Homo sapiens and a Sixth Mass Extinction Event

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Abstract

While we likely bear more than a small level of responsibility for the possibility of a sixth mass extinction event and there are predictive studies on the extinction of a range of flora and fauna, Homo sapiens appears to have been overlooked. Those who do consider the extinction of our species look at it as a potential rather than a inevitable event. Studies that predict species extinction have focused on a range of flora and fauna but in regard to Homo sapiens there are, with one notable exception, no predictive studies, only considerations of possible ways this may occur. The exception believes extinction of Homo sapiens will happen in 10,000 years. We agree that extinction will happen, but we disagree on the timing. Given the decline in fertility between 2019 and 2024 and employing a probabilistic projection method in conjunction with 66% confidence intervals for the world as a whole, we find that by 2039 the world population will be between 8.4 billion and 9.0 billion; by 2139 it will be between 1.4 billion and 1.9 billion; by 2239 it will be between 4.5 million and 6.3 million. Human extinction will occur between the years 2339 and 2449, or between 314 and 424 years from now. Given its pace, our extinction may be too late for the world to avoid a sixth mass extinction event. Unlike other species, however, we would remain unique - our extinction would be due to internal rather than external circumstances.
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Introduction

While we likely bear more than a small level of responsibility for the possibility of a "sixth mass extinction event" (Barnosky et al., 2011; Wilson, 1992) and there are there predictive studies on the extinction of a range of flora and fauna (e.g., Foster, et al., 2023; Jones, Zurrell, and Wiesner, 2023; Liu et al., 2024; Toussaint et al., 2021), Homo sapiens appears to have been overlooked. Those who do consider the extinction of our species look at it as a potential rather than a inevitable event (Bostrom, 2002, 2009, 2013; Bostrom and Ćirković, 2011; Ćirković, Sandberg, and Bostrom, 2010; Cohn, 2021; Diamond, 2011; Ehrlich, 1969; Lutz and Qiang, 2002; Meadows et al., 1972; Posner, 2004; Raup, 1986; Spears and Geruso, 2025). This same "potential" viewpoint also is found directly and indirectly in the work of social, economic, and biological theorists such as Herbet Spencer, (Hofstadter, 1944; Spencer, 1864), Karl Marx (Keqing and Foster, 2023; Vettese, 2020) Buckminster Fuller (1969). Charles Darwin, (1869), Garrett Harding (1968) and E.O Wilson (1992), among others, which suggests the high level of concern we have about the extinction of our species.

The lone exception to this viewpoint is Henry Gee (2025: 233), who not only believes human extinction is likely but that it will happen within 10,000 years. His view is based on several factors, including the desire for fewer children, advancement of contraceptive technology, the cost of having and raising children, the lack of genetic diversity in our species, climate change, our dominance of the world's natural economy, our dependence on a narrow range of plant-based food, and the evolutionary record, which shows that of the many varieties of hominins that came into being only one remains – us. Putting all of this together, Gee (2025) argues that our species reached its peak in the 1960s and that, like the Roman Empire, it is now on the path of decline and eventual fall. Swanson and Tayman (2025a) examined Gee's from a demographic perspective and found that Homo sapiens will likely be extinct by 2394. Because they used a deterministic approach (Swanson and Tayman, 2025a), we add more specificity to their finding by using a probabilistic approach.

Barring the implausible possibility that fertility rates in below replacement countries will go back above replacement level (Goldin, 2021; Hellstrand et al., 2021; Hwang, 2023; Wolf et al., 2011) and the rates in high fertility countries will not continue to decline (OECD, 2024), we agree with Gee that extinction will happen but we disagree on the timing: The work we present here suggests that humans will be extinct much faster. We disagree on the timing because in examining current world population estimates (2020 and 2025) by age (0-4, 5-9,…80-84, 85+) available from the U.S. Census Bureau (2025), we found that in trending out the (dramatic) five year rate of change in the Child-Adult Ratio (CAR, the number aged 0-4 divided by the number aged 15-44) over their respective five year periods, the human population would become extinct by 2339, only 314 years from now.

As an overview of the basis for these arguments, we first discuss current and future assumptions about the level of fertility, followed by a description of the methods and data we use and our results, We end the paper with a discussion.

