Title: 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.

Keywords: conservation action, environmental perturbations, extinction risk, life history, population dynamics, vital rates

1. Introduction

Conservation biology is often described as a crisis discipline focused on preventing biodiversity loss and supporting urgent, evidence-based management decisions (Kareiva & 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, 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 & Railsback 2005), and integrated population models (Schaub & 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 & 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 (Metcalf & 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 (iv) 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 & Brook's journal-ranking method (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 their 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 & 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 & 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 & 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 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 & 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 & 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 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 & 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 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 (Mensinger *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 towards 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 & 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 & 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 disturbance 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.

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 & 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), 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 (31 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-lability have received limited attention (< seven 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-lability, 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-lability 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 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 covariance, 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 & 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 be guided, wherever possible, by ecological, demographic, and evolutionary processes. Doing so will improve the robustness and effectiveness of conservation strategies and help preserve biodiversity into the future.

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Figure captions

Figure 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, ≥50%). The magnitude and duration of the transient phase reflect the population's demographic resilience to this perturbation.

Figure 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.

Figure 1

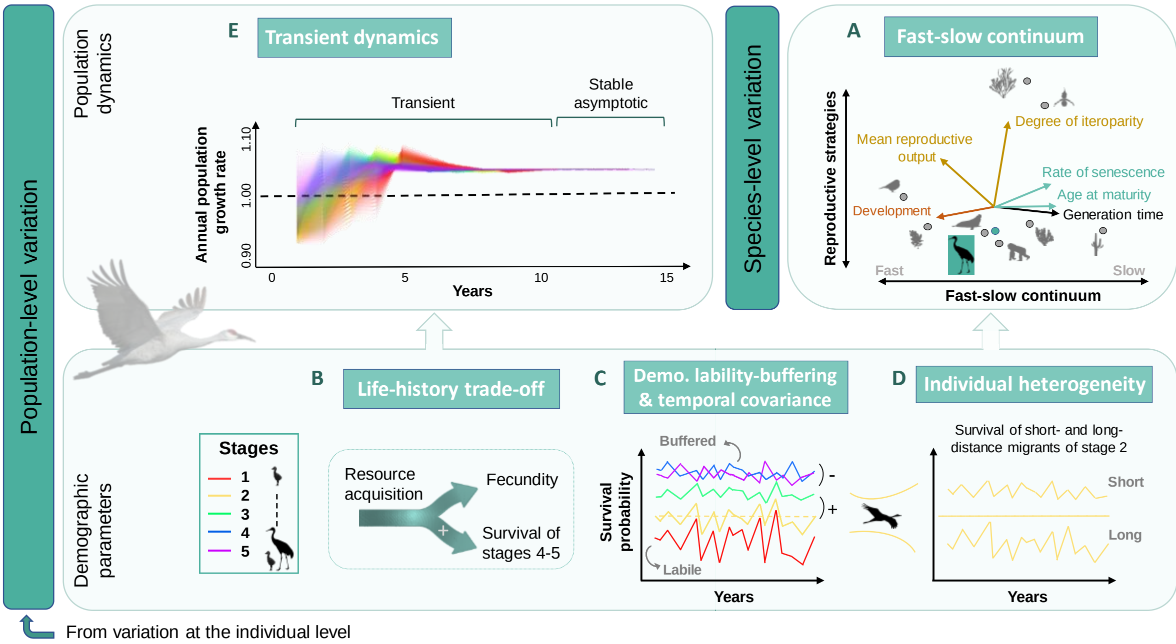
Population-level variation
Population dynamics
E
Transient dynamics
Transient
Stable asymptotic
Annual population growth rate
1.10
1.00
0.90
0
5
10
15
Years
Species-level variation
A
Fast-slow continuum
Reproductive strategies
Mean reproductive output
Degree of iteroparity
Rate of senescence
Age at maturity
Generation time
Development
Fast
Slow
Fast-slow continuum
Demographic parameters
B
Life-history trade-off
Stages
1
2
3
4
5
Resource acquisition
Fecundity
Survival of stages 4-5
C
Demo. lability-buffering & temporal covariance
Buffered
Labile
Survival probability
Years
D
Individual heterogeneity
Survival of short- and long-distance migrants of stage 2
Short
Long
Years
From variation at the individual level

