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Mammal Review

REVIEW OPEN ACCESS

The Ecological and Societal Roles of the Eurasian Lynx: Evidence and Assumptions

Joe Premier[1] | Deborah Brady[2,3] | Samantha Cartwright[2] | Suzanne T. S. van Beeck Calkoen[4] | Nicolas De Pelsmaeker[5] | Amelia Holmes[2] | Eva Sanchez Arribas[6,7] | Adam F. Smith[8] | Nadège C. Bonnot[9,10] | Ian Convery[3,11] | Nina Gerber[12] | Dries P. J. Kuijper[5] | Deniz Mengüllüoğlu[13] | Axel Moehrenschlager[14,15] | Craig Shuttleworth[16] | Faye Whiley[2,17] | Rok Cerne[18] | Bart Donato[2] | Sheng Li[19] | Marco Heurich[1,20,21]

[1]Department of National Park Monitoring and Animal Management, Bavarian Forest National Park, Grafenau, Germany | [2]The Lifescape Project, The Willows, Long Stratton, UK | [3]Zoology, Centre for National Parks and Protected Areas (CNPPA), Institute of Science and Environment, University of Cumbria, Ambleside, UK | [4]Professur für Forstzoologie, TU Dresden, Tharandt, Germany | [5]Mammal Research Institute, Polish Academy of Sciences, Białowieża, Poland | [6]Department of Ecological Dynamics, Leibniz-Institut für Zoo- und Wildtierforschung (IZW), im Forschungsverbund Berlin e.V, Berlin, Germany | [7]Institute of Ecology, Technische Universität Berlin, Berlin, Germany | [8]School of Biology and Environmental Science, University College Dublin, Science Centre, Dublin 4, Ireland | [9]Université de Toulouse, INRAE, CEFS, Castanet-Tolosan, France | [10]LTSER ZA PYRénées GARonne, Auzeville Tolosane, France | [11]IUCN Commission on Ecosystem Management (Europe), Bonn, Germany | [12]Foundation KORA, Carnivore Ecology and Management, Ittigen, Switzerland | [13]Department of Evolutionary Genetics, Leibniz-Institut für Zoo- und Wildtierforschung (IZW), im Forschungsverbund Berlin e.V, Berlin, Germany | [14]Panthera, New York, New York, USA | [15]IUCN Conservation Translocation Specialist Group, Gland, Switzerland | [16]School of Environmental and Natural Sciences, Bangor University, Bangor, UK | [17]Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Canterbury, UK | [18]Slovenia Forest Service, Ljubljana, Slovenia | [19]School of Life Sciences, Institute of Ecology, Peking University, Beijing, China | [20]Chair of Wildlife Ecology and Management, Faculty of Environment and Natural Resources, University of Freiburg, Freiburg, Germany | [21]Institute for Forestry and Wildlife Management, Campus Evenstad, University of Inland Norway, Koppang, Norway

Correspondence: Marco Heurich (marco.heurich@wildlife.uni-freiburg.de)

Received: 2 April 2026 | **Revised:** 18 September 2026 | **Accepted:** 23 September 2026

Keywords: apex predator | behavioural effects | biodiversity facilitation | conservation | consumptive | disease dynamics | ecosystem services | *Lynx lynx* | trophic interactions

ABSTRACT

Introduction: Apex predators exert top-down pressure on food webs that can shape ecosystem dynamics, while also holding symbolic and utilitarian value for human communities. As human impacts increase, understanding these ecological and societal roles becomes increasingly important for biodiversity conservation and ecosystem management.

Hypothesis: Among apex predators, the Eurasian lynx (*Lynx lynx*; hereafter "lynx") stands out for its relatively low conflict potential and broad public acceptance. Tolerance of lynx could maintain or help restore ecosystem processes in increasingly human-modified landscapes. Far-reaching ecological functions are frequently documented for large carnivores and often postulated for the lynx, yet the evidence base has never been systematically compiled.

Methods: We synthesised research on the ecological and socioeconomic impacts of the lynx to evaluate its role in contemporary ecosystems. Given the few studies available, we qualitatively assessed the ecological effects of lynx, including trophic interactions and symbolic roles.

Discussion: Lynx influence prey and mesopredator populations both consumptively and non-consumptively, though consumptive trophic cascades were observed only in northern regions, and non-consumptive trophic cascades only at fine timescales when perceived predation risk was elevated. Socioeconomic research has focused mainly on burdens associated with lynx, that is, "disservices", like livestock predation, with less attention to potential benefits, like herbivore limitation in silviculture, that

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may constitute ecosystem services. Lynx hold intrinsic value for most people but their assumed roles as flagship or umbrella species, remain weakly evidenced and for some stakeholders the lynx may have a counter-role.
Conclusions: We conclude that the lynx's ecological and societal importance likely exceeds current literature, but key assumptions about its ecosystem functions remain insufficiently tested. We urge interdisciplinary research leveraging ongoing translocations and ecological gradients, including Asia, to test lynx effects and clarify their full contribution to ecosystem functioning and biodiversity in the Anthropocene.

1 | Introduction

Large carnivores can exert top-down pressure by predating on herbivores and mesopredators, potentially limiting their population sizes (Soulé et al. 1988; Estes et al. 2011; Ripple et al. 2014). The risk of predation can also have non-consumptive effects as prey develop antipredator traits, including vigilance, grouping, and spatiotemporal avoidance behaviour (Edmunds 1974; Lima and Dill 1990). Antipredator responses may follow spatiotemporal variation in perceived risk (Brown et al. 1999). These must be balanced with behaviours necessary for survival, like foraging (Verdolin 2006), such that avoiding or occupying risky areas can negatively affect prey physiology and fitness (Creel et al. 2007). Consumptive and non-consumptive effects can cascade to lower trophic levels (Pace et al. 1999; Schmitz et al. 2000; Ripple et al. 2016), with the latter potentially more important (Preisser et al. 2005). However, growing evidence suggests such effects are highly context-dependent and cannot be assumed (Hobbs et al. 2024).

Top-down effects, including trophic cascades, are shaped by the predator's dietary niche. Specialists, for example, may exert stronger top-down pressure on specific prey while generalists exert more complex, distributed pressure across several prey species (Holt 1977; Jiang and Morin 2005; McLellan et al. 2010). The extent to which predation imposes limits on prey abundance depends on mortality being additive to other causes like starvation or disease (Errington 1946). Selective predation for young or weakened prey is more likely compensatory, reducing population effects even at high predation rates (Bartmann et al. 1992). Impacts on prey populations are also modulated by the functional response of predation rates to prey density (Holling 1959), which can cause predation rates to peak at low to moderate prey densities (Messier 1994). These factors underpin the emergence of top-down effects.

Apex predators belong to a guild that each simultaneously exert top-down pressure. Sympatric apex predator species can avoid competition by exploiting different resources or the same resources at different times (Hardin 1960). However, dominant predators can suppress subordinates through interference competition and intraguild predation (Palomares and Caro 1999). Compositional dynamics, like loss or recovery of an apex predator, can alter niche occupancy and competition, with consequences possible for trophic effects (Terborgh et al. 2001; Ripple et al. 2014). Therefore, apex predators' ecosystem functions including top-down effects depend inherently on the predator guild context (Estes et al. 2011; Finke and Denno 2005). Human activities further complicate this, perturbing top-down effects by acting as a super-predator (Clinchy et al. 2016) and bottom-up effects by altering resource availability (Muhly et al. 2013). Therefore, in human-dominated landscapes impacts may be unpredictable, producing unexpected interactions and outcomes (Kuijper et al. 2016, 2024).

Changes in prey abundance, composition and behaviour caused by apex predators can be beneficial functions for humans, so-called ecosystem services (Crooks and Soulé 1999; Côté et al. 2004; Wolf and Ripple 2018; Alston et al. 2019; Carpio et al. 2021). However, these functions are contingent on specific predator–prey interactions. For example, if predation is primarily compensatory, due to selective predation of young or weakened prey, regulation of prey population health might be enhanced (Mech and Peterson 2003), while functions depending on prey population suppression, like browsing reduction, may be stronger under additive mortality (Côté et al. 2004). Predation also generates carrion resources that can facilitate biodiversity (Barton et al. 2013) regardless of mortality mode. Although humans may broadly benefit from these functions, those sharing landscapes with large terrestrial mammalian carnivores can experience economic and personal hardship through "ecosystem disservices", such as livestock depredation (Goodrich 2010; Rust and Marker 2014). Consequently, socioeconomic assessments often focus on costs rather than benefits (Rode et al. 2021). Besides their utility, apex predators are recognised for their intrinsic value (Karlsson and Sjöström 2008; Newsom et al. 2025) that is often leveraged for conservation (Macdonald et al. 2017), although their suitability as flagship, umbrella, or indicator species is context-dependent (e.g., Sergio et al. 2008). Whether positive or negative, studies synthesising large terrestrial mammalian carnivores' impacts have largely neglected these socioeconomic aspects (LaBarge et al. 2022).

Several large terrestrial mammalian carnivores have recolonised parts of their former ranges (Chapron et al. 2014; Wilmers et al. 2025). Alongside natural recolonisation, reintroductions have reinstated some apex predators historically absent from ecosystems (Seddon et al. 2014). Besides species conservation, restoring apex predators also aims to restore ecological processes lost in human-dominated ecosystems (Lipsey et al. 2007). However, an understanding of species' ecological roles and transparent communication of these should underpin this (e.g., Mech 2012), providing managers with evidence for restoration actions (Perino et al. 2019) and to improve public acceptance (Bruskotter and Wilson 2014).

The Eurasian lynx (*Lynx lynx*, hereafter lynx) is a solitary, primarily crepuscular, stalking apex predator (Breitenmoser et al. 2015) that has returned to parts of its former range in recent decades (Linnell et al. 2009). The lynx primarily feeds on mid-sized ungulates (Breitenmoser and Haller 1993; Mattisson, Andrén, et al. 2011) or hares (*Lepus* sp.; Mengüllüoğlu

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et al. 2018), depending on prey abundance (Khorozyan and Heurich 2023a), and is sympatric with several carnivores across its vast palearctic distribution (Karmacharya et al. 2016; Cong et al. 2024). The lynx's range in high and mid latitudes with low to medium productivity implies conditions favouring top-down effects (Oksanen and Oksanen 2000). Therefore, lynx have the potential to influence prey populations and broader ecosystem dynamics. Despite increasing interest in large carnivores' ecological roles, evidence for the lynx's ecosystem functions and societal impacts remains fragmented across disciplines. Consequently, it remains unclear which impacts are well supported by empirical evidence.

Almost three decades ago, Breitenmoser (1998) proposed that the return of large carnivores, including lynx, to Europe offered an opportunity to investigate apex predators' ecological roles, especially in human-dominated landscapes. Still, their effects are subject to debate (Kuijper et al. 2016; van Beeck Calkoen et al. 2022). The lynx remains an ideal model species because its recolonisation is ongoing and it spans environmental, ecological, and human disturbance gradients. We collated apex predators' key impacts as a framework (Tables 1 and 2) for a literature review to identify and synthesise lynx's key documented roles in: (i) ecosystem impacts, including consumptive and non-consumptive pathways, biodiversity facilitation, and disease and pathogen dynamics, and (ii) socioeconomic impacts, including roles as a flagship, umbrella, or indicator species. Thereby, we aimed to clarify whether the lynx has meaningful effects on ecosystems and socioeconomics, or if the evidence is currently lacking.