World Fertility Levels

Estimating fertility (and mortality) for the world as a whole is not an easy task. Assembling the records from individual countries and attempting to harmonize them is a major task in itself. Adding to this task is the fact that some countries have "vital statistics" that are more or less complete, but many do not (Pullum, 2004; Swanson, 2024a). Adair et al. (2023) report that of 194 countries, civil registration of births was only 77%, while completeness of vital statistics was only 63%. They found that the gap in completeness between civil registration and vital statistics for births is most pronounced in countries with lower civil registration completeness. Methodological tools (see, e.g., Popoff and Judson, 2003) and sample surveys are used to provide estimates where vital records are known or thought to be incomplete (see, e.g., Philippine Statistics Authority (PSA) and ICF, 2023). However, these are samples, subject not only to sampling error, but also to coverage, non-response, and measurement error (Swanson, 2013: 13-16).

Keeping the difficulty in mind, here are three current estimates of the world fertility in terms of the Total Fertility Rate (TFR): (1) 2.2 (Population Reference Bureau, 2025); (2) 2.25 (United Nations, 2024b); and (3) 2.29 (U.S. Census Bureau, 2025). Carney (2024) argues that the above replacement rates are too high and that it is likely that the world's fertility level is already below replacement.

The UN and Census Bureau fertility levels are present in world projections made by these organizations, as well as anyone else using these same data, respectively. In the case of the UN's projections, its medium variant has the 2100 population at 10,288,515 (UN, 2024a). Underlying this projection is a TFR that in 2024 is equal to 2.2464 (rounded above to 2.25) and by 2100 is 1.8390 (United Nations, 2024b). If either the TFR trend is extended to a longer-term projection or held constant at its 2100 level and extended to a longer-term projection, the medium variant of the UN's projection would ultimately yield a human population of zero. Similarly, underlying the U.S. Census Bureau's projections of the world population are TFRs of 2.31 in 2024 and 2.29 in 2024 and 2025, respectively (U.S. Census Bureau, 2025). These values are inherent in the Bureau's 2100 projection of the world population, 10.9 billion, which has an accompanying TFR of 1.81 (U.S. Census Bureau, 2025). Clearly, as is the case for the UN's projection, if this projection were extended further into the future, it also would yield a human population of zero.

The Cohort Component Method of Population Projection

Current and future world fertility, in the form of a TFR that overall is near replacement level, is inherently embedded in the fertility component of the approach employed in these projections - the Cohort Component method (CCM) (George et al., 2004; Smith, Tayman, and Swanson, 2013: 155-182; Yusuf, Martins and Swanson, 2014: 231-253). As its name suggests, the CCM requires the application of the components of population change – fertility, mortality, and migration to the age-gender structure at the projection's launch year. We begin with a discussion of the CCM, which also forms a point of departure for the forthcoming discussion of the Hamilton-Perry method, which we employ in this paper.

There are three *components of change* in a population: mortality, fertility, and migration. The overall growth or decline of a population is determined by the interplay among these three components. The exact nature of this interplay can be formalized in the *basic demographic equation*:

$$P_l - P_b = B - D + IM - OM, \quad [1]$$

Where P_l is the population at the end of the time period; P_b is the population at the beginning of the time period; and B, D, IM, and OM are the number of births, deaths, in-migrants, and out-migrants during the time period, respectively. The difference between the number of births and the number of deaths is called *natural change* (B – D); it represents population growth coming from within the population itself. It may be either positive or negative, depending on whether births exceed deaths or deaths exceed births. The difference between the number of in-migrants and the number of out-migrants is called *net migration* (IM – OM); it represents population growth coming from the movement of people into and out of the area. It may be either positive or negative, depending on whether in-migrants exceed out-migrants or out-migrants exceed in-migrants.

The basic demographic equation can also be extended to apply to age groups, age-sex groups, and age-sex-race groups, as well as age-sex-ethnicity groups. This type of extension forms the logical basis of the and can be used to project a population into the future by age, age and sex, or by age, sex, and race. Once launched, these components (which are frequently modified as the projection moves into the future based on assumptions about their direction) are applied to the resulting age-gender structure at each cycle of the projection. At the world level, there is no migration, which eliminates the need for this component in world population projections.