Figure 2

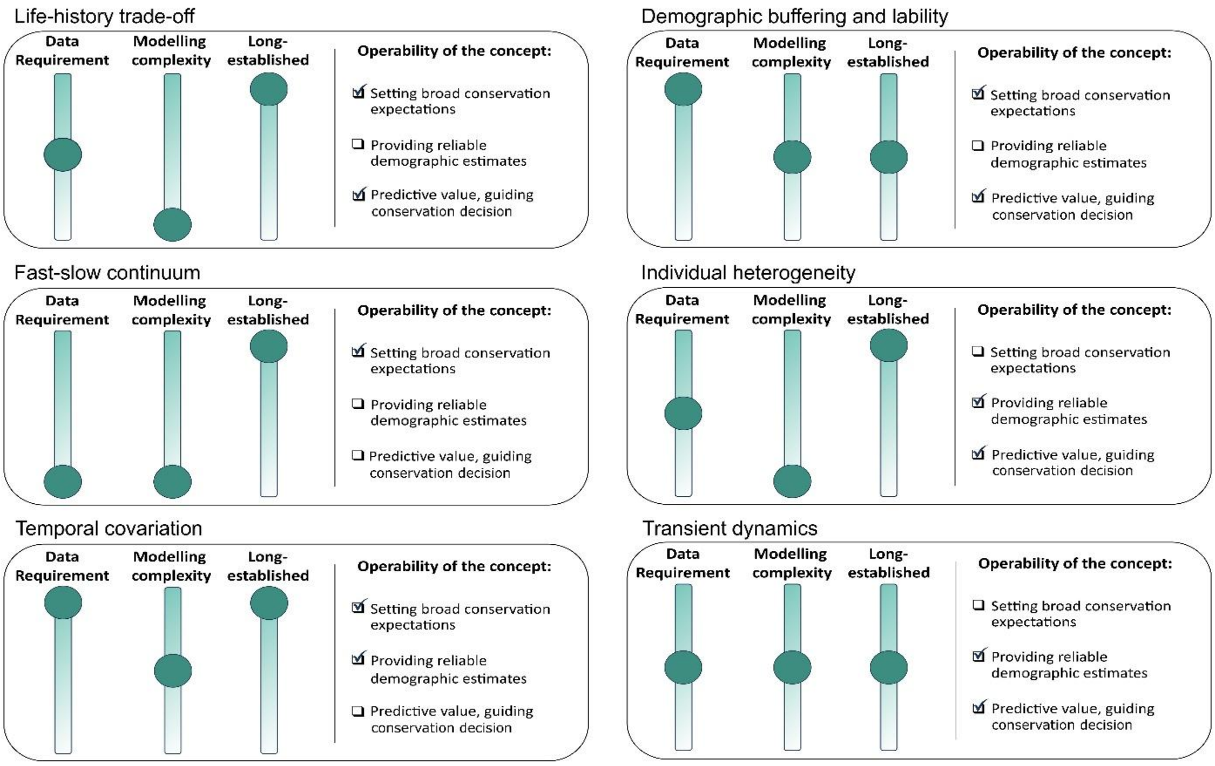
Life-history trade-off
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision
Demographic buffering and lability
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision
Fast-slow continuum
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision
Individual heterogeneity
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision
Temporal covariation
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision
Transient dynamics
Data Requirement
Modelling complexity
Long-established
Operability of the concept:
Setting broad conservation expectations
Providing reliable demographic estimates
Predictive value, guiding conservation decision

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 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.	Hilde *et al.* (2020) Koons *et al.* (2009)
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	Cam *et al.* (2013); Hamel *et al.* (2018b)

	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).	
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 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 resilience, including the damping ratio (Caswell 2001).	Capdevila *et al.* (2020b); Stott *et al.* (2011)

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 populations and their demographic resilience to perturbations	16 (1)
	2. Identify and design the best conservation or management strategy and/or assess responsiveness to conservation/management actions	17 (1)

Appendix

S1 - Set of journals included in the six Web of Science searches

The search was restricted to a predefined set of journals in conservation ecology (listed below), including the 31 conservation journals ranked in 2022 according to Bradshaw & Brook's journal-ranking method (2016) and two additional journals, The Journal of Wildlife Management and Global Change Biology. It covered publications with cut-off dates ranging from February 2024 to January 2025, depending on the concept (see S2-S7).

- Ambio
- Animal conservation
- Aquatic conservation: Marine and Freshwater Ecosystems
- Basic and applied ecology
- Biodiversity and Conservation
- Biological conservation
- Biological invasions
- Bird conservation international
- Conservation biology
- Conservation genetics
- Conservation letters
- Conservation physiology
- Conservation science and practice
- Conservation & society
- Ecological applications
- Ecological Management & Restoration
- Ecology and society
- Emu – Austral Ornithology
- Endangered species research
- Environmental conservation
- Frontiers in Ecology and the Environment
- Global Change Biology
- Insect Conservation and Diversity
- Journal for Nature Conservation
- Journal of applied ecology
- Journal of insect conservation
- Nature Ecology & Evolution
- One earth
- Oryx
- People and nature
- Restoration ecology
- The Journal of Wildlife Management
- Tropical Conservation Science

S2 - Life-history trade-off

- **Full list of keywords used in Web of Science query (up to Apr. 2024):**

(ALL=(((life-history OR life history) AND (trade-off* OR tradeoff*)) OR (survival AND (trade-off* OR tradeoff*)) OR (reproduction AND (trade-off* OR tradeoff*)) OR (growth AND (trade-off* OR tradeoff*)) OR (fitness AND (trade-off* OR tradeoff*))))

- **Number of conservation studies relying on the 'Life-history trade-off' concept, categorized by conservation applications and studied organismal groups (Table S2.1)**

Table S2.1 Number of articles categorized by studied organismal groups and type of conservation applications. Only articles in which the concept was quantified are included, excluding theoretical studies. Studies predominantly based on modelling are indicated in parentheses.

Organismal groups	***Conservation applications***			***Total***
	1	*2*	*3*	
Arthropods (mixed)	(1)			(1)
Actinopterygii	2(1)	1	1	4(1)
Amphibia	1			1
Anthozoa (corals)	1(1)		2	3(1)
Aves	2		1	3
Mammalia	1			1
Bivalvia	1			1
Reptilia	1			1
Magnoliopsida (trees)		1	5	6
Magnoliopsida (shrubs)		1	1	2
Magnoliopsida (herbaceous)	1		1	2
Plants mixed	1	1		2
Total	11(3)	4	11	**26(3)**

- **Number of conservation studies categorized by conservation applications and trade-offs defined in terms of life-history traits (Table S2.2)**

Table S2.2 Life-history traits involved in trade-offs across the selected articles, categorized by type of conservation applications. Articles referring to "maintenance” and "longevity" are grouped together under “survival”. Two articles dealing with fitness-related traits (resistance to bleaching, competitive ability) that could not be linked to a single life-history trait are included in the final selection but excluded from this table. Numbers in square brackets indicate the number of articles that examined the three types of trade-offs.