2 | Literature Search

We conducted a comprehensive literature search with no temporal restrictions in the 'Web of Science' database (in March 2026), targeting publications on all roles and impacts of lynx (Box 1). We retained only primary research published in international, peer-reviewed journals and removed duplicates. The search was restricted to English-language publications, likely excluding relevant articles published in national journals (e.g., Russian-language). We identified relevant articles as those assessing potential impacts of lynx (*Lynx lynx* only), as outlined in Tables 1 and 2. Relevant articles were categorised according to the potential roles and counted as observations within: ecosystem impacts (Table 1) (Section 4), including consumptive (Section 4.1) and non-consumptive effects (Section 4.2), intraguild interactions with other apex predators (Section 4.3), biodiversity facilitation (Section 4.4), disease and pathogen dynamics (Section 4.5) and socioeconomic impacts (Table 2) (Section 5), including costs and burdens (Section 5.1), benefits and value (Section 5.2), and role as a flagship, umbrella, or indicator species (Section 5.3). For Section 5.3, only articles that attempted to evaluate the efficacy of lynx in these roles were considered. Articles covering more than one topic were categorised as observations in both. We also recorded each study's publication year and country. We visualised spatiotemporal trends to highlight research effort allocation, using the software R v4.3.1 (R Core Team 2025) and the packages ggplot2 (Wickham 2016) and sf (Pebesma 2018; Pebesma and Bivand 2023). Due to the heterogeneous contexts, topics, and methods among studies, the sample (297 articles) was inadequate for a systematic review or meta-analysis. We therefore synthesise the information on lynx ecosystem impacts qualitatively.

3 | Research Distribution

Screening removed 1848 articles leaving 297 articles relevant to our review (Data S1). The earliest was published in 1980 and more than half were published since 2015. Most articles were about the lynx's European range, with only around 10% from Asia (Figure 1). As some articles counted for more than one topic, there were 341 observations across subtopics (Figure 2). Research was dominated by the topic of consumptive effects (117 observations). Socioeconomic impacts were second, but 29 articles (37%) reported only the existence of impacts, not human implications, leaving just 50 articles. Subsequently, disease and pathogen dynamics (60 observations) and non-consumptive effects (55 observations) were the next most researched topics. Trophic cascades (indirect effects of lynx on lower trophic levels) were rarely explored, with two and six articles about cascading consumptive and non-consumptive effects, respectively. Biodiversity facilitation relevant topics were considered in 21 articles, though all regarded scavenging or kleptoparasitism of lynx kills. Nine articles assessed the role of the lynx as a flagship, umbrella, or indicator species. Taken together, these findings suggest that while ecological aspects of lynx impacts have received increasing attention, social and economic perspectives remain poorly integrated, a theme developed below.

4 | Ecosystem Impacts of Lynx

4.1 | Consumptive Effects

Most studies focused on the consumptive effects of lynx, specifically direct trophic interactions (115 articles; Figure 2c). Of these, more than half addressed lynx consumption, including lynx diet composition, kill rates, and selectivity (65 articles), which offers restricted insight into the numerical impact of predation on prey populations because lynx diet exhibits seasonality (Oliveira et al. 2025), includes scavenged prey (De Pelsmaeker et al. 2024), and some prey individuals may not contribute to population growth, for example, juveniles. Still, they indicate which species could be affected. The lynx is an adaptable, opportunistic predator, consuming over 50 species across its range, suggesting it is range-wide a generalist. Regionally lynx appear more specialised, typically on ungulates in temperate forests and hares in steppe, boreal forests and tundra (Khorozyan and Heurich 2023a). Yet secondary or alternative prey items often contribute significantly, whether larger or smaller prey, like red deer, lagomorphs, rodents and birds (Okarma et al. 1997; Odden et al. 2006; Krofel et al. 2011).

4.1.1 | Effects on Herbivore Prey Populations

Mid-sized wild ungulates are consumed in proportion to their availability, while hares generally become important when ungulates are scarce (reviewed by Khorozyan and Heurich 2023a). Ground-feeding birds (*Galliformes*) are

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TABLE 1 | Potential ecosystem impacts of apex predators, that is, hypotheses, including selected literature from our search that found evidence of these impacts for lynx or found no impact. "Not studied" indicates no studies on the hypothesis were found in our literature search for lynx.

			Lynx evidence	
Pathway	**Impacted trophic level**	**Apex predator impacts (hypotheses)**	**Impact as hypothesised**	**Impact inconsistent with hypothesis or no impact**
Consumptive (Section 4.1)	Herbivore prey populations (Section 4.1.1)	Predation limits herbivore abundance (Lack 1954)	Roe deer (Jędrzejewska et al. 1997; Nilsen, Gaillard, et al. 2009; Melis et al. 2009, 2010; Heurich et al. 2012; Andrén and Liberg 2015), red deer (van Beeck Calkoen et al. 2023)	Roe deer (Tröger et al. 2021)
	Mesopredator populations (Section 4.1.2)	Lethal interference competition limits mesopredator abundance (Soulé et al. 1988)	Red fox (Helldin et al. 2006; Elmhagen et al. 2010; Pasanen-Mortensen et al. 2013)	Red fox (Wikenros, Aronsson, et al. 2017)
	Trophic levels below primary prey (cascades) (Section 4.1.3)	Predation on herbivores reduces the amount of herbivory (Morris and Letnic 2017).	Deer browsing (Angelstam et al. 2017)	
		Predation on mesopredators increases abundance of their prey (Crooks and Soulé 1999)	Mountain hare (Elmhagen et al. 2010)	
Non-consumptive (Section 4.2)	Herbivore prey populations (Section 4.2.1)	Herbivores respond to varying levels of perceived risk with antipredator behaviour (Brown et al. 1999), affecting: Spatiotemporal avoidance (Bergerud et al. 1984; Lima and Dill 1990; Bongi et al. 2008)	Roe deer (Mysterud and Østbye 1995; Ewald et al. 2014; Norum et al. 2015; Gehr, Hofer, Ryser, et al. 2018; Soyumert et al. 2019; Bonnot et al. 2020; van Beeck Calkoen et al. 2021; Sunde et al. 2022; van Beeck Calkoen, Di Nicola, et al. 2026), reindeer (Tablado et al. 2014)	Hare (Tang et al. 2019; Naderi et al. 2021; Sunde et al. 2022), roe deer (Ratikainen et al. 2007; Samelius et al. 2013)
		Vigilance and grouping behaviours (Kats and Dill 1998; McArthur et al. 2014; Sönnichsen et al. 2013; Schmidt and Kuijper 2015)	Vigilance: roe deer (Eccard et al. 2017; van Beeck Calkoen, Di Nicola, et al. 2026), red deer (van Beeck Calkoen, Di Nicola, et al. 2026), beaver (Rosell and Sanda 2006)	Vigilance: red deer (van Beeck Calkoen et al. 2021), roe deer (Sunde et al. 2022), European hare (Sunde et al. 2022)
		Antipredator behaviour may affect individual fitness (Creel et al. 2007)	Roe deer (Bonnot et al. 2018; Gehr, Hofer, Ryser, et al. 2018)	Roe and red deer (Zbyryt et al. 2018), domestic sheep (Mabille et al. 2016)

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TABLE 1 | (Continued)

Pathway	Impacted trophic level	Apex predator impacts (hypotheses)	Lynx evidence	
			Impact as hypothesised	**Impact inconsistent with hypothesis or no impact**
	Mesopredator populations (Section 4.2.2)	Mesopredators respond to varying levels of perceived risk with antipredator behaviour (Brown et al. 1999), affecting: Spatiotemporal avoidance (Bergerud et al. 1984; Lima and Dill 1990; Bongi et al. 2008)	Red fox (Tang et al. 2019; Haswell et al. 2020; Nasanbat et al. 2021; Cong et al. 2024; Li et al. 2024), raccoon dog (Selonen et al. 2022), sable (Guo et al. 2017)	Red fox (Wikenros, Jarnemo, et al. 2017; Akbaba and Ayaş 2021; Selonen et al. 2022), European badger (Selonen et al. 2022; Cano-Martínez et al. 2024), European wildcat (Dyck et al. 2022)
		Vigilance behaviour (Kats and Dill 1998; McArthur et al. 2014; Sönnichsen et al. 2013; Schmidt and Kuijper 2015)	Red fox (Wikenros, Jarnemo, et al. 2017; Sunde et al. 2022)	
		Antipredator behaviour may affect individual fitness (Creel et al. 2007)	Domestic dog (Samuel et al. 2020)	
	Trophic levels below primary prey (cascades) (Section 4.2.3)	Antipredator behaviours of herbivores affect distribution and selectivity in herbivory (Kuijper et al. 2013)	Intensity: beaver (Rosell and Czech 2000), red deer (van Beeck Calkoen et al. 2021; van Beeck Calkoen, Di Nicola, et al. 2026)	Distribution: deer browsing (Bubnicki et al. 2019; van Beeck Calkoen et al. 2022). Selectivity: red deer (van Beeck Calkoen et al. 2021; van Beeck Calkoen, Di Nicola, et al. 2026)
		Antipredator behaviours of mesopredators affect distribution of their prey (Gordon et al. 2015)		Not studied
Intraguild interactions with other apex predators (Section 4.3)		Lethal interactions between apex predators could affect their own populations (Elbroch et al. 2020)	Lethal interactions (Petrunenko et al. 2016; Gu et al. 2018; Nayeri et al. 2022; Sidorovich 2022)	With wolves, no evidence (Wikenros et al. 2010)
		Interactions between apex predators could influence consumptive effects (Bruno and Cardinale 2008)	With wolves: red deer (van Beeck Calkoen et al. 2023), red fox (Wikenros, Aronsson, et al. 2017), roe deer (Melis et al. 2009)	
		Nonlethal interactions between apex predators could affect their own behaviour or fitness (Elbroch et al. 2015)	Avoidance of snow leopard (Zhong et al. 2022; Byambasuren et al. 2024; Cong et al. 2024), kleptoparasitism by wolverine and bear (Krofel and Jerina 2016; Mattisson, Andrén, et al. 2011)	No impact of wolves (Wikenros et al. 2010)
		Interactions between apex predators could affect non-consumptive effects (Finke and Denno 2005; Bruno and Cardinale 2008)		Not studied

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TABLE 1 | (Continued)

Pathway	Impacted trophic level	Apex predator impacts (hypotheses)	Lynx evidence	
			Impact as hypothesised	**Impact inconsistent with hypothesis or no impact**
Biodiversity facilitation (Section 4.4)		Apex predators produce carrion resources (Okarma et al. 1997; Carter et al. 2007) that facilitates biotic communities (Barton et al. 2013)	Mammals (Selva and Fortuna 2007; Khalil et al. 2014; Rauset et al. 2015; Wikenros, Aronsson, et al. 2017)	Soil and vegetation (Teurlings et al. 2020)
Disease and pathogen dynamics (Section 4.5)		Higher lynx abundance lowers herbivore prey and mesopredator abundance impacting zoonotic diseases (Ostfeld and Holt 2004)		Tick abundance correlated with herbivore but not lynx abundances (Jaenson et al. 2012, 2018)
		Selective predation of frail or disease-weakened herbivore prey and mesopredators could regulate wildlife disease prevalence (Packer et al. 2003)	Semi-domestic reindeer (livestock - Haglund 1966; Pedersen et al. 1999), red deer (Okarma et al. 1997; Heurich et al. 2016)	Roe deer (Okarma et al. 1997; Andersen et al. 2007)
		Apex predators assist scavenger community maintenance via resource facilitation (Baruzzi et al. 2018), thereby reducing pathogen persistence by accelerating decomposition of diseased carrion (Le Sage et al. 2019)		Not studied

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TABLE 2 | Potential socioeconomic impacts of apex predators, that is, hypotheses, including selected literature from our search that found evidence lynx had these impacts or found no impact. "Not studied" indicates no studies on the hypothesis was found in our literature search for lynx.