The Hamilton-Perry Method of Population Projection

Instead of using the CCM approach, we employ its algebraic equivalent, the Hamilton-Perry (H-P) method (Baker et al., 2017: 251-252). Unlike the CCM approach, the H-P method does not apply the separate components of population change to the age-sex structure at the launch year. Instead, it computes cohort change ratios (CCRs) using two counts of the age-structure in question, typically five or ten years apart, which directly capture mortality and migration. The fertility component uses a "child-adult ratio" from the most recent age structure data or a "child-woman ratio" for a projection by gender. It is well- suited for generating a projection of the population of the world, per the framework found in Swanson et al. (2023): (1) It corresponds to the dynamics by which a population moves forward in time; (2) there is information available relevant to these dynamics; (3) the time and resources needed to assemble relevant information and generate a projection is minimal; and (4) the information needed from the projection is generated by the H-P method.

The H-P method moves a population by age (and sex) from time t to time t+k using cohort-change ratios (CCRs) computed from data in the two most recent data points (e.g., censuses or estimates). It consists of two steps. The first uses existing data to develop CCRs, and the second applies the CCRs to the cohorts of the launch year population to move them into the future. The formula for the first step, the development of a CCR, is:

$${}_nCCR_{x,i} = {}_nP_{x,i,t} / {}_nP_{x-k,i,t-k}, \quad [2]$$

where

${}_nP_{x,i,t}$ is the population aged x to x+n in area i at the most recent census/estimate (t),

${}_nP_{x-k,i,t-k}$ is the population aged x-k to x-k+n in area i at the 2nd most recent census/estimate (t-k),

k is the number of years between the most recent census/estimate at time t for area i and the census/estimate preceding it for area i at time t-k.

The basic formula for the second step, moving the cohorts of a population into the future, is:

$${}_nP_{x+k,i,t+k} = ({}_nCCR_{x,i}) \times ({}_nP_{x,i,t}), \quad [3]$$

where

${}_nP_{x+k,i,t+k}$ is the population aged x+k to x+k+n in area i at time t+k

Given the nature of the CCRs, they cannot be calculated for the youngest age group (e.g., ages 0-4 if it is a five-year projection cycle; 0-9 if it is a ten-year projection cycle), because this cohort came into existence after the census/estimate data collected at time t-k. To project the youngest age group, we use the "Child-Adult Ratio" (CAR), where the number in the youngest age group at time t is divided by the number of adults at time t who are of childbearing age (e.g., 15-44). It does not require any data beyond what is available in the census/estimate sets of successive data.

The CAR equation for projecting the population aged 0-4 is:

Population 0-4: $_5P_{0,t+k} = ({_5P_{0,t}} / {_{30}P_{15,t}}) \times ({_{30}P_{15,t+k}})$, [4]

where

P is the population,

t is the year of the most recent census, and

t+k is the estimation year.

Projections of the oldest open-ended age group differ slightly from the H-P projections for the age groups beyond age 10 up to the oldest open-ended age group. If, for example, the final closed age group is 80-84, with 85+ as the terminal open-ended age group, then calculations for the $CCR_{i,x+}$ require the summation of the three oldest age groups to get the population age 75+ at time t-k:

$$_\infty CCR_{75,i,t} = {_\infty P_{85,i,t}} / {_\infty P_{75,i,t-k}} \quad [5]$$

The formula for estimating the population of 85+ of area i for the year t+k is:

$$_\infty P_{85,i,t+k} = ({_\infty CCR_{75,i,t}}) \times ({_\infty P_{75,i,t}}). \quad [6]$$

An issue that is found in the cohort change ratio for the terminal, open-ended age group (which in our case is 85 years and over) in a projection where migration is not a component of population change is that like the equivalent probability of survival in an abridged life table, deaths are not uniformly distributed within the interval (Chiang, 1984: Lahiri, 2018; Swanson, Bryan, and Chow, 2020). This issue tends to exaggerate the length of life for those aged 85 and over in an abridged life table and in an H-P projection. Because of it, we set the extinction of the human race 25 years after the point at which only those aged 85 and over are alive, which translates into the assumption that nobody lives beyond 110. While there are documented cases of people living beyond 110 years (Barbi et al., 2018), given the lack of social-economic and health support for them if there is nobody under the age of 110, we believe this is a reasonable approximation to the extinction of those aged 85 and over, as we discuss later

A disadvantage of the H-P method is that it can lead to unreasonably high estimates in rapidly growing places and unreasonably low projections in places experiencing population losses (Baker et al., 2017). Since the CCR and other extrapolation methods are based on population changes within a given area, it is essential to develop geographic boundaries that remain constant over time. Neither of these issues is a problem when the H-P method is applied to a country, much less the world as a whole.

