HISTORY AND POPULATION CHANGE
IN THE HERERO OF SOUTHERN AFRICA

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and
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History and Population Change in the Herero of Southern Africa

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Introduction

The Herero are a prosperous group of Bantu-speaking cattle and goat pastoralists who occupy scattered homesteads in northwestern Botswana. Historical changes in their mortality and fertility documented previously show that the health of this population has improved remarkably in the last century (Pennington and Harpending, 1991; Harpending and Pennington, 1999a; Harpending and Pennington, 1999b). In this paper, we use these findings to address important issues in the history of Herero and in the history of northwestern Botswana. We also discuss how improvements in survivorship and reproductive performance correspond to changes in population growth rates, social structure and individual reproductive success.

Several volumes have been written about the Herero-German War of 1904–1907 in Namibia (Bley, 1971; Drechsler, 1980; Bridgeman, 1981). Although it is clear that well over half the Herero were killed during the conflict, the true toll extracted by the war is unknown. Those who escaped to Botswana became the ancestors of most of the Herero in this study. In the first part of this paper we reconstruct the age structure of the founding Herero population in Botswana to learn more about demographic implications of the war. We estimate the sizes of the 1906 refugee and present-day Herero populations in Botswana by projecting an inferred age structure using fertility and mortality rates from previous research. Our analysis shows that the number who fled to Botswana has been significantly underestimated and that children suffered the highest mortality during the war years.

In the second part of this paper, we discuss the relationship between changes in Herero demographic rates and changes in social structure. The 1986 population pyramid suggests that there is a wave of births about every 22 years. Since generation times in human populations are typically longer, and since the period of a wave in a population approaching stability is approximately one generation long, it appears that low fertility prevailing during the early part of this century has reduced the generation time and, consequently, the mean age of childbearing in this population. We estimate generation time using the eigenvalues of four Leslie matrices that encapsulate the transition from very low to very high fertility schedules in this population. There are several implications of reduced generation times for individual reproductive strategies. We also examine the relative importance of changes in mortality and fertility on population growth rates.
Background

The analysis below is based on 611 maternity histories collected by the authors between 1987-1989 from Herero living in dispersed homesteads west of the Okavango Delta in the Ngamiland District of Botswana. Over 3,500 individuals living in this region were ascertained through the maternity histories. Throughout the first half of this century fertility was unusually low so that the total fertility rate was 2.7 (Pennington and Harpending, 1991). The low Herero fertility rates were attributed to the sterilising effects of sexually transmitted diseases. Probably in response to the introduction of antibiotics in northwestern Botswana, fertility began increasing so that the total fertility rate of women reproducing in 1976-1986 was 7.0. We have also documented decreases in mortality among Herero. Life expectancy at birth for both sexes has increased from about 50 years (before 1969) to 65 years (1966 through 1986) (Harpending and Pennington, 1991b). We have reported extensively on other aspects of Herero fertility, mortality, child care practices and household economics elsewhere (Harpending and Pennington, 1990; Harpending and Pennington, 1991a; Pennington, 1991a; Pennington, 1991b).

Most of the Herero in Botswana descended from refugees who fled Namibia during the Herero-German War of 1904-07. We use the term Herero to refer to the two closely related groups of Herero-speaking people in Botswana, the Herero proper and the Mbanderu. In Botswana they are recognized as prosperous and highly ethnic cattle herders.

Estimating the number of Herero

It is well-known that many Herero escaped a German genocide campaign in Namibia by fleeing to Botswana, but how many Herero were saved is unknown. In this section, we shed some light on this important event in the history of Herero and northern Botswana. We construct a series of Leslie matrices from estimates of Herero fertility and mortality and infer the 1986 refugee age structure from Herero population pyramid recorded in the 1950s. We project the inferred population pyramid using the Leslie matrices and arrive at estimates of the number of refugees there must have been to produce the present-day Herero population in Botswana.
The population projection matrix

The age structure of a population pyramid reflects the balance of births and deaths occurring among its members. The number of individuals at each age depends on the number of individuals who were born in the past and their chances of surviving each age. The number of newborns in a year is determined by the number of nature females and the rate at which they reproduce. This process can be modeled with a population projection matrix. The properties of the matrix, developed by P.H. Leslie in the 1940s (Leslie 1945, 1948), are well documented. The basic form of the Leslie matrix for the female population is

\[
A = \begin{bmatrix}
F_1 & F_1 & F_2 & \cdots & F_j \\
F_1 & 0 & 0 & \cdots & 0 \\
0 & F_1 & 0 & \cdots & 0 \\
\vdots & \ddots & \ddots & \ddots & \vdots \\
0 & \cdots & 0 & F_{j-1} & 0 \\
\end{bmatrix}
\]