			Lynx evidence	
Category	**Subcategory**	**Apex predator impacts (hypotheses)**	**Impact as hypothesised**	**Impact inconsistent with hypothesis or no impact**
Socioeconomic (Section 5)	Economic value (costs/benefits)	Livestock depredation has costs (Goodrich 2010; Rust and Marker 2014), including damages, compensation and mitigation	Chen et al. (2016), Widman and Elofsson (2018), Gervasi et al. (2021), etc.	Kovařík et al. (2014)
		Predation lowers herbivory, bringing savings in forestry and farming (Putman and Moore 1998; Apollonio et al. 2010; Petersson et al. 2019; Pfeffer et al. 2021)		Not studied
		Predation saves money by reducing wildlife vehicle collisions (Gilbert et al. 2017)		Not studied
		Apex predators generate income in conservation, ecotourism, and hunting (Martín-López et al. 2007; Arnett and Southwick 2015; Macdonald et al. 2017)	Willing to pay or travel (Ericsson et al. 2007; Bartczak and Meyerhoff 2013; Bartczak et al. 2016; Giergiczny et al. 2022; Notaro and Grilli 2022)	Hunting (Lozano Galindez et al. 2020; Lozano et al. 2021)
	Social value (burdens/benefits)	Socio-cultural burdens of domestic animal depredation (Kellert et al. 1996; Naughton-Treves et al. 2003; Convery et al. 2005) and game competition (Skogen and Krange 2003)	Domestic animals (Liukkonen et al. 2009; Hameed et al. 2022; Whiley and Tzanopoulos 2024), game (Lüchtrath and Schraml 2015; Smolko et al. 2025)	
		Apex predator presence brings burden of fear/ personal risk (Jacobsen et al. 2022).	Pohja-Mykrä and Kurki (2014), Johansson et al. (2012)	
		Apex predator improves connections to nature and benefitting human wellbeing (Rode et al. 2021; Barragan-Jason et al. 2023)	Recreation (Giergiczny et al. 2022)	Misconceptions (Lescureux and Linnell 2010; Lescureux et al. 2011)
		Predation reduces personal burden by reducing wildlife vehicle collisions (Gilbert et al. 2017)		Not studied

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TABLE 2 | (Continued)

Category	Subcategory	Apex predator impacts (hypotheses)	Lynx evidence	
			Impact as hypothesised	Impact inconsistent with hypothesis or no impact
Flagship, umbrella, and indicator species (Section 5.3)	Flagship	Apex predators attract funding/support for conservation (Bowen-Jones and Entwistle 2002; Walpole and Leader-Williams 2002)	Assumed (e.g., Niedziałkowska et al. 2006; Breitenmoser et al. 2008), popularity (Schlegel and Rupf 2010)	Linnell et al. (2000)
	Umbrella	Apex predators help conserve/restore ecosystems and biodiversity (Thornton et al. 2016)	Rozylowicz et al. (2011)	Linnell et al. (2000)
	Indicator	Apex predator presence indicates ecosystem and habitat intactness (Natsukawa and Sergio 2022)	Human impacts (Morrison et al. 2007)	Linnell et al. (2000)

BOX 1 | Web of Science Query.

(Eurasian lynx OR *Lynx lynx* OR Felis lynx) AND (diet OR predation OR kill OR facilitation OR provision OR release OR competition OR limit OR fear OR olfactory OR forage OR vigilance OR browsing OR selectivity OR scavenging OR disease OR transmission OR top-down OR bottom-up OR direct OR indirect OR consumptive OR non-consumptive OR lethal OR nonlethal OR density mediated OR trait mediated OR numerical OR mortality OR survival OR trophic OR resource OR carrion OR role OR effect OR function OR service OR benefit OR value OR cost OR risk OR impact OR compensation OR mitigation OR interaction OR influence OR cascade OR anti predator OR behaviour OR positive OR negative OR attract OR avoid OR partition OR coexist OR balance OR surrogate OR keystone OR indicator OR umbrella OR sentinel OR flagship OR rewilding OR restoration)

only consumed significantly in boreal and montane regions (Jędrzejewski et al. 1993). Generally, wild boar (*Sus scrofa*) and red deer males (*Cervus elaphus*, Heurich et al. 2016) were avoided when smaller prey was available (Jędrzejewski et al. 1993). Selective predation based on species, sex or age has been reported, suggesting lynx prefer certain species, individuals or differences in prey behaviour (Okarma et al. 1997; Molinari-Jobin et al. 2002; Heurich et al. 2012, 2016; Mejlgaard et al. 2013; Melis et al. 2013). Conversely, Andersen et al. (2007) and Okarma et al. (1997) found lynx in Norway and Poland, respectively, did not selectively hunt roe deer (*Capreolus capreolus*) individuals by sex, age or condition, likely due to the lynx's stalking strategy and the deer's low dimorphism. Lynx kill sites (17 observations) are generally characterised by dense vegetation cover (Lone et al. 2014). Further, differences between the habitat used by living ungulates and the habitat at kill sites suggest individual prey behaviour affects their mortality risk (Belotti et al. 2013).

Prey survival analysis (22 observations) reveals the effect of predation on individual mortality risk. For instance, roe deer that remained in familiar areas were only half as likely to be preyed upon by lynx as those that left their habitual space-use or used habitat that favours stalking (Gehr et al. 2020). Further, adult roe deer survival rates declined by almost 20% after lynx recolonised an area in Germany (Heurich et al. 2012). However, whether lynx will lower prey abundance depends on predation being additive to other causes of mortality and there being no increase in reproductive output under predation risk. For roe deer, the evidence indicated that lynx predation is additive to other mortality causes (Melis et al. 2010; Andrén and Liberg 2015; Gehr, Hofer, Pewsner, et al. 2018), and roe deer did not increase reproductive output under harsh conditions, including lynx predation (Nilsen, Gaillard, et al. 2009).

The effect of lynx on prey populations, in terms of abundance, density, and growth rates was investigated 19 times (Figure 2d). Geographic replicates across Europe showed lynx presence lowered roe deer abundance (Melis et al. 2009, 2010), while there was little effect on red deer abundance (van Beeck Calkoen et al. 2023). Roe deer population growth rates declined after lynx recolonised south-central Sweden

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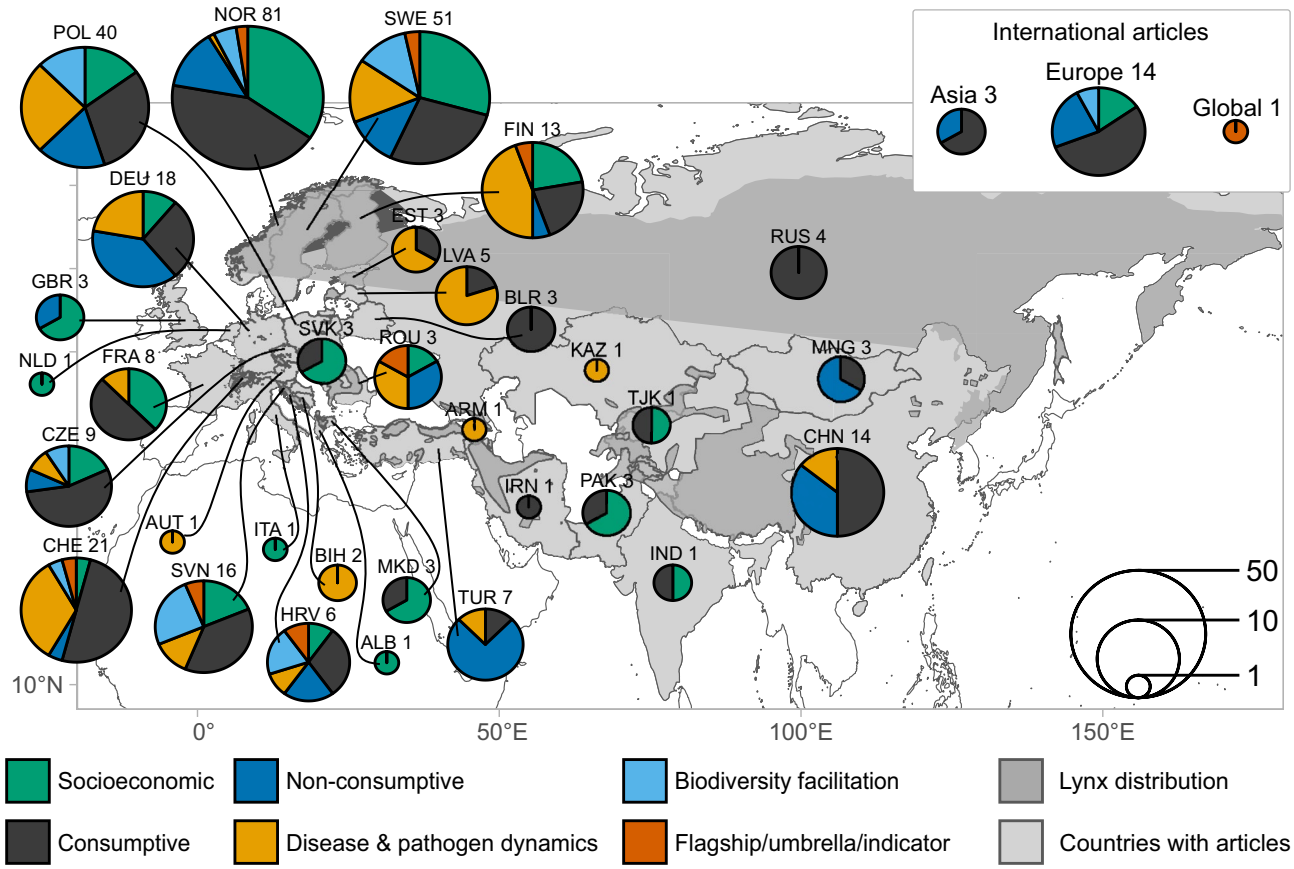


FIGURE 1 | The global distribution of Eurasian lynx (dark grey; IUCN red list, Breitenmoser et al. 2015) with the number of articles as well as distribution among topics (pie charts) for each country (ISO3 country codes; light grey). Articles covering two countries were counted as one observation for each, and those with global, European, or Asian extents were counted separately as international articles.

