



Perspective

Contribution and applications of demographic concepts to conservation

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ABSTRACT

Studying the demographic processes that shape how populations respond to environmental changes has long provided insights for conservation biology. Recent theoretical advances have deepened our understanding of these processes, yet their application in conservation remains unclear. We conducted a literature search to examine how six key demographic concepts — life-history trade-offs, the fast–slow continuum, temporal covariation among demographic parameters, demographic buffering and lability, individual heterogeneity and transient dynamics — have been used in conservation, and discussed their potential benefits and limitations.

Their applications fall into three main categories: improving estimates of demographic parameters, population dynamics, and extinction risk; predicting the magnitude and duration of population responses to disturbances or conservation actions; and identifying the demographic processes most relevant for guiding conservation decisions. Individual heterogeneity and the fast–slow continuum were widely used, likely due to their low data and analytical requirements, allowing broad predictions of species' vulnerability and informing conservation decisions. Trade-offs explained how populations adapt to anthropogenic disturbances, invasions or conservation actions. Conversely, temporal covariation and buffering–lability were rarely applied, despite their value for improving projections and assessing populations' capacity to cope with environmental variability. Limited use reflects data and modelling needs, and, for temporal covariation, lack of direct conservation guidance. Transient dynamics, highlighting short-term responses and demographic resilience, are relevant because they match the timescale of many conservation projects.

We argue that even modest monitoring efforts can capture essential demographic processes, and that their systematic integration, directly or via inference from related systems, could strengthen long-term conservation outcomes.

1. Introduction

Conservation biology is often described as a crisis discipline focused on preventing biodiversity loss and supporting urgent, evidence-based management decisions (Kareiva and Marvier, 2012; Primack, 2008; Soulé, 1985). Its core objectives include avoiding species extinctions, maintaining population viability, and preserving ecological functions. Throughout this paper, we use the term “conservation” primarily in the sense of population-based conservation, i.e., approaches that rely on demographic data and models to understand population dynamics and

inform management decisions. While conservation decisions often occur under uncertainty and limited knowledge, a deeper understanding of the mechanisms driving population dynamics is essential to mitigating risks and achieving successful outcomes. In this context, demography provides essential insights into the structure and functioning of populations (Caswell, 2001; Lande, 1988) and offers a rich set of quantitative tools to inform conservation decisions (Speakman et al., 2025).

Demography investigates how individuals contribute to population growth, decline, or stability by analysing the parameters and life-cycle transitions that drive population dynamics. In a conservation context,

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it provides a framework for understanding which processes—such as reduced survival, lower reproductive output, or limited recruitment—are most responsible for population change and, therefore, where management actions can be most effective. Over the past two decades, tools such as matrix population models (Caswell, 2001), integral projection models (Ellner et al., 2016), individual-based models (Grimm and Railsback, 2005), and integrated population models (Schaub and Kéry, 2021) have gained increasing use in applied conservation (e.g., Heinrichs et al., 2023; Messerman et al., 2023). These tools are particularly useful for projecting population trajectories and evaluating extinction risks under different management scenarios, providing a quantitative basis for decision-making.

In parallel, theoretical advances in demography have deepened our understanding of population trajectories and their underlying mechanisms. Among these, demographic concepts such as demographic buffering and lability (e.g., Gascoigne et al., 2025), temporal correlations among demographic parameters (e.g., Fay et al., 2022b), individual heterogeneity (e.g., Hamel et al., 2018a), life-history trade-offs (e.g., Bliard et al., 2025), the fast-slow continuum (e.g., Stott et al., 2024), and transient dynamics (e.g., Hinrichsen, 2025) have received growing attention in theoretical studies. Despite their potential to improve population projections and risk assessments and to inform adaptive management (Buhnerkempe et al., 2011; Gerber and Kendall, 2016), these concepts appear underused in applied conservation, as reflected by persistent demographic data and knowledge gaps across many taxa of conservation concern (Conde et al., 2019; Paniw et al., 2021). Calls have also been made to better integrate demography with other disciplines such as evolution (Metcalfe and Pavard, 2007), population genetics and genomics (Lowe et al., 2017), climate change ecology (Paniw et al., 2021), and functional ecology (Salguero-Gómez et al., 2018) to foster theoretical developments and practical applications. We argue that closer integration between conservation biology and demography could provide a promising avenue to translate recent theoretical advances in demography into practical applications for biodiversity conservation.

Broadly, demography can inform conservation through two complementary approaches: (1) a comparative approach that positions species and populations along general axes of life-history variation (e.g., speed of life), and (2) a mechanistic, system-specific perspective that models the processes driving population dynamics under real-world constraints (e.g., environmental forcing, small population size, isolation, or ongoing decline). In this framework, the fast-slow continuum and classic life-history trade-offs primarily underpin the comparative approach, whereas concepts such as demographic buffering and lability, temporal correlations, individual heterogeneity, and transient dynamics are useful in the mechanistic approach. Importantly, life-history trade-offs are central to both perspectives: they define the evolutionary constraints that generate broad axes of variation across species (Healy et al., 2019), and they also determine how individuals allocate limited resources when facing ecological stressors, thereby shaping demographic responses of populations (Kentie et al., 2020).

Here, we examine how six key demographic concepts, listed above, can contribute to conservation biology. Using examples from the literature and from our own work, we (i) review how these concepts have been applied in conservation; and (ii) assess their potential benefits for conservation practice while discussing limitations that may constrain their broader application, including data requirements, modelling complexity, and disciplinary boundaries. With this approach, our study aims to foster closer integration between demographic theory and conservation practice, and highlight promising directions for future research and application.