The diagonal entries \(F_i, i = 1, 2, 3, \ldots, j\), are the probabilities that a female in age class \(i\) survives from time \(t\) to \(t+1\). The \(F_i\) entries in the top row are the expected numbers of births to females in the \(i\)th age classes from time \(t\) to \(t+1\). Following convention, we have used 5-year age and projection intervals so that individuals in age class \(i\) are aged 0-4, 5-9, and so forth, and each projection \(t\) predicts the population five years in the future. In the projection below, we have computed estimates for \(j = 10\) age classes.

For convenience, we have projected the female population only. Since the number of females in a population is roughly half the number of males, a good approximation is possible using a one-sex model. More complicated two-sex models have not produced consistently more accurate projections (Keyfitz, 1985).

A population is projected by multiplying the \(j \times j\) matrix \(A\) by a \(1 \times j\) vector of population. Each \(n_i\) in the vector

\[
n'(t) = (n_{i(0)}, n_{i(0)}, n_{i(0)}, \ldots, n_{i(0)})
\]

is the number of females in age class \(i\) at time \(t\). \(n'(t)\) is the transpose of the column vector \(n(t)\). Given a schedule of \(F_i\) and \(F_j\), future population can be predicted by iterating the process \(n(t + 1) = An(t)\).  

3
There are several ways of estimating $P_i$. Since the probability that an
$z$-year-old survives five more years is $l(z+5)/l(z)$, the probability that
individuals in age class $i$ survive five more years can be estimated by

$$P_i = \frac{l(x)+l(x+1)+l(x+2)+l(x+3)+l(x+4)}{l(x-5)+l(x-4)+l(x-3)+l(x-2)+l(x-1)},$$

where $z = 5i$. This formula is a weighted average of survival at each age over
the interval. The formula given by Keyfitz (1969) in which $P_i = \frac{L_i}{L_{i+1}}$,
where $L_i$ is the total number of years lived by individuals in age-class $i$, is
probably more familiar to most human demographers. Our estimate is more
precise since we have counted survival at each age of the interval.

Harpending and Pennington (1991b) computed survivorship for two pe-
riods, before 1966 and in 1966–1986. The corresponding schedules of $P_i$ are
given in Table 1. We will use both survival schedules in the projection of
population.

The $F_i$ are the fertilities of females in the interval $i$. They are different
from age-specific fertility rates because they take into account the probabil-
ity that some females will die and fail to reproduce during the projection
interval. In addition, females reproduce at different rates as they age during
t to $t+1$. Following Caswell (1989, eqn. 2.22), we estimated the fertilities
using the formula

$$F_i = \frac{l(2.5) m_i + P_i m_{i+1.5}}{2}.$$

This formula is equivalent to those found in more standard demographic
sources such as Keyfitz (1969). $m_i$ is the number of girl births to females
in age class $i$. It is estimated by multiplying the annual age-specific fertility
rate of females in the $i$th age class by the fraction of births that are girls and
the width of the age class. We assume that the fraction of girls is always
0.488, which is the actual proportion of all Heeroo births that were female.
The term $l(2.5)$, which is the probability of surviving half the projection
interval of the first age class, is empirically estimated from the equation
$[l(2) + l(3)]/2$ to be 0.827 during the early period and 0.932 during the
recent period.

We have computed $F_i$ for four periods using age-specific fertility rates
given by Pennington and Harpending (1991). They are listed in Table 1.

