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Abstract

A pattern of population crash and rapid recovery is a common feature of the pacification and settlement experience of the Indigenous Peoples of tropical South America. In spite of the obvious importance of these events to the demographic and anthropological sciences as a whole, as well as their significant practical implications, little is known about the microdemographic determinants of these paired phenomena. Utilizing methods of asymptotic and stochastic demographic analysis, we reconstruct the microdemographic drivers of this history among one Indigenous population: the Northern *Ache* of Eastern Paraguay. We then explore the implications of these relationships for understanding the overall demographic turnaround being observed within similar groups as well as for the future trajectory of the Northern *Ache* in particular.

It is thought that *Tupi-Guarani* speakers, such as the *Ache*, have inhabited the *Alto Parana* watershed of Eastern Paraguay and Southwestern Brazil (Fig. 1) for as many as 10,000 years (Hill and Hurtado 1996). While a number of early ethnographers recorded contact with various *Ache* bands over the centuries since Europeans first colonized the Americas (Techo 1897; Lozano 1873; Manthusen, 1912), it was not until the late 1960s that direct contacts began with the Northern *Ache* in particular (Hill and Hurtado 1996; Clastres 1972). The drivers of this contact were similar to that observed among other Indigenous groups: virgin-soil epidemics, armed conflict, and territorial encroachment eventually led to the

pacification and settlement of the Northern *Ache* during the 1970s [see Hill and Hurtado (1996) for a complete narrative]. While it is estimated (Hill and Hurtado 1996) that 560 Northern *Ache* were alive in 1970, by 1980 only 369 remained. This catastrophic population decline spanned a 1971–1978 settlement period and was driven primarily by infectious disease mortality that appeared to follow an age/sex-specific pattern favoring the survivorship of young females (Hill and Hurtado 1996). By 2000, Hill and Hurtado (unpublished data) estimated a total of 760 Northern Ache based on a direct census of each Northern *Ache* community. This suggests an extraordinary population recovery occurred among this group in the twenty years following their devastating pacification and settlement experience. Hamilton et. al. (2014), in a more comprehensive review of growth rates in recently contacted Amazonian groups, report annual population growth rates of approximately four percent for most groups. From this perspective, the population recovery observed among the Ache is impressive—it would need to exceed five percent per year to result in the observed growth reported for the 1970–2000 period.

This pattern of population crash and recovery is common to many of the surviving Indigenous Peoples of tropical South America (McSweeney and Arps 2005; Hamilton et. al. 2014), but little is currently understood about the microdemographic determinants of this turnaround (McSweeney and Arps 2005; Gomes 2000; Brea 2003). Understanding the microdemographic drivers of these

phenomena is important for both scientific and practical reasons. Why does the experience of surviving Indigenous groups of tropical South America differ so significantly from that observed upon the Native Peoples of North America, whose population loss was often extended and whose recovery has only more recently come to be observed (Snipp 1989; Schoemaker 1999; Jackson 1994)? What are the potential contributors to population recovery among these groups in general? With the European colonization of the Americas and catastrophic population loss among the Native inhabitants of these continents constitutes one of the most significant demographic events in human history, the importance of understanding the determinants of this phenomena is a basic question in the demographic and anthropological sciences. On the practical level, the demographic future of these groups has been little examined and is of undeniable pragmatic importance as they are the most rapidly growing groups in South America (McSweeney and Arps 2005; Hamilton et. al. 2014; Jackson 1994). With over 100 uncontacted bands remaining within remote sections of Amazonia as of 2014 (Hamilton et. al. 2014), understanding the dynamics of population crash and recovery among these groups is important for preventing similar collapses in the future. With this background in mind, we report the results of a comprehensive demographic analysis of the microdemographic determinants of population crash and recovery among the Northern, for which previously published, high-quality demographic microdata that span pre and post-settlement periods exist [see

Materials and Methods section and Hill and Hurtado (1996), for a complete description of this database].

In this paper, we use methods of both asymptotic and stochastic demographic analysis to contrast the population dynamics of the Northern *Ache* during Forest and Reservation periods and estimate the age/sex-specific structure of settlement-period mortality. We assess the impacts of these microdemographic factors on their subsequent population recovery and examine the role of an observed differential survivorship of young women (ages 10–14 and 15–19 at the time of settlement) on that recovery. Extending these analyses, we describe the impact of Reservation-period vital rates on the demographic future of the Northern *Ache*. Last, we discuss these observations in light of what they mean in terms of the overall population recovery now being observed among the Indigenous Peoples of tropical South America (McSweeney and Arps 2005; Hamilton et. al. 2014).

Materials and Methods

Models of Asymptotic Population Dynamics

Trajectories of population growth or decline are the result of variation in the schedules of birth, death, and migration that constitute *components* of population change (Caswell 2010; Wachter 2012). Population change is an arithmetic process of accumulation or decline that depends upon these rates:

1. $$N_{t+1} = N_t + [B_{t,t+1} - D_{t,t+1} + I_{t,t+1} - E_{t,t+1}]$$

[**N** for a population count, **B** for births **D** for deaths, **I** for Immigration and **E** for Emigration and **t** for "time" in the subscript]. In a population in which immigration and emigration are rare or negligible in magnitude [such as the Northern *Ache*, see Hill and Hurtado (1996)], we may ignore the effects of migration and population growth may be represented as exponential accumulation or decline that is dependent upon birth and death rates alone—which together determine an overall population growth rate *r* (Lotka 1992; Caswell 2010):

$$2.\ N_{t+1} = N_t * e^{(b-d)} \quad \text{or} \quad N_{t+1} = N_t * e^r$$

[**b** for the crude birth rate, **d** for the crude death rate, **r** as the exponential growth rate]. Crude vital rates such as those in equation 2 depend, of course, on the observed age-structure of the population as vital rates are a non-linear function of age (Lotka 1992; Caswell 2010). Young men and older persons are at a higher risk of dying while younger women are more likely to give birth. As such, models of population dynamics often require a consideration of age. Age-structure may be captured by partitioning a population total N_t into a vector of age-specific counts:

$$3.\ N_t = \begin{matrix} n_1 \\ n_2 \\ n_3 \end{matrix}$$

[**n** for a population sub-grouping]. These population counts may be made to vary as a function of associated vital rate schedules—P_i for survivorship and F_i for fertility—such that the age-specific population counts at one time step forward (assuming reproductive maturity in the second age interval and death upon cessation of reproduction in this example) may be predicted as the following series of equations:

$$4.\ n_1 = \Sigma\ [\,(\,n_2 * F_2) + (n_3 * F_3)]$$

$$5.\ n_2 = n_1 * P_1$$

$$6.\ n_3 = n_2 * P_2$$

Counts in the first age interval n_1 are a sum of the products of counts in adult age-categories and corresponding fertility rates. Counts in adult age intervals depend upon the base population observed in each age category in conjunction with previous births (for n_2) or population counts and survivorship rates at each successive age interval. A sum of this vector provides a total population count at each time-step moving forward with such a model. This model may be expanded to include any number of age classes. In population analysis, typically a female only population is considered since measuring fertility of females is more straightforward (Preston et. al. 2003; Keyftiz and Caswell 2005).