2. Literature search

We examined six demographic concepts: (i) life-history trade-offs, (ii) the fast-slow continuum, (iii) temporal covariation among demographic parameters, (iv) demographic buffering and lability, (v) individual

heterogeneity, and (vi) transient dynamics (Fig. 1). We selected them for their central role in recent demography and their potential to shape population responses to environmental changes and management interventions. To identify the primary conservation applications associated with each concept, we conducted a literature search using the Web of Science Core Collection. We restricted this search to a predefined set of conservation journals, including those ranked in 2022 according to Bradshaw and Brook (2016), and two additional journals publishing applied conservation studies (full list in Appendix S1). For each concept, a set of keywords was selected based on its definition (main keywords in Table 1; full list in Appendices S2-S7, S9), meaning that our search mainly identified studies explicitly applying these concepts. Articles selected according to the screening criteria (Appendix S9) were assigned to application categories based on the purpose for which the concept was used within the study context. Studies focusing on captive populations and laboratory experiments were excluded.

3. Applications of demographic concepts in conservation

3.1. Life-history trade-offs

Individuals at the expanding edges of their range — whether in the context of biological invasion or climate-driven range shifts — often exhibit higher reproductive and/or dispersal abilities than conspecifics in core populations (Chuang and Peterson, 2016). However, greater energy investment in reproduction and/or dispersal often comes at the expense of other functions, such as survival. Such negative correlations between life-history traits are known as life-history trade-offs (LHTOs). Most often, they arise because organisms must allocate the limited amount of energy they acquire to different functions (Stearns, 1992; see Table 1 for other mechanisms). Investing more in one trait inevitably comes at the expense of another, and natural selection should favour the allocation strategy that maximizes fitness. LHTOs have been widely studied to explore variation in life-history strategies at multiple levels, ranging from individual-level processes to interspecific patterns. Spatial or temporal variation in environmental conditions, such as those experienced during range expansion and biological invasions, can induce shifts in optimal allocation strategies, altering the observed correlation among life-history traits. Investigating these shifts within and across populations helps clarify the ecological and evolutionary mechanisms by which environmental changes affect populations. This knowledge can inform effective conservation and management measures, such as preventing the expansion of introduced species.

We identified three primary applications of LHTO in conservation (Table 2). Firstly, it has been used to understand and predict plastic or micro-evolutionary responses of populations to anthropogenic pressures, especially climate change and harvest (Application 1, $n = 14$ articles). For instance, LHTOs between growth, survival, and reproduction were accounted for by Holt and Jørgensen (2014) to better predict life-history adaptations of Atlantic cod (*Gadus morhua*) in response to warming temperatures. Secondly, this concept provides a framework to understand the ability of introduced species to invade their new environment (Application 2, $n = 4$). For instance, plants introduced into new habitats and released from their co-evolved herbivores tend to reallocate energy from defense to reproduction (Rotter and Holeski, 2018). Lastly, the concept has been used to assess the demographic consequences of management, and to inform future actions, particularly restoration efforts (Application 3, $n = 11$). For example, the effectiveness of coral transplantation is influenced by how species resolve the survival-growth trade-off (Montero-Serra et al., 2018). Most applications focused on comparisons between populations ($n = 12$) or on interspecific patterns ($n = 8$). Fewer studies examined individual variation ($n = 5$), or temporal ($n = 2$) and environmental shifts ($n = 3$) in LHTO within populations.

Because LHTOs arise from constraints — most notably energetic constraints — that can be modulated by anthropogenic pressures and

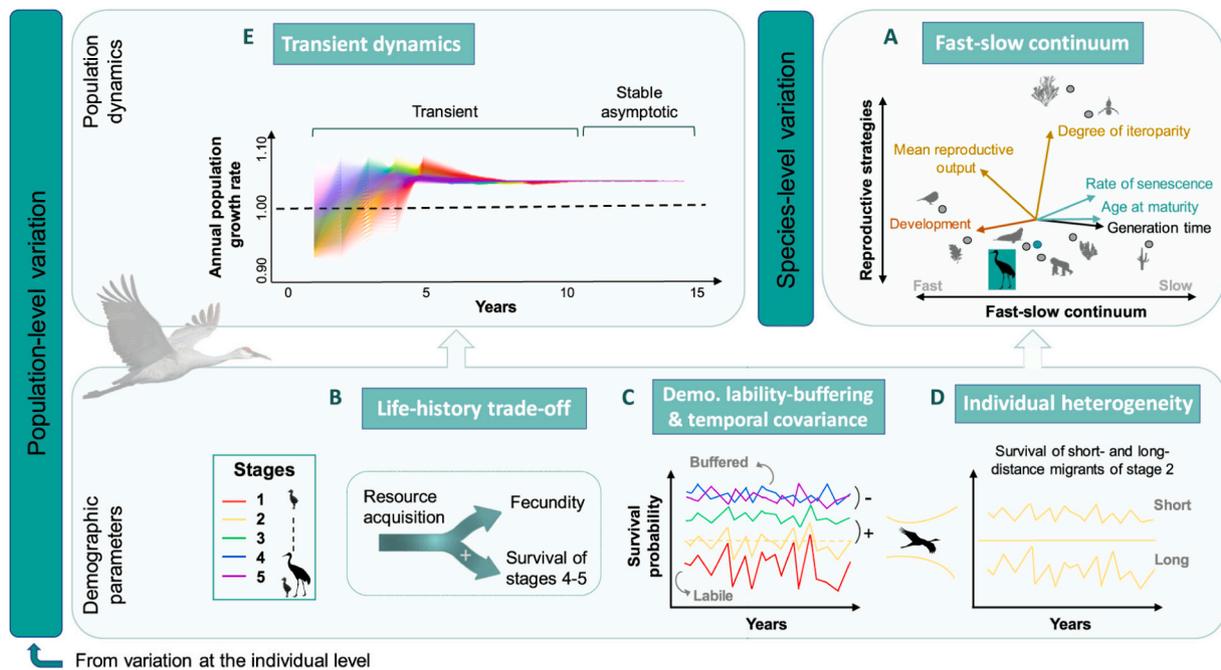


Fig. 1. Schematic view of the relationships between demographic concepts and the ecological levels at which they are defined and commonly applied. The demographic parameters (mean, variance) and migratory tactics shown in the figure are hypothetical and were chosen for illustration purposes.

