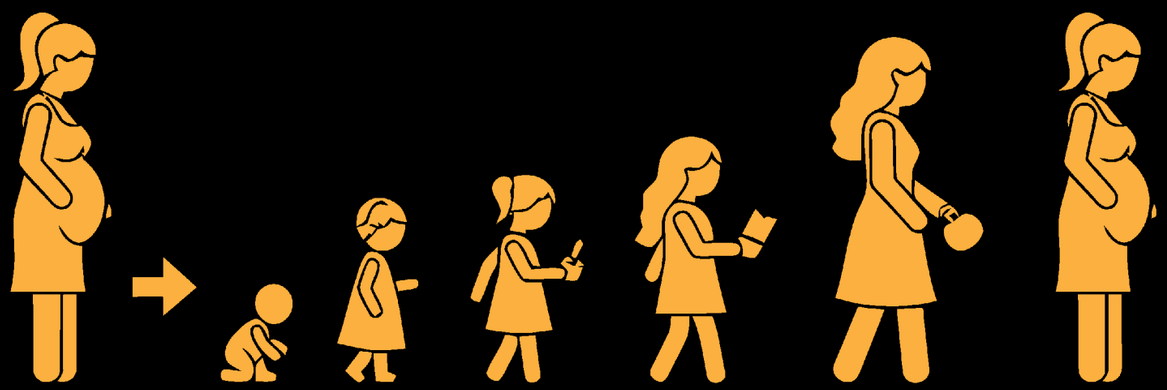
Towards a transdisciplinary demographic theory of birth and death trajectories

What are the basic principles of birth and death?

What determines how birth and death risks change with age?

And what types of organisms follow what types of birth and death trajectories over the course of life?

A theory of birth and death is lacking. And research typically studies these opposite processes separately. But are they so separate?



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DISSEMINATION
Born Once – Die Once

The born once die once project seeks to find shared principles of birth and death, working towards the vision of a transdisciplinary theory of birth and death across systems and scales.

> Demographers conventionally study birth and death in separate fields … now could be the right time to make a connection.

Background

What are birth and death trajectories?

People are born, exist for a while and die. When people are studied collectively as a population, their risk of birth and death can be calculated based on the number of births and deaths within a population of a certain size.

As people grow older and change with age, the risks of birth and death change accordingly. This is true not just for humans but for any other organism. For example, in many animal populations, including humans, the risk of dying at different ages is initially high for newborns, then quickly falls to reach the lowest levels around reproductive maturity and mostly rises thereafter as age increases, typically in an exponential manner. Similarly, birth rates equal zero before puberty; they then increase, level off and for many species fall and reach zero again towards the end of life.

These patterns of changing risks of birth and death over age are called age-trajectories of birth and death. They concisely summarise the life course of individuals in a population from a macro-level, demographic perspective. Demographers conventionally study birth and death in separate fields referred to as fertility and mortality research. This makes sense as the reasons why we are born and why we die differ vastly. Yet, now could be the right time to make a connection.

Main hypothesis

Shared constraints of ageing on patterns of birth and death

The connection of birth and death is the central theme and hypothesis of this ERC project. Although birth and death fundamentally differ in nature, recent decades have seen common trends. People are living longer and giving birth later. Notably, this implies that birth and death happen to bodies that are increasingly affected by ageing. And an ageing body successively loses its capacity to survive and reproduce. Since survival and reproduction happen in the same body, we hypothesise that birth and death face similar constraints set by ageing. Thus, as trends of delay in birth and death push against the limits of ageing, we expect that those limits may be pushing back, leaving distinct marks on the patterns.

As the first of two main ambitions, the project seeks empirical evidence to support the hypothesis that birth and death share analogous regularities in macro-level age patterns. These, we propose, reflect the basic constraints of human ageing, where shared somatic mechanisms jointly constrain reproductive and actuarial ageing, and eventually, predictably.