Lotka (1922), Fisher (1930) and others have provided numerous explanations of the general proof that population growth—and other demographic parameters—are ergodic: over long periods of time the population age-structure and growth rate will stabilize into an equilibrium (Keyfitz 1971; Coale 1972; Keyfitz and Caswell 2005). At this asymptotic equilibrium, the population will grow at a constant rate and display a constant proportional age-structure. This population is known as a *stable equivalent* and its existence may be proven either analytically or through simulation (Caswell 2000; Keyfitz 1971; Coale 1972; 15,19,43–45). The stationary population, in which birth and death rates are equal, is a special case of the stable equivalent that is utilized in some forms of population analysis (Keyfitz 1971; Coale 1972; Coale and Demeny 1966). At this equilibrium, estimates of the *asymptotic* growth rate (**r**) may be made using the Euler-Lotka equation (Euler 1970/1760; Lotka 1956; Fisher 1930):

$$7.\ 1 = \sum L_x m_x * e^{-rx}$$

[L_x is survivorship from birth to age x, m_x is fertility within that age interval]. The Euler-Lotka **r** is an asymptotic parameter because it measures the population growth rate upon convergence to the stable equivalent age-structure. This occurs if, and only if, a set of vital rate schedules remain constant over a long period of time, though the conclusions are indifferent of the initial age-structure (Lotka 1922, 1956; Coale and Demeny 1966; Coale 1972; Keyfitz and Caswell 2005). As

such, differences between groups (or within the same group over time) in
asymptotic demographic parameters represent differences in underlying processes
involved (Fisher 1930; Lotka 1922; Caswell 2001; Wachter 2012; Lotka 1956)
with only information on vital rate schedules required for analysis in the case of a
closed population.

The classical model of asymptotic population dynamics presented thus far
may be extended within the language of linear algebra, facilitating a number of
useful analyses (Leslie 1945, 1948; Caswell 2001). First, survivorship and fertility
schedules may be formulated within a Leslie matrix (Leslie 1945, 1948)
containing age-specific fertilities on the top row and age-specific survivorship
along the subdiagonal. This matrix forms the basis of many methods of
population analysis. In the simple case of three age classes, with maturity
occurring at the second age-interval and reproduction continuing until death it is
formulated as:

$$\begin{array}{cccc} 0 & F_2 & F_3 & 0 \\ P_1 & 0 & 0 & 0 \\ 0 & P_2 & 0 & 0 \\ 0 & 0 & P_3 & 0 \end{array}$$

If we denote this matrix **A**, and multiply it against a population base in column
vector format we arrive at a matrix equivalent of the series of equations depicting
population growth by sub-groups presented above. Caswell (2001) refers to this as

the "projection equation" because it allows updating of a base population count in light of vital rate schedules in an iterative fashion:

$$8.\ n_{t+1} = An_t$$

Though it may be used in iterative simulation to project a population forward in time, the Leslie matrix is really a fundamental depiction of asymptotic population dynamics (Caswell 2001; Leslie 1945, 1948; Schoen 2010). If utilized in a projection, this framework could yield an estimate of the "transient" or empirical growth rate between two points in time as:

$$9.\ r = \frac{N_{t+1}}{N_t}\ \text{ or }\ \frac{\sum n_{i,t+1}}{\sum n_{i,t}}$$

Because, however, these relationships are captured in the form of the Leslie matrix ($\mathbf{A}$), we may leverage the power of matrix theories to facilitate an analysis of asymptotic population dynamics of a population based solely on vital rates schedules (Caswell 2001; Keyfitz and Caswell 2005).

The Leslie matrix is positive and non-negative in all entries. The Perron-Frobenius theorem (Gantmacher 1959; Shores 2007) provides a mathematical proof that projections based upon the Leslie matrix will converge upon a stable equilibrium. Furthermore, an analytic solution exists for the population growth rate equivalent to the Euler-Lotka $\mathbf{r}$ (Lotka 1922, 1956) as well as for associated parameters such as the stable age-distribution (Espenshade and Campbell 1977; Schoen 2010), the rate of convergence (damping ratio) of a population upon this

stable distribution (Caswell 2001; Schoen 2010), and age-schedule of

reproductive value (Fisher 1930). Each quantity describes an important aspect of

asymptotic population dynamics. The stable age-distribution describes the percent

of persons within each age interval (like a population pyramid) at equilibrium

(Lotka 1922, 1956; Espensahde and Campbell 1977; Kim and Schoen 1993),

reproductive value provides a measure of the impact of each woman of a given

age on overall population growth (Fisher 1930; Galindo 2007), and the rate of

convergence captured in the damping ratio provides a percentage measure of how

much closer the population is to approaching the stable equivalent at each time

step in the population model (Schoen 2010; Caswell 2001).

These calculations are readily handled through the relationship between

the Leslie matrix and its associated right and left eigenvectors (Caswell 1996,

2001; Keyfitz and Caswell 2005):

$$\textbf{10. } Aw_i = \lambda_i w_i$$
$$\textbf{11. } v_i A = \lambda_i v_i$$

Solutions for the associated eigenvectors are obtained by solving the characteristic

equation of the Leslie matrix:

$$\textbf{12. } \det(A - \lambda_i I) = \textbf{0}$$

This analytic solution captures the exponential population growth rate (λ_1), the

stable age distribution ($\mathbf{w_i}$—right eigenvector) and the reproductive value

schedule ($\mathbf{v_i}$—left eigenvector). Caswell (2001:73–74) provides a readable

explanation of how the characteristic equation is equivalent to the discrete form of

Lotka's integral equation for solving for an asymptotic population growth rate

(Euler 1970; Lotka 1922, 1956), to which the interested reader is referred.

While the stable age-distribution is essential to the population growth rate

upon reaching equilibrium (Charlesworth 1980; Caswell 2001), the reproductive

value vector provides information on the relative contribution of females of a

given age upon future population increase (Fisher 1930; Galindo 2007; Williams

1966; Pianka and Parker 1976). Fisher's Reproductive Value equation (Fisher

1930) grows out of the net reproduction ratio:

$$13. \ R_0 = \sum l_x m_x$$

This provides the expected number of offspring that a single female at birth

should be expected to contribute to future population growth under the

assumption that current survival and fertility rates continue (Lotka 1922, 1956;

Caswell 2001; Preston et. al. 2003). Fisher's concept attempts to capture the

proportional contribution of a single female to overall population growth,

requiring a consideration of age-specific values:

$$14. \ R_x = \frac{1}{e^{-rx}l_x} \sum l_x m_x \ \text{ or } \ R_x = \sum l_x m_x e^{-rx}$$

In this form, Fisher's Reproductive value weights current reproduction by

population growth, borrowing metaphors from finance to explain expected

contributions of a single woman to future population growth under a scenario

involving a juvenile period during which reproduction does not occur (Fisher 1930; Preston et. al. 2003; Keyfitz and Caswell 2005). Williams (1966a) introduced a useful distinction for our purposes, partitioning current and future reproduction, with expected future reproduction (or Residual Reproductive Value in his language) as the product of survivorship to the current age interval and reproductive value at that age:

$$15.\ RRV_x =\ L_x * R_x$$

While both forms relate reproductive value to the concept of discounting, in this study we wanted to use the concept of reproductive value to capture the potential effects of contact-related mortality differences by age and sex to the post-settlement population recovery observed among the Northern. On this basis, we borrowed the concept of residual reproductive value, but related it to the net reproduction ratio, considering future numeric contribution to population growth without scaling/discounting for anticipated future population growth to obtain a proportional estimate of contribution:

$$16.\ R_x = 5 * \sum_{x=y}^{\omega} l_y m_y$$

This formula allows numeric estimation of future reproductive contributions, with partitioning of future childbearing, adjusted for the use of five-year grouped data on age-specific fertility and survivorship.

