45	57	56	0.057	-0.002	-0.573	-0.004	-0.577	0.561	0.032
45 to 50	57	48	0.000	-0.017	-0.582	-0.043	-0.625	0.535	0.000
50 to 55	57	47	0.000	-0.019	-0.668	-0.048	-0.716	0.489	0.000
55 to 60	44	53	0.000	0.019	-0.764	0.047	-0.717	0.488	0.000
60 to 65	53	38	0.000	-0.033	-0.671	-0.083	-0.754	0.470	0.000
65 to 70	38	32	0.000	-0.017	-0.837	-0.043	-0.880	0.415	0.000
70 to 75	39	22	0.000	-0.057	-0.923	-0.143	-1.066	0.344	0.000
75 to 80	21	23	0.000	0.009	-1.210	0.023	-1.187	0.305	0.000
80+	7	10	0.000	0.036	-1.164	0.089	-1.075	0.341	0.000
			#Births						
			227					NRR	0.633

B=# of births.

Table 6: Details of the NRR* calculation for the period 1891 to 1901

1891 to 1901 Farm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	157	142	0.000	-0.010	0.000	-0.025	-0.025		0.000
5 to 10	167	126	0.000	-0.028	-0.050	-0.070	-0.121	0.886	0.000
10 to 15	190	155	0.000	-0.020	-0.191	-0.051	-0.242	0.785	0.000
15 to 20	190	137	0.048	-0.033	-0.293	-0.082	-0.375	0.688	0.033
20 to 25	116	123	0.134	0.006	-0.456	0.015	-0.442	0.643	0.086
25 to 30	107	115	0.230	0.007	-0.427	0.018	-0.409	0.664	0.153
30 to 35	100	78	0.246	-0.025	-0.391	-0.062	-0.453	0.636	0.156
35 to 40	90	90	0.251	0.000	-0.515	0.000	-0.515	0.597	0.150
40 to 45	94	100	0.080	0.006	-0.515	0.015	-0.500	0.607	0.049
45 to 50	94	103	0.011	0.009	-0.484	0.023	-0.461	0.630	0.007
50 to 55	74	85	0.000	0.014	-0.439	0.035	-0.404	0.668	0.000
55 to 60	83	84	0.000	0.001	-0.369	0.003	-0.366	0.693	0.000
60 to 65	63	64	0.000	0.002	-0.363	0.004	-0.359	0.698	0.000
65 to 70	64	69	0.000	0.008	-0.355	0.019	-0.337	0.714	0.000
70 to 75	45	51	0.000	0.013	-0.318	0.031	-0.287	0.751	0.000
75 to 80	32	40	0.000	0.022	-0.255	0.056	-0.199	0.819	0.000
80+	26	35	0.000	0.030	-0.144	0.074	-0.069	0.933	0.000
			#Births						
			187					NRR	0.634

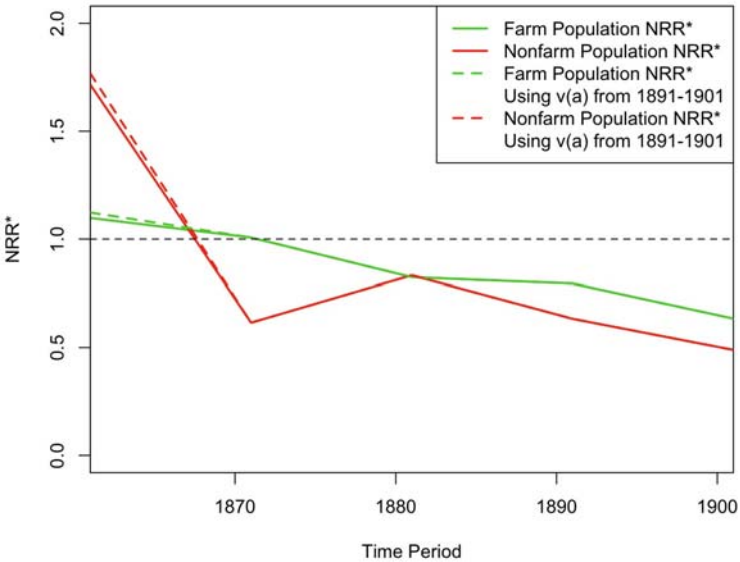
Table 6: (Continued)