Life-history trade-offs	***Conservation applications***			***Total***
	1	*2*	*3*	
Growth / Survival	5	1	6	12
Reproduction / Survival	3		3	6
Growth / Reproduction	2	2		4
Total	10 [3]	3	9 [2]	**22 [5]**

Note: Applications 1-3 correspond to: 1) Understand and predict plastic or micro-evolutionary responses of populations affected by anthropogenic disturbances; 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; and 3) Understand the demographic consequences of management actions and inform future management actions, most notably restoration efforts

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S3 - Fast-slow continuum of life histories

- **Full list of keywords used in Web of Science query (up to Dec. 2024):**

ALL=("slow-fast continuum") OR ALL=("fast-slow continuum") OR ALL=("fast-slow life-history continuum") OR ALL=("variation in life history strategies") OR ALL=("Variation in life history traits") OR ALL=("life-history strategies") OR ALL=("life history strategies") OR ALL=("life-history strategy") OR ALL=("life history strategy") OR ALL=("axis of life history strategies") OR ALL=(" r-/K-Selected") OR ALL=("r-K Strategies") OR ALL=("K-selected species") OR ALL=("r-selected species") OR ALL=("r-Strategy") OR ALL=(" K-Strategy") OR ALL=("fast-living species") OR ALL=("slow-living species") OR ALL=("fast life histories") OR ALL=("slow life histories") OR ALL=("fast life history") OR ALL=("slow life history") OR ALL=("fast-slow life history") OR ALL=("slow-fast life history") OR ALL=("pace of life continuum") OR ALL=("pace of life") OR ALL=(" fast-slow life history spectrum")

- **Number of conservation studies relying on the 'fast-slow continuum' concept, categorized by conservation applications, main keywords and organismal groups (Tables S3.1 and S3.2, respectively)**

Table S3.1 Number of articles categorized by keywords and type of conservation applications. Only articles in which the concept was quantified (rather than discussed) are included, excluding theoretical studies.

Keywords used in articles	***Conservation applications***						***Total***
	1	*2*	*3*	*4*	*5*	*6*	
Fast-slow continuum	12	1	9	5	3	2	32
r-/K-selected species	2		1				3
r/K & fast-slow continuum		1			1	1	3
Pace of life			1				1
Pace of life & Fast-slow continuum			1		1	1	3
Long-lived/short-lived species			1				1
Fast-slow growing species			1	1			2
Total	14	2	14	6	5	4	**45**

<u>Table S3.2</u> Number of articles categorized by studied organismal groups and type of conservation applications. Only articles in which the concept was quantified are included, excluding theoretical studies. Numbers indicate the number of articles that focused on a specific organismal group, with the number "(1)" representing one study involving two different organismal groups (below, Mammalia and Insecta).

Organismal groups	***Conservation applications***						***Total***
	1	*2*	*3*	*4*	*5*	*6*	
Mammalia	2		2 (1)	1	2		7 (1)
Aves	3	1	2	1	1	1	9
Actinopterygii	2	1	1			1	5
Chondrichthyes			1				1
Reptilia	4		2				6
Amphibia	2		2				4
Malacostraca	1						1
Benthic invertebrates						1	1
Woody species (>1900 species)						1	1
Woody and herbaceous species			2	2			4
Mixed: mostly forbs and woody species; cacti, ferns, graminoids				1			1
Insecta			(1) Diptera, Coleoptera, Lepidoptera		1 Lepidoptera		1 (1)
Mixed: Anthozoa (corals), Demospongiae, Liliopsida (seagrass)				1			1
Mixed: other			1 Mammalia, Reptilia, Aves		1 Vertebrates, plants, invertebrates		2

<u>Note</u>: Conservation applications 1-6 correspond to: 1) Species description and predictability on a species' vulnerability to extinction or ability to adapt; 2) To serve methods-oriented applications; 3) to compare and assess species' responses to anthropogenic disturbances and infer outcomes for other species along the fast-slow continuum and guide conservation efforts; 4) To predict species' responses to conservation actions and assess effectiveness; 5) To explain variation in vulnerability to extinction; 6) To serve as an index of community health and functioning, and measure changes in community composition or succession in response to environmental changes .

Additional information:

Application 3 - Studies comparing the impact of anthropogenic disturbances on species (quantified as species' vulnerability, resilience, demographic responses or energetic investment/cost) along the fast-slow continuum of life histories often encompass a broad range of disturbance sources (n= 14, Table 2). These disturbances mostly include climate and land use changes (e.g., Albaladejo-Robles et al. 2023); habitat degradation and agricultural intensification (e.g., Harper et al. 2008); fishing/harvesting/overexploitation/individual collection (e.g., Schindler et al. 2002 with consequences at the species and food web levels - applications 3 and 6); and hydraulic disturbance (e.g., McManamay et al. 2015, using the Equilibrium-Periodic-Opportunistic continuum, Table S3.4).

Application 4 - Most studies using the fast-slow continuum to test and assess the success of conservation actions between species refer to translocation or reintroduction programs (n= 6; e.g., Ducatez & Shine, 2019).