Several important associated parameters may be derived analytically from the overall asymptotic model of population dynamics described here. First, since at equilibrium the largest eigenvalue (λ_1) comes to dominate the solution of the projection equation, the ratio of the values of this eigenvalue and the next greatest one provide a measure of the rate of convergence upon the stable equivalent implied by a given vital rates schedule. It is useful to think of eigenvalues as "stretching" transformations of a single vector of age-specific population counts (Gantmacher 1959; Caswell 2001), which makes it intuitive that the greatest increase in total population count will be related to the impact of births. This is the population renewal process of Lotka (1922, 1956). The ratio of the dominant eigenvalue (capture births) to the next largest will diminish as the population converges upon its equilibrium, and this ratio provides a measure of how much, in percentage terms, the population is converging upon this equilibrium during each projection period. This value is known as the damping ratio (Letkovich 1971; Caswell and Werner 1978):

$$17. \ \rho = \frac{\lambda_1}{|\lambda_2|}$$

The damping ratio may, in turn, be utilized to estimate a time to convergence where **x** represents the number of time-steps in a projection required before the numerator will be some pre-determined number of times greater than the second. There is an arbitrariness to this value; however, in most studies **x** is set to 10 by

convention (Caswell 2001; Kalisz and McPeek 1992) and the time to convergence

upon this relationship is estimated as:

$$18.\ t_x = \frac{\log(x)}{\log(\rho)}$$

Together, the analytic solutions described here provide estimates of the

asymptotic growth rate, reproductive value schedule, and stable equivalent age

structure and facilitate a comprehensive analysis of long-run population dynamics

implied by a given set of vital rates captured in the Leslie matrix (**A**). The

ergodocity theorem that underlies these results is insensitive to measurement

uncertainty in estimation of vital rates, and hold for stochastic versions of these

models: even stochastic populations converge (Tuljapurkar and Lee 1997; Cohen

1985; Sykes 1969).

Demographic Elasticities and Asymptotic Population Growth Rates

The model of asymptotic population dynamics developed here suggests that the

population growth rate and other asymptotic demographic parameters should be

sensitive to variation in the age-specific survival and fertility rates captured in the

Leslie matrix (**A**). Since the dominant eigenvalue captures the asymptotic growth

rate associated with this matrix, perturbations of the specific $\mathbf{a_{ij}}$ values within it

should produce measurable differences in long-run estimates of this parameter

(Caswell and Werner 1978; Caswell 2000; de Kroon et al. 2000). The

measurement of these impacts using analytic solutions based on implicit

differentiation (Caswell 2001; Caswell and Werner 1978; Kalisz and McPeek

1992) allows assignment of absolute sensitivities (24) to each $\mathbf{a_{ij}}$ entry in the

Leslie matrix:

$$19.\ s_{ij} = \frac{\partial \lambda}{\partial a_{ij}}\ or\ v_i w_j$$

The right term provides a strong hint about the impact of each $\mathbf{a_{ij}}$ entry

(and the vital rate it corresponds to) on population growth: it is the product of the

reproductive value vector and the stable population vector: the left and right

eigenvalues associated with the Leslie matrix (Caswell 2000, 2001, 2010; de

Kroon et. al. 2000). While this allows a consideration of the relationship between

specific age-specific schedules of mortality and fertility and asymptotic

population growth rates, sensitivities measure absolute changes in λ_1 and don't

consider the fact that fertility and mortality schedules are measured on different

scales (Caswell 2001). As such, Caswell and others (Caswell and Werner 1978;

Caswell 2000; deKroon et. al. 2000) have proposed the use of elasticities, which

scale to 1 and capture the *proportional sensitivity* of asymptotic population

growth to shifts in each element of the Leslie matrix, as a useful alternative

analytic tool:

$$20.\ e_{ij} = \frac{\partial \log \lambda}{\partial \log a_{ij}}$$

Elasticities (or sensitivities for that matter) may be presented in a matrix that corresponds to the a_{ij} entries of the Leslie matrix and, therefore, facilitates an immediate and intuitive assessment of the impact of changes in each element and the asymptotic population growth rate (Caswell and Werner 1978; Caswell 2000; deKroon et. al. 2000). Here, we employ a prospective strategy (Caswell 2000; de Kroon et. al. 2000; Wisdom and Mills 1997) designed to examine differences between Forest and Reservation periods in terms of the sensitivity of population growth rate (λ_1) with respect to changes in specific a_{ij} elements of the Leslie matrix.

Stochastic Demographic Analysis and Simulation

Since elasticities are the first derivatives of the change in λ_1 with respect to changes in specific a_{ij} elements of the Leslie matrix (Caswell and Werner 1978; Kalisz and McPeek 1992; Caswell 2000) variation in vital rates or other forms of stochasticity are irrelevant to their computation, or to the comparison between periods (Caswell 2000, 2001). Two goals of this paper: (1) assessment of the hypothesis that the differential survivorship of young Northern *Ache* women has positively impacted subsequent population recovery and (2) characterization of differences in population growth rate between the two periods (Forest and Reservation), however, are enhanced by the use of stochastic demographic approaches that incorporate uncertainty into Leslie matrix entries (Heyde and

Cohen 1985; Tuljapurkar and Lee 1997; Brault and Caswell 1993; Sykes 1969;

Tuljapurkar 1986).

To assess the impact of the age/sex structure of settlement mortality and

the role of the differential survivorship of young Northern women, we used

monte-carlo simulation to assign uncertainties to each a_{ij} element of the Leslie

matrix (Brault and Caswell 1993; Heyde and Cohen 1985; Tuljapurkar 1986;

Caswell 2001; Lemieux 2009; Taylor and Karlin 2001). Specifically, we

conceptualized each element as corresponding to a Bernoulli random trials model

proposed by Chiang (1961, 1984) with a specific average proportion:

$$21. \, q_x = \frac{events}{trials}$$

and standard deviation thereof:

$$22. \, sd_q = \sqrt{\frac{q_x * (1 - q_x)}{N}}$$

Using this data model, we used monte-carlo resampling (LeMieux 2009;

Taylor and Karlin 2001) to create a set of 10,000 random Leslie matrices,

assuming independence of matrix entries. Most studies utilizing monte-carlo

resampling (Linstrom et. al. 2011; Brault and Caswell 1993; Caswell et. al. 1998;

Hunter et. al. 2010) have used naive resampling algorithms (see LeMieux 2009)

that are subject to "burn-in" bias because of the autocorrelation inherent to the use

of random number generators and tend to underestimate variance in a simulated

expectation (LeMieux 2009; Gardiner 1983; Taylor and Karlin 2001). Here, we used a thinning method, utilizing only every 100th matrix to arrive at a total of 100 uncorrelated random matrices each for the Forest and Reservation periods. For each of these 100 matrices, the asymptotic growth rate (λ_1) was recomputed, permitting estimation of its mean and variance as in Caswell et. al. (1998) and Brault and Caswell (1993). With uncertainty in asymptotic growth rates thus quantified, we then compared the population growth rates between Forest and Reservation periods using a two-group t-test comparison using the Welch-Sattherwaithe approximation (Sattherwaite 1946; Welch 1947) using the STATA software package (Version 12).