(Andrén and Liberg 2015) and lynx caused negative growth rates in Norway (Nilsen, Gaillard, et al. 2009). Lynx likely exert a strong effect on medium sized ungulates because they can kill prime-aged individuals that are important for reproductive output (Gervasi et al. 2012). The effect of lynx on roe deer and red deer was greater, that is, synergistic effect, when occurring alongside wolves (*Canis lupus*, Melis et al. 2009; van Beeck Calkoen et al. 2023) but also depends on the additive mortality of human harvest, on one hand, but also human regulation of lynx population density on the other (Melis et al. 2013; Andrén and Liberg 2024). For example, no change in roe deer abundance was detected in the years following a lynx reintroduction project (Tröger et al. 2021), potentially as the small lynx population has not fully established and roe deer can immigrate (Carpentier et al. 2024).

Resource availability naturally limits prey density and therefore lynx density bottom-up (Herfindal, Linnell, Odden, et al. 2005). But prey make use of anthropogenic resources in cultivated mosaic landscapes comprising meadows, crops, and forest (Dupke et al. 2017). Further, supplementary feeding, especially during harsh winters, often successfully improves deer condition, and hence densities, for recreational hunting (Milner et al. 2014). As such, natural prey regulation is difficult to achieve due to the overwhelming supply of prey caused by the lack of bottom-up resource limitation (Melis et al. 2009), convoluted by the dominance of human hunting on ungulate population dynamics (Melis et al. 2013). Further, a supply of domestic animals could also perturb lynx top-down limitation of wild prey densities. Numerous articles (32 observations) explored lynx livestock depredation, mostly on sheep (*Ovis aries*; e.g., Stahl et al. 2001) and semi-domestic reindeer (*Rangifer tarandus*; e.g., Åhman et al. 2014). Lynx kill sheep where livestock practises bring sheep closer to lynx or to lynx prey's preferred habitats (reviewed by Khorozyan and Heurich 2023b). In contrast to sheep, which are generally a small part of lynx diet across Europe and Asia, in arctic regions of Scandinavia where other ungulates are scarce semi-domestic reindeer are a vital prey for lynx (Pedersen et al. 1999). Although lynx abundance was negatively correlated with domestic animal abundance in Sweden (Herfindal, Linnell, Moa, et al. 2005; Hobbs et al. 2012), the density of livestock and other regional factors could be more important for livestock depredation than the density of lynx (Dalerum et al. 2020). In Norway, large carnivore abundance, including lynx, correlated positively with domestic animal losses but this did not affect domestic animal growth rates and bottom-up effects were more important for domestic animal losses (Tveraa et al. 2014). These findings suggest that lynx are not limiting domestic animal population sizes in Scandinavia but lynx impacts on wild prey populations depend partly on the availability of domestic prey (Gervasi et al. 2014; Mattisson et al. 2014). However, it is important to note that in Scandinavia, lynx densities are regulated by lynx harvest (Andrén and Liberg 2024) and elsewhere in Europe lynx are illegally regulated by poaching (Premier et al. 2025).

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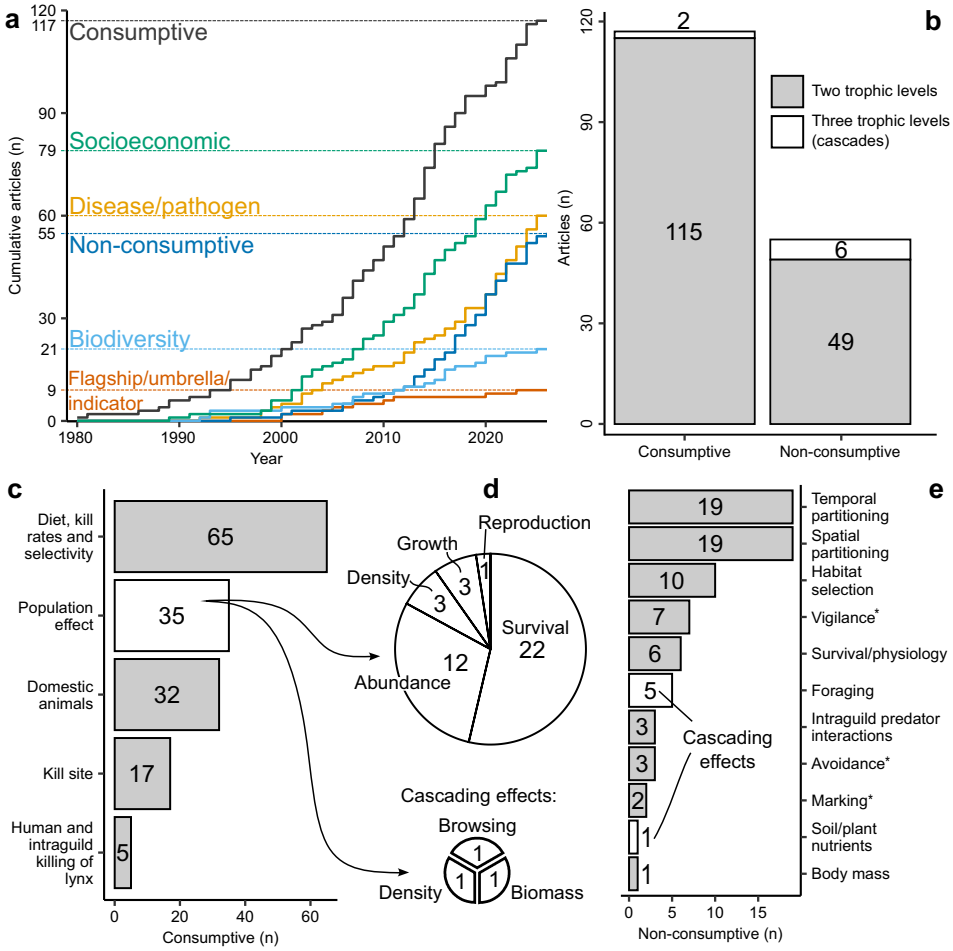


FIGURE 2 | Distribution of research foci over time (a) and between two trophic level (i.e., impact on prey species) and three trophic level (i.e., cascading impacts on lower trophic level mediated by prey species) effects in consumptive and non-consumptive articles (b). The frequency each subtopic was observed, *n*, within consumptive (c) and non-consumptive articles (e), as well as the investigated quantities (e.g., abundance, survival, biomass, etc.) investigated for two trophic level (i.e., direct) and three trophic level (i.e., cascading) consumptive effects (d). Besides intraguild subtopics, in panels (c), (d), and (e), all subtopics refer to herbivore and mesopredator prey. Immediate responses to olfactory cues are marked with * in panel (e).

Although hares represent a significant lynx prey, our search identified no articles on the consumptive effects of lynx on hare populations. Evidence shows lynx can limit roe deer abundance through consumption (Jędrzejewska et al. 1997; Andrén and Liberg 2015). Beyond our search, theory assumes that ungulate specialist lynx should have low impacts on hare populations, and vice versa, unless the secondary prey is particularly rare (Barraquand et al. 2015). Although the lynx seems like a dietary generalist across its range (Khorozyan and Heurich 2023a), regionally it tends toward specialisation on specific prey (Jędrzejewski et al. 1993; Odden et al. 2006; Mengüllüoğlu et al. 2018).

The population-level consequences of specialisation may depend on two opposing processes. A numerical response in a specialist predator creates positive feedback in the predator–prey cycle, with predator density strengthening additive mortality during prey population growth phases (Murdoch et al. 2003). However, prey switching can dampen the numerical response to preferred prey, buffering predator populations against prey scarcity and maintaining additive mortality on preferred prey at densities where a stricter specialist would suffer (Van Baalen et al. 2001).

Russian-language literature suggests that hare-specialist lynx shift their predation toward ungulates or birds when hares are scarce, but their population densities still track temporal fluctuations in hare availability (Zaitsev and Krinitzin 2010; Sedalischev et al. 2014)—mirroring the Canada lynx (*Lynx canadensis*)–snowshoe hare (*Lepus americanus*) relationship (Hone et al. 2007). A similar numerical response was demonstrated in roe deer-specialist lynx (Andrén and Liberg 2024), yet alternative prey availability and higher carrying capacity dampened cyclic tendencies.

For roe deer-specialist lynx, several factors explain their capacity to regulate medium-sized ungulate populations: high kill efficiency at low prey densities (steep type II functional response; Nilsen, Linnell, et al. 2009), predation of reproductively prime individuals (Okarma et al. 1997; Gervasi et al. 2012), comparable population growth rates between predator and prey (Andrén et al. 2006; Andrén and Liberg 2015), and dietary supplementation with alternative prey (Odden et al. 2006).

These effects are further modulated by sympatry with other predators (including humans and wolves), which can synergistically intensify predation pressure (Melis et al. 2013; Gehr,

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Hofer, Pewsner, et al. 2018; van Beeck Calkoen et al. 2023; Carpentier et al. 2026), and bottom-up climatic, environmental, and human factors affecting prey numbers or vulnerability (Melis et al. 2009; Nilsen, Linnell, et al. 2009). In many regions, human-caused lynx mortality, including legal and illegal killing, appears to be the most prevalent factor driving lynx population dynamics (Cretois et al. 2021; Premier et al. 2025), suggesting suppression of the numerical response of lynx to prey (Nilsen, Linnell, et al. 2009; Andrén and Liberg 2024) and potentially constraining lynx functions and effects. This emphasises that top-down consumptive effects are prey and context-specific, and that long-term data necessary to investigate them remain scarce.

4.1.2 | Effects on Mesopredator Populations

Mesopredators make up a notable proportion of lynx diet (Odden et al. 2006). Several articles investigated potential consumptive effects of lynx on red fox (*Vulpes vulpes*), a common Eurasian mesopredator. In one area of Sweden, the red fox population declined after lynx recolonised with lynx predation additive to other mortalities (Helldin et al. 2006). In Norway, lynx and red fox abundances were negatively correlated (Elmhagen et al. 2010), and lynx presence was associated with lower red fox abundance across Europe (Pasanen-Mortensen et al. 2013). Sunde et al. (1999) found lynx left more tissue uneaten at red fox carcasses compared to herbivore carcasses, consistent with interference competition rather than predation solely for food. Indeed, red fox compete with lynx by preying on roe deer fawns (Panzacchi et al. 2008). However, in Sweden, the presence of wolf meant lynx and red fox abundances were positively correlated (Wikenros, Aronsson, et al. 2017), and in the absence of lynx, fox populations likely benefitted more from lower exploitation competition than lower interference competition (Selås and Vik 2006).