Species differ in their life-history strategies, often aligning with the **fast-slow continuum of life histories** (A; adapted from Capdevila et al., 2020a). For example, sandhill cranes (*Grus canadensis*) represent a relatively slow strategy, characterized by delayed maturity, a long lifespan, and low fecundity. These trait combinations are mainly driven by **life-history trade-offs** that emerge at the individual level and scale up to shape population- and species-level patterns (B). In slow-living species, natural selection tends to favour strategies that allocate relatively more resources to survival, particularly among mature stages (e.g., stage 5) over immediate reproductive output. Trade-offs and temporal environmental variability cause these demographic parameters (stage-specific survival, growth, fecundity) to vary and co-vary through time (positive or negative **temporal covariance**; C). According to the **demographic buffering** hypothesis, the demographic parameters that most strongly influence long-term population growth are expected to be more buffered against environmental variation (e.g., low variation in survival of stage 5) to help maintain long-term population growth under fluctuating conditions. Variation (**lability**) in some demographic parameters can also be beneficial when natural selection favours responsiveness to environmental conditions that disproportionately enhance those parameters when conditions improve, outweighing the fitness costs of reduced rates in poor years. **Individual heterogeneity**, driven by physiological, morphological and/or behavioural differences, such as migratory tactics (D), further contributes to this (co)variation. For example, some individuals may consistently survive and reproduce more successfully than others in a population, or survival rates across different age classes may vary in synchrony with environmental conditions. Together, these processes shape population dynamics and influence long-term growth. When a disturbance occurs, whether positive (e.g., following a conservation action) or negative (e.g., sport harvesting), it can temporarily disrupt the population's structure, leading to **transient dynamics** before reaching again the long-term, asymptotic growth (E; effects of initial crane stage structure on transient population growth, adapted from Gerber and Kendall, 2016. Lines represent different scenarios of initial stage structure and for each scenario, colours indicate the initial stage with the majority of individuals, $\geq 50\%$). The magnitude and duration of the transient phase reflect the population's demographic resilience to this perturbation.

interventions, and because LHTOs themselves condition population and species responses to these changes, considering them can be key to understanding and predicting demographic responses to environmental changes or to conservation and management actions. Given their central role in the evolution of life-history strategies, LHTOs also help clarify how species adapt to rapidly changing environments (e.g., Wang et al., 2017). Their strong theoretical basis and valuable insights make them particularly relevant for broader application in conservation.

3.2. Fast-slow continuum of life histories

Can we predict a species' vulnerability to environmental disturbances based on its life-history traits, and thereby anticipate both its extinction risk and that of other species with similar traits? Answering this question is certainly central to the application of the fast-slow continuum in conservation. This concept quantifies how species vary along a gradient of co-varying life-history traits, shaped by ecological and evolutionary pressures, including life-history trade-offs (Table 1). At the fast end of this continuum, species tend to mature early and have high reproductive rates and short lifespans, while those at the slow end display the opposite traits. Understanding the diversity of life-history strategies, along with the ecological drivers and adaptive mechanisms that shape them, has been an important focus in evolution, ecology and

conservation (Ducatez and Shine, 2019; Stott et al., 2024).

Across the 55 reviewed conservation studies, six main applications emerged (Table 2). These range from studies describing the life-history strategy of single species and predicting their extinction risk or vulnerability to disturbances (Application 1, $n = 15$; Waldron et al., 2013); to methods-oriented applications, such as guiding data imputation for species with incomplete life-history information; or accounting for variation in life histories when quantifying population- or species-level trends (Applications 2, $n = 3$; Horswill et al., 2019). The most common application involves comparing populations' and species' responses, often quantified as vulnerability or resilience to ongoing threats (e.g., land use and climate changes, overfishing/exploitation), thereby inferring outcomes for other species along the fast-slow continuum and informing conservation measures (Application 3, $n = 18$; S3; Schindler et al., 2002). The continuum has also been used to assess whether a species' or population's position along it can explain the effectiveness of conservation actions, such as translocation success (Application 4, $n = 9$; Ducatez and Shine, 2019), as well as their vulnerability to extinction and susceptibility to threats (Application 5, $n = 5$; Koleček et al., 2014), and infer responses in other species or populations.

While the concept was initially defined at the species level, it has also been applied at both the community and within-species levels, and may be useful not only among populations but also among individuals (Del

Table 1

Definitions, main keywords, and key studies recommended as a first introduction to each of the six demographic concepts.

Concept [main keywords]	Definition	Getting started with the concept
Life-history trade-off	Direct or lagged negative correlation(s) between two or more fitness-related traits (such as age at maturity, growth, reproduction, survival, and lifespan) due to the limited amount of energy that organisms can acquire and must allocate among traits (Stearns, 1992). Life-history trade-offs occur at the individual level, but are often measured at the population level. They arise not only from limited resources, but from a combination of genetic, developmental, physiological, structural, and ecological constraints, all of which restrict the simultaneous optimization of multiple fitness components (Garland et al., 2022).	Stearns (1992)
Fast-slow continuum [fast-slow continuum; r-/K-selected species; pace of life; variation in life-history strategies]	The fast-slow continuum refers to one major axis of life-history variation across species , reflecting different strategies in speed of life (Stearns, 1976). This continuum ranges from short-lived, fast-growing species with high fecundity at one end, to long-lived species with low fecundity and late age at first reproduction at the other, reflecting a diversity of life-history strategies throughout.	Stott et al. (2024)
Temporal covariation [temporal/demographic correlation/covariation; demographic compensation]	Population-level covariation between demographic parameters within a population over time. Temporal covariation is positive (/negative) when two or more demographic parameters — either different (e.g., reproduction and adult survival) or the same across life stages (e.g., survival of juveniles and yearlings) — increase or decrease synchronously (/in opposite direction). Environmental stochasticity, together with other processes such as density-dependence and life-history trade-offs, influence population-level covariation in demographic parameters (Tuljapurkar, 1982).	Fay et al. (2022b)
Demographic buffering and lability [Environmental canalization; demographic buffering; demographic lability]	In a population, buffered and labile demographic parameters (e.g., age-specific survival or fecundity) are characterized by low and high fluctuations, respectively, in response to temporal variation in the environment. Lability and buffering are adaptive when they lead to an overall increase (for lability) or stable long-term	Hilde et al. (2020) Koons et al. (2009)