- **Ten theoretical/modelling articles with conservation goal and applications:** In these articles, the authors simulated a range of life history strategies or two contrasting strategies (slow vs fast-living species) to explore mainly whether life history traits can help to determine a species' resistance and resilience to disturbance (n= 4), or to identify which conservation measure can be efficient regarding the considered life histories (n=3).

Table S3.3 Number of theoretical studies grouped by category of conservation application.

Conservation applications	*N articles*
1. Species description and predictability on a species' vulnerability to extinction, ability to adapt	1
2. To serve methods-oriented applications	1
3. To compare and assess species' responses to anthropogenic disturbances	4
4. To predict species' responses to conservation actions and assess effectiveness	3
5. To explain variation in vulnerability to extinction	0
6. To assess community functioning in regards of environmental changes	1

- **From the literature search, eleven articles (and two articles that only discussed the concept) referred to the fast-slow continuum (or r/K concept) at the intraspecific scale.**

Three main applications were identified by comparing life histories and pace of life between populations. It was commonly applied to explain, predict, or highlight disturbance-induced changes in life history traits between populations, as an adaptive response to new environment(s). These disturbances include climate change, disease, urbanization or invasion that induce changes in life history strategies of i) native species (e.g., comparison between populations with or without the presence of an invasive species e.g., Sharma et al. 2021) or ii) newly established and potentially invasive species (comparison between locations, e.g., Dean et al. 2023). The two articles that discussed the concept of fast-slow continuum also used it in the context of invasion-driven and establishment-driven shifts in life histories between populations.

The concept was also useful to evaluate and then improve efficiency of conservation action (e.g., conservation stocking of eels as a recovery tool, where matching the life-history characteristics of donor and recipient sub-populations was found to be important; Stacey et al. 2015). The third and last application category focuses on quantifying intraspecific variation in life histories to reliably assess extinction risk of an endangered species in the face of multivariate environmental stressors, and guide conservation actions (Monnet et al. 2022).

- **Other continuums of life history variation**

Thirteen studies relied on different continuum of life history variation among fish and bivalves, including the Equilibrium-Periodic-Opportunistic continuum (n= **8**; Table S3.4).

Table S3.4 Other continuums reported in studies grouped by conservation application. Brackets indicate if a study (and the use of a specific continuum) belongs to two categories of conservation application.

Organismal groups	***Conservation applications***				***Total***
	2	*3*	*4*	*6*	
Equilibrium-Periodic-Opportunistic continuum	1	4	3		8
Continuum based on functional groups (traits related to reproduction, dispersal, development time and synchronisation)			1		1
Continuum based on species' foraging behavior/guilds		1			1
Continuum based on species' reproductive strategy, diet specialization and foraging behaviour		1			1
Continuum based on competitivity and stress tolerance		(1)		(1)	1
Continuum based on competitivity, reproductive effort and lifespan			(1)	(1)	1

References:

Albaladejo-Robles, G., Böhm, M., & Newbold, T. (2023). Species life-history strategies affect population responses to temperature and land-cover changes. *Global Change Biology*, 29(1), 97-109. https://doi.org/10.1111/gcb.16454

Dean, E.K., Drake, D.A.R. & Mandrak, N.E. (2023) Non-linear effects on the population performance of Bighead Carp under different maturation schedules. *Biological Invasions* 25, 3567–3581. https://doi-org/10.1007/s10530-023-03126-z

Ducatez, S., & Shine, R. (2019). Life-history traits and the fate of translocated populations. *Conservation Biology*, *33*(4), 853-860. https://doi.org/10.1111/cobi.13281

Harper, E. B., Rittenhouse, T. A., & Semlitsch, R. D. (2008). Demographic consequences of terrestrial habitat loss for pool-breeding amphibians: predicting extinction risks associated with inadequate size of buffer zones. *Conservation Biology*, 22(5), 1205-1215. https://doi.org/10.1111/j.1523-1739.2008.01015.x

McManamay, R. A., & Frimpong, E. A. (2015). Hydrologic filtering of fish life history strategies across the United States: implications for stream flow alteration. *Ecological Applications*, 25(1), 243-263. https://doi.org/10.1890/14-0247.1

Monnet, G., Corse, E., Archambaud-Suard, G., Grenier, R., Chappaz, R., & Dubut, V. (2022). Growth variation in the endangered fish Zingel asper: Contribution of substrate quality, hydraulics, prey abundance, and water temperature. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 32(7), 1156-1170. https://doi-org/10.1002/aqc.3818

Sharma, A., Dubey, V.K., Johnson, J.A. et al. (2021) Introduced, invaded and forgotten: allopatric and sympatric native snow trout life-histories indicate brown trout invasion effects in the Himalayan hinterlands. *Biological Invasions* 23, 1497–1515. https://doi.org/10.1007/s10530-020-02454-8

Schindler, D. E., Essington, T. E., Kitchell, J. F., Boggs, C., & Hilborn, R. (2002). Sharks and tunas: fisheries impacts on predators with contrasting life histories. *Ecological Applications*, 12(3), 735-748. https://doi.org/10.1890/1051-0761(2002)012[0735:SATFIO]2.0.CO;2

Stacey, J. A., Pratt, T. C., Verreault, G., & Fox, M. G. (2015). A caution for conservation stocking as an approach for recovering Atlantic eels. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 25(4), 569-580. https://doi-org/10.1002/aqc.2498