The age structure of the refugee population

If birth and death rates are constant, a population will eventually grow at a
constant rate and approach a stable age distribution. As a result, the pro-
Table 1: Survival and fertility in the next five years by period. \( F_i \) is the probability that a female in age class \( i \) survives the projection interval and \( P_i \) is the expected number of female births to women in age class \( i \) during the projection interval.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( P_i ) (-1965)</th>
<th>(-1966-1986)</th>
<th>( F_i ) (-1956)</th>
<th>(-1957-1966)</th>
<th>(-1967-1976)</th>
<th>(-1977-1986)</th>
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<tr>
<td>1</td>
<td>0.9163</td>
<td>0.5571</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.9704</td>
<td>0.9940</td>
<td>0</td>
<td>0</td>
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<tr>
<td>3</td>
<td>0.9674</td>
<td>0.9947</td>
<td>0.1286</td>
<td>0.1713</td>
<td>0.2176</td>
<td>0.2195</td>
</tr>
<tr>
<td>4</td>
<td>0.9726</td>
<td>0.9842</td>
<td>0.3023</td>
<td>0.3748</td>
<td>0.5386</td>
<td>0.5659</td>
</tr>
<tr>
<td>5</td>
<td>0.9702</td>
<td>0.9804</td>
<td>0.2822</td>
<td>0.3832</td>
<td>0.5785</td>
<td>0.6467</td>
</tr>
<tr>
<td>6</td>
<td>0.9707</td>
<td>0.9937</td>
<td>0.1562</td>
<td>0.2908</td>
<td>0.4624</td>
<td>0.5518</td>
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<td>7</td>
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<td>0.9843</td>
<td>0.0879</td>
<td>0.1784</td>
<td>0.3340</td>
<td>0.4420</td>
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<tr>
<td>8</td>
<td>0.9654</td>
<td>0.9772</td>
<td>0.0689</td>
<td>0.1131</td>
<td>0.2068</td>
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<tr>
<td>9</td>
<td>0.9603</td>
<td>0.9610</td>
<td>0.0265</td>
<td>0.0540</td>
<td>0.0923</td>
<td>0.0960</td>
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<tr>
<td>10</td>
<td>0.9504</td>
<td>0.9771</td>
<td>0</td>
<td>0.0136</td>
<td>0.0155</td>
<td>0.0166</td>
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<td>11</td>
<td>0.9393</td>
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<td>0</td>
<td>0</td>
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<td>14</td>
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<td>0</td>
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</tr>
<tr>
<td>15</td>
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<td>0.8220</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>17</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>19</td>
<td>0.3708</td>
<td>0.3692</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

A portion of population at each age will become constant from year to year, whatever the initial distribution (Keyfitz, 1968; Caswell, 1989). Meanwhile, perturbations that cause unusual features will persist and provide clues about history.

The population pyramid in the right panel of Figure 1 is the smoothed 1986 Herero population pyramid from Harpending and Pennington (1991a). The pyramid reflects the 1986 Herero age-sex distribution and shows an apparent wave originating early in this century that we suggest is the result of excessive mortality among subadult Herero during the war years. The center panel of Figure 1 is a redrawning of a population pyramid constructed by Gordon Gibson, who censused several Herero homesteads in Ngamiland in 1953 (Gibson, 1959). The pyramid shows the age structure of 240 males.
and females by 5-year birth cohorts. The distribution of individuals born in 1903 to 1968 in this pyramid reflects the distribution of population aged 0 to 40 in 1903, when the refugee Herero population was founded. The age range represented encompasses most of the female reproductive span. Apparently, a small proportion of individuals of reproductive age founded the Herero population. A burst of births would follow as the refugee population matured, and this birth surge would be echoed in subsequent generations. Although Gibson’s sample is small, his pyramid is characterized by the same pinches and bulges suggested by our pyramid in the right panel of the figure.

Gibson’s pyramid is also similar in shape to population pyramids from censuses of Herero conducted by Günther Wagner in Namibia in 1950–1951 (Wagner, 1957; Köhler, 1959a, 1959b, 1959c; 1999a). A pyramid compiled from four censuses in these sources is in the left panel of Figure 1. The pyramid reflects the proportions of population born in five-year periods and reflects the age distribution of 3,422 males and 3,643 females. The censuses were taken on the Ovitoto (Wagner, 1957), Otjorongoro (Köhler, 1959c), Ovijitusso (Köhler, 1959b) and Waterberg (Köhler, 1959c) Native Reserves.

Figure 1: Population pyramids of Herero in Botswana and Namibia. Left panel: The age-sex distribution of 7,065 Herero in Namibia in 1951 compiled from four censuses. The left half of the pyramid shows the proportion of males, the right side shows the proportion of females. Center panel: The age distribution of 2,401 male and female Herero in Ngamaland in 1953. Right panel: Smoothed 1986 age-sex distribution of Herero in this study. Left side is males, right side is females. See text for sources.