The evidence mostly indicates that lynx limit red fox abundance, consistent with interference competition or red fox serving as an alternative prey whose density and growth rates are low enough in some areas for mortality to be additive. Whether this is the case for other mesopredators is unclear but likely depends on dietary overlaps, prey availability, sympatric apex predators, and human activities, including those that may alter lynx density or perturb bottom-up resource limitations.

4.1.3 | Cascading Consumptive Effects

In Finland, lynx recolonisation provided an opportunity to test the mesopredator release hypothesis with respect to red fox and their mountain hare prey (*L. timidus*; Elmhagen et al. 2010). Hare abundance increased with lynx abundance, indicating that with lynx absent, red fox were released from predation and exerted greater pressure on hare populations. Red fox abundance limitation by lynx (Pasanen-Mortensen et al. 2013) is also consistent with the mesopredator release hypothesis. However, impacts may vary because lynx prefer hares in some regions despite ungulate availability (Pulliainen et al. 1995; Mengüllüoğlu et al. 2018) and sometimes foxes may benefit from carrion of lynx kills.

Angelstam et al. (2017) explored the cascading effect of apex predator (wolf, bear and lynx) occurrence on large herbivore (moose, red deer and roe deer) abundance and vegetation with 10 geographic replicates in the boreal biome. Occurrence of more apex predator species, including lynx, reduced large herbivore abundances and browsing intensity on several tree species. However, the explicit link to predator abundances was missing in the study and the authors highlighted that forest and wildlife management practices can alter this link. Indeed, humans can limit lynx abundance, which in turn has cascading effects on wild and domestic prey (Herfindal, Linnell, Moa, et al. 2005; Melis et al. 2010).

Lynx broadly occupy ecosystems with a restricted prey base and few competitors (Willig et al. 2003); this relative simplicity should allow research to disentangle cause-and-effect relationships and derive solid, evidence-based conservation and human-lynx coexistence implications. Despite this, the evidence for cascading consumptive effects triggered by lynx remains narrow. The complexity of delineating consumptive effects on prey alone is magnified when linking multiple trophic levels in dynamic ecosystems, where climate, environment, and human factors affecting predator and prey populations, and non-consumptive effects, vary simultaneously.

4.2 | Non-Consumptive Effects

4.2.1 | Effects on Herbivore Prey Behaviour

4.2.1.1 | Spatiotemporal Partitioning. Lynx hunt mainly in crepuscular and nocturnal periods, even without human disturbances (Smith et al. 2024), to take advantage of their stalking hunting tactic (Heurich et al. 2014). In response, prey should shift activity to daytime. Indeed, when comparing 12 roe deer populations throughout Europe, roe deer were found to exhibit more diurnal activity in areas with lynx than without lynx (Bonnot et al. 2020). In Türkiye and Mongolia, lynx had similar crepuscular behaviour as hares (*L. europaeus*, Naderi et al. 2021; *L. tolai*, Tang et al. 2019), more so than roe deer in Türkiye (Soyumert et al. 2019), suggesting that hares do not temporally avoid lynx, whereas roe deer do.

Prey may also spatially avoid locations where the risk of lynx predation is higher. However, in Germany, roe deer selected habitats primarily for food resources before lynx predation avoidance (Dupke et al. 2017). Similarly, in Scandinavia, roe deer neither altered habitat selection after lynx returned (Samelius et al. 2013), nor preferred open areas to reduce their predation vulnerability (Ratikainen et al. 2007). These results suggest stalking by lynx, combined with their low density and high hunting efficiency, leaves prey little room for spatial avoidance. Prey might approach anthropogenic landscape features to reduce predation risk (i.e., human-shield effect; Berger 2007; Lone et al. 2014). However, since prey species often forage in agricultural areas, forest openings, and meadows (Dupke et al. 2017) it is unclear whether this reflects resource concentration or predation avoidance. In contrast, at finer spatial scale, roe deer choose bed sites with acoustic characteristics maximising predator detection (Mysterud and Østbye 1995) and, at night, favour areas of less

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dense understorey vegetation (Ewald et al. 2014), conceivably to avoid lynx. In the Swiss Alps, roe deer proactively avoided riskier areas both day and night in the summer and even intensified their avoidance during nighttime when the immediate risk of encountering a lynx was high (Gehr, Hofer, Ryser, et al. 2018). Indeed, roe deer typically used less dense habitats than found at lynx kill sites (Norum et al. 2015). In Norway, reindeer avoided forested areas when conditions allowed, conceivably as antipredator behaviour, but increased forest use in late winter when resources were scarce, thereby increasing lynx predation risk (Tablado et al. 2014). When experimentally exposed to lynx olfactory cues, most studies showed roe deer and red deer reduced visitation duration and/or frequency (Wikenros et al. 2015; Sunde et al. 2022; van Beeck Calkoen et al. 2021; van Beeck Calkoen, Di Nicola, et al. 2026), potentially as a fine-scale spatial anti-predator strategy specific to lynx. Although wild ungulates seem to avoid high risk areas, European hares showed no such avoidance (Sunde et al. 2022).

Within an area, prey may exhibit specific movement strategies in an attempt to reduce predation risk (e.g., Humphries and Driver 1970). For instance, when facing strong lynx predation risk, roe deer reduced their movement rates, potentially as a strategy to lower detection probability (Gehr, Hofer, Ryser, et al. 2018). Besides this work, herbivore movement has not been linked to lynx predation risk avoidance. Studies outside the literature search rather connect broad scale movement patterns, like migrations, to environmental conditions (Cagnacci et al. 2011; Mysterud et al. 2012; Schai-Braun et al. 2023).

4.2.1.2 | Nonspatial Antipredation. Red deer in an enclosure did not alter their vigilance behaviour due to lynx olfactory cues (van Beeck Calkoen et al. 2021). Contrastingly, wild-living roe and red deer increased vigilance in response to lynx olfactory cues (Eccard et al. 2017; van Beeck Calkoen, Di Nicola, et al. 2026) with the highest vigilance seen in adults during winter nights when accompanied by offspring (van Beeck Calkoen, Di Nicola, et al. 2026) and for red deer in the forest (van Beeck Calkoen, Balkenhol, et al. 2026). However, two studies found no change in vigilance of roe deer and European hares to lynx olfactory cues (Sunde et al. 2022; Wikenros et al. 2015). Eurasian beaver (*Castor fiber*) reduced territorial marking more with olfactory cues of sympatric lynx than control scents (Rosell and Sanda 2006), suggesting risk avoidance at the cost of reproductive fitness. No studies have yet investigated grouping behaviour as an antipredator strategy for lynx predation risk.

4.2.1.3 | Physiological and Fitness Effects. In Sweden, roe deer in an area recently recolonised by lynx and wolf, had higher cortisol levels than an area missing large carnivores (Bonnot et al. 2018), whereas in Poland red and roe deer showed lower, less fluctuating cortisol in areas with large carnivores compared to human-dominated areas without them (Zbyryt et al. 2018). This suggests lynx can cause physiological stress in prey, but humans cause greater stress. One article showed roe deer occupying areas of constantly high lynx risk were fourfold more likely to succumb to non-lynx mortality than those in low lynx risk areas (Gehr, Hofer, Ryser, et al. 2018), suggesting a non-consumptive effect on prey fitness. In Norway, the antipredator behaviour of ewes did not appear to affect lamb growth (Mabille et al. 2016).

Non-consumptive lynx effects on herbivores were documented in ungulates, although their distribution is driven foremost by forage; at fine scales, prey seem to mitigate lynx predation by avoiding risky habitats or immediate risk cues. Vigilance responses to olfactory cues varied with no clear context dependency, but generally ungulates avoided or reduced activity near lynx scents, potentially to continue foraging when risk cannot be avoided (Schmidt and Kuijper 2015). A non-consumptive effect on herbivore survival was found, but effects on reproduction are unknown. Human activities could alter potentially cascading effects of antipredator responses because human-related risks are highly predictable and often dominate lynx predation in prey population regulation (Melis et al. 2013). Research on hares is scarce, but they seem less temporally plastic than ungulates and are unfazed by lynx cues, perhaps compensated by alternative life history strategies.

4.2.2 | Effects on Mesopredator Behaviour

Some mesopredators seem to avoid temporal overlaps with lynx: in Croatia red foxes were more nocturnal in places where lynx and wolf were active (Haswell et al. 2020) and in Mongolia, lynx overlapped less temporally with red fox than Asian badger (*Meles leucurus*) and raccoon dog (*Nyctereutes procyonoides*; Tang et al. 2019). In China, red fox and leopard cat (*Prionailurus bengalensis*) appeared more nocturnal than lynx (Li et al. 2024). In contrast, lynx in Türkiye overlapped more with red fox than southwest Asian badger (*Meles canescens*) and *Martes* spp. (Akbaba and Ayaş 2021). In all cases, lynx were sympatric with at least one other large carnivore, meaning lynx effects could be confounded by antagonistic or synergistic interactions. Temporal overlap also depends on diet, because mesopredators with different dietary niches to lynx could be active at different times and places, like red fox and Tibetan fox (*Vulpes ferrilata*) in China (Cong et al. 2024).

In Finland, lynx presence correlated with European badger (*Meles meles*) occurrence but not with red fox, while invasive racoon dog was negatively associated (Selonen et al. 2022). At waterholes in Mongolia, red foxes showed no significant spatial overlap with lynx (Nasanbat et al. 2021). In Romania, red fox and European wildcat (*Felis silvestris*) occurrence generally correlated with lynx occurrence, though overlap with wildcat was promoted by rugged terrain and less dense forests (Dyck et al. 2022, 2025). In northeastern China, sable (*Martes zibellina*) preferred areas with lower lynx occurrence, potentially because both hunt hares there (Guo et al. 2017). In Norway, although lynx correlated with European badger occurrence in summer, mesopredator occurrence was predominantly driven by bottom-up factors (Cano-Martínez et al. 2024). At fine scales, large carnivore sympatric red foxes were attracted to lynx scent, while increasing vigilance, perhaps to gather information on carrion (Wikenros, Jarnemo, et al. 2017; Sunde et al. 2022). Heart rates of untrained domestic dogs (*Canis familiaris*) increased on detecting lynx scents and they left the site sooner than controls (Samuel et al. 2020), suggesting that physiological responses could also affect wild mesopredators.

The evidence of lynx non-consumptive effects on mesopredators mainly concerns niche partitioning and red fox behavioural

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responses to lynx cues, confirming such effects exist. However, the fitness implications are unknown and complicated by benefits from carrion provisioning, but could particularly affect mesopredators with dietary overlaps with lynx.

4.2.3 | Cascading Non-Consumptive Effects

Six studies investigated the cascading non-consumptive effect of lynx on herbivores and vegetation. van Beeck Calkoen et al. (2022) showed higher deer browsing intensity and diet quality at sites with higher lynx predation risk, and Bubnicki et al. (2019) found no landscape-scale association between lynx and deer browsing distribution; neither result indicates a non-consumptive trophic cascade. In three studies employing olfactory cues, Eurasian beaver and deer species reduced foraging when exposed to lynx scent (Rosell and Czech 2000; van Beeck Calkoen et al. 2021, van Beeck Calkoen, Di Nicola, et al. 2026), whereas another study showed a reduced visitation rate, which also implies less foraging (Wikenros et al. 2015), though browsing selectivity or forage quality intake of red deer was unaffected (van Beeck Calkoen et al. 2021; van Beeck Calkoen, Di Nicola, et al. 2026). These results differ in scale; the latter focused on immediate cues of elevated risk, the former on risk integrated over longer periods, suggesting lynx predominantly affect herbivore foraging non-consumptively when the perceived risk is immediate.