To further ascertain the role of differential survivorship of young females on population recovery, we extended this uncertainty analysis to include a stochastic simulation experiment in which the number of women in the age groups 20 to 24 and 25 to 29 were randomly varied up or down according to a normal distribution with a mean of 0 and standard deviation of 1 (chosen for uniformity as well as because this would avoid negative values in these age groups). A stochastic demographic projection was implemented using the uncertainty estimates obtained using monte carlo resampling of the Leslie matrix elements and the randomly pulsed 20–24 and 25–29 year old 1980 population counts. A transient 1980 to 2000 exponential population growth rate (that does not depend upon asymptotic convergence as does λ_1) was computed as:

$$23. \; r = \ln \left(\frac{N_{1980}}{N(proj)_{2000}} \right) / 4$$

To estimate the relationship between this transient rate of growth and shifts in the

simulated base population to increases or decreases in the base population within

age-groups with improved settlement-period survivorship (women ages 10 to 19

in 1970), we followed the example of Wisdom, Mills, and colleagues (Wisdom

and Mills 1997; Wisdom et. al. 1965) and employed simple linear regression of

the estimated growth rates on the simulated count of women in each of these two

age groups (while holding all others constant) to model the coefficients associated

with a one woman increase in survivorship. Regressions were made with omission

of the constant term to isolate the effect of the counts of women (Casella 1983;

Turner 1960).

Last, to project the future of the Northern _population recovery given

current information, a stochastic demographic projection based on the estimated

λ_1 of the Reservation period was made using the method proposed by Lewontin

and Cohen (1969) and reviewed in Caswell (2001). Utilizing the estimated

distribution of λ_1 allows the projection of the total population from a 2002 Hill

and Hurtado Census base (n=760) to remain sensitive to variation in vital rates

while providing a simple method for projecting population totals with uncertainty

(Lewontin and Cohen 1969; Caswell 2001) as:

$$24. \; N_t = N_0 * e^{rt}$$

This is equivalent to *parametric bootstrapping* (Efron 1981; Hunter et. al. 2010) and provides a mechanism of stochastic population projection with computation of the range between median, 2.5^{th}, and 97.5^{th} percentiles defining a credibility interval about them (Heyde and Cohen 1985; Tuljarpurkar and Lee 1997; Brault and Caswell 1993; Caswell 2001; Linstrom 2011; Hunter et. al. 2010).

Database Development: Ache Life History Data

We utilized data collected by anthropologists Hill and Hurtado (1996) and previously published in the *Ache Life History: The Ecology and Demography of a Foraging People* (Aldine de Gruyter 1996). We refer to it here from here forward as the "ALH data." Data reported in the ALH volume were collected over a ten year period between 1982 and 1992, through a combination of retrospective collection of reproductive histories (including both births and offspring deaths) and direct household census-taking (Hill and Hurtado 1996). The ALH data were drawn from a total of 435 interviews that collected information on every child ever born to a Northern *Ache* woman between 1930 and 1992, including stillbirths as well as late-term miscarriages. Comprising the complete reproductive history of 219 women, these interviews capture data on children ever born, their sex, their age at death, and their cause of death. Approximately thirty-three percent of these interviews were taken from the mother herself, an additional 35 percent came from interviews of either her sister or daughter, another 21 percent came from

daughters of deceased mothers, and the remaining 11 percent were drawn from close relatives including either nieces or first cousins (Hill and Hurtado 1996:95). The nature of these data required cross-checking and validation; Hill and Hurtado report that 65 percent of these interviews were cross-validated once or more with close kin or through reinterview of the mother (94). Reliability of these histories was very high: 98 to 100 percent of the time interviewees agreed on sex of the child, while 82 to 96 percent of the time they agreed on the number of live births. Likewise, 98 percent of the time interviewees agreed on the age at death of the recorded individual. Since age is not a particularly important Ache social category and the Northern *Ache* historically did not possess a sophisticated calendric system, actual birthdates were only available for individuals born after 1977 when Catholic Missionaries began to record births. To assign ages to individuals born before 1977, a relative age-listing system was developed (Hill and Hurtado 1996:112, 73–74) to assign ages to these individuals and then validated against known birth dates in the post-1977 period through comparison of aging of past individuals with assessments of the correspondence between assessments and observed age of living individuals. This master age-list was comprised of a total of 1,930 individual rankings and observed errors were far less than a percentage point for ages of individuals born one year or more apart and rose to only 19 percent when ranked individuals were born within the same year (Hill and Hurtado 1996:121). The quality of the ALH data is considered to be high and

precise enough to accomplish the comparisons reported in this study, which are robust to age-estimation errors.

Results

The asymptotic population dynamics of the Northern *Ache* during Forest and Reservation periods differ in terms of both fertility and mortality structures (Fig. 2; Table 1–2). While total fertility rates differ little between the two periods, (8.09 vs. 8.51), the schedule of child-bearing during the Reservation period is shifted toward a greater magnitude of births occurring in earlier age-intervals. Survivorship is greatly increased in both sexes, especially among males under 15 years of age (Fig. 2). Overall, life-expectancy is nearly ten years greater during the Reservation period (45.60 vs. 37.10 in the Forest). As the Northern *Ache* are an essentially closed population with little known immigration or emigration (Hill and Hurtado, 1996), these shifts should be anticipated to result in younger age-structure, an accelerated population growth (especially in the short-term), and more rapid convergence upon the asymptotic growth rate (Keyfitz 1971, 1973; Coale 1972), even when uncertainty in vital rates is considered (Heyde and Cohen 1985; Tuljapurkar and Lee 1997). The asymptotic growth rates for the two periods (1.08 vs 1.10) are significantly different [a stochastic analysis—see Caswell (2001) and Brault and Caswell (1993)—suggest at the alpha = 0.0001 level] and the damping ratios suggest that the time to convergence to a stable

population structure and growth rate is reduced from 131 years in the Forest period to 99 during the Reservation period). As expected, generation times are shorter when estimated based on the Reservation period data (29.20 vs. 31.22)— suggesting that the time to convergence in the Reservation period will occur within one less generation than in the Forest. These observations suggest that the Reservation period may be coherently interpreted within the framework of the demographic transition, where survivorship rates improve while fertility remains higher before subsequently beginning to fall (Caldwell 1976; Kaplan 1994).

The analysis of demographic elasticities (Caswell and Werner 1978; Caswell 2000; deKroon et. al. 2000) suggests that the relative contribution of these patterns to shifts in population growth rate (Table 3) are attributable to both improvements in juvenile survivorship (0 to 20 years) and increased fertility during young adulthood (20 to 30 years). The overall patterns of these elasticities are similar between the two periods, with the contribution of early-life survivorship ranging between 4 and 6 times greater than those associated with age-specific fertility in any interval or across either period. Overall, it is noteworthy that during the Reservation period, the contribution of age-specific fertilities is between .1 and .05 greater than during the Forest period. Unsurprisingly, these contributions continue to be concentrated at the highest levels among young females (20–24 and 25–29 years). While the overall proportional contribution of fertility effects is lower those associated with survival

during the Reservation period (Table 2), these impacts could be important to population recovery when combined with the differential preservation of young women described by Hill and Hurtado (1996), who suggested that Northern *Ache* females aged 10 to 19 years of age appeared to be more likely to survive the settlement period than other age/sex groups. If so, then these trends in fertility during the Reservation period might have non-trivial impacts on the observed population recovery among the Northern *Ache* from 1980 to 2002.