1891 to 1901 NonFarm Population	1	2	3	4	5	6	7	8	9
Age	N(1)	N(2)	v(a)	r(a)	Eq 7 First term	Eq 7 Second term	Col 5+Col 6	exp(Col 7)	Contribution to NRR*
0 to 5	181	111	0.000	-0.049	0.000	-0.122	-0.122		0.000
5 to 10	102	95	0.000	-0.007	-0.244	-0.018	-0.262	0.769	0.000
10 to 15	112	78	0.000	-0.036	-0.280	-0.090	-0.370	0.690	0.000
15 to 20	88	59	0.082	-0.040	-0.461	-0.100	-0.561	0.571	0.047
20 to 25	62	70	0.203	0.012	-0.661	0.030	-0.630	0.532	0.108
25 to 30	77	64	0.258	-0.018	-0.600	-0.046	-0.646	0.524	0.135
30 to 35	76	60	0.264	-0.024	-0.693	-0.059	-0.752	0.472	0.124
35 to 40	70	49	0.137	-0.036	-0.811	-0.089	-0.900	0.407	0.056
40 to 45	56	38	0.055	-0.039	-0.989	-0.097	-1.086	0.338	0.019
45 to 50	48	53	0.000	0.010	-1.183	0.025	-1.158	0.314	0.000
50 to 55	47	40	0.000	-0.016	-1.133	-0.040	-1.174	0.309	0.000
55 to 60	53	31	0.000	-0.054	-1.214	-0.134	-1.348	0.260	0.000
60 to 65	38	39	0.000	0.003	-1.482	0.006	-1.476	0.229	0.000
65 to 70	32	32	0.000	0.000	-1.469	0.000	-1.469	0.230	0.000
70 to 75	22	22	0.000	0.000	-1.469	0.000	-1.469	0.230	0.000
75 to 80	23	22	0.000	-0.004	-1.469	-0.011	-1.480	0.228	0.000
80+	10	9	0.000	-0.011	-1.492	-0.026	-1.518	0.219	0.000
			#Births						
			182					NRR	0.489

B=# of births.

When we examine the estimates of the NRR* for this period in Figure 6, we see that the non-farm segment of the population initially exhibited higher net reproduction compared to the farm population. In addition, this rate was subject to higher variability than the farm population.

Figure 6: Estimates of the net reproduction rate accounting for migration (NRR*) for the farm and non-farm segments of the population of the northern Orkney islands, 1851 to 1901



For example, the variance in the NRR for the farm population was 0.03 daughters/woman, while the variance for the non-farm population was 0.47 daughters/woman. This represents nearly a sixteen-fold difference, and is significant when compared using a F-test for equal variances (F ratio=0.136, p=.039). This suggests that the non-farm segment of the population may have been subject to larger population fluctuations, possibly due to temporal variations in the Orkney labor market. This finding further suggests that the farm population could be considered more stable, despite its net decline in total size over the period. This lends support to the findings from an earlier analysis that found a small advantage for farm households with respect to child survival and fertility timing. This also suggests that the farm families may have been adapted to a more conservative pattern of reproduction and household formation than non-farm families, who may have been more governed by local economic fluctuations and availability of wage work. As a supplement to the main analysis, I have conducted a sensitivity analysis of the 1851 to 1861 value of NRR* to changes in the *v(a)* distribution. To investigate the influence of this difference in lower mean age for marriages between 1855 to 1861 on the eventual calculations, I substitute the value of *v(a)* for the period 1891 to 1901 into the calculations for the period 1851 to 1861. The use of this *v(a)* distribution changes the NRR* of the 1851 to 1861 period slightly, with the non-farm NRR* increasing to 1.768 (an increase of 1.3%) and the farm NRR* increasing to 1.123 (a change of just over 1%). This suggests that the general pattern of the NRR* for this period is relatively stable with respect to the value of v(a) calculated from these marriages, despite the younger average age at marriage for these mothers.