Before turning to a discussion of the probabilistic approach we use (which is followed by a description of our input data and the projection results), it is helpful to note that like the CCM, the H-P method is grounded in demographic theory. Barring unforeseeable catastrophes and other events that have very low probabilities of occurring (Taleb, 2010), the closer one comes to having accurate data embedded in a method that is grounded in demographic theory, the more accurate the projection method will likely be (Swanson et al., 2023).

ARIMA/Espenshade-Tayman Approach to Probabilistic Population Projections

The approach we take here follows that of Swanson and Tayman (2025), which employs the ARIMA (Auto-Regressive Integrated Moving Average) time series method in conjunction with work by Espenshade and Tayman (1982), whereby we can translate the uncertainty information found in the ARIMA method's forecast to the population forecast provided by the CCM approach. As described by Smith, Tayman, and Swanson (2001: 172-176), an ARIMA model attempts to uncover the stochastic processes that generate a historical data series. The mechanism of this stochastic process is described—based on the patterns observed in the data series—and that mechanism forms the basis for developing forecasts. Up to three processes can represent the stochastic mechanism: autoregression, differencing, and moving average. The most general ARIMA model is usually written as ARIMA (p, d, q), where p is the order of the autoregression, d is the degree of differencing, and q is the order of the moving average.

In regard to this study, the patterns of the autocorrelation (ACF) and partial autocorrelation functions (PACF) were used to find the correct values for p and q (Brockwell and Davis, 2016: Chapter 3). The ARIMA model shown here had random residuals and the smallest possible values for p, d, or q, as determined by the Ljung-Box test (Ljung and Box, 1979). We chose an "adequate" ARIMA model using these criteria. We note that there may be other versions that also are "adequate" and that further refinement of the selection process can be done (e.g., using the augmented Dickey-Fuller test (Dickey and Fuller, 1979) to identify the amount of differencing required to achieve a stationary time series).

Before turning to a description of the Espenshade-Tayman approach, we first clarify our use of the term "confidence interval" in regard to forecast uncertainty. It is more common to use the term "forecast interval" or "prediction interval" in the context of forecasting because a "confidence interval," strictly speaking, applies to a sample (Swanson & Tayman, 2014: 204). However, underlying the approach we describe herein is the concept of a "superpopulation," which, as discussed later, describes a population that is but one sample of the infinity of populations that will result by chance from the same underlying social and economic cause systems (Deming & Stephan, 1941). The concept of viewing a forecast as a sample leads us to choose the term "confidence interval" rather than forecast interval or prediction interval.

We use annual world historical data of total population and land area in square meters to compute population density annually from 1950 to 2020 found at the IDB site to implement the ARIMA model found in the NCSS statistical package (NCSS, 2024) and launch from the annual world forecasts found at the same site for 2021-2060. We use "density" because the Espenshade-Tayman (1982) method for translating uncertainty information does so from an estimated "rate," which in this case is the "rate" of population density. Thus, the 95% confidence intervals generated by the ARIMA world "density" forecasts are translated to the CCM-based world population forecast. Other denominators could be used in developing such a "rate, such as the ratio of the population to housing units. However, using the land area as the denominator provides a virtually constant denominator over time, thereby reducing the effort in assembling the "rate" data. It also serves as a stabilizing element regarding the use of ARIMA in that it dampens the effect of short-term population fluctuations more effectively than, say, housing units, which also can fluctuate over time and not always in concert with population fluctuations. As should be obvious, the data assembled to develop the ARIMA density forecast should encompass the base data used to develop the population projection in terms of the total population numbers. The data we use meets this condition in that the ARIMA model covers the annual period from 1950 to 2020 and the population projection data use the total 2020 population, supplemented by earlier data in the examination of trends.