Table 1 (continued)

Concept [main keywords]	Definition	Getting started with the concept
	population growth in varying environments (Hilde et al., 2020; Koons et al., 2009; Le Coeur et al., 2022). According to the demographic buffering hypothesis , natural selection is expected to favour low variance in demographic parameters that have the strongest influence on population growth in stable environmental conditions.	
Individual heterogeneity [individual heterogeneity; individual quality; frailty; among individual variation; personality; individual behaviour; temperament]	Individual heterogeneity refers to any observed or unobserved (i.e. measured or latent) source of variation in a given trait among individuals, irrespective of its influence on fitness (i.e. fitness and non-fitness-related traits; Hamel et al., 2018b). The variation in traits within and among individuals has also been referred to as among-individual variation, and individual quality, frailty, personality and temperament (e.g., Firth et al., 2018; Halstead et al., 2012). These terms have been used focusing, for example, on the among-individual variance in demographic parameters (Fay et al., 2022a), or on differences among individuals only associated with traits that underlie fitness components (Milenkaya et al., 2013). Individual heterogeneity can be fixed or dynamic whether individual differences are shaped early in life conditions and persist or change throughout life, respectively (see Cam et al., 2013 for a discussion of this terminology).	Cam et al. (2013); Hamel et al. (2018b)
Transient dynamics [transient demography; transient dynamics; demographic resilience]	Transient dynamics capture the short-term, non-stable dynamics of a population that arise from temporary shifts in its age or stage structure (Hastings, 2004). These changes occur when the population is not in a stable state, for instance, following a perturbation that affects certain stages or ages more than others. Transient dynamics can be used to quantify demographic resilience and anticipate a population's response to disturbances. Demographic resilience refers to the ability of populations to resist and recover from alterations in their demographic structure, usually with concomitant change in population size (Capdevila et al., 2020b). Different metrics can be used to quantify the demographic	Capdevila et al. (2020b); Stott et al. (2011)

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Table 1 (continued)

Concept [main keywords]	Definition	Getting started with the concept
	resilience, including the damping ratio (Caswell, 2001).	

Giudice, 2020; but see Van De Walle et al., 2023). Comparison of life-history strategies between populations was studied mainly to identify local adaptive responses to disturbances (Appendix S3). At the community level, the composition and diversity of life-history strategies serve as indicators of community health and functioning, and can also reveal community shifts or successions in responses to environmental stressors (e.g., ocean warming, agricultural intensification; Application 6, $n = 5$; Guerrero et al., 2024).

Overall, the fast-slow continuum has been widely used in conservation to help predict long-term viability and guide conservation efforts. However, it only partially captures the full spectrum of life-history variation, highlighting the need to consider additional axes, such as developmental or reproductive patterns (Stott et al., 2024; Fig. 1A), and local ecological processes to improve its predictive value in conservation. For some organisms, other continuums may be more relevant ($n = 13$), including the Equilibrium-Periodic-Opportunistic continuum of life-history strategies for fish and bivalves ($n = 8$; Table S3.4; Winemiller and Rose, 1992).

3.3. Temporal covariation among demographic parameters

At the population level, demographic parameters such as growth and survival rarely vary independently over time. Instead, they covary, and the strength and direction of these covariances can lead to substantial changes in population dynamics and long-term growth (Tuljapurkar, 1982). Covariation is positive (negative) when two or more demographic parameters in a population increase or decrease simultaneously (in opposite direction) over time. Such covariation is shaped by environmental stochasticity, along with other processes such as life-history trade-offs and density-dependence (Fay et al., 2022b). When positive, it amplifies the benefits of favourable years (e.g., years with high food availability) when multiple demographic parameters exceed their long-term mean, while also exacerbating the negative effects experienced during unfavourable years. Strong positive covariance among demographic rates amplifies population fluctuations and, in some cases, reduces long-term growth, thereby increasing extinction risk. By contrast, negative covariance buffers population responses against environmental and demographic variability. Ignoring temporal (co)variation among demographic parameters in population models can hinder the identification of parameters that most influence long-term population growth, and may result in less reliable estimates of extinction risk (Earl, 2019).

Four conservation studies investigated temporal covariation to quantify population dynamics more accurately in response to environmental variability and, in turn, improve extinction risk estimates (Application 1, $n = 4$, Table 2; Doak et al., 1994). This allows for more effective conservation planning and reliable assessment of the effectiveness of conservation and management actions (Application 2, $n = 2$; Johnson et al., 2010). Temporal covariation has also been explored to understand how populations may buffer the effects of climate change (Kissel et al., 2019) or incidental take (McGowan et al., 2011) through density-dependent processes. This phenomenon, known as demographic compensation, arises when negative effects on certain demographic parameters (e.g., reduced survival of large fishes due to harvesting) are offset by density-dependent increases in other parameters (e.g., increased survival of smaller individuals; Application 3, $n = 3$). Identifying demographic compensation in a population can help refine

Table 2

Main conservation applications associated with each demographic concept, and the number of conservation articles referring to each application category. Studies that rely on a modelling or theoretical approach are indicated in brackets.