5. Conclusions

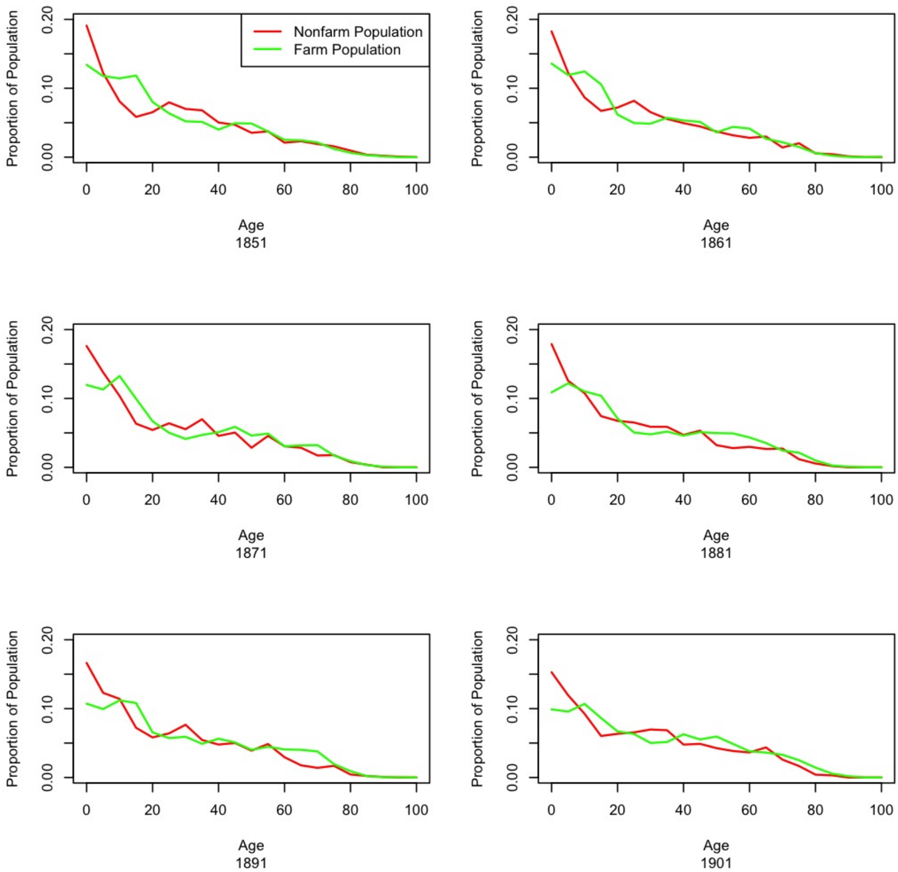
The goal of this paper was to examine the relative growth rates for the farming and non-farming segments of the population of the northern Orkney islands, Scotland, over the period 1851 to 1901 using age-specific growth rates and the variable-r method for estimating the NRR*. At the end of the 19th century, the entire population of the islands was in sustained decline, mostly due to emigration to foreign labor markets. However, the intention of this paper was to assess whether the farming population was reproducing itself at a more stable rate compared to the non-farm population over this period of population change. The "conserved" nature of the growth was thought to be indicative of a higher degree of population sustainability for the farming population of the Northern Isles. When I suggest that the farming population exhibited a "conserved" growth pattern, I am referring to the relative stability of the farming population. In particular, the farming population exhibited a marginally positive growth rate relative to the non-farming segment of the population over the mid- to late-19th century. I argue that this stability is the result of a complex interaction between birth spacing and lower infant and childhood mortality. My findings also appear to indicate that, while completed family sizes may have been larger in farming families, the effects of birth spacing and reduced infant and childhood mortality could have led to a better demographic balance for these households. In addition, I would argue that these demographic and household dynamics combined with the tradition of keeping land within families and purchasing land when it became available with resources gained from non-farm labor.