Note: The number of individuals in this census were reported for non-standard age classes. In compiling the numbers from the four censuses, we have assumed that the age classes 0–5, 6–10, 11–15, ... 96–100 used in the Ovitoto census corresponded to the age classes 0–4, 5–9, 10–14, ... 95–99.
Although members of other tribes residing on these reservations may have been included in the censuses, the reservations were occupied mostly by Herero. The largest census was of the Waterberg Reserve in which 1,622 males and 1,588 females were ascertained. At the Otjohorongo Reserve, Wagner enumerated 996 males and 1,121 females. Both Waterberg and Otjohorongo were 95% Herero in 1951. The censuses at Otiototo and Otjiutu enumerated 111 and 693 males and 138 and 796 females, respectively. Over 80% of the population in these reserves was Herero in 1951. None of the sources included details about how the data were collected.

Gibson (1959) attributed the pinch of 1904 to children dying crossing the desert to Botswana or because parents had to abandon them in Namibia. However, the same pinches are apparent in all of the Herero pyramids of Namibia. It is more likely that the pinches are a result of an experience common to both populations, such as the war. They are not present in population pyramids of other ethnic groups in Namibia, such as the Tswana and Bergdama.

A deficit of young men and female children is apparent in the Namibian population pyramid. We do not know whether the asymmetry is due to differential mortality or to sex differences in migration patterns. For example, more young men than women may be away from the reserves because they have jobs in town, or they may have died at a higher rate than their female age-mates. Wagner (1957) suggested that there were fewer girls than boys because girls were sent to live with relatives in urban areas while boys were kept at home to help tend livestock. It is also possible that there were fewer female Herero children because they had higher mortality than males. Harpending and Pennington (1991a) observed that, until recently, girls had higher mortality than boys. Although this finding is not statistically significant, the female deficit in the Namibian pyramid suggests the differences in mortality may be real. Pennington and Harpending (1988) also observed a significantly higher mortality rate among the female infants of Kung living at Ghanzi cattleposts in the 1960s but not among traditional Kung hunter-gatherers. It is possible that female children were more susceptible than males to prevailing diseases, such as TB, at the cattleposts.

Despite its anomalies, the female age structure of the Namibian pyramid is a useful guide for inferring the population structure of Herero in Botswana after the war. We have approximated the 1906 female age distribution by constructing a pyramid that looks like the Namibian pyramids of 1951 after projecting it 45 years. The resulting inferred 1906 Herero population pyramid is in the left panel of Figure 2. The center panel, which compares the
inferred 1906 pyramid projected to 1951 with the 1951 census data from Namibia, indicates how well the inferred pyramid matches the actual data. The right panel compares the inferred 1906 pyramid projected to 1986 with the population pyramid (from Harpending and Pennington, 1991a). Although the 1906 age structure was constructed independently of the 1986 population pyramid produced by our survey, there is congruence between the two pyramids.

We used the age distribution implied by the Namibian censuses rather than Gibson's because the Namibian sample is much larger and is less likely to be biased by sampling error than the census of Gibson. Therefore, the Namibian data are probably more representative of the population structure of Herero in Botswana. Because most of the people older than 55 in 1906 (those born before 1866) were dead in 1951, we are unable to infer much about the 1906 age structure after this age. In drafting the 1906 pyramid in Figure 2, we assumed that the proportion of Herero aged 45 or more declined at the rate predicted by the mortality estimates during the early period. It is possible that older people may have died at a higher rate than average because of war-time stresses. Age may have also rendered them less mobile and able to escape the Germans hunting them down. However, our approximation is a reasonable guess.

At the older ages, the inferred 1906 pyramid projected to 1951 matches
the Namibian data well, but predicts too few children. The actual 1951
population of Namibia has 200 more females. We do not know to what ex-
tent the discrepancies are due to real differences in demographic rates and
to what extent they are due to sampling error. It is possible that effective
treatment for sexually transmitted diseases (STDs) that cause sterility (see
Pennington and Harpending, 1991) became available in Namibia sooner than
in Botswana, resulting in a higher birth rate in Namibia in the 1940s. Even
before antibiotics, Namibia had STD clinics on the reservations in which in-
jections were administered (see Wagner, 1957). A comparison of the Herero
pyramids from the census by Gibson and from the censuses by Wagner in
Figure 1 supports this interpretation. The proportion of children in the
Botswana population is much smaller than in the Namibian population. In
any case, the close fit between the projected and actual 1986 Herero pop-
ulation suggests that the inferred pyramid is a good predictor of the 1986
population in Botswana and that there is a remarkable degree of consistency
in our estimates of demographic rates. The increase in the birth rate in the
late 1950s is obvious.