The vision

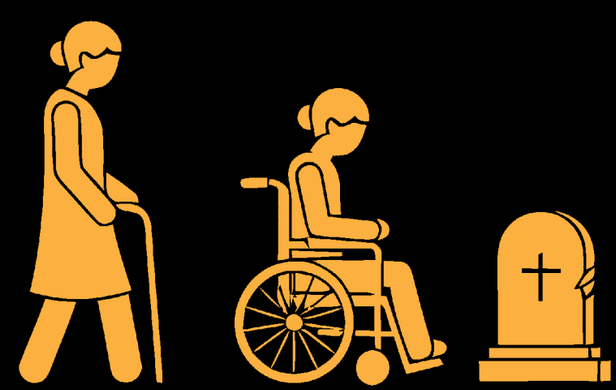
Towards a transdisciplinary demographic theory of birth and death

Through step-by-step revealing of shared regularities, we aim to identify shared principles that can form the basis of a demographic theory of birth and death. A theory of birth and death should explain why, and predict under what conditions, a population follows certain risk patterns over age, ordered by generic groups of increasing, constant and decreasing risks. (Baudisch and Vaupel, 2012). As these generic groups reflect generic types of ageing (Baudisch and Vaupel, 2012), current theories of ageing would be extended by a theory of birth and death.

Birth and death of the body depend on the birth and death of its parts, which depend on smaller parts and so on. Hence, a theory of birth and death eventually should connect scales of observation. Obtaining empirical data and models, such as those at the genome, proteome or cellular level, however, is far from trivial and expensive, to say the least.

To overcome this obstacle with a focus on finding principles, we take a much simpler step instead: moving one level up. Thus, we will investigate formation (birth) and dissolution (death) patterns of human collectives. The simplest collectives for which data are readily available in population registers are couples, families and households.

It is then our second main ambition to investigate regularities in birth and death patterns of collectives, and how these link to analogous regularities identified for individuals. To do so, we develop



new formal demographic methods and apply existing ones.

This work will lay the foundation for connecting the birth and death processes of parts to the birth and death processes of the whole.

Ultimately, a theory of birth and death holds the potential to become truly transdisciplinary. That an entity emerges, exists for a while and dissolves again holds true not only for organisms but for any phenomenon within or around us. Animate and inanimate matter take form and eventually disappear again across various scales of observation. Molecules, polymers and cells form and disintegrate. Organisations, cultures and empires rise and fall. Consumer products get produced and break. Even emotions, thoughts and ideas arise and fade away again. We argue that the concepts of birth and death provide a comparative baseline across the sciences as shared and fundamental properties of any subject of interest to human investigation.

Within this broad vision, we highlight that age is just a number. In this context, it makes sense only if it meaningfully encodes probabilities of birth and death. For many species, such as plants, insects or metamorphic animals, however, stage patterns rather than age patterns will be more informative.

The innovation

A shift in perspective from mother to child

The key innovation to realise this project lies in recognising and overcoming what hindered progress in studying birth in the past.

> This project rests on an unusual premise: instead of studying birth from a woman's perspective, we shift perspective to the child who is born.

It was difficult because why and when people have children depends on a multitude of entangled causes. These include personal values, preferences and individual choice, which are hard to capture. Also, mathematically modelling fertility over age implies less elegant expressions with several parameters. Such models have been found to perform the worst among existing methods to forecast cohort fertility (Bohk-Ewald, Li and Myrskylä, 2018).

By contrast, mortality occurs comparatively orderly over age and can be modelled by relatively simple mathematical models, such as the exponential function. And mortality has shown strong regular patterns over time. For example, the annually highest value observed around the world in the mean age at death has been increasing linearly over more than 180 years (Oeppen and Vaupel, 2002). Thus, the idea emerged to somehow take advantage of the simple and elegant models and patterns known from mortality research.

To that end, a key insight came from observing that much of the strength of mortality modelling derives from the fact that we only die once. By comparison, fertility modelling is challenged because women may give birth multiple times, once or never. Handling multiple and uncertain events requires mathematically more involved methods than those capturing single and certain events.

Therefore, this project rests on an unusual premise: instead of studying birth from a woman's perspective, we shift perspective to the child who is born. For each child, birth certainly happened and only once.

The child's perspective on fertility is largely unexplored, allowing for a break from the detailed, entangled causes related to mothers and fathers coming together, starting families and deciding on family sizes, all of which are conditioned by education, income, housing and a host of other factors. It enables us to focus on the bare bones of the process. From a necessarily retrospective point of view, a child is simply born, for whatever reason. Its mother was of a certain age when the child was born. Although more information can be included as available and relevant for the research question, information on age-specific birth counts is all that is needed for studying age-trajectories of birth. Thereby, unlike much of the current research on fertility, this project explicitly takes a macro-level perspective on birth patterns.

The *Born once, die once* approach (Baudisch and Alvarez, 2021) sets the conceptual stage for mathematically expressing birth and death using analogous measures within a shared, novel framework that enables previously disconnected research to be linked, allowing for direct comparison and connection.