Based on preliminary analyses which have shown a slight advantage for farm families in terms of longer birth intervals and lower rates of infant and childhood mortality, I suggest that the farming segment of the population might also have enjoyed an aggregate net advantage of a more stable NRR* relative to the non-farm segment of the population. I think this finding indicates a certain degree of correspondence between the macro-level calculations and the individual-level analysis. While the differences between the farm and non-farm populations were less noticeable in terms of consistently higher growth rates, what is apparent is that the farm segment of the population displayed less variability in age-specific growth rates and the NRR* compared to the non-farm population.

I do find some support for the initial hypothesis stated in the introduction: namely, that the farming segment of the population exhibited a more stable growth pattern during the late 19th century. Further inspection of the data is necessary to provide more substantive results, and to carry these analyses into the 20th century. The results make sense when we consider what the age-specific growth rate and the NRR* are measuring: i.e., relative growth of population age groups and population net reproductive success with allowances for migration. If the patterns visible in the current analysis hold up to further examination, the assumption that the farming segment of the population maintained a certain level of demographic sustainability over this period would appear to be confirmed. I argue that this phenomenon is attributable to the nature of the Orkney farming population, which mainly consists of families who have inhabited the islands (and in many cases the same houses) since the 15th century (Marwick 1952; Scott et al. 2003).

Unfortunately, since the age-specific growth rates are really a combination of inter-census fertility, mortality and migration, we cannot say with confidence what factors determined the relative success or failure of specific age groups in the inter-census period (Horiuchi and Preston 1988). However, evidence based on historical documents, ethnographic work, and unpublished sources indicate that emigration was a dominant force during this period, so many of the observed negative growth rates are probably attributable to population loss through emigration (Anderson and Morse 1993a, 1993b). Furthermore, the NRR* is most certainly an underestimate of the NRR because of the effects of emigration. The relatively low variability in the NRR* in the farm population implies that there may have been some mechanism (longer birth spacing, family support networks, and relatively higher socioeconomic status) that allowed farm families to exhibit a more stable pattern of reproduction and survival compared to the non-farm population. But, in addition to the effects of fertility and mortality, migration could have been a stable strategy as well in this setting. If farm families had too many children to allow for each to have access to some land (or land rights), these children were likely to emigrate to other shores. Likewise, if insufficient opportunities existed for male or female children, irrespective of landholding, they could choose to migrate and sell (or forfeit the lease) the resources they had to provide for better lives elsewhere. Thus, when we consider the net effects of migration on the stability of the NRR* in the farming population, we can see that a stable emigration rate over this time may have contributed to the observed stability of the NRR*. Indeed, when a sensitivity analysis of the NRR* is conducted (calculations not shown here), where the farm *v(a)* distribution is used to calculate the NRR* for the non-farm population, the differences are found to be negligible (average NRR* using non-farm *v(a)* =0.85, using farm *v(a)* = 0.857), thus indicating that it is the underlying difference in age structure of the populations that contribute most to the observed differences. To visualize this, I present the age distributions of the farm and non-farm populations for each census year in Figure 7.

Figure 7: Age distributions for the farm and non-farm segments of the population of the northern Orkney islands, 1851 to 1901



While the differences may to some extent be attributable to differences in mortality, the differences in shape suggest that the non-farm population had a much more “migrant” age distribution than the farm population.

With respect to the performance of the variable-r method in this particular setting, I suggest that the method can prove useful, especially in studies of historical populations (Cachinero-Sanchez 1985; Gage 1985; Gage et al. 1986). Additionally, studies focusing on evolutionary hypotheses should find great value in the variable-r method and the NRR and NRR* as measures of population growth, sustainability, and overall reproductive success (Kaplan and Gurven 2008; Metcalf and Pavard 2006). One limitation of the method, as evidenced in this analysis, is that, while the method was designed to work with less than ideal data, there may be some numerical instabilities that result when it is used in very small anthropological populations. Given this limitation, users should be aware that results might be inherently biased because of very small population sizes, especially when the population is categorized by age and other characteristics. Finally, I hope that the utility of the approach taken in this analysis can be used in other circumstances in which relative reproduction and growth of subpopulations is of interest. It is not difficult to imagine applying such procedures to problems of differential growth of racial/ethnic groups or growth of sub-regions of a particular country.

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