As alluded to earlier, underlying the Espenshade-Tayman method is the idea that a sample is taken from a population of interest. In this case, the ARIMA results represent the sample, and the CCM forecasts represent the population. This interpretation is derived from the idea of a "superpopulation" (Hartley & Sielken, 1975; Sampath, 2005; Swanson & Tayman (2012: 32-33). This concept can be traced back to Deming and Stephan (1941), who observed that even a complete census, for scientific generalizations, describes a population that is but one of the infinity of populations that will result by chance from the same underlying social and economic cause systems. It is a theoretical concept that we use to simplify the application of statistical uncertainty to a population forecast that is considered a statistical model in this context. This approach is conceptually and mathematically different from the classical frequentist theory of finite population sampling (Hartley and Sielken (1975), but as pointed out by Ding, Li, and Miratrix (2017), in practical terms, these two approaches result in identical variance estimators.

Swanson and Tayman (2025c) compared the intervals generated by this approach for the world as a whole to those generated by the UN for the world as a whole using a Bayesian approach (UN 2024a; United Nations, 2024c). They found that the UN 95% intervals are narrower than the 95% intervals produced from the IBD using the ARIMA/Espenshade-Tayman process. The range in 2050 for the UN interval is six hundred million persons, 37 percent lower than the range from the IDB forecast paired with the ARIMA density model (960 million persons).Although the specific 95% confidence intervals have not been discussed for years other than 2050 in the UN report on its probabilistic world population forecasts, they are available in an Excel file (UN, 2024c). Swanson and Tayman (2025c) used them to produce "half-widths" for the 2030, 2040, 2050, and 2060 UN forecasts. They are, respectively, 0.53%, 1.49%, 2.51%, and 3.76%; the half widths that Swanson and Tayman (2025c) constructed of the IDB forecasts for 2030, 2040, 2050, and 2060 are, respectively, 1.60%, 3.35%, 4.94%, and 6.28%. Although the difference narrows between 2030 and 2060, the uncertainty intervals constructed for the IDB forecasts are wider than those found for the UN forecasts. However, like the UN uncertainty intervals, those generated by the ARIMA/Espenshade-Tayman process increase over time, an important feature because one expected uncertainty to increase over time.

Projection Input Data and Projection Results

As input data, we employ data provided by the U.S Census Bureau via its International Data Base (2025) for 2019 and 2024, which are structured into five-year age groups (0-4, 5-9,…,75-79, 80-84) with 85+ being the terminal, open-ended age group. Table 1 shows the input data along with the 2019-2024 CCRs and the 2019 and 2024 CARs calculated from them. As expected, the CCRs are all less than 1.0, since they only reflect the mortality in moving from a younger to an older age group. They also show the typical mortality pattern by age, with mortality levels increasing with age, most dramatically after age 70. The drop in world fertility levels during the last five years is clearly evident, as the CAR declines by 7.5% between 2019 and 2024.

Table 2 shows the probabilistic (with both 95% confidence intervals and 66% confidence intervals) world population projection from 2024 to 2339, the year of likely extinction. The point projection is based on two key assumptions: 1) the mortality rate based on the 2019-2024 CCRs is unchanged, and 2) the 7.5% drop in the fertility rates, as measured by the CAR, continues every five years into the future. The world population is currently 8.1 billion. In 2039, the world population projection is 8.7 billion people. One hundred years later, the population declines to 1.7 billion, a change of -80%. By 2239, the world population is only 5.4 million, a decline of over -99% between 2139 and 2239. Population extinction occurs in the year 2394 under the point projection, 369 years from now. We use both the 95% and 66% confidence intervals because Swanson and Tayman(2014) found that 95% confidence intervals may often be too wide to be useful.

Accompanying the changes in the total population are dramatic shifts in the age composition of the world population toward the elderly, In 100 years (2124), the youngest age group is just 5.1% of the population, down from 32.4% in 2025. The share of the working ages (20-64) increases from 57.3% in 2024 to 62.5% in 2074, then starts a continuous decline. In 2124, that segment of the population (51.7%) is slightly below its share in 2024 (57.3%). Conversely, the share of the oldest age group (65+) rises dramatically from 10.3% in 2024 to 43.2% in 2124. By 2284, there are no more people aged under 20, 9.9% of the population is aged 20-64, and 90.1% are 65 years of age or older.