S4 - Temporal covariation among demographic parameters

- **Full list of keywords used in Web of Science query (up to Jan. 2025):**

(ALL=("temporal correlation$" AND "demographic parameter$") OR ALL=("temporal correlation$" AND "demographic rate$") OR ALL=("temporal correlation$" AND "vital rate$") OR ALL=("correlation$" AND "demographic parameter$") OR ALL=("correlation$" AND "parameter") OR ALL=("correlation$" AND "vital rate$") OR ALL=("demographic correlation$") OR ALL=("vital rate correlation$") OR ALL=("temporal covariation$" AND "demographic parameter$") OR ALL=("temporal covariation$" AND "demographic rate$") OR ALL=("temporal covariation$" AND "vital rate$") OR ALL=("temporal covariation$" AND "parameter$") OR ALL=("covariation$" AND "demographic parameter$") OR ALL=("covariation$" AND "vital rate$") OR ALL=("demographic covariation$") OR ALL=("vital rate covariation$") OR ALL=("temporal covariance$" AND "demographic parameter$") OR ALL=("temporal covariance$" AND "demographic rate$") OR ALL=("temporal covariance$" AND "vital rate$") OR ALL=("temporal covariance$" AND "parameter$") OR ALL=("covariance$" AND "demographic parameter$") OR ALL=("covariance$" AND "vital rate$") OR ALL=("demographic covariance$") OR ALL=("vital rate covariance$") OR ALL=("demographic compensation"))

We did not include articles on temporal covariation of demographic parameters between populations, compared along geographical and environmental gradients (i.e., 'demographic compensation' defined as changes in opposite directions in mean demographic parameters across populations - see Villellas et al. 2015). Only articles examining compensatory mechanisms within a population were considered.

- **Number of conservation studies using the 'temporal covariation' concept, categorized by conservation applications and organismal groups (Tables S4.1)**

Table S4.1 Number of articles categorized by studied organismal groups and type of conservation applications. The number of articles refers to those in which the concept was quantified rather than discussed (theoretical studies in square brackets).

Organismal groups	*Conservation applications*			*Total*
	1	*2*	*3*	
Magnoliopsida	1	1		2
Actinopterygii	1 [1]			1 [1]
Reptilia	1			1
Mammalia		1	1	2
Amphibia			1	1
Aves			1	1
Total	3 [1]	2	3	**8 [1]**

Note: Applications 1-3 correspond to: 1) Accurately assess the contribution of demographic parameters to population growth and provide realistic, unbiased estimates of population dynamics, resilience and extinction risk; 2) Better assess and improve the efficiency of management plans or conservation actions; and 3) Identify compensatory mechanisms ("demographic compensation").

Reference:

Villellas, J., Doak, D. F., García, M. B., & Morris, W. F. (2015). Demographic compensation among populations: what is it, how does it arise and what are its implications? *Ecology letters*, 18(11), 1139-1152. https://doi.org/10.1111/ele.12505

S5 - Demographic buffering and lability

- **Full list of keywords used in Web of Science query (up to Dec. 2024):**

(ALL=("Environmental canalization" OR "Canalized fitness component" OR "Canalization of survival" OR "Canalization of fertility" OR "Life-history buffering" OR "Life history buffering" OR "Demographic buffering" OR "Buffering hypothesis" OR "Buffering of demographic rates" OR "Buffering of demographic parameters" OR "Buffering in the vital rates" OR "Buffered against environmental variability" OR "temporal variation in vital rates" OR "temporal variation in demographic parameters" OR "Demographic lability" OR "life history lability" OR "life-history lability" OR ("lability" AND "vital rates") OR ("lability" AND "demographic parameters") OR "Labile fertility" OR "Labile demography"))

- **Keyword occurrence (Tables S5.1) and list of organismal groups studied (Table S5.2) across the six selected articles on the 'demographic buffering and lability' concept, categorized by type of conservation application**

Table S5.1 Keyword occurrence across the selected articles, categorized by type of conservation application.

Keywords used in articles	*Conservation applications*	
	1	*2*
Environmental canalization	2	
Demographic buffering	2	2
Demographic lability		
Buffering hypothesis	2	

Table S5.2 Number of articles categorized by studied organismal groups across the six selected articles, with (1) indicating one study involving two different organismal groups.

Organismal groups	*Conservation applications*		*Total*
	1	*2*	
Actinopterygii	0	1	1
Aves	2 (1)	0	2 (1)
Mammalia	1 (1)	0	2 (1)
Forb (Equisetopsida)	0	1	1
Total			**6 studies**

Note: Application 1: Assessing whether a population's buffering capacity is maintained following environmental or anthropogenic perturbations, and to forecast extinction risks; **Application 2:** Assessing population's recovery capacity and responsiveness to conservation/management actions

S6 - Individual heterogeneity

- **Full list of keywords used in Web of Science query (up to Feb. 2024):**

ALL=("individual heterogeneity" OR "individual quality" OR "frailty" OR "among individual variation" OR "personality" OR "individual behavior" OR "individual behaviour" OR "temperament")

- **Article classification on the 'individual heterogeneity' concept by keyword occurrence (Tables S6.1), definition use (Table S6.2), organismal groups studied (Table S6.3), and type of heterogeneity (Table S6.4) categorized by type of conservation application**

Note: Applications 1-5 correspond to: 1) Assessing behavioural traits with high individual variation that may influence conservation and management outcomes, in order to inform and refine strategies; 2) Reducing bias in demographic parameter estimates, thereby improving inference on population dynamics; 3) Evaluating stressor factors on specific individuals that can impact population structure and persistence, and potentially affect ecosystem-level processes; 4) Identifying key individuals to support effective population management or invasive species control; 5) Assessing individual traits that affect reproductive success of population/species to improve conservation and management outcomes.