Hill and Hurtado (1996) provide no demographic or statistical analysis of the proposed differential survivorship of young Northern *Ache* females during settlement, or its impact upon subsequent population recovery. However, since their database provides a 1970 census count of all Northern *Ache* living at the time, we analyze this proposition directly by projecting a 1970 base population forward to 1980, then comparing it to the actual observed 1980 population count. This allowed us to obtain a direct estimate of the age/sex structure of settlement-period mortality within this group (Table 4). We tested the null hypothesis of no difference between the groups using two-group proportion tests based on the Welch-Satterwaithe approximation (Sattherwaite 1946; Welch 1947) and confirmed the differential survivorship of Northern *Ache* women aged 10 to 19 years at the initiation of the settlement period at the alpha = 0.05 significance level. Utilizing Williams' (1966) partitioning of expected reproduction into current and future components (Pianka and Parker 1975) we estimate that at each

surviving female within the 10 to 14 year age group at the initiation of the settlement period would contribute 8.5 future offspring over the course of her lifetime. Similarly, surviving females aged 15 to 19 years would be anticipated to add 7.2 children over the course of their reproductive lives (Williams 1966; Pianka and Parker 1975).

Discussion

These asymptotic results suggest that the differential survivorship of young Northern women during settlement would have positively impacted population recovery during the Reservation period; however, this conclusion rests upon the assumption that that the population has converged upon a stable age-structure and associated growth rate when it clearly has not had time to do so based on the time to convergence reported in Table 1 (Coale 1972; Lotka 1922; Schoen 2010). To assess the transient dynamics relevant to their recent population recovery (1980–2002) without assumptions of population stability, we employed methods of stochastic demography to perturb the age-structure of a 1980 base population while projecting it to 2000 using Reservation period vital rates. Table 5 presents the estimated impact of each woman on 1980–2000 projected growth rates. While the numeric value of the estimated coefficient may seem low, when considered in the context of even a handful of additional women surviving in each age-group, the expected impact is important. Specifically, it is estimated that each additional

woman surviving in either age group would positively impact the 5 year population growth rate between 1980 and 2000 by as much as .006. This would result in a three percentage point increase in the asymptotic five-year growth rate if five women survived who otherwise would not have. Both sets of results suggest the idea that differential survivorship of young women has been an important component of population recovery among the Northern *Ache* after the tragic 1971–1978 settlement period. Unfortunately, no analysis has been conducted to examine why young women in particular were more likely to survive the settlement period than either men or women of other ages.

A stochastic projection based on a 2002 Census count of Ache villages conducted by authors Hill and Hurtado (n = 760), in conjunction with the estimated Reservation period asymptotic population growth rate, suggests that if this positive trend continues it will have a rather startling impact on the demographic future of the Northern *Ache* (Fig. 3). The 50th percentile projection suggests that the population will grow to over 2,00 persons by 2052 (n = 2,063)— a nearly tripling from the base of 760 persons recorded in 2002. A more conservative estimate at the 2.5th percentile is not significantly less impressive, suggesting that the population will reach 1,713 persons. A high projection (97.5th percentile) suggests it will climb to 2,490 persons by 2052. The 50th and 97.5th percentile projections both imply an approximate tripling of the Northern *Ache* population over the 50 year projection horizon.

Previous researchers have focused upon the potential importance of fertility as a microdemographic determinant of population recovery among the Indigenous Peoples of tropical South America [Gomes 2000; Brea 2003; but see McSweeney and Arps (2005)]. Our analysis suggests that among the Northern population, recovery is driven not only by fertility, but also by large increases in life-expectancy—in accordance with demographic transition theory (Caldwell 1976; Kaplan 1994). In the context of the Northern, it appears that fertility comprises a return to overall Forest-period levels, with an notable increase in magnitude in earlier age-intervals. When this fertility is combined with such large increases in early-life survivorship, it is clear that rapid population growth should be expected during the foreseeable future of the Northern (Preston et. al. 2003; Wachter 2012). Our observation that the age/sex-specific patterns of survivorship during the period of population crash observed during the 1971–1978 settlement period has impacted subsequent population recovery among the Northern is a novel one with a multiplicative effect in light of return to Forest-period fertility. Unfortunately, it is one which may not be observable for any other such group; the data utilized here constitute a unique resource. The paucity of available demographic microdata for pre and post-contact periods places a large limitation on what we may know about the impact of pacification and settlement-period mortality on subsequent population recovery among similar populations (Brea 2003; Gomes 2000; McSweeney and Arps 2005). The collection of better

demographic data for surviving groups is a necessity of adequate future planning

(McSweeney and Arps 2005; Hamilton et. al. 2014) and should be designed to

support appropriate demographic analyses, including population projections.

  The effect of population momentum (Keyfitz 1971, 1973; Coale 1972;

Keyfitz and Caswell 2005; Schoen 2010) is likely to have a long-lasting

accelerating impact on Northern *Ache* population growth, as observed in our

stochastic projection (Fig. 3). It remains to be seen, however, how the most

rapidly modifiable component of change—fertility—may shift in the near future.

It is likely that the fertility decisions of women within populations undergoing

rapid socio-cultural and economic change such as the Northern *Ache* are

exceedingly complex (Snopkowski and Kaplan 2014) and the role of land

constraints remains unexamined in the current analysis (Hamilton et. al. 2014;

Walker et. al. 2013). Hill and Hurtado (1996) suggest that this is demonstrably

true among the Northern *Ache* in particular as women face significant trade-offs

between child-rearing, resource collection, and more modern goals such as

education (Hurtado et. al. 1985, 1992; Snopkowski and Kaplan 2014). Until such

a time as the Northern *Ache* women choose to reduce fertility, demography will

be destiny. While this population recovery is in many respects encouraging, in the

case of the Northern *Ache* this rapid population growth is likely to place

significant strains on a limited resource base resulting from both territorial

restriction and destruction of ancestral lands (McSweeney and Arps 2005;

Hamilton et. al. 2014). It also certainly presents challenges related to meeting both their public health and educational needs (Salzano and Hurtado 2004). While the Northern *Ache* and similar groups have justifiably received a large amount of attention for the tragic events surrounding their contact, pacification, and settlement experiences, they now merit an equal amount of attention as they attempt to plan for a healthy and sustainable future.

Acknowledgments

Literature Cited

Bongaarts, J. 1994. Population policy options in the developing world. *Science* 263:771–776.

Brault, S., and H. Caswell. 1993. Pod-specific demography of killer whales (*Orcinus orca*). *Ecology* 74:1,444–1,454.

Brea, J. 2003. "Population Dynamics in Latin America." In *Population Bulletin of the Population Reference Bureau*. Washington, DC: PRB. 581:1–38.

Caldwell, J. 1976. Toward a restatement of demographic transition theory. *Popul. Dev. Rev.* 2:321–366.

Casella, G. 1983. Leverage and regression through the origin. *Am. Stat.* 37:147–152.

Caswell, H. 1996. An analysis of life-table response experiments II. Alternative parameterizations for size and stage-structured models. *Ecol. Mod.* 88:73–82.