Lynx do not entirely consume kills, leaving resources to the environment (Okarma et al. 1997). Accordingly, Teurlings et al. (2020) hypothesised a cascading effect from lynx to soil nutrients and vegetation, but detected no effects despite leaving entire carcasses. Lynx kills occur in low density, and carrion is distributed by scavenger and decomposer communities (Ray et al. 2014), making it improbable to detect local soil and vegetation effects from a single carcass.

Despite interest in trophic cascades, few studies have linked lynx with antipredator behaviours and resulting impacts on a third trophic level. Antipredator responses are believed to affect the spatiotemporal distribution of prey behaviours, but so far, the evidence suggests foraging is only affected when prey perceive immediate risk. This has been hypothesised for habitats where prey have difficulty avoiding predation risk (Schmidt and Kuijper 2015). Although expected to have larger impacts than consumptive effects (Preisser et al. 2005), whether non-consumptive trophic cascades meaningfully, or predictably, affect human-dominated ecosystems remains uncertain (Kuijper et al. 2016, 2024), and detecting long-term effects on vegetation and forests would require significant effort.

4.3 | Intraguild Interactions With Other Apex Predators

We found some evidence of direct interference competition between lynx and similar or dominant apex predators, most often via kleptoparasitism (21 articles). Kleptoparasites consume prey killed by another predator at a cost to the active predator, in this case the lynx (Krofel and Jerina 2016). Brown bear (*Ursus arctos*) and wolverine were identified as apex predator kleptoparasites of lynx (Krofel and Jerina 2016; Mattisson, Andrén, et al. 2011). Bears in Slovenia consumed on average 15% of the edible biomass from lynx kills (Krofel et al. 2012). In Scandinavia, wolverines could reduce their predation effort during winter by taking advantage of lynx kills (Mattisson et al. 2016), which improved the reproductive fitness of female wolverines (Rauset et al. 2015). Indeed, lynx and wolverine population trends were correlated (Khalil et al. 2014). Although kleptoparasitism increases hunting effort and energetic costs for lynx, fitness effects were implied but not documented.

Lethal interactions including intraguild predation also constitute interference. Lynx have been predated by Amur tiger (*Panthera tigris tigris*; Petrunenko et al. 2016; Gu et al. 2018) but likely represent a negligible part of tiger diets (Kerley et al. 2015). In Iran, lynx were killed by free-ranging dogs, typically adjacent to or within protected areas, documenting another human-related impact (Nayeri et al. 2022). Conversley, anecdotal evidence outside the literature search showed lynx killing adult wolves and pups at den sites in Belarus (Sidorovich 2022).

Indirect interactions were mainly studied by quantifying niche overlaps. Generally, apex predators avoided close encounters; for example, lynx with wolverines (*Gulo gulo*; López-Bao et al. 2016), but niche overlaps exist. Sympatric snow leopard (*Panthera uncia*) and lynx showed similar temporal niches (Nasanbat et al. 2021; Zhong et al. 2022), likely for prey stalking, with overlaps elevated during colder periods (Wang et al. 2025). However, lynx avoided sites with little shrub cover where snow leopard may occur (Byambasuren et al. 2024) and consumed more small mammals than the ungulate specialised snow leopard (Zhong et al. 2022; Cong et al. 2024), suggesting spatial and dietary partitioning. Spatial partitioning of both prey and predators can promote sympatry (May et al. 2008; Schmidt et al. 2009; Dyck et al. 2022). Temporal partitioning could also promote coexistence, with lynx more nocturnal or crepuscular (Heurich et al. 2014) and wolves more diurnal (Smith et al. 2024).

To date, little research has quantified how sympatry with other apex predators affects lynx fitness or populations. In Sweden, wolves recolonised a lynx inhabited area with no measurable impact on lynx den sites, home ranges, or juvenile survival despite sharing roe deer prey, suggesting minor competition effects (Wikenros et al. 2010). In some regions, lynx potentially avoid resource competition with wolves by specialising on hares, like in Türkiye (Mengüllüoğlu et al. 2018; Mengüllüoğlu et al. 2019). At biogeographical scales the lynx's dietary niche seems driven by ungulate availability rather than competition (Khorozyan and Heurich 2023a). As most large carnivores live at low densities and tend toward prey generality (Jędrzejewski et al. 2002; Khorozyan and Heurich 2023a), niche overlaps and lethal interactions appear avoidable. Russian literature, outside our search, suggests wolf abundance could negatively affect lynx abundance due to competition (Salkina and Eremin 2017).

Apex predator interactions seem to modulate the lynx's niche and potentially populations, but research has scarcely considered how these interactions affect lower trophic levels. That said, there was a synergistic consumptive effect on roe deer and red deer when lynx occurred alongside wolves (Melis et al. 2009;

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van Beeck Calkoen et al. 2023). Non-consumptive effects should arise from prey's perception of the landscape of fear, reflecting overlapping spatiotemporal risks from apex predators and humans (Lone et al. 2014; Gehr, Hofer, Pewsner, et al. 2018; Bonnot et al. 2020). For prey, human-related risks are more predictable and avoidable than lynx predation risk; human recreation is mostly during the daytime, hunting is seasonal, and roads are spatially discrete (Bonnot et al. 2013). This could dilute or overrule prey's responses to predators (Kuijper et al. 2016; van Beeck Calkoen et al. 2022). Alternatively, prey may not experience a benefit of heightening vigilance or altering foraging, compared to other predators or humans, because of lynx's ephemeral presence (Eccard et al. 2017), which would mean non-consumptive lynx effects are unaffected by predator interactions. So far, potential synergistic or antagonistic non-consumptive effects of apex predators on herbivores are unexplored.

When resources are scarce, competitors abundant or human disturbance reduces niche-space, competition among apex predators could increase (Smith et al. 2024). The lynx's diel activity cycles reflect its hunting strategy regardless of competitors, but lynx might shift spatial or dietary niche to avoid dominant stalking predators, potentially affecting prey. The lynx's spatial and dietary niche plasticity means it could function as a mesopredator or apex predator, depending on the predator guild. As discussed for consumptive effects, this could have consequences for lynx effects, yet how this may influence ecosystems remains unclear.

4.4 | Biodiversity Facilitation

Biodiversity facilitation was mainly documented as lynx provisioning of carrion resources to scavengers, including kleptoparasites. Besides the apex predator kleptoparasites discussed, prominent scavengers included mesopredators, like red fox (Kidawa and Kowalczyk 2011) and golden jackal (*Canis aureus*; Krofel et al. 2022), and numerous facultative scavengers like wild boar and crows (Selva et al. 2005). Though vertebrate scavengers are likely outcompeted by invertebrates in summer (Ray et al. 2014). In Poland, red fox ate more carrion during winter and spring when hares and rodents are scarce (Jędrzejewski and Jędrzejewska 1992). Similarly, after lynx recolonised southern Sweden, red fox consumed more roe deer (Helldin and Danielsson 2007), indicating lynx kills offer meaningful resources for mesopredators. In local studies, lynx kills attracted larger scavenging communities than ungulates that died of other causes (Selva and Fortuna 2007), potentially because predator kills were in better condition than other carrion (Selva et al. 2005). Whether this affects diversity or abundance of decomposers and scavengers is unknown, and no effect on vegetation has been detected (Teurlings et al. 2020).

Despite plausible pathways via top-down effects on prey, no conclusive link was documented between lynx functions and biodiversity. However, the evidence shows that lynx provide meaningful resources to scavengers and decomposers, which likely vary with lynx diet and species communities. Carrion provisioning by lynx has not been linked with the abundance, diversity, and function of carrion-visiting biota more broadly—despite their importance for the detritus cycle (Barton et al. 2013). Further, carrion provides habitat, nesting material, and secondary forage like maggots or fungi (e.g., Baruzzi et al. 2018).

4.5 | Disease and Pathogen Dynamics

Evidence that lynx selectively prey on weaker individuals was ambiguous, and no articles investigated implications for disease dynamics. For larger prey, like reindeer or red deer, lynx may select poorer-condition individuals (Haglund 1966; Okarma et al. 1997; Pedersen et al. 1999), while for roe deer, articles found no selection for condition (Okarma et al. 1997; Andersen et al. 2007). Potentially due to the size of reindeer and red deer relative to lynx. For ungulate population health regulation, selective predation of larger ungulates by lynx could improve herd health without affecting population growth, while for smaller ungulate species lynx remove frail individuals by chance, also contributing to herd health. For roe deer, lynx likely regulate disease prevalence more effectively than human hunters, because humans select prime individuals (Andersen et al. 2007).

How lynx and other species' scavenging affect pathogen transmission is unclear due to the complex interplay between environment, pathogens, and hosts. If the lynx supports scavenger populations (Khalil et al. 2014; Wikenros, Aronsson, et al. 2017), its presence could accelerate carrion removal, but this remains untested. Beyond the literature search, large carnivores feeding helps smaller scavengers access carrion by opening carcasses (Selva et al. 2003). In combination with their own scavenging (De Pelsmaeker et al. 2024), lynx could thereby shorten pathogen persistence in the landscape; however, scavenging also poses an infection risk (e.g., Iberian lynx, Tobajas et al. 2023).

By modulating prey and mesopredator abundances (Helldin et al. 2006; Melis et al. 2009, 2010; Pasanen-Mortensen et al. 2013; Andrén and Liberg 2015), which can be reservoirs of pathogens, lynx may indirectly influence vector-borne disease risk. For humans, livestock, and domestic animals, tick distribution and the prevalence of tick-borne pathogens are of particular interest. Research from Sweden shows human tick bites correlated with roe deer abundance (Jaenson et al. 2012). A second study found a correlation between roe deer and hare abundances and human tick-borne encephalitis, but no correlation with lynx abundance (Jaenson et al. 2018).

Wild-living lynx can also be a host or transmission vector in pathogen dynamics, with research reporting viral infections (Gregor et al. 2024), bacterial infections (Heiderich et al. 2024), parasitic infections (Szczęsna et al. 2008), and tick-borne zoonoses (Orkun 2022). Therefore, lynx could be part of disease transmission pathways, even as a definitive host (Scherrer et al. 2023), but their contribution is likely lower than that of higher density species.