Concepts	Conservation applications	Number of studies
Life-history trade-offs	1. Understand and predict plastic or micro-evolutionary responses of populations affected by anthropogenic disturbances	11 (3)
	2. Understand how species establish and spread in novel or altered environments and use this knowledge to guide risk assessments and early detection efforts of invasion	4
	3. Understand the demographic consequences of management actions and inform future management actions, most notably restoration efforts	11
Fast-slow continuum	1. Describe a single species, justify the study's relevance based on its life history, predict its vulnerability and extinction risk to disturbances, and identify conservation needs	14 (1)
	2. Serve methods-oriented applications	2 (1)
	3. Compare species' responses to environmental and/or anthropogenic disturbances to infer outcomes for other species along the fast-slow continuum and guide conservation efforts	14 (4)
	4. Explain and predict species' responses to conservation actions, assess their effectiveness, and inform future conservation measures	6 (3)
	5. Explain variation in vulnerability to extinction	5
	6. Serve as an index of community health and functioning, and measure changes in community composition or succession in response to environmental changes	4 (1)
Temporal covariation	1. Accurately assess the contribution of demographic parameters to population growth and provide realistic, unbiased estimates of population dynamics, resilience and extinction risk	3 (1)
	2. Better assess and improve the efficiency of management plans or conservation actions	2
	3. Identify compensatory mechanisms ("demographic compensation")	3
Demographic lability – buffering	1. Assess whether a population's buffering capacity is maintained following environmental or anthropogenic perturbations, and to forecast extinction risks	4
	2. Assess population's recovery capacity and responsiveness to conservation/management actions	2
Individual heterogeneity	1. Identify behavioural traits for conservation/management	30
	2. Reduce bias in demographic parameter estimates, thereby improving inference on population dynamics	19
	3. Evaluate stressor factors on specific individuals that can impact population structure and persistence, and potentially affect ecosystem-level processes	13
	4. Identify key individuals to support effective population management or invasive species control	20
	5. Assess individual traits that affect reproductive success of population/species to improve conservation and management outcomes	5
Transient dynamics	1. Better estimate the extinction risk and key demographic parameters of	16 (1)

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Table 2 (continued)

Concepts	Conservation applications	Number of studies
	populations and their demographic resilience to perturbations	
	2. Identify and design the best conservation or management strategy and/or assess responsiveness to conservation/management actions	17 (1)

management interventions (e.g., fishing quotas, management strategies for invasive species).

Despite its importance for accurately predicting population trajectories, relatively few conservation studies have explicitly investigated temporal covariation (9 studies, 2 with only brief mention; Table S4.1). Some studies, however, may have empirically accounted for it when modelling population dynamics over several years (e.g., Nakaoka, 1996). This highlights the importance of multi-year population monitoring to accurately capture temporal environmental variation and demographic covariation, which contribute to more effective conservation decisions.

3.4. Demographic buffering-lability

In populations of slow-living species, adult survival rates are generally high and show little annual variations. Because population growth in these species is particularly sensitive to even small changes in adult survival, this rate is expected to be buffered against environmental variation by natural selection (Hilde et al., 2020; Table 1). This process, known as demographic buffering, corresponds to the low temporal variation of some demographic parameters (at the population level) in response to environmental variability, while others fluctuate more widely, a process known as demographic lability (Fig. 1C). Lability and buffering are adaptive when they confer positive effects on long-term population growth rate (Le Coeur et al., 2022). According to the 'demographic buffering hypothesis', selection should favour reduced variation in the demographic parameters with the strongest influence on population growth, such as adult survival in slow-living species. Understanding the demographic buffering-lability strategies in a population provides insights into its overall capacity to cope with environmental variability and short-term perturbations. This is particularly relevant for conservation, as it helps anticipate population responses to perturbations, and assess whether a population's buffering-lability capacity is maintained or challenged when environmental conditions deviate from their typical range of variability (e.g., increased environmental variability or more frequent extreme events associated with climate change). Insights into these dynamics are critical for assessing and mitigating extinction risk in species of conservation concern.

In this context, four conservation studies investigated whether the demographic buffering capacity of a population was maintained or challenged under increases in climate variability and local extreme events in mammals and seabirds (e.g., Forcada et al., 2008), or following a major human-induced shift in food availability in a population of Eurasian vultures (Almaraz et al., 2022; Application 1). Another type of application involves assessing species' responses to conservation or management actions and their effectiveness in maintaining or restoring populations' demographic buffering capacity, for example in restoration projects or harvest management plans (Application 2, $n = 2$). Size-selective harvesting, for instance, can modify populations' buffering-lability strategies over the long term. It can shift populations toward size classes that are more sensitive to environmental variability, thereby increasing the overall population vulnerability (Gamelon et al., 2019). Such effects can be mitigated through appropriate management actions (Goto, 2023). To date, conservation studies have not specifically addressed adaptive lability. Investigating both buffering and lability

provides a framework to identify species likely to be vulnerable, as well as those potentially resilient to increased environmental variability under climate change — a perspective that remains largely unexplored empirically.

3.5. Individual heterogeneity

Individuals often respond differently to anthropogenic disturbances or relocation to unfamiliar environments. These differences are frequently linked to intrinsic characteristics – such as age, sex, physiological condition, or personality – that influence individual fitness. For instance, bolder individuals may fare worse in human-dominated landscapes due to greater exposure to disturbances, provided that shyer individuals can access suitable refuges (Assandri et al., 2017). Such among-individual differences, whether associated with fitness-related traits (Fay et al., 2022a) or not (Hamel et al., 2018b; Table 1), are referred to as individual heterogeneity. Individual heterogeneity can scale up to shape population-level patterns in life-history traits and fitness outcomes, with implications that extend to higher ecological levels. Recognizing and studying this variation can reveal traits associated with success under specific conditions, thereby informing more effective conservation and management strategies at broader ecological scales. Although typically implemented at the population, species, or community level, incorporating among-individual variation could significantly enhance their effectiveness (Jolles et al., 2020).