Employing a probabilistic projection method in conjunction with 66% confidence intervals, we find: by 2039 the world population will be between 8.4 billion and 9.0 billion; by 2139 it will be between 1.4 billion and 1.9 billion; by 2239 it will be between 4.5 million and 6.3 million. and by 2339 there will be no humans. re. Under this confidence limit, population extinction occurs between the years 2339 and 2449, or between 314 and 424 years from now.

Table 1. World population input data, CCRs and CARs

Age group	2019	2024	CCR
0 to 4	673,612,665	646,202,360	
5 to 9	667,710,912	667,775,896	0.99134
10 to 14	636,570,689	664,986,444	0.99592
15 to 19	601,991,281	633,797,040	0.99564
20 to 24	591,419,519	600,189,731	0.99701
25 to 29	602,625,686	589,354,041	0.99651
30 to 34	589,258,403	599,052,875	0.99407
35 to 39	537,712,957	584,415,902	0.99178
40 to 44	488,273,876	530,890,175	0.98731
45 to 49	475,747,986	480,137,829	0.98334
50 to 54	435,661,787	464,162,310	0.97565
55 to 59	369,556,392	420,078,544	0.96423
60 to 64	316,199,923	349,209,578	0.94494
65 to 69	257,401,498	289,929,534	0.91692
70 to 74	183,787,811	224,477,292	0.87209
75 to 79	128,656,826	147,938,707	0.80494
80 to 84	84,147,776	90,332,565	0.70212
85+	64,359,623	73,152,714	0.49259
All Ages	7,704,695,610	8,056,083,537	
			Pct. chg. 2019-2024
CAR	0.19747	0.18266	-7.5%

Source: US Census Bureau (2025). Calculations by authors.

Table 2. World Probabilistic Population Projections, 2039 to Extinction

Year	66% LL	Projection	66% UL	Half-Width[a]
2039	8,417,212,332	8,694,429,342	8,971,647,600	3.19%
2139	1,427,112,563	1,680,285,710	1,933,458,857	15.07%
2239	4,528,524	5,398,420	6,268,316	16.11%
Extinction Year	2339	2394	2449	

[a] ((UL - LL) / 2) / Projection × 100

Discussion

Because the CAR is the key element in the projection, it is worthwhile to start the discussion with it, which is somewhat equivalent to the General Fertility Rate (GFR) but expanded to include males. For example, the population aged 0-4 at a point in time is primarily influenced by past births but it also is influenced by deaths and includes net migration. It is a ratio that measures the population per 1,000 women and men of childbearing age, which here we define as 15 to 44 years of age. It provides a good picture of current fertility or fertility within a given year and has the advantage of being easy to explain. Still, it is primarily driven by changes in the underlying age structure of the population, which means, for example, if people in their 40s have very few children and the population over 40 increases, the GFR will decrease if the underlying age-specific fertility rates (ASFRs) are not changing, specifically for those aged 40-44. This, however, is a fine point that does not substantively affect the projections. Similarly, if we changed the CAR so that its denominator ranged from age 10 to age 54 (as is the case with the projections done by the United Nations (2024a, 2024b), it would not substantively affect the H-P projections. Speaking of the UN Projections, Swanson and Tayman (2025a) used its 2020 and 2025 data (United Nations, 2025) to develop a trended 2020-2025 CAR in conjunction with 2020-2025 data to generate a deterministic H-P projection to compare with their deterministic H-P projection using IDB data. They found the results similar to be very similar. Starting with a 2025 world population of approximately 8.232 billion, they found that by 2360 less than 1,000 would remain, all of which would be gone by 2430, only 36 years more than the extinction date (2394) found using the IDB data in their deterministic H-P projection. In a similar vein, the selection of a different base period for the CAR trends (e.g., 1999 –2024, 2009-2024, 2014-2024) for a current forecast jump-off point (i.e., 2024) would also yield similar results to those we report here in that they will lead to extinction, whether with the IBD or UN data. Additionally, if a different jump-off point with various base periods (e.g., 2020, with a based period of 2010-2020 or 2015-2020) the result would be the same. Following up on this, we also note that if we hold the CAR constant once the point is reached where the world population begins to decline (2049, whereupon the CAR is 0.123715), the world population will still become extinct – it will just take a few hundred years longer than what we report here.