Evidence of mechanisms, like reducing prey abundance, selective hunting and scavenging, makes a regulatory function for lynx in disease and pathogen dynamics plausible. Although lynx alone may not strongly impact red deer density (van Beeck Calkoen et al. 2023), selective predation might still contribute to herd health. From theory, we may expect lynx functions to

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have their largest impacts in low to moderately productive ecosystems (Holling 1959; Oksanen and Oksanen 2000). However, research linking lynx abundance to pathogen prevalence remains scarce and is complicated by lynx's divergent effects on prey and mesopredators. For humans, tick-borne diseases are among the most important wildlife diseases in Eurasia (Petney et al. 2012; Orkun et al. 2017; Gray et al. 2024) and the effects of lynx on herbivores and mesopredators mean we could expect cascading effects for tick-borne pathogens, context specific as with consumptive effects. Given the interconnected wellbeing of wildlife, domestic animals, and humans (Destoumieux-Garzón et al. 2018), lynx –as part of biodiversity– could potentially help reduce disease risk, but supporting evidence is missing.

5 | Socioeconomic Impacts of Lynx

The social dimensions of human-lynx interactions, including attitudes, perceptions, and preferences, were observed 26 times, and the valuation of costs and benefits was observed 24 times (Figure 3). A further 29 articles focused on depredation of domestic animals. These articles highlighted the potential impact of lynx on human stakeholders (mainly sheep farmers and reindeer herders; Khorozyan and Heurich 2023b), but they provided no information about potential socioeconomic consequences. We therefore excluded these 29 articles from this section. Half of the remaining articles came from Northern Europe and just eight were from Asia (11%).

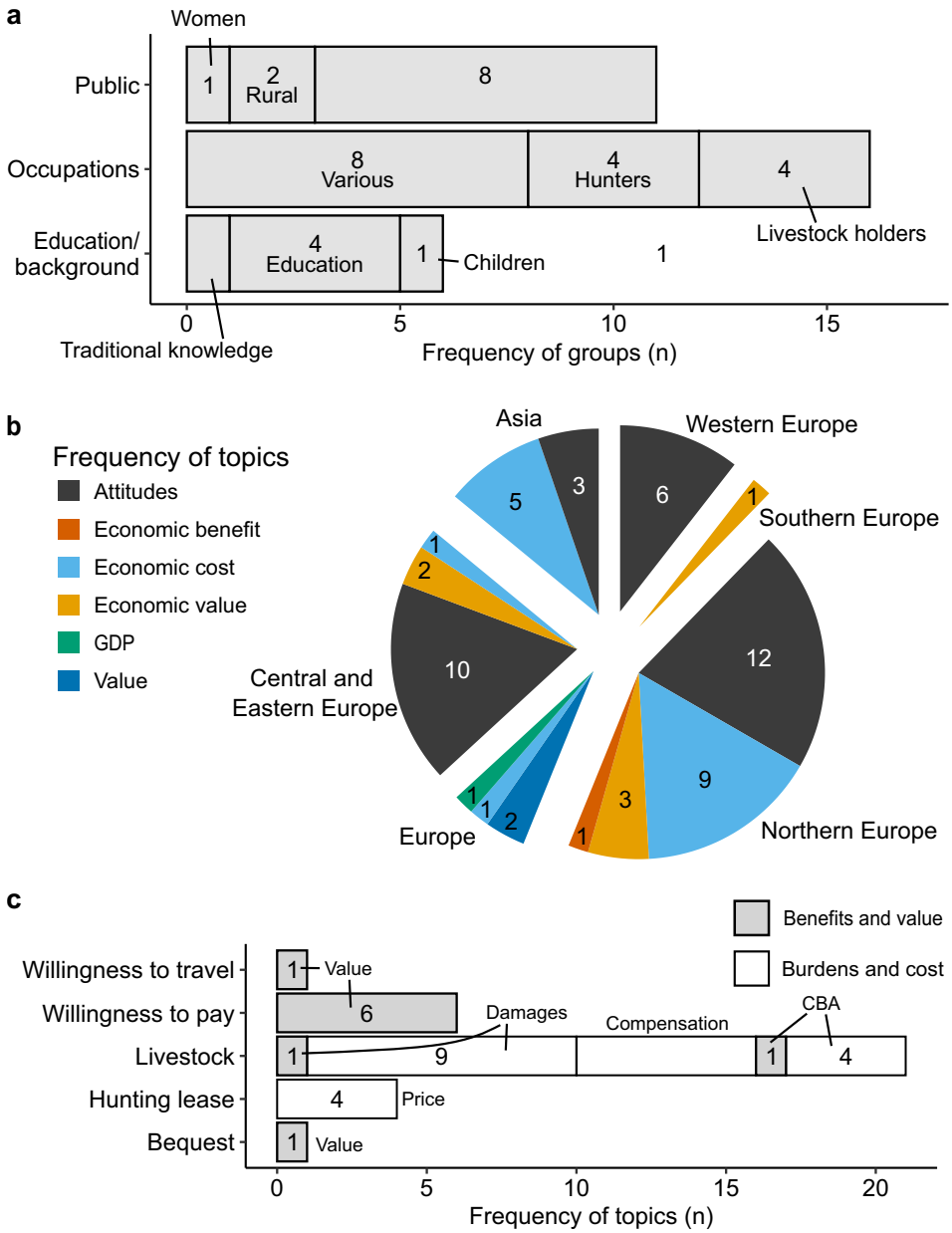


FIGURE 3 | Distribution of socioeconomic research observations across (a) respondents in attitude and perception surveys, (b) geographic regions (European regions after Publications Office of the European Union 2025) where GDP refers to Gross Domestic Product, and (c) impacted features, including the preference features "willingness to pay" for lynx, for example costs, or "willingness to travel", for example to lynx areas, and where CBA refers to Cost–Benefit Analysis. We assigned the region 'Europe' when two or more European regions were studied.

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5.1 | Costs and Burdens for Society

Lynx are known to prey on livestock, like domestic sheep (Odden et al. 2002) or reindeer (Skonhoft et al. 2017), losses widely reported as economic damage. The economic impacts on livestock holders are often modulated by compensation (Tveraa et al. 2014; Chen et al. 2016; Kaim et al. 2025). Lynx depredation may be a smaller economic factor for livestock holders than others, such as consumer demand (Kovařík et al. 2014). Yet in arctic Fennoscandia, lynx predation on semi-domesticated reindeer puts lynx occurrence directly at odds with herders' livelihoods (Mattisson, Odden, et al. 2011). Furthermore, depredation can affect emotional bonds, cultural continuity, and social pride, impacts that are difficult to address with financial reimbursements alone (Liukkonen et al. 2009).

The perceived competition for game, especially roe deer, between human hunters and lynx is common in Europe (Liukkonen et al. 2009; Lüchtrath and Schraml 2015; Smolko et al. 2025). In Sweden, higher lynx abundance even reduces hunting ground rental values (Lozano et al. 2021). Hunters are not typically compensated for game reduction or damage to their sociocultural identity (Lüchtrath and Schraml 2015) but in grey literature hunters' burden in some areas is offset with flat-rate payments for lynx presence (Luchsprojekt Harz, n.d.).

Negative attitudes toward lynx often stemmed from concerns about personal safety (Pohja-Mykrä and Kurki 2014), potential or experienced attacks on pets or domestic animals (Whiley and Tzanopoulos 2024), or dominating views of nature (Kaltenborn et al. 1999). Equally, negative attitudes may develop from conflicts with lynx management or reintroductions (Liukkonen et al. 2009; Lüchtrath and Schraml 2015; Whiley et al. 2026), or through misinformed association with other predators (Trajçe et al. 2019). We found scant research on public perceptions of the lynx across its Asian distribution, but in rural Pakistan views toward lynx were negative due to potential risk to poultry (Hameed et al. 2022). The lynx's "invisibility" seems to contribute to people's knowledge gaps and misconceptions (Lescureux and Linnell 2010; Lescureux et al. 2011).

Outside the literature search, Khorozyan and Heurich (2023b)'s review highlighted that impacts on livestock holders depended mainly on practices like grazing animals in or near forests. Between 2005 and 2012 in Europe, the compensation cost incurred per lynx per year averaged €700 (Bautista et al. 2019). Investment to mitigate livestock damages, in funding, education, or materials, can reduce subsequent compensation claims, but represents a significant upfront cost (Khorozyan and Waltert 2019). However, where other large carnivores also occur, damages from lynx tend to be low as livestock protection methods target these more conspicuous threats (Rigg et al. 2011). Notably, in northern Fennoscandia, lynx conservation has large impacts on the culture, identity, and livelihoods of indigenous Sámi people because lynx occurrence there is contingent on the depredation of reindeer herds (Axelsson-Linkowski et al. 2020; Kaiser et al. 2025). Despite this, negative sentiments of the Sámi toward lynx often stem more from the accumulation of external factors that erode their autonomy than from predators alone (Torp 2001).

5.2 | Benefits and Value for Society

A positive economic impact of lynx livestock depredation was observed due to a peculiarity of compensation payments to reindeer herders (Skonhoft et al. 2017). Lynx predation primarily affects semi-domestic reindeer that would otherwise succumb to other mortality causes (i.e., compensatory mortality, see e.g., Tveraa et al. 2003), which arguably incentivises keeping herds larger than ecologically appropriate because the risks are offset by compensation (Næss et al. 2011). Several articles attempted to value lynx with questionnaire surveys. Typically, respondents who were willing to pay for lynx conservation had socioeconomic characteristics related to positive lynx attitudes (Ericsson et al. 2007). There was also a greater willingness to pay for lynx than for wolves (Broberg and Brännlund 2008) and for management that conservatively maintained lynx populations (Bartczak and Meyerhoff 2013; Bartczak et al. 2016; Notaro and Grilli 2022). Respondents' fear indicated their willingness to pay for governmental policies that covered lynx costs (Johansson et al. 2012). Beyond paying impact-related costs, a study in Norway and Poland showed respondents would travel further for recreation in forests occupied by lynx, but preferred avoiding bears and wolves (Giergiczny et al. 2022). Where the lynx is a game species, selling hunting licences provides income to landowners or governments, however, any increase in hunting lease price associated with higher lynx abundance is likely outweighed by the decrease due to lower attractiveness for ungulate hunting (Lozano Galindez et al. 2020).

The lynx receives wide acceptance, especially compared to other apex predators (Kleiven et al. 2004; Trajçe et al. 2019; Smolko et al. 2025) and irrespective of Gross Domestic Product (Kojola et al. 2018), garnering positive public attitudes both inside (Bath et al. 2008; Schlegel and Rupf 2010; Whiley and Tzanopoulos 2024) and outside (Van Heel et al. 2017; Bavin et al. 2023; Pearson and Carpenter 2025) its distribution. Many survey respondents believe lynx have intrinsic value (Karlsson and Sjöström 2008; Krofel et al. 2025; Smolko et al. 2025), which is difficult to quantify monetarily. Knowledge is a key indicator of attitudes and perceptions toward lynx (Dieser and Bogner 2019). Respondents with game hunting, nature, and outdoor-pursuit interests, or higher education, tend to be more positive (Røskaft et al. 2003). In some groups, there is a strong affinity for lynx (Schlegel and Rupf 2010), reflected in some people's preference for recreation in lynx-inhabited forests (Giergiczny et al. 2022) or for trophy hunting of lynx (Fischer et al. 2013).

