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PERSPECTIVE

Harnessing iEcology data to uncover invasive species behaviour

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Abstract

1. Invasive animal species threaten ecosystems, biodiversity and human livelihoods. Behavioural traits such as boldness, exploratory tendencies, learning ability and social interactions are known to influence invasion success. Yet these behavioural traits remain underexplored due to challenges in observing behaviour across large spatial and temporal scales.
2. The emerging field of iEcology—studying ecology using digital data such as online photos, videos, sounds and text, generated for other purposes—offers a novel and scalable approach for investigating invasive species behaviour.
3. Here, we demonstrate the application of iEcology to uncover novel insights into the behaviour of invasive species, such as dominance over the native species, interactions with native species or increased tolerance to humans, all critical for assessing