Conservation applications relying on this concept include: assessing behavioural traits with high individual variation that may influence conservation and management outcomes, in order to inform and refine strategies (Application 1, $n = 30$; Moseby et al., 2023); reducing bias in demographic parameter estimates, thereby improving inference on population dynamics (Application 2, $n = 19$; Halstead et al., 2012); evaluating stressor factors on specific individuals that can impact population structure and persistence, and potentially affect ecosystem-level processes (Application 3, $n = 13$; Milenkaya et al., 2013); identifying key individuals to support effective population management or invasive species control (Application 4, $n = 20$; Lopez et al., 2012); and assessing the individual traits that affect species' or population's reproductive success to improve conservation and management outcomes (Application 5, $n = 5$; Hamel et al., 2012). Most studies accounted for non-fitness ($n = 54$) and fitness ($n = 30$) traits, and a few for both traits ($n = 3$; Table S6.2). While early studies focused on observed (or measured) traits like age or sex (Milenkaya et al., 2013), there has been increasing emphasis on quantifying unobserved (latent) factors that may be attributed to individual behaviour, morphology, life-history or physiology (Exposito-Granados et al., 2020; Table S6.4).

Selecting individuals can improve ecosystem management and conservation outcomes. For instance, the success of translocation and reintroduction programs depends on pre- or post-release differences in individual behaviour and personality, which influence survival (West et al., 2019). Similarly, invasive species control can benefit from targeting individuals with specific traits (e.g., more prone to disperse), including recalcitrant individuals under adaptive control strategies (Johnstone et al., 2024). However, it is crucial to evaluate how practitioner actions (e.g., agricultural, management) shape population composition and intraspecific diversity to avoid counterproductive phenotypic selection (Mensing et al., 2021). Individual heterogeneity is likewise central in human-wildlife conflict mitigation, where identifying conflict-prone individuals—such as damage-making brown bears (Berezowska-Cnota et al., 2023)—enables more targeted and effective interventions.

Future studies should account for individual heterogeneity to reduce bias in population dynamics estimates (Cubaynes et al., 2010), although data limitations remain a major constraint in conservation and demographic studies (Conde et al., 2019). Evidence from the literature suggests that considering among-individual traits in conservation planning has been useful to directly guide actions. Further research into

neurobiological, genetic, and disease-related factors that shape these traits will deepen our understanding and guide more evidence-based conservation (Firth et al., 2018; Gamble et al., 2020).

3.6. Transient dynamics

At equilibrium, a population reaches a stable age or stage structure, meaning the proportion of individuals in each (st)age and the population's (asymptotic) growth rate are constant over time. In protected areas like no-take marine reserves, fish populations are expected to tend toward this equilibrium, and the factors favouring long-term growth and stability are well documented (White et al., 2013). However, over the short term, i.e. the first years or decades following reserve establishment, fish populations can undergo surprising dynamics: population abundance can remain stable, decline or oscillate periodically, regardless of the long-term outcome. Such patterns can all stem from the same underlying process: transient population dynamics (Table 1, Fig. 1E). It occurs before a population reaches its stable distribution, a condition that may never be achieved in a disturbed environment, or when it is pushed away from it (Capdevila et al., 2020b; Stott et al., 2011). Deviations from the stable distribution are caused by disturbances or human interventions that differentially affect some life stages, for example when the establishment of a marine reserve enhances survival of mature individuals, or conversely, when fishing pressure preferentially targets them over immature stages (Anderson et al., 2008). Depending on which life stages are affected (e.g., mature individuals) and how their demographic parameters changed (e.g., increased or decreased survival and/or fecundity), the perturbation will differently influence transient dynamics, causing oscillations in population size and structure of varying duration and intensity until the population reaches its asymptotic state. Understanding the consequences of these deviations and populations' demographic resilience to perturbations lies at the core of conservation biology.

Transient dynamics is of particular importance in conservation because: 1/ a species' potential for transient dynamics can guide more efficient conservation or management actions by preferentially targeting specific classes of individuals; 2/ small populations undergoing a transient dynamics phase may face high risk of extinction, as oscillations in abundance can periodically bring population size near the quasi-extinction threshold (Table 2; Ezard et al., 2010). The concept of transient dynamics has been applied in conservation to better estimate the extinction risk and key demographic parameters of populations of threatened species, sometimes in the context of population reintroduction or reinforcement programmes (Application 1, $n = 17$; Gaoue, 2016; Wong and Ticktin, 2015). It has been also used to identify the best sustainable exploitation strategy (for practical examples, see Buhnerkempe et al., 2011; Goto, 2023) or the best management strategy for invasive species (Application 2, $n = 18$; Miller and Tenhumberg, 2010). In these contexts, populations are likely to deviate from their expected stable distribution, and studying the resulting transient dynamics helps quantify their demographic resilience to disturbances or management actions (Capdevila et al., 2020b). In a broader sense, demographic imbalances (e.g., biased sex ratios or skewed age/stage structure) are already commonly addressed in the literature on small populations and conservation translocations, although they are not always explicitly identified as transient dynamics. We believe transient dynamics and demographic resilience warrant greater attention in conservation, as transient effects occur on timescales more realistic and relevant to many conservation projects than asymptotic dynamics (Ezard et al., 2010). The main challenge is that it requires (st)age-specific demographic and abundance data, and therefore involves monitoring many individuals over several years. This can be difficult for rare or elusive species (Couturier et al., 2013), or may require more time than allowed by management decisions.