The most remarkable feature of the inferred 1906 pyramid is the general
deficit of population below the age of 20. Although it is possible that the
pinch in the pyramid is due to preexisting conditions, the tapering of popu-
lation down to births occurring during the peak of hostilities suggests that
it is due to excessive mortality among children during the war. The German
genocide campaign caused the Herero to be unusually mobile. Most also lost
all their livestock. Whether the excess mortality was due to sickness, star-
vation or abandonment, children appear to have suffered the most during a
period of conflict. The unusual age structure, present in both the male and
female population, may have implications useful for studies of other
historic and prehistoric populations. Deficits of subadults are not unusual
in population pyramids constructed from prehistoric skeletal remains, al-
though sample sizes are frequently too small and preservation of remains
too irregular to draw firm conclusions about them.

Projection of the population

Although the number of Herero who came to Botswana in flight from the
Herero-German War is unknown, previous research suggests that there must
have been at least 2,000 refugees. Tluu (1985) uncovered figures estimat-
ing that 500-1,500 refugees settled in Botswana because of the war. Al-
naes (1989) cites sources in which 200-300 refugees were counted in Ghanzi.
District and 1,500 were counted in the Batawana Reserve (Ngamiland) so
the number of refugees would be upwards of 1,700-1,800. A few hundred
more Herero had already migrated to Botswana late in the 19th century.
In 1946, when Botswana still enumerated its population by ethnic group,
5,798 Herero were counted in Botswana (Research Publications, 1973). The
growth rates implied by the estimates of refugees and the 1946 enumerated
population suggest extraordinarily high annual growth rates of at least 2.8%.
The unusual age structure of the 1909 population would contribute to a more
rapid increase than in a stable population, but the implied growth rate is
probably underestimated due to an undercount of population in the census.
Although the quality of demographic data in Botswana has improved in re-
cent decades, the 1946 government census was subject to large enumeration
errors (Central Statistics Office, 1981). The greatest difficulties occurred in
remote areas like western Ngamiland, where even today there are few roads
and population density is low. Given the low rates of fertility during the
first half of this century, population growth of this magnitude is unlikely.
As we will show below, the population in the first half of the century was
nearly stationary.

Present-day estimates of Herero put their number at more than 10,000.
Wilmsen (1982) estimated that there were 15,000 Herero living in remote
areas of Botswana. Wilmsen did not state the year in which his estimate
refers, but it is probably a rough estimate of their number in the late 1970s.
Based on a survey of homesteads, Almagor (1982a) estimated that there
were 5,000 Mbanderu in the Lake Ngami area in 1978. Lake Ngami is the
Mbanderu heartland, so Almagor's estimate would encompass most Mban-
deru in Botswana. Vivelo (personal communication, August 1990) guessed
that there were 7,000 Herero proper in Botswana in 1973. The two esti-
mates combined indicate that there were about 12,000 Herero-speakers in
Botswana in the mid-1970s. Although Vivelo was careful to distinguish be-
tween Herero proper and other Herero speakers in his estimate, his figure is
based on communications he had with government, medical and veterinary
officials of Botswana who may be less accustomed to making distinctions be-
tween the two groups. Many non-Herero we met in Botswana were not aware
that Mbanderu are a separate people. We also knew many Herero proper and
Mbanderu who had difficulty identifying themselves as only Herero or only
Mbanderu. Herero and Mbanderu intermarried so many have relatives be-
longing to both tribes. Consequently, there is probably some overlap in the
populations defined by Vivelo and Almagor as Herero proper or Mbanderu.

Thus, 12,600 is probably an over-estimate of the number of Herero-speakers
Table 2: Estimates of the number of Herero in Botswana in 1906-1986. The 1946, 1976 and 1986 are population sizes predicted by projecting the inferred 1906 population pyramid from a range of starting values that represent hypothetical sizes of the refugee population. The last column shows how large the Herero population would have been had there been no infertility.