Some may argue that the use of a simple forecasting method such as which we employ here lacks "real world" predictive ability To such an argument we reply that Green and Armstrong (2015) find that while no evidence shows complexity improves accuracy, complexity remains popular among (1) researchers because they are rewarded for publishing in highly ranked journals, which favor complexity; (2) methodologists, because complex methods can be used to provide information that supports decision makers' plans; and (3) clients, who may be reassured by incomprehensibility.

All of the other events that could potentially occur before our forecasted time period of extinction that can be labeled as "extinction level" (Bostrom, 2022, 2009, 2013; Bostrom and Ćirković, 2011; Ćirković, Sandberg, and Bostrom, 2010; Posner, 2004), which include a giant asteroid strike, volcanic eruptions, plagues, wars involving nuclear, biological, or chemical weapons, rapid climate change, loss of food, are like the zero birth scenario: they get us to the same destination, small numbers of scattered survivors that will ultimately result in zero people – just sooner.

As just noted, in their deterministic H-P projection, Swanson and Tayman (2025a) found that Homo sapiens would be extinct by 2394 if the current decline in birth rates continues. The probabilistic approach we have taken here using the same data generates an extinction date of 2339, which is 55 years sooner because we selected the point at which the lower boundary of the 95% confidence fell below zero as the extinction year. Swanson and Tayman (2025a) also considered the effect on the population of old survivors (aged 65 years and over) would have given the absence of working-age people and the accompanying collapse of services and found that it was likely that Homo sapiens would be extinct 40 year earlier, which is close to 2339, the year that the probabilistic forecast found as the extinction point.

The roles available to women and the status of these roles are integral to the pace of fertility reduction as found in the CAR change shown in Table 1. This change includes transformations underway or largely completed and include changes in intergenerational wealth transfers associated with completing the demographic transition (Caldwell, 2006; Lee and Mason, 2011) and investments in women's education, which have proven especially effective at lowering fertility rates because better educated women tend to marry later and have fewer, healthier children (Sobotka, Beaujouan and Bavel, 2017). These transformations are accompanied by regional variations in the advancement of contraceptive technology, the cost of having and raising children, the lack of genetic diversity in our species, climate change, our dominance of the world's natural economy, and our dependence on a narrow range of plant-based food. Although there is regional variation in the reasons (the desire for fewer children, advancements in contraceptive technology, the worldwide rise in male and female infertility, the cost of having and raising children in modern and modernizing economies and the fact that populations worldwide are aging beyond the age group in which reproduction is both possible and feasible) these factors have come together such that they have resulted in the force driving human extinction for the world as a whole – declining fertility.

Root, Guzzo, and Clark (2025) argue that fears about falling birth rates in the U.S. are based on faulty assumptions and that it is unlikely that fertility in the U.S. will go and stay below replacement level. While assumptions made by others may be faulty, we use current empirical data that shows that the world's fertility is declining dramatically. Barring the improbable possibility that fertility rates in below-replacement countries will go back above replacement level (Goldin, 2021; Hellstrand et al., 2021; Hwang, 2023; Wolf et al., 2011) and that in countries with rates at or above replacement levels will not continue to decline (OECD, 2024), we argue that our assumption that this trend will continue is sound, consistent with arguments presented by Spears and Geruso (2025), and with the trends evident beyond 2080 in the projection done by IHME (2025). In addition, it is worth noting here that while long range forecasting comes with uncertainty, it is not simply "crystal ball gazing" (Alkema et al., 2015; Armstrong, 1985; Basten, Lutz, and Scherbov, 2013; IHME, 2025; Inoue, 2017; Lutz, 1996; Lutz, Sanderson, and Andruchowitz, 2017; Raftery and Ševčíková, 2023;. Raftery, Alkema, and Gerland, 2014; Swanson, 2019, 2024b; Swanson and Tayman, 2017; Swanson and Tayman, 2025c; United Nations, 2024a, 2024c, 2025; U..S. Census Bureau, 2025; Vollset, Goren, Yuan, et al., 2020) and neither is probabilistic population forecasting (Alders, Keilman, and Cruijsen, 2007; Alho and Spencer, 2005; Alho, Cruijsen, and Keilman, 2008; Alkema et al., 2015; Bijak and Bryant, 2016; Goldstein, Lutz, and Pflug, 1994; Hyndman and Booth, 2007; Keilman, 2017, 2020a, 2020b; Lutz, Sanderson, and Andruchowitz, 2017; Pflaumer, 1992; Raftery, Alkema, and Gerland, 2014; Swanson and Beck, 1995; Swanson and Tayman, 2014, 2024, 2025b, 2025c; Swanson, Tayman, and Cline, 2025; Tayman, Smith, and Lin, 2007; United Nations, 2024a, 2024c, 2025; Wilson, 2013; Yu et al., 2023; Zakria and Muhammad, 2009)). Unlike Root, Guzzo and Clark (2025) who have no experience in the field of forecasting and summarily dismiss it, there are clearly many demographers who engage in forecasting and agree with Romaniuc (2010:14) that "Uncertainty should not be a deterrent to exploring the future."