Table S6.1 Number of articles categorized by keywords and type of conservation applications. Only articles in which the concept was quantified (rather than discussed) are included, excluding theoretical studies.

Keyword used in articles	***Conservation applications***					***Total***
	1	***2***	***3***	***4***	***5***	
Indiv. heterogeneity	1	13	1	1		16
Indiv. quality	1		3	1	3	8
Frailty		2				2
Among indiv. variation			1		1	2
Indiv. behaviour	4	2	1			7
Personality	4		1	7		12
Temperament	1		2			3
Indiv. heterogeneity & Indiv. quality					1	1
Indiv. heterogeneity & Indiv. quality & Personality	1					1
Indiv. heterogeneity & Frailty		1				1
Indiv. heterogeneity & Among indiv. variation	3			1		4
Indiv. heterogeneity & Among indiv. variation & Personality				1		1
Indiv. heterogeneity & Personality		1				1
Indiv. quality & Indiv. behaviour			1			1
Indiv. quality & Personality	1			1		2
Among indiv. variation & Indiv. behaviour	1			1		**2**
Among indiv. variation & Indiv. behaviour & Personality	3			1		4
Among indiv. variation & Indiv. behaviour & Personality & Temperament	2		1			3
Among indiv. variation & Personality	1			3		4
Among indiv. variation & Personality & Temperament	1					1
Indiv. behaviour & Personality	3		2	1		6
Personality & Indiv. behaviour						0
Personality & Temperament	3			2		5
Total	30	19	13	20	5	**87 studies**

<u>Table S6.2</u> Number of articles categorized by definition use (Fitness or Non-Fitness related trait) and type of conservation applications. Only articles in which the concept was quantified (rather than discussed) are included, excluding theoretical studies.

Definition used	***Conservation applications***					***Total***
	1	***2***	***3***	***4***	***5***	
Fitness	8	7	5	5	5	30
Non-fitness	22	12	7	13		54
Fitness & Non-fitness			1	2		3
Total	30	19	13	20	5	**87 studies**

<u>Table S6.3</u> Number of articles categorized by organismal groups studied and type of conservation applications. Only articles in which the concept was quantified (rather than discussed) are included, excluding theoretical studies.

Organismal group	***Conservation applications***					***Total***
	1	***2***	***3***	***4***	***5***	
Mammalia - terrestrial	13	13	2	5	1	34
Mammalia - marine		2				2
Aves	12		6	4	3	25
Actinopterygii	2	1	3	5		11
Reptilia	2	2	1			5
Amphibia	1					1
Insecta		1		1		2
Arachnida			1	1		2
Malacostraca				1		1
Liliopsida				1		1
Mixed: Actinopterygii & Malacostraca				1		1
Mixed: Magnoliopsida & Insecta					1	1
Mixed: Actinopterygii & Amphibia				1		1
Total	30	19	13	20	5	**87 studies**

<u>Table S6.4</u> Number of articles categorized by type of heterogeneity (Measured* or Latent**; with the number of variables considered, in brackets) and type of conservation applications. Only articles in which the concept was quantified (rather than discussed) are included, excluding theoretical studies.

Type of heterogeneity	***Conservation applications***					***Total***
	1	***2***	***3***	***4***	***5***	
Measured [1]	1	1	4	1	1	8
Measured [2]		1		1		2
Measured [3]	2	1	1	1	1	6
Measured [4]					1	1
Latent [1]	17	15	3	9	1	45
Latent [2]				1		1
Latent [3]				1		1
Measured&Latent [2]	6		3	4		13
Measured & Latent [3 to 4]	3	1				4
Measured & Latent [5 to 7]	1		2	2	1	6
Total	30	19	13	20	5	**87 studies**

* Measured variables include: i) Sex; ii) Age; iii) Morphological measurements (e.g., size, length, gut fullness), iv) Mass; v) Body condition; vi) Reproduction output; vii) Reproduction state or life stage; viii) Physiology, epidemiology or stress; ix) Other (e.g., enclosure type, generation in captivity).
** Latent variables include: i) Behaviour; ii) Personality, boldness, temperament or tolerance; iii) Movement, spatial use or foraging; iv) Reproduction investment, parental behaviour or maternal allocation; v) Latent heterogeneity; vi) detection.

Additional information: supplementary studies/further reading (individual heterogeneity):

In our study, we excluded review or fully experimental studies. However, we recommend further reading with recommendation of new approaches for future studies that reveal the importance of the concept of individual heterogeneity not only at the population but also at the ecosystem level:

- Include functional multi-trait covariation (e.g., affected by sex, long-term selection history and short-term environmental conditions) that can have a cascading ecological response to anthropogenic global changes (Pauli et al., 2020).
- Individual phenotypic diversity is a complex phenomenon that needs to be considered in ecosystem-based studies. The ultimate realization is that maintaining or increasing individual trait diversity may enhance the resilience of not only species but also entire ecosystems to environmental perturbations. Individuals are of central importance for ecosystem-based approaches (Ward et al., 2016).