<table>
<thead>
<tr>
<th>Number of refugees</th>
<th>Size of projected population</th>
<th>Without infertility</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>1946</td>
<td>1976</td>
</tr>
<tr>
<td>1000</td>
<td>1,158</td>
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<tr>
<td>2000</td>
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</tr>
<tr>
<td>10000</td>
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<td>12,924</td>
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</tbody>
</table>

in Botswana. In our study, we ascertained about 3,500 Herero-speakers living in Botswana in 1987-1989. Since we sampled only a fraction of the total population, the number of Herero in Botswana today must be two to three times this figure.

To what extent the estimates of population at the various points in time agree can be assessed by projection. From the estimates of \( P_t \) and \( F_t \) in Table 1 above, we constructed four Leslie matrices describing population dynamics in the period through 1956 and in the periods 1957-1966, 1967-1976 and 1977-1986. We then projected the inferred 1906 population age distribution to 1986. The sizes of the 1946, 1976 and 1986 Herero populations projected from a range of refugee population sizes is listed in Table 2.

From the table it is clear that the various estimates of population are not in accord. If there were only 2,000 Herero in Botswana in 1906, the 1946 census enumerated several thousands more Herero than predicted by the population projection. If there were at least 6,000 in 1946 and around 12,000 in the 1970s, then there must have been 6,000 to 9,000 Herero in 1906. These figures imply that there were 9,400 to 14,100 Herero in 1986. Based on the frequency of multiple ascertainment of individuals in our study, our impression is that we sampled about one-fourth to one-third of the total population, suggesting that there were between 10,500 to 14,000 Herero in 1986.
A reasonable compromise of all these estimates suggests that there were about 8,000 Herero in 1906 and that the population grew to about 12,500 in 1986. Since most of the 1906 population were refugees from Namibia, our analysis indicates that the number of Herero refugees has been significantly underestimated. It appears that the people of Botswana saved many more Herero from the Germans than previously realized.

It is possible that migration of Herero into Botswana may bias these estimates. However, since Herero consider Namibia their homeland, most of the migration is in that direction. Therefore, if anything, there were even more refugees.

The last column of Table 2 shows how many Herero there would be had current levels of fertility prevailed throughout the century. If there had been no subfertility, the population of Herero in Botswana today would be 12 times its present size, regardless of its initial size. If our estimate of 8,600 Herero in 1906 is correct, then there would have been nearly 106,000 in Botswana today. Instead of representing a very small fraction of the total population of Botswana, the Herero would have comprised about 16% of all the people. Because the population of Botswana as a whole apparently did not experience pathological subfertility in the past, the Herero probably constitute a smaller fraction of the population today than they did after their flight from Namibia.

The effect of subfertility on population age structure

Pathologically low fertility also appears to have resulted in a population structure in which the proportion of Herero grandparents to parents has shifted. Figure 3 contrasts the actual 1986 population structure with the age structure that would have resulted had the Herero reproduced at their current level of fertility since fleeing Namibia. This pyramid suggests that, for its current level of fertility, the proportion of grandparents to grandchildren is much higher than expected. The proportion of parents to children in the older generation is also higher than expected. The pincers and bulges apparent in the actual 1986 pyramid are not suggested by the hypothetical pyramid with the higher fertility rate.

The female side of the smoothed 1986 Herero age distribution in Figure 4 also shows an apparent wave that we have already attributed to excessive mortality among subadults during the Herero-German War of 1904-1907.
Figure 3: Hypothetical age structure of Herero without subfertility. The hypothetical pyramid is contrasted with the actual age structure of the 1988 population constructed from this study.

Apart from its historical significance, the wave is interesting because it causes an unusual distribution of population. At every period of the wave, the number of children relative to the number of adults fluctuates. This means that children born during the pinch have relatively more adult kinmen to provide for them and that they will have fewer same-aged competitors than children born half a generation later. The pyramid also suggests that the length of the apparent wave is unusually short. Troughs in the apparent wave appear about every 22 years, several years shorter than calculations for most populations given in Keyfitz and Flieger (1971). Since the length of a wave is generally longer in human populations, the short wave length in the smoothed pyramid suggests that shortened reproductive spans resulting from STDs in the first half of the century may be responsible for increasing the frequency of oscillation in the pyramid and, consequently, for reducing generation time and the mean age of childbearing in this population. We test this hypothesis and discuss its implications below.
Generation time and the length of waves