The results we present only consider current age-related survivorship probabilities, and the changes expected in age groups under decreasing fertility. Consider the absence of working-age people and the accompanying collapse of social and health services, as well as the economy as a whole. In the 2006 movie *Children of Men* (based on the prescient book by P.D. James (1993), male sperm counts have fallen so low that births worldwide have ended. This dystopian movie is set in England 20 years after the end of births, where a semblance of civil order remains. At the same time, other complex societies worldwide have already collapsed or are well into the process of collapse. Cohn (2021) and Diamond (2011) provide more images of collapsing complex societies, which suggest that the road to extinction may not be as smooth as our forecast and the process will not be pretty. The scenarios that can be visualized from their work suggest the survivorship rates (the CCRs) would most likely be lower than those used in our forecast beyond 200 years from now due to societal collapse. Given this, the time to extinction would likely be quicker than reported than the deterministic forecast result reported by Swanson and Tayman (2025a), particularly after 2359 when there would be nobody under the age of 65 to help support those aged 65 and over, and many of those alive would have difficulty supporting themselves and assisting in the support of others. Under these dystopian scenarios, it is easy to envision a "Lord of the Flies" situation in reverse, where scattered groups of survivors are not adolescents as found in the book by Golding

(1954) but scattered groups of old people. So, considering the collapse of the family, social and health services, and the economy, it is plausible that the human population of the world could be gone within 314 years per our probabilistic forecast – maybe sooner.

There are hints that human extinction is inevitable. Miller (2020) notes that Enrico Fermi wondered why we have not detected at least one planet in our neighborhood that birthed a civilization and goes on to cite Robin Hanson's "Great Filter" as the force that prevents life being birthed in a star system from going on to colonize other star systems. In addition to the reasons behind this force listed by Miller (2020) it may be the case that civilizations expended the resources on their home planets before they could plant their flags elsewhere. This idea underlies Buckminster Fuller's (1970) book *Operating Manual for Spaceship Earth*. It also is consistent in a "Catch-22" (Heller, 1961) way with the work of Stibel (2025) who presents evidence that humans survived the climatic volatility of the Late Pleistocene period was because our brain size growth slowed down as symbolic communication, external memory systems, and cumulative culture emerged, which facilitated cognitive offloading into material and social domains. The "Catch-22" part of this development is that our cognitive offloading has led us far down the path to the exhaustion of resources and possibly to the point where we will not survive the collapse of the complex social and economic structures that we have constructed and in which we currently reside.

Future research could pursue a "bottom-up" forecasting approach (Smith, Tayman, and Swanson, 2001: 126-127), one that produces forecasts for, say, each of the five regions of the world as defined by the United Nations (Africa, Americas, Asia, Europe, and Oceania) and sums them up to obtain the forecast for the world as a whole. This approach would reveal regional differences in the timing of extinction and likely result in a slightly – but not significantly – different extinction period for the world as a whole. One could apply either the formal or informal variation of the "error propagation" method to the regional confidence intervals to obtain confidence intervals for the world as a whole (Swanson and Tayman, 2014).

Our results are consistent with Gee's (2025) argument that extinction will happen, but they are not in terms of the timing: The work we present here suggests that humans could be extinct in 314 years, well before the 10,000 years posited by Gee. Unfortunately, our extinction may be too late for the world to avoid a sixth mass extinction event. Unlike other species, however, we would remain unique - our extinction would be due to internal rather than external circumstances. Accordingly, in closing, we agree with Romaniuc (2010) that forecasting provides interested agents with information that can lead to corrective actions in such a way as to steer events in a desirable direction.

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Data availability

The data for this study are available from the corresponding author.