References:

Pauli, B.D., Edeline, E., Evangelista, C., 2020. Ecosystem consequences of multi-trait response to environmental changes in Japanese medaka, Oryzias latipes. Conserv. Physiol. 8. https://doi.org/10.1093/conphys/coaa011

Ward, T.D., Algera, D.A., Gallagher, A.J., Hawkins, E., Horodysky, A., Jørgensen, C., Killen, S.S., McKenzie, D.J., Metcalfe, J.D., Peck, M.A., Vu, M., Cooke, S.J., 2016. Understanding the individual to implement the ecosystem approach to fisheries management. Conserv. Physiol. 4, cow005. https://doi.org/10.1093/conphys/cow005

S7 Transient dynamics

- **Full list of keywords used in Web of Science query (up to Dec 2024):**

(ALL=("transient demography" OR "transient dynamics" OR "demographic resilience" OR "short-term population dynamics"))

- **Number of conservation studies relying on the 'transient dynamics' concept, categorized by main keywords and type of conservation applications, and organismal groups (Tables S7.1 and S7.2, respectively)**

Table S7.1 Number of articles categorized by keywords and type of conservation applications. Theoretical studies that didn't include the analysis of field data are indicated in square brackets.

Keywords used in articles	***Conservation applications***		***Total***
	1	*2*	
Transient dynamics	15 [1]	16 [1]	31 [2]
Transient demography	0	0	0
Demographic resilience	0	0	0
Short-term population dynamics	1	0	1
Transient dynamics AND Demographic resilience	0	1	1
Total			**33[2] studies**

Table S7.2 Number of articles categorized by studied organismal groups and type of conservation applications. Two theoretical studies that didn't include the analysis of field data were excluded. Numbers indicate the number of articles that focused on each organismal group. One article focused on both Mammalia and Magnoliopsida, another article focused on Algae, Echinodermata and Crustacea, and a third article focused on Insecta, Reptilia, Aves and Mammalia.

Organismal groups	***Conservation applications***		***Total***
	1	*2*	
Actinopterygii	0	8	8
Algae	0	1	1
Aves	3	2	5
Crustacea	0	1	1
Echinodermata	0	1	1
Insecta	2	2	4
Magnoliopsida	7	3	10
Mammalia	3	3	6
Reptilia	1	1	2

Note: Applications 1 and 2 correspond to 1) Better estimate the extinction risk and key demographic parameters of populations of threatened species and their demographic resilience to perturbations; 2) Identify the best conservation or management strategy and/or assess responsiveness to conservation/management actions.

S8 - Criteria for data requirements and modelling complexity across demographic concepts

Table S8.1 Data requirements for studying each concept and quantifying associated metrics were evaluated based on three criteria: 1) sample size; 2) monitoring duration (i.e., no temporal replicate needed, medium, or long time series); 3) number of demographic traits measured. TS= time series.

Demographic concepts	*Sample size*	*Monitoring duration*	*Number of distinct demographic traits*	*Score used in figure 2 (low, medium, high)*
Life-history trade-off	Moderate	At least 2 time points	≥1 (often 2)	Medium
Fast-slow continuum	Small / moderate	No TS needed	≥2	Low
Temporal covariation	Moderate	Long-term TS	≥2	High
Demographic buffering-lability	Moderate	Long-term TS	≥2	High
Individual Heterogeneity	Large	No TS needed (but better to have repeated measurements)	≥1	Medium
Transient dynamics	Moderate	Medium-length TS (some years during and after the disturbance)	Multiple	Medium

Table S8.2 Modelling complexity for each concept was determined based on the type of models required to quantify the demographic outcomes (regression models, capture-mark-recapture models, population models) and the number of analytical steps (one- or two-steps). A two-step process involves quantifying time- and (st-)age-specific demographic parameters, and then integrating them into population models. In Figure 2 and throughout the manuscript, we focus on models of minimal complexity used to quantify demographic outcomes. For each concept, more sophisticated approaches are possible (e.g., models with latent variables, multivariate mixed models, or complex structured population models). These approaches are indicated in grey. CMR models is for capture-mark-recapture models.

Demographic concepts	***Type of models needed (regression models, CMR models, population models)***	***One or two-step process***	***Score used in Fig. 2 (low, medium, high)***
Life-history trade-off	Regression models and/or CMR models are required, or population models if assessing trade-offs from temporal covariance among multiple parameters. A more sophisticated approach to estimating trade-offs involves multivariate CMR or integrated population models, which explicitly propagate uncertainty in demographic estimates, or mechanistic frameworks such as Dynamic Energy Budget models.	1	Low
Fast-slow continuum	Simple regression or CMR models required to quantify some demographic parameters, but no extra modelling needed to categorize population/species as fast or slow-living organisms.	0-1	Low
Temporal covariation	Mixed-effect models and/or CMR models and covariance/correlation estimates. A more sophisticated approach involves multivariate CMR or integrated population models to account for uncertainty.	1	Medium
Demographic buffering-lability	i) Regression/CMR models to quantify time and stage-specific demographic parameters, and ii) structured population models to quantify buffering and lability. It is possible to quantify demographic parameters directly into population models (integrated population models) or from multivariate, hierarchical models.	2	Medium
Individual heterogeneity	Regression models and/or CMR with individual covariates required. More complex approaches can be applied to consider individual heterogeneity as a latent variable (e.g., finite mixture models or mixed effect models quantifying random individual effects). Individual-based models are also used.	1	Low
Transient dynamics	i) Regression/CMR models to quantify time and stage-specific demographic parameters, and ii) structured population models to quantify resilience and transient metrics	2	Medium

S9 – Full search queries and template of the table summarizing the screening criteria