Natural periodicity is a characteristic of age-structured populations such that the wave resulting from a perturbation has a period about equal to the length of one generation (Keyfitz and Flieger, 1971; Keyfitz, 1972; Coale, 1972). That is, given a fixed set of fertility and mortality rates, a surge of births occurring at a particular point in time will be echoed a generation later when the excess births mature to reproduce themselves. Thus, the length of the period $T_2$ is approximately equal to the generation time $T$ (Keyfitz, 1968; Caswell, 1989), where $T$ is the number of years a population growing at a rate $r$ will increase by a factor of the net reproduction rate ($NRR$), and the $NRR$ is the expected number of baby girls born to a newborn female (e.g., Keyfitz and Flieger, 1971).

Generation time can be derived from Lotka's renewal equation (Keyfitz and Flieger, 1971) in which $e^{CT} = NRR$ so that $T = \ln(NRR/r)$. $T$ has been shown to be equal to the mean age of childbearing $\mu$ in the stationary population (Keyfitz, 1968). In populations with positive growth, $T$ is usually no more than one or two years less than $\mu$ (Keyfitz and Flieger, 1971; Coale, 1972). Since the length of the generation time reflects the age at which reproduction is concentrated, populations with longer generation times have reproduction concentrated at older ages compared to populations with shorter generation times (Coale, 1972). The correlation between
$T$ and $\mu$ indicates that the average mother in populations with longer generation times will be older than in those with shorter generation times, and it follows then that, all things being equal, the average grandmother must be younger as well.

Using the Leslie matrix to measure generation time and population growth

The length of a population wave can be derived from its Leslie matrix. The eigenvalues of a Leslie matrix have their analogues in the Lotka integral equation such that $\ln \lambda_1 = r$, where $\lambda_1$ is the dominant eigenvalue of the matrix and $r$ is the intrinsic population growth rate. For $i > 1$, the $\lambda_i$ are complex so that their relationship to other roots $r_i$ in the Lotka model are not one-to-one (Keyfitz, 1968). Rather, the frequency of the natural periodicity is given by (Caswell, 1989, eqn. 4.38)

$$P_i = \frac{2\pi}{\tan^{-1} \frac{\Im(\lambda_i)}{\Re(\lambda_i)}}$$

where $\lambda_2$ is the second eigenvalue in magnitude with $\Im(\lambda_2)$ being the imaginary part and $\Re(\lambda_2)$ being the real part.

To test the hypothesis that infertility has reduced the frequency of oscillation in the Herero population, the series of Leslie matrices constructed for projecting the population were analyzed to identify temporal changes associated with increases in fertility.

Results

The eigenvalues for each Leslie matrices were obtained using routines in GAUSS by Aptech Systems on an IBM compatible PC. The annual growth rate ($\frac{1}{5} \lambda_1$ because we have five-year projection intervals) and the second eigenvalue associated with the Leslie matrix for each period are listed in Table 3. The last column of the table lists the frequencies estimated using the formula for $P_i$ above and multiplied by five, the length of the age intervals. The $\lambda_1$ for the period of low fertility during the first half of the century indicates that, following their flight to Botswana, the Herero population was slowly declining at a rate of about -0.51% per year. The intrinsic rate of population growth became positive following the recovery from infertility initiated in the mid-1950s. The population is currently growing at a rate of nearly 3.6% per year.
Table 3: Population growth and the frequency of oscillation.

<table>
<thead>
<tr>
<th>Period</th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
<th>$P_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1957</td>
<td>-0.0051</td>
<td>0.0952 ± 0.7131</td>
<td>21.64</td>
</tr>
<tr>
<td>1957 - 1966</td>
<td>+0.0103</td>
<td>0.1990 ± 0.6830</td>
<td>22.47</td>
</tr>
<tr>
<td>1967 - 1976</td>
<td>+0.0309</td>
<td>0.3660 ± 0.6651</td>
<td>29.36</td>
</tr>
<tr>
<td>1977 - 1986</td>
<td>+0.0355</td>
<td>0.3955 ± 0.7223</td>
<td>29.37</td>
</tr>
</tbody>
</table>

The second eigenvalues show that the frequency of the natural periodicity in the population has increased from a low of 21.6 in the first period to 22.5 in the first 16-year period of recovery from infertility, to over 29 years in the last two decades. Comparisons with populations in Keyfitz and Flieger (1971) suggest that frequencies of less than 25 years are unusual. Of the populations studied, those with the shortest generation times tended to have low growth rates, but the pattern is not clear. Many populations with the highest growth rates had generation times of intermediate length.