4. Discussion

Conservation biology aims to protect and maintain biodiversity by supporting evidence-based practice and decision-making (Primack, 2008; Soulé, 1985). Our literature search highlights how demographic concepts can contribute to this fundamental goal, primarily by addressing three objectives: 1) providing accurate estimates of demographic parameters and population dynamics, thereby enabling reliable assessment of population trends and extinction risks; 2) predicting the strength, nature, and duration of population and species responses to disturbances, whether negative or positive; and 3) understanding the demographic and ecological processes most relevant for guiding or refining conservation decisions. Several concepts have been applied beyond their original ecological scale (e.g., fast-slow continuum at intraspecific and community levels; individual heterogeneity up to ecosystem implications). This scaling-up of demographic concepts aligns with broader trends in conservation biology over the past decades, which increasingly embrace integrative and cross-scale perspectives (Kareiva and Marvier, 2012; Mace, 2014).

The six demographic concepts examined range from long-established to more recently developed, and from more theoretical concepts aimed at understanding the mechanisms driving changes (e.g., LHTO), to those with a priori a more practical applicability for conservation (e.g., transient dynamics). They also differ in maturity, typical scale of application, and practical cost (in terms of data requirements, modelling effort, and interpretability), which makes direct comparisons across concepts inherently imperfect. Among the six concepts, individual heterogeneity and the fast-slow continuum, two long-established concepts, were by far the most studied. The strong emphasis on individual heterogeneity (87 studies) likely reflects that it directly informs conservation decisions, encompasses diverse traits, and can be analysed with only minimal theoretical requirements, using methods that range from relatively simple multivariate models to more complex models with latent states (Hamel et al., 2018a). For the fast-slow continuum (50 studies at the population level), its widespread use likely reflects modest data needs and modelling complexity, enabling rapid comparisons among species and generating broad expectations of vulnerability and responses. Its simplicity allows quick assessment and integration into conservation planning; though its limited resolution yields only general expectations (Fig. 2). Many applications of the LHTO have also been reported (29 studies). As a fundamental concept in ecology and evolution, the LHTO informs conservation by providing predictive insight regarding the adaptive responses of populations to anthropogenic disturbances, invasions or management actions. Nevertheless, several studies refer to demographic concepts only as a way to interpret potential mechanisms, rather than formally incorporating them in analyses. Given their relevance for management, we encourage their more systematic use.

By contrast, concepts of temporal covariation among demographic parameters and buffering-ability have received limited attention (< ten articles). While temporal covariation is crucial for understanding mechanisms and obtaining reliable estimates that can inform conservation decisions, it does not provide direct conservation guidance per se, which may explain its lower prevalence in conservation studies. Buffering-ability, on the other hand, is still benefiting from ongoing developments and can be technically difficult to quantify, especially for lability. Both concepts rely on detailed, long-term demographic data, which may also constrain their current application in conservation (Fig. 2).

Two concepts that are increasingly discussed in the literature, buffering-ability and transient dynamics have been used in conservation articles to characterise a population's capacity to be buffered against, or recover from perturbations (past or future), respectively, as well as the demographic processes underlying these responses. Transient processes are critical because populations and communities targeted by conservation are often small and subject to stochastic or persistent disturbances (e.g., climate change), making stable stage equilibrium