Caswell, H. 2000. Prospective and retrospective perturbation analyses: Their roles in conservation biology. *Ecology* 81:619–627.

Caswell, H. 2001. *Matrix Population Models. Construction, Analysis, and Interpretation*, 2nd ed. New York: Sinauer.

Caswell, H. 2010. Life-table response experiment analysis of the stochastic growth rate. *J. Ecol.* 98:324–333.

Caswell, H., and P. A. Werner. 1978. Transient behavior and life history analysis of teasel (*Dipsacus sylvestris huds.*). *Ecology*. 59:53–66.

Caswell, H., S. Brault, A. Read et al. 1998. Harbor porpoise and fisheries: An uncertainty analysis of incidental mortality. *Ecol. Appl.* 8:1,226–1,238.

Charlesworth, B. 1980. *Evolution in Age-Structured Populations*. New York: Plenum.

Chiang, C. L. 1961. Standard error for the age-adjusted death rate. In *Vital Statistics, Special Reports*. USDHEW, PHS, Washington, DC: US Government Printing Office. 47:271–285.

Chiang, C. L. 1984. *The Life Table and Its Applications*. Malabar: Krieger Publishing Company.

Clastres, P. 1972. *Chronique des Indiens Guayaki. Ce que Sevant les Ache, Chasseur Nomdades du Paraguay*. Paris: Pion.

Coale, A. 1972. *The Growth and Structure of Human Populations: A Mathematical Investigation*. Princeton: Princeton University Press.

Coale, A., and P. Demeny. 1966. *Regional Model Life Tables and Stable Populations*. New York: Academy Press.

Cohen, J. E. 1985. Stochastic demography. *Encylopedia of Statistical Sciences,* vol. 8. New York: Wiley.

De Kroon, H., J. Groenendael, and J. Ehrlen. 2000. Elasticities: A review of methods and model limitations. *Ecology* 81:607–618.

Efron, B. 1981. Nonparametric etimates of standard error: The jackknife, the

 bootstrap, and other methods. *Biometrika* 68:589–599.

Espenshade, T., and G. Campbell. 1977. The stable equivalent population, age

 composition, and Fisher's reproductive value function. *Demography*

 14:77–86.

Euler, L. 1970 (1760). A general investigation into the mortality and

 multiplication of the human species. *Theoretical Population Biology*

 1:307–314.

Fisher, R. 1930. *The Genetical Theory of Natural Selection*. New York: Plenum.

Gantmacher, F. R. 1959. *Matrix Theory.* New York, NY: Chelsea Publishing Co.

Gardiner, C. W. 1983. *A Handbook of Stochastic Methods for Physics, Chemistry,*

 and the Natural Sciences. New York: Springer.

Gomes, M. P. 2000. *The Indians and Brazil*. Gainesville: University of Florida

 Press.

Hamilton M., R. Walker, and D. Kesler. 2014. Crash and rebound of indigenous

 Populations in Lowland South America. *Scientific Reports* 4:1–5.

Hamilton, W. D. 1966. The Moulding of Senescence by Natural Selection. *J.*

 Theor. Pop. Biol. 12:12–45.

Heyde, C. C., and J. E. Cohen. 1985. Confidence intervals for demographic

 projections based on products of random matrices. *Theor. Pop. Biol.*

 27:120–153.

Hill, K., and A. M. Hurtado. 1996. *Ache Life History: The Ecology and Demography of a Foraging People*. New York: Aldine de Gruyter.

Horvitz, C.C., W. Schemske, and H. Caswell. 1997. The Relative "Importance" of Life-History Stages to Population Growth: Prospective and Retrospective Analyses. In S. Tuljapurkar and H Caswell, editors. *Structured Population Models in Marine, Terrestrial and Freshwater Systems*. New York: Chapman and Hall.

Howell, N. 1976. *Demography of the Dobe Kung*. New York: Academic Press.

Hunter, C. M., H. Caswell, M. Runge et al. 2010. Climate change threatens polar bear populations: A stochastic demographic analysis. *Ecology* 91:2,883–2,897.

Hurtado, A., K. Hawkes, K. Hill et al. 1985. Female subsistence strategies among ache hunter-gatherers of Eastern Paraguay. *Hum. Ecol*. 13:1–28.

Hurtado, A., K. Hill, H. Kaplan et al. 1992. Trade-offs between female food acquisition and child care among Hiwi and Ache foragers. *Hum. Nature* 3:185–216.

Jackson, R. 1994. Indian population decline: The missions of Northwestern Spain, 1687–1840. Albuquerque: University of New Mexico Press.

Kaplan, H. 1994. Evolutionary and wealth flows theories of fertility: Empirical tests and new models. *Popul. Dev. Rev*. 20:753–791.

Kalisz, S., and M. McPeek. 1992. Demography of an age-structured annual: Resampled projection matrices, elasticity analyses, and seed bank effects. *Ecology* 73:1,082–1,093.

Keyfitz, N. 1971. On the momentum of population growth. *Demography* 8:71–80.

Keyfitz, N. 1973. Individual mobility in a stationary population. *Pop. Stud.* 27:335–352.

Keyfitz, N., and H. Caswell. 2005. *Applied Mathematical Demography*, 3rd ed. New York: Springer.

Lefkovich, L. P. 1971. Some comments on the invariants of population growth. In *Statistical Ecology*, G. P. Patil, E. C. Pieliou, and W. E. Waters, eds. University Park: Penn State Press, 337–360.

Lemieux, C. 2009. *Monte Carlo and Quasi-Monte Carlo Sampling.* New York: Springer.

Leslie, P. H. 1945. On the use of matrices in certain population mathematics. *Biometrika* 33:183–212.

Leslie, P. H. 1948. Some further notes on the use of matrices in population mathematics. *Biometrika* 35:213–245.

Lewontin, R., and D. Cohen. 1969. On population growth in a randomly varying environment. *Proc. Nat. Acad. Sci.* 62:1,056–1,060.

Linstrom, J., R. Reeve, and S. Salvidio. 2011. Bayesian salamanders: Analyzing the demography of an underground population of European plethodontid *Speleomante strinattii* with state-space modeling. *BMC Ecol.* 10:4–13.

Lotka, A. J. 1956. *Elements of Mathematical Biology*. New York: Dover.

Lotka, A. J. 1922. The dtability of the normal age distribution. *Proc. Nat. Acad. Sci* 5:339–345.

Lozano, P. 1873. *Historia de la Conquista del Paraguay*, vol. 1. Buenos Aires: Rio de La Plata, y Tucuman.

Maynthusen, F. 1912. Mitteilungen aus dem Gebiete der Guayaki. *Acta del SVII International Congress of Americans, Buenos Aires, 1910.*

McSweeney, K., and S. Arps. 2005. Indigenous populations in Lowland Latin America. *Lat. Am. Res. Rev.* 40:3–29.

Pianka, E., and W. Parker. 1975. Age-specific reproductive tactics. *Am. Nat.* 109:453–464.

Preston, S., P. Hueveline, and M. Guillot. 2003. *Demography: Measuring and Modeling Population Processes*. Oxford: Blackwell.

Psacharapolous, P., and H. Patrinos. 1994. *Indigenous Peoples and Poverty in Latin America.* New York: World Bank.

Rose, F. G. 1960. *Classification of Kin, Age Structure, and Marriage amongst the Groote Eylandt Aborigines.* Oxford: Pergamon Press.