Life-history trade-offs

(ALL=(((life-history OR life history) AND (trade-off* OR tradeoff*)) OR (survival AND (trade-off* OR tradeoff*)) OR (reproduction AND (trade-off* OR tradeoff*)) OR (growth AND (trade-off* OR tradeoff*)) OR (fitness AND (trade-off* OR tradeoff*))))
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Fast-slow continuum

ALL=("slow-fast continuum") OR ALL=("fast-slow continuum") OR ALL=("fast-slow life-history continuum") OR ALL=("variation in life history strategies") OR ALL=("Variation in life history traits") OR ALL=("life-history strategies") OR ALL=("life history strategies") OR ALL=("life-history strategy") OR ALL=("life history strategy") OR ALL=("axis of life history strategies") OR ALL=(" r-/K-Selected") OR ALL=("r-K Strategies") OR ALL=("K-selected species") OR ALL=("r-selected species") OR ALL=("r-Strategy") OR ALL=(" K-Strategy") OR ALL=("fast-living species") OR ALL=("slow-living species") OR ALL=("fast life histories") OR ALL=("slow life histories") OR ALL=("fast life history") OR ALL=("slow life history") OR ALL=("fast-slow life history") OR ALL=("slow-fast life history") OR ALL=("pace of life continuum") OR ALL=("pace of life") OR ALL=(" fast-slow life history spectrum")
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Temporal covariation

(ALL=("temporal correlation$" AND "demographic parameter$") OR ALL=("temporal correlation$" AND "demographic rate$") OR ALL=("temporal correlation$" AND "vital rate$") OR ALL=("correlation$" AND "demographic parameter$") OR ALL=("correlation$" AND "parameter") OR ALL=("correlation$" AND "vital rate$") OR ALL=("demographic correlation$") OR ALL=("vital rate correlation$") OR ALL=("temporal covariation$" AND "demographic parameter$") OR ALL=("temporal covariation$" AND "demographic rate$") OR ALL=("temporal covariation$" AND "vital rate$") OR ALL=("temporal covariation$" AND "parameter$") OR ALL=("covariation$" AND "demographic parameter$") OR ALL=("covariation$" AND "vital rate$") OR ALL=("demographic covariation$") OR ALL=("vital rate covariation$") OR ALL=("temporal covariance$" AND "demographic parameter$") OR ALL=("temporal covariance$" AND "demographic rate$") OR ALL=("temporal covariance$" AND "vital rate$") OR ALL=("temporal covariance$" AND "parameter$") OR ALL=("covariance$" AND "demographic parameter$") OR ALL=("covariance$" AND "vital rate$") OR ALL=("demographic covariance$") OR ALL=("vital rate covariance$") OR ALL=("demographic compensation"))
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and

Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Demographic buffering and lability

(ALL=("Environmental canalization" OR "Canalized fitness component" OR "Canalization of survival" OR "Canalization of fertility" OR "Life-history buffering" OR "Life history buffering" OR "Demographic buffering" OR "Buffering hypothesis" OR "Buffering of demographic rates" OR "Buffering of demographic parameters" OR "Buffering in the vital rates" OR "Buffered against environmental variability" OR "temporal variation in vital rates" OR "temporal variation in demographic parameters" OR "Demographic lability" OR "life history lability" OR "life-history lability" OR ("lability" AND "vital rates") OR ("lability" AND "demographic parameters") OR "Labile fertility" OR "Labile demography"))
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Individual heterogeneity

ALL=(“individual heterogeneity" OR “individual quality" OR “frailty" OR “among individual variation" OR “personality" OR “individual behavior” OR “individual behaviour” OR “temperament")
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Transient dynamics

(ALL=("transient demography" OR "transient dynamics" OR "demographic resilience" OR "short-term population dynamics"))
AND
SO=("conservation letters" OR "nature ecology & evolution" OR "Frontiers in Ecology and the Environment" OR "Conservation biology" OR "Biological conservation" OR "One earth" OR "Ambio" OR "People and nature" OR "Ecological applications" OR "Ecology and society" OR "Animal conservation" OR "Biodiversity and Conservation" OR "Biodiversity & Conservation" OR "Basic and applied ecology" OR "Biological invasions" OR "Endangered species research" OR "Oryx" OR "Conservation physiology" OR "Conservation science and practice" OR "Aquatic conservation: Marine and Freshwater Ecosystems" OR "Environmental conservation" OR "Conservation genetics" OR "Journal of insect conservation" OR "Bird conservation international" OR "Conservation & society" OR "Ecological Management & Restoration" OR "Journal for Nature Conservation" OR "Tropical Conservation Science" OR "Journal of applied ecology" OR "Emu – Austral Ornithology" OR "Emu" OR "Global Change Biology" OR "The Journal of Wildlife Management" OR "Insect Conservation and Diversity" OR "Restoration ecology")

Template of the table summarizing the screening criteria used for the six concepts.

Additional columns specific to each concept were added (e.g., definition use [Fitness or Non-Fitness related trait(s)] and type of heterogeneity [latent or measured] for individual heterogeneity; Life-history traits involved in trade-offs for LHTO). See details in Appendix S2-S7. Y or N: Yes or No

Author names	Year of publication	Journal	Relevant abstract for the concept? [Y or N]	Keywords used in the article (related to the concept)	Is the article a review? [Y or N]	Population type [wild, captive, experimental]	Is the main purpose of the article conservation-related? [Y or N]	Is the concept discussed or quantified?	Organismal groups [mammalia, reptilia, actinopterygii, amphibia, magnoliopsida, etc]	Species name	Species status [invasive, exploited, threatened or other conservation interest]	Conservation application category	Short description of the study