Ongoing work

Evidence for shared regularities and a joint mathematical framework

In a team of several postdocs with a background in quantitative population analysis, we are systematically exploring whether known macro-level regularities for death also hold for birth. To do so, we are applying a shared analytical toolbox to measure birth and death patterns. We developed those tools by integrating the *Born once, die once* approach with existing frameworks of fertility and reproduction in population mathematics (Baudisch and Polizzi, 2025). Discovering simple and elegant mathematical relationships between basic summary measures (Baudisch and Aburto, 2024) also supports our work. Helpful tools are also hidden in the large and scattered existing literature on formal demographic models and frameworks of fertility and reproduction, which we are currently reviewing.

One of our tools is a novel risk function of birth. In applying this function, preliminary evidence (Baudisch and Alvarez, 2021) and ongoing research indicate that under certain conditions, the risk of birth rises exponentially, just as the risk of death. Likewise, ongoing research finds that over the past four decades, the annual record mean age at birth has been rising linearly, just as the annual record mean age at death has. Further known regularities of death also seem to reveal similar signals for birth.

> Working towards a theory of birth and death deepens our understanding of the fundamental properties of existence.

The value to society

Why it matters to connect birth and death

Working towards a theory of birth and death deepens our understanding of the fundamental properties of existence. For society, such a deeper understanding would have tangible relevance.

Firstly, our work suggests a strong leverage point for targeted future research efforts to tackle ageing. If our evidence supports the hypothesis that shared constraints of ageing limit survival and reproduction, then research should target traits that affect both survival and reproduction. This could lead to interventions that improve reproductive ageing and promote healthy longevity jointly.

Secondly, identifying connected and simple regularities in birth and death patterns would support the development of coherent forecasting models to improve population projections. This is not just a technicality. Uncertainty in fertility patterns challenges current population forecasts, where population prospects range from a growing to a shrinking world population depending on the assumption of different fertility scenarios.

In human populations, reliable projections are fundamental for public planning to ensure long-term fiscal sustainability, viable pension and healthcare systems, viable labour markets and appropriate public infrastructure. For ecological and evolutionary applications in non-human populations, population projections provide key information for population management, enabling the prediction of a species' risk of extinction or explosion, and the measurement of evolutionary fitness. In the face of population ageing and climate change, population changes may become increasingly distorted and more difficult to predict. Hence, the pressure is on to gain a deeper understanding of birth and death patterns.

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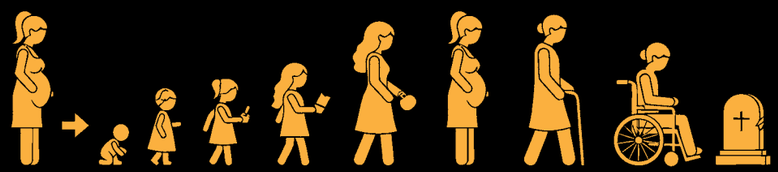

BORN ONCE DIE ONCE

PROJECT SUMMARY

Birth and death appear to be separate processes that frame life from opposite ends. Yet, recent evidence on joint trends suggests potential connections. This project hypothesises that birth and death patterns share common determinants. To test this, formal demographic methods are applied to systematically investigate whether known regular patterns in mortality also hold for fertility. The project further explores shared regularities in birth and death patterns of collectives, defined as groups of individuals that can form and dissolve. By contributing demographic evidence for shared determinants of birth and death patterns, the project's results will inform research on targeted interventions to jointly improve future reproductive ageing and healthy lifespan. It will also aid coherent population forecasting in a fast-changing world.

PROJECT LEAD PROFILE

Annette Baudisch is Professor at the Interdisciplinary Centre on Population Dynamics. As a mathematician and demographer by training, with insights into biology, economics and computer science, her research advances concepts, theories and methods for studying age patterns of mortality and fertility. Honoured by the Max Planck Society with the Otto Hahn Medal in 2007 for outstanding scientific achievements, her PhD thesis, *Inevitable Aging?*, shook a paradigm. It opened a new field of research by changing the question of 'why we age' to 'why we age, but others do not'. Her formal distinction between the pace and the shape of ageing earned the *Trailblazer Award for Demographic Analysis*. Her research has been published in *Science*, *Nature*, and *Proceedings of the National Academy of Sciences*, as well as in a range of key disciplinary journals of demography and biology.

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