Salzano, F. M., and A. M. Hurtado. 2004. *Lost Paradises and the Ethics of Research and Publication.* New York: Oxford.

Satterwaithe, F. E. 1946. An approximate distribution of estimates of variance components. *Biometrics Bull*. 2:110–114.

Schoemaker, N. 1999. *American Indian Population Recovery in the Twentieth Century.* Albuquerque: University of New Mexico Press.

Shores, T. 2007. *Linear Algebra and Its Applications.* New York: Prentice-Hall.

Snipp, C. M. 1989. *American Indians: The First of This Land.* New York: Russell Sage.

Snopkowski, K., and H. Kaplan. 2014. A synthetic biosocial model of fertility transition: Testing the relative contribution of embodied capital theory, changing cultural norms, and women's labor force participation. *Am. J. Phys. Anth*. 154:322–333.

Sykes, Z. M. 1969. Stochastic versions of the matrix model for population dynamics. *J. Am. Stat. Assoc*. 64:111–130.

Taylor, H., and S. Karlin. 2001. *An Introduction to Stochastic Modeling*, 3rd ed. New York: Academic.

Techo, N. 1897. *Historia de la Provincia del Paraguay*. Madrid: de la Compania de Jesus.

Tuljapurkar, S., and R. Lee. 1997. Demographic uncertainty and the stable equivalent population. *Math. Computat. Model*. 26:39–56.

Tuljapurkar, S. 1986. Demographic applications of random matrix products. In *Random Matrices and Their Applications,* J. E. Cohen, H. Kesten, and C. M. Newman, eds. Providence: American Mathematical Society.

Turner, M. 1960. Straight line regression through the origin. *Biometrics* 16:483–485.

Wachter, K. 2012. *Essential Demographic Methods*. New York: Oxford.

Walker, R., and M. Hamilton. 2014 Amazonian societies on the brink of extinction. *Am. J. Hum. Biol*. 26:570–572.

Welch, B. L. 1947. The generalization of the "students" problem when several different population variances are involved. *Biometrika* 34:28–35.

Williams, G. C. 1966. Natural selection, the costs of reproduction, and a refinement of Lack's principle. *Am. Nat.* 100:687–690.

Wisdom, M., and S. Mills. 1997. Sensitivity analysis to guide population recovery: Prairie chickens as an example. *J. Wildlife Manage.* 61:302–312.

Wisdom, M., S. Mills, and D. Doak. 2000. Life-stage simulation analysis: Estimating vital rate effects on population growth for conservation. *Ecology* 81:628–641.
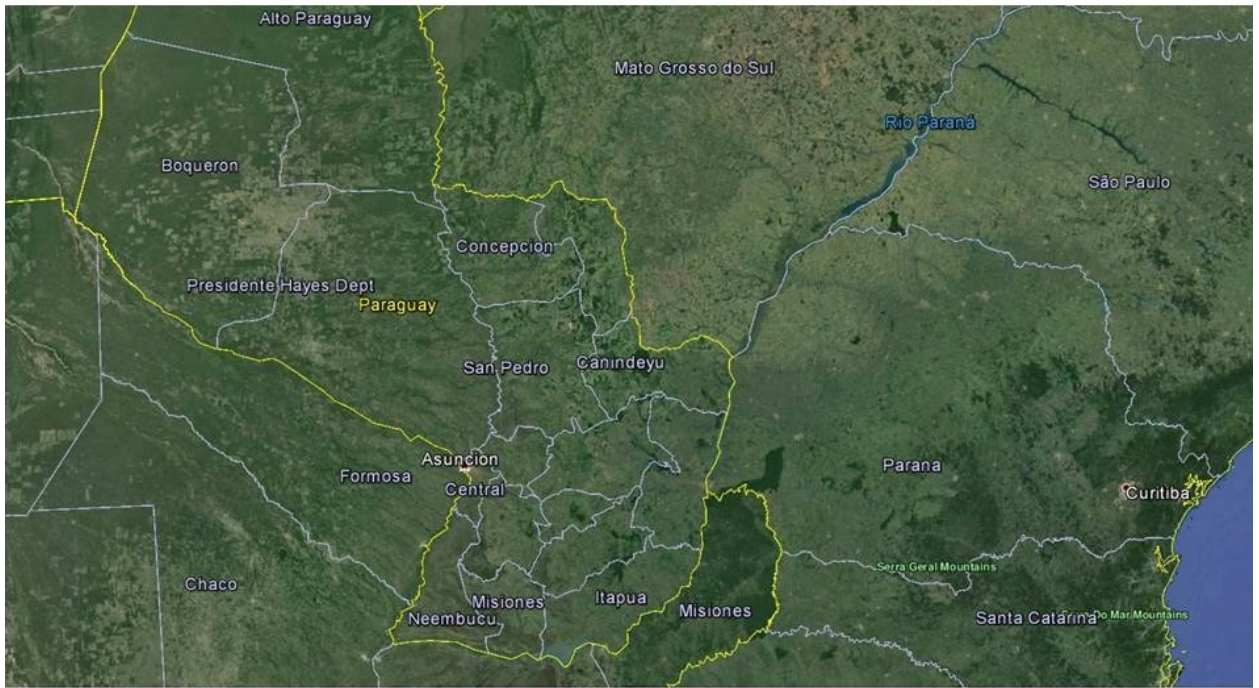
Fig. 1. The Northern *Ache*'s ancestral homeland, the Alto Parana watershed, is located in the Eastern Paraguayan Provinces of Canindeyu and Itapua—bordering the Southernmost portion of Brazil.

Fig. 2. Northern *Ache* age-specific fertility are broadly similar during Forest and Reservation periods; however, mortality risk for both sexes differs markedly between the two. These results are broadly consistent with demographic transition theory.
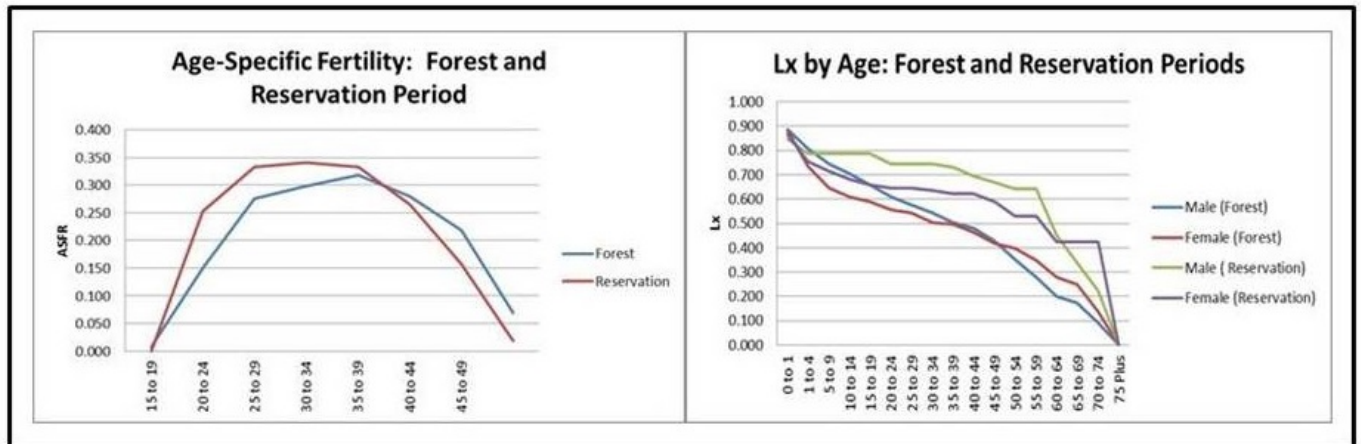
Fig. 3. Stochastic population projections at 2.5[th], 50th (median), and 97.5[th]

percentiles—based on parametric bootstrapping of the population growth rate R

[see Brault and Caswell (1993)].