Based on observations in teasel (a plant) populations in which a negative correlation between $P_2$ and $\lambda_1$ was found, Caswell (1989) suggested that more rapidly growing populations may be associated with shorter generation times. Since increases in population growth rates among Herero are associated with longer periods of oscillation, Caswell’s suggestion cannot always be true. Instead, this study suggests that the magnitude of the peak in reproductive rates may have the most dramatic effect on the frequency $P_2$ in human populations. The curves of the age-specific fertility rates for the earliest periods (see Pentington and Harpending, 1991) are relatively flat. The curve becomes sharply peaked following the period 1957-1966, after which the most substantial increase in $P_2$ occurs. While increases in fertility have resulted in dramatic increases in population growth rates, these increases are more gradual.

All else being equal, a shorter generation time means that women are younger, on the average, when they give birth. It also means that the grandmother of the average child in a population is also younger, and therefore more likely to be alive.

The intrinsic rate of population growth has increased dramatically among Herero in the last four decades. The rate of population growth across the continent of Africa as a whole is believed to have increased dramatically since the 1950s. Demographers have generally attributed these increases to declining mortality. This analysis of Herero, however, shows that decreases
in subfertility had a much larger impact on population growth. Herero life expectancy at birth increased by about 15 years. This big decline in mortality translates into only moderate increases in population growth rates. Substituting the \( P_i \) from the recent period into the diagonal of the Leslie matrices for the periods before 1966 causes the population growth rates to increase to only -0.09% and 1.5%. Using the \( P_i \) of the early period in the recent two Leslie matrices equate to population growth rates of 2.7% and 3.1%. Although lower mortality has a significant impact on population growth, the effect is small in comparison to growth from increased fertility. The changes in mortality caused no changes in the estimates of generation time.

Dyson and Murphy (1985) also found that decreases in mortality cannot account for the increases in population growth rates observed in many developing countries. They attributed much of the increase in fertility to shorter birth spacing because of less breast-feeding but also to the reduction of sterility-causing diseases. Subfertility throughout Africa is well-documented, and the reduction of factors causing involuntary termination of childbearing in women is surely responsible for large increases in the rate of population growth throughout Africa (Frank, 1983).

**Summary**

A reconstruction and projection of the 1906 Herero population suggest that the number of Herero who came to Botswana as refugees of the Herero-German War of 1904–1907 in Namibia has been significantly underestimated. Based on the 1946 census, the projection indicates that there were at least 6,000 refugees. Estimates of their number in the 1970s suggest that there may have been as many as 9,000 refugees. These estimates imply that there are 11,000–14,000 Herero in Botswana today.

The shape of the present-day Herero population pyramid reflects the structure of its founding population, which was composed of a large proportion of females just entering their childbearing years and a shortage of children. The aging of these women into their peak reproductive years and a subsequent decline in the proportion of reproductive-aged women probably produced an apparent wave in the pyramid today. Evidence for infectious infertility afflicting this population through the mid-1950s can be seen in the narrow structure of the upper portion of the pyramid, while its recently broadened base is indicative of a gradual shift to higher rates of fertility.
Because of their low levels of fertility, the Herero population has not increased much in this century. Our population projection suggests that there would have been between 75,000 to 111,000 Herero in Botswana today had their current level of fertility prevailed since their arrival as refugees. As a result, the proportion of population in Botswana represented by Herero has probably been declining.

The leading eigenvalue \( \lambda_1 \) of the Leslie matrix for the Herero population in the first half of this century indicates that population growth was -0.51% per year. Recovery from infertility is responsible for transforming the Herero from a declining population into one experiencing extremely high population growth rates of about 3.6% per year, a finding of great importance to policy planners in parts of Africa still characterized by high levels of involuntary infertility. The decrease in infertility has resulted in an increase in the period of oscillation in the population from about 22 to 29 years. Since the period of oscillation is approximately equal to generation time, which is correlated with the mean age of childbearing in a population, these findings suggest that more children today are being born to mothers who are older than in previous decades.

We also examined the relative importance of declining mortality and increasing fertility on population growth rates. Although the decrease in Herero mortality contributed to increasing the rate of population growth, increases in fertility had a much greater impact.
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