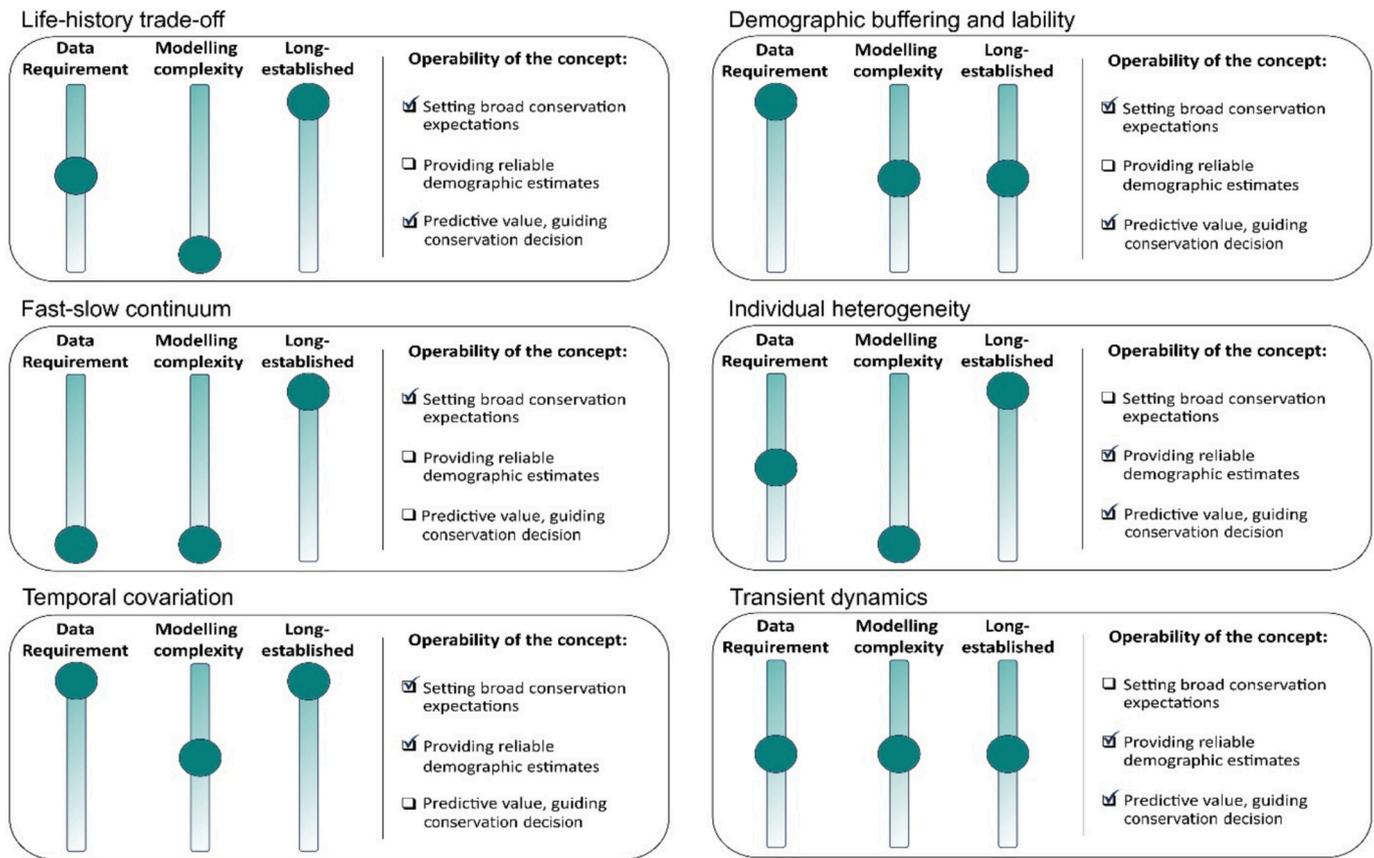


Fig. 2. Limitations and contributions of the six demographic concepts to conservation practice, evaluated through key criteria: (i) Data requirements (considering monitoring duration, sample size, and number of demographic traits measured; Table S8.1), (ii) Modelling complexity (type of models and number of analytical steps required for models of minimal complexity, see detail in Table S8.2), (iii) concept maturity (long-established concept in demography VS under active development), and (iv) Operability for conservation applications. Levels are ranked as low, medium and high. The operability of each concept was assessed according to three criteria: (i) Ability to set general ecological and conservation expectations based on limited demographic outcomes, (ii) Capacity to provide robust and reliable estimates of key demographic metrics; and (iii) Usefulness for guiding conservation decisions by providing detailed demographic outcomes. This qualitative synthesis is intended to be evaluative rather than prescriptive, and should be interpreted in light of the study goals and practical constraints.

unlikely (Ezard et al., 2010). While these two concepts provide complementary insights, their application requirements and the nature of their outputs differ, which may explain differences in use (35 studies for transient dynamics, six for buffering-lability). Medium-term monitoring is necessary to detect a disturbance and to quantify its transient effects on population dynamics. This provides disturbance-specific insights that can guide or refine conservation actions. In contrast, quantifying buffering-lability requires long-term monitoring and provides general predictions about how a population may respond to future disturbances.

Conservation practice faces multiple constraints, including limited resources, urgent timelines, and the need to act under high uncertainty and within complex socio-political contexts (Sabo et al., 2024). Biological and methodological challenges add further obstacles, such as working with small, vulnerable, or cryptic populations, or the difficulty of monitoring large numbers of individuals across extended periods and spatial scales (White, 2019). Conservation must navigate these constraints by balancing data collection with information gain to support effective planning and long-term outcomes, from anticipation and decision-making to evaluating success (Watts et al., 2020). From a demographic perspective, understanding the mechanisms underlying a population's or species' responses to disturbances or conservation actions depends on repeated measurements of a sufficiently large number of individuals, which may not always be compatible with conservation constraints. As a result, some concepts remain underused despite their clear predictive value and potential to inform management (Fig. 2). Importantly, however, “underuse” does not necessarily imply

suboptimal practice: in some applied contexts, simpler demographic summaries or models may already provide sufficient information for robust decisions.

Nevertheless, we believe that with a moderate monitoring effort of 4–6 years, many metrics associated with demographic concepts can be quantified with reasonable reliability across a wide range of life histories (e.g., individual heterogeneity, transient dynamics, LHTO). While others require longer time series to be estimated accurately (e.g., temporal covariation, demographic buffering-lability), they can be at least implicitly accounted for even if they are not the primary focus. For instance, population models built from multi-year monitoring data (such as matrix population models) inherently capture covariation among demographic parameters within each year and the observed variation between years, although the interannual correlations are not explicitly estimated. Producing more robust information on demographic and ecological processes strengthens evidence-based planning and decisions, and reduces the risk of obtaining misleading ecological predictions. In that respect, delaying immediate action when possible may improve conservation strategies and their outcomes (Iacona et al., 2017). When replication across individuals or time is limited, we encourage practitioners to familiarize themselves with these concepts, as this knowledge can guide the design and implementation of effective conservation actions. For example, knowing that some behavioural traits can influence reintroduction success allows managers to optimize selection strategies for release (e.g., West et al., 2019). Other important concepts not included in this search, such as demographic senescence, the Allee effect

or carry-over effects (e.g., Robert et al., 2015; Stephens and Sutherland, 1999; Sutton et al., 2021), could further support conservation goals. We therefore recommend reviewing demographic studies, including those on the target species and on species with similar life histories, to better anticipate the range of possible demographic processes relevant to each conservation project. General demographic knowledge and concepts can be integrated into population projection models even when data for the target population are incomplete, helping with parameter imputation and the inclusion of known mechanisms into predictions.

Overall, conservation biology and demography have been closely interconnected for decades, and our review shows that demographic knowledge and tools still contribute substantially to conservation goals. Both disciplines focus on long-term population stability and viability, which are central to biodiversity conservation across ecological levels. Even under constraints of urgency and uncertainty, decisions should, wherever possible, be guided by knowledge of ecological, demographic, and evolutionary processes. Doing so will improve the robustness and effectiveness of conservation strategies and help preserve biodiversity into the future.

CRedit authorship contribution statement

Christie Le Coeur: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Jan Perret:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Aurélien Besnard:** Writing – review & editing, Formal analysis. **Sarah Cubaynes:** Writing – review & editing, Formal analysis, Data curation. **Célian Monchy:** Writing – review & editing, Formal analysis, Data curation. **Marwan Naciri:** Writing – review & editing, Formal analysis, Data curation. **Mónia Nakamura:** Writing – review & editing, Formal analysis, Data curation. **Olivier Gimenez:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors claim no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2026.111776>.

Data availability

This study was based entirely on a literature search using the Web of Science Core Collection. No original data or code were generated or analyzed.

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