Table 1. *Ache* Survivorship and Reproduction, Forest and Reservation Periods

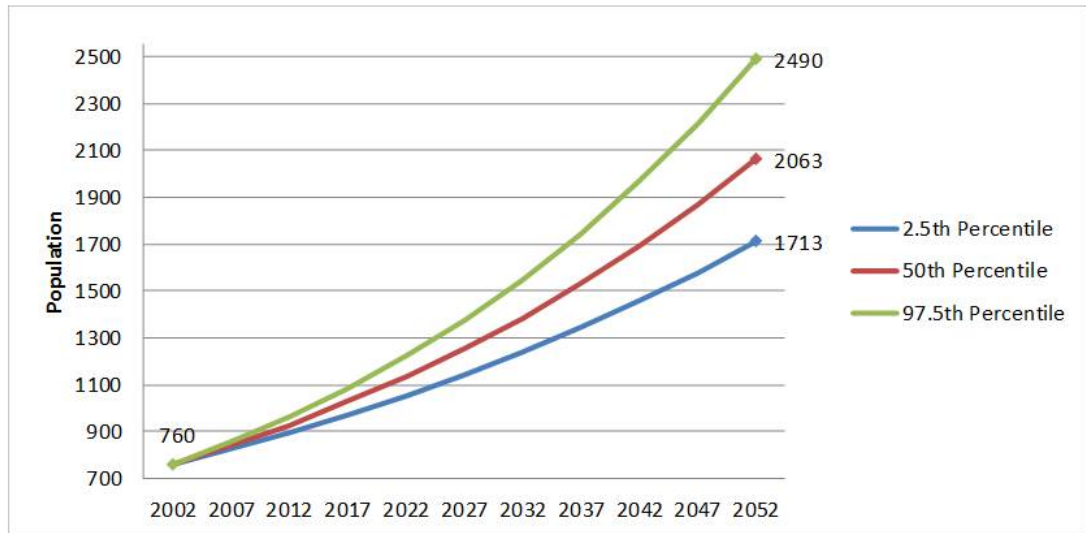| Age	Forest (1930-1978)			Reservation (1978-1993)		
	Lx (Male)	Lx (Female)	mx	Lx (Male)	Lx (Female)	mx
0 to 1	0.885	0.884		0.846	0.867	
1 to 4	0.807	0.734		0.788	0.753	
5 to 9	0.743	0.644		0.788	0.715	
10 to 14	0.706	0.609	0.008	0.788	0.683	0.000
15 to 19	0.659	0.588	0.151	0.788	0.660	0.253
20 to 24	0.610	0.555	0.275	0.744	0.647	0.333
25 to 29	0.577	0.544	0.298	0.744	0.647	0.341
30 to 34	0.542	0.504	0.318	0.744	0.635	0.333
35 to 39	0.504	0.497	0.279	0.730	0.621	0.265
40 to 44	0.479	0.463	0.219	0.696	0.621	0.157
45 to 49	0.429	0.419	0.069	0.670	0.590	0.019
50 to 54	0.350	0.398		0.641	0.531	
55 to 59	0.280	0.347		0.641	0.531	
60 to 64	0.198	0.280		0.449	0.425	
65 to 69	0.174	0.249		0.337	0.425	
70 to 74	0.090	0.138		0.224	0.425	
75 Plus	0.000	0.000		0.000	0.000	

Table 2. Characteristics of Stable Equivalent Populations
(Forest vs Reservation Periods)

Growth Parameters	Forest	Reservation
lambda (1)*	1.08	1.10
Damping Ratio	1.09	1.12
Time to Convergence	131	99
NRR	1.57	1.68
TFR	8.09	8.51
e0	37.10	45.60
Generation Time (T)	31.22	29.20
Stable Equivalent Proportions		
c (0 to 4)	0.104	0.112
c (5 to 9)	0.110	0.109
c (10 to 14)	0.098	0.099
c (15 to 19)	0.089	0.090
c (20 to 24)	0.081	0.081
c (25 to 29)	0.074	0.074
c (30 to 34)	0.068	0.067
c (35 to 39)	0.061	0.061
c (40 to 44)	0.056	0.055
c (45 to 49)	0.051	0.051
c (50 to 54)	0.046	0.046
c (55 to 59)	0.041	0.041
c (60 to 64)	0.037	0.037
c (65 to 69)	0.032	0.032
c (70 to 74)	0.029	0.027
c (75 plus)	0.024	0.017

* Difference at asymptotic convergence would be significant at the alpha = 0.05 level.

Table 3. Elasticity of R to Vital Rate Schedules
Forest vs Reservation Periods

Age	Forest		Reservation	
	Survivorship	Fertility	Survivorship	Fertility
0 to 4	0.101		0.121	
5 to 9	0.124		0.138	
10 to 14	0.123	0.001	0.138	0.000
15 to 19	0.111	0.012	0.116	0.022
20 to 24	0.091	0.020	0.090	0.026
25 to 29	0.072	0.020	0.065	0.025
30 to 34	0.052	0.019	0.043	0.022
35 to 39	0.037	0.015	0.027	0.016
40 to 44	0.026	0.011	0.019	0.009
45 to 49	0.023	0.003	0.018	0.009
50 to 54	0.023		0.018	
55 to 59	0.023		0.018	
60 to 64	0.023		0.018	
65 to 69	0.023		0.018	
70 to 74	0.023		0.018	
75 Plus	0.023		0.010	

Table 4. Estimated Impact of Settlement-Related Mortality on *Ache* Age/Sex Structure

Age	1980 Projected		1980 Observed	
	Male	Female	Male	Female
0 to 4	0.208	0.229	0.237	0.274
5 to 9**	0.153	0.157	0.119	0.109
10 to 14	0.119	0.101	0.088	0.080
15 to 19	0.092	0.054	0.098	0.080
20 to 24*	0.079	0.064	0.077	0.126
25 to 29*	0.080	0.042	0.093	0.109
30 to 34	0.049	0.090	0.570	0.086
35 to 39	0.063	0.085	0.068	0.080
40 to 44*	0.053	0.063	0.041	0.023
45 to 49	0.033	0.012	0.046	0.017
50 to 54*	0.022	0.037	0.021	0.000
55 to 59*	0.020	0.026	0.010	0.006
60 to 64*	0.017	0.024	0.010	0.006
65 Plus	0.012	0.015	0.015	0.006

*Females significantly different at the alpha =0.05 level. **Both males and females significantly different at the alpha = 0.05 level.

Table 5. Simulated Impact of Differential Survivorship of Young Women on Northern Ache Population Growth: 1980-2000

Age at Settlement	Age in 1980	Coefficient	Impact of n = 5 on r	Impact of n =10 on r
10 to 14	20 to 24	0.0058	0.0292	0.0583
15 to 19	25 to 29	0.0057	0.0285	0.0569