Outside the literature search, a lynx reintroduction in Germany was shown to generate over €8 million in tourism revenue annually (White et al. 2016). Several sectors potentially benefitting from ecosystem functions of lynx were not investigated. For example, those incurring personal and financial costs related to herbivores, like agriculture and silviculture (Valente et al. 2020; Hardalau et al. 2024), or due to wildlife-vehicle collisions (Mrtka and Borkovcová 2013; Gren and Jägerbrand 2019; Linnell et al. 2020), could benefit from top-down limitation of herbivore abundance. Further, many ecosystem components, like biodiversity, are irreplaceable natural capital 'assets', which makes their monetary valuation difficult (Admiraal et al. 2013). Besides economics, the cultural significance of the lynx was not evaluated, yet it symbolises intelligence (Schenda 1995) and has

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left its mark across European cultural history (Malkmus and Schalansky 2022), though likely to a lesser extent than wolves and bears.

The economic costs of lynx are well described, in terms of livestock depredation, whereas the social burdens are evidenced but difficult to quantify. The same is true for positive socioeconomic impacts of lynx, which have been reported but rarely quantified. The economic value of lynx, in terms of savings across various sectors, could be important to provide arguments for ecosystem restoration because intrinsic value, which depends on individual perceptions, is less quantifiable. However, it should be noted that ecosystem services often come with reciprocal 'disservices' for other stakeholders; for example, lower deer density may benefit silviculture while negatively impacting hunters. Although lynx likely provide benefits to human societies, the local context is important to understand lynx's full socioeconomic and cultural value, which across most of lynx's distribution is unstudied.

5.3 | Flagship, Umbrella, and Indicator Roles

In this section, we categorised nine articles that attempted to assess the efficacy of lynx in fulfilling the role of a flagship ($n = 2$), umbrella ($n = 2$), or indicator species ($n = 7$).

Although the lynx was often described as a flagship species within all categories of the literature (e.g., Niedziałkowska et al. 2006; Breitenmoser et al. 2008), its efficacy was rarely tested. In a comparison of potential flagship species among Swiss school attendees, the lynx was noted for its general popularity, which would make it a good flagship, but attendees of agricultural schools had greater reservations (Schlegel and Rupf 2010). Similarly, Linnell et al. (2000) argued large carnivores, including lynx, were inappropriate flagships in Scandinavia because hunters and livestock holders can have very negative attitudes toward them, potentially harming conservation more broadly. From the wider socioeconomic literature, others agree the conflict potential of apex predators makes them prone to becoming negative conservation symbols among some stakeholders (Lüchtrath and Schraml 2015). Though, in contrast, Trajçe et al. (2019) argued that lynx should be handled distinctly from wolves and bears in conservation strategies because the lynx makes a less controversial focal species.

Looking beyond the literature search, lynx conservation in Europe has attracted substantial financial support. Since 1992, EU LIFE projects matching the phrase "*Lynx lynx*" have received approx. €59 million, whereas projects matching the phrase "*Bolbelasmus unicornis*", for the endangered European earth-borer beetle (Juřena 2022), received around 5% of this (European Commission 2025). Corresponding Web of Science searches (February 2026) returned 4699 publications for lynx and just six for the beetle. Although attitudes do vary (Linnell et al. 2000; Bath et al. 2008; Whiley and Tzanopoulos 2024), the infrequency of attacks on livestock and pets, as well as all but non-existent risk to humans, likely shapes positive perceptions, making lynx a suitable flagship in many countries. Together, these factors tend to show the lynx can serve as a flagship species, but a true assessment of its efficacy compared to other flagships remains outstanding.

The umbrella role of lynx—linked to possible biodiversity gains via trophic cascades and resource facilitation—was rarely explored. Some authors argue that the lynx has relatively simple ecological requirements, making its conservation less complex than broader biodiversity goals (Linnell et al. 2000). Rozylowicz et al. (2011) found that in regions with weak forest regulation or few protected areas, conserving large carnivore habitat would support vertebrate biodiversity and landscape connectivity—benefitting 55% of bird and 80% of mammal species in Romania. Evidence of the lynx as a conventional indicator species was also scarce and several ($n = 4$) were rather related to observations of bioindication (e.g., Gnamuš et al. 2000). In Fennoscandia where they are hunted, the lynx was judged a poor indicator due to its tolerance of commercial forests and the expense of monitoring (Linnell et al. 2000) and because lynx densities were not necessarily higher in protected areas (Terraube et al. 2020). Although intact large-mammal faunas can indicate human impacts (Morrison et al. 2007), the indicator value of carnivore populations for biodiversity is confounded by governance and management factors and may instead indicate societal acceptance (Linnell et al. 2001; Terraube et al. 2020).

Outside the literature search, protecting ecological processes is a key strategy in conservation (Bennett et al. 2009); therefore, lynx conservation could be an umbrella measure for wider ecosystem protection. Lynx distribution reflects large, forested areas, suggesting lynx may indicate habitat extent, fragmentation, and connectivity. For instance, in Scandinavia, habitat connectivity was sufficient for lynx to recolonise without assistance (Hemmingmoore 2023), whereas this has not been the case elsewhere in Europe (Chapron et al. 2014). Lynx could be an indicator of connectivity, albeit confounded by acceptance and tolerance. Despite contra-arguments and lacking quantitative research, lynx traits could befit an umbrella or indicator species. Lynxes prefer habitats with lower human disturbances (Ripari et al. 2022) and rest and hunt in heterogenous habitats (Belotti et al. 2013; Hočevar et al. 2021), indicative factors for many taxa (Tews et al. 2004; Heidrich et al. 2023). Further, the lynx serves as a flagship through visibility and funding, at least in parts of Europe, though the impact of "lynx money" on biodiversity and ecosystem functioning is not clear.

6 | Conclusions

Knowledge of lynx ecosystem roles is growing, but the evidence remains strongly concentrated on direct trophic interactions, leaving broader ecosystem effects poorly resolved. Studies show lynx *can* generate cascading consumptive effects in some ecosystems despite human influences on top-down and bottom-up processes (Elmhagen et al. 2010; Angelstam et al. 2017). Research on non-consumptive trophic cascades has shown that some herbivore prey species reduce their foraging intensity when exposed to immediate lynx predation risk (Rosell and Czech 2000; van Beeck Calkoen et al. 2021; van Beeck Calkoen, Di Nicola, et al. 2026). But evidence that consumptive and nonconsumptive effects translate into longer-term changes in forest dynamics is currently lacking (Bubnicki et al. 2019; van Beeck Calkoen et al. 2022). Where evidence is weak or inconclusive, the competing but not exclusive, explanations remain: some apex predator effects may have comparatively small impacts compared to

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other ecosystem drivers (Mech 2012; Alston et al. 2019; Hobbs et al. 2024), or, given the complexity and variation in ecosystems and the difficulty in establishing robust counterfactuals at scale (e.g., Wilmers et al. 2025), the research-base for lynx is still inadequate (Table 1). Nonetheless, uncertainty of the strength of effects, especially cascading effects, should not undermine the case for conserving or restoring large carnivores (e.g., Vucetich et al. 2015). Indeed, the importance of large carnivore conservation and restoration may be considered distinct from the cascading impacts of large carnivore conservation and restoration (Allen et al. 2017; Alston et al. 2019).

Socioeconomic research has similarly provided an incomplete picture. Although research has focused on economic costs, or disservices, of lynx, potential ecosystem service benefits remain understudied (Rode et al. 2021). At the same time, many people attribute substantial intrinsic value to the presence and persistence of lynx (Karlsson and Sjöström 2008; Krofel et al. 2025). Roles in biodiversity facilitation and disease and pathogen dynamics remain understudied and may be important for ecosystem resilience. Likewise, the frequently invoked roles of lynx in conservation as a flagship, umbrella, or indicator species were rarely quantitatively evaluated.

Globally, the state of nature and biodiversity is being eroded (WWF 2024), reducing ecosystem resilience and the natural insurance this offers (Folke et al. 1996; Yachi and Loreau 1999). The recovery of lynx therefore offers opportunities not only for species conservation but also for restoring ecological interactions in human-modified ecosystems. However, the magnitude and context dependence of these effects must be established empirically rather than inferred from other large-carnivore systems. It is important to revisit popularised assumptions (Mech 2012; Alston et al. 2019; Hobbs et al. 2024), including expectations of widespread trophic cascades, to ensure restoration arguments are transparent and evidence-based; at the same time, the absence of evidence should not be interpreted as evidence of absence, because many proposed lynx functions have simply not yet been tested at appropriate spatial and temporal scales (Tossens et al. 2025).

In this review we attempted to qualitatively assess the hypothesised impacts of apex predators for lynx, drawing on mixed evidence across short- and long-term studies that applied various approaches, including telemetry, hunting bags, snow tracking, camera trapping, and even social dimensions research, on spatial scales varying from several kilometres to continents. Although we must acknowledge this mix of evidence precluded a quantitative assessment and carries limitations (Allen et al. 2017), it can also provide motivation to tackle these questions systematically. Future progress will require interdisciplinary approaches that integrate ecological and socioeconomic perspectives, long-term monitoring, and comparative studies across ecological gradients and regions. Ongoing recolonisation and translocation programmes provide valuable natural experiments to test how lynx influence ecosystems under different environmental and social conditions (Andrén and Liberg 2024; Kuijper et al. 2024; Whiley and Tzanopoulos 2024). Attention should be given to poorly studied parts of the species' range, especially Asia, and to linking documented effects on prey behaviour and populations to consequences for biodiversity and ecosystem functioning. Such research would allow the ecological and societal roles attributed to lynx to be distinguished more clearly between those supported by evidence, those that are context dependent, and those that remain assumptions.

Author Contributions

Joe Premier: conceptualization, methodology, data curation, investigation, visualization, project administration, writing – original draft, writing – review and editing. **Deborah Brady:** conceptualization, methodology, supervision, writing – review and editing, project administration, funding acquisition, writing – original draft. **Samantha Cartwright:** conceptualization, writing – original draft, writing – review and editing. **Suzanne T. S. van Beeck Calkoen:** writing – review and editing, writing – original draft. **Nicolas De Pelsmaeker:** writing – original draft, writing – review and editing. **Amelia Holmes:** writing – original draft, writing – review and editing. **Eva Sanchez Arribas:** data curation, writing – review and editing, methodology. **Adam F. Smith:** writing – original draft, writing – review and editing. **Nadège C. Bonnot:** writing – review and editing. **Ian Convery:** writing – review and editing. **Nina Gerber:** writing – review and editing. **Dries P. J. Kuijper:** writing – review and editing. **Deniz Mengüllüoğlu:** writing – review and editing. **Axel Moehrenschlager:** writing – review and editing. **Craig Shuttleworth:** writing – review and editing. **Faye Whiley:** writing – review and editing. **Rok Cerne:** writing – review and editing. **Bart Donato:** writing – review and editing. **Sheng Li:** writing – review and editing. **Marco Heurich:** conceptualization, supervision, writing – review and editing, funding acquisition, project administration.

Acknowledgements

Open Access funding enabled and organized by Projekt DEAL.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study are available in the Supporting Information of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** mam70049-sup-0001-DataS1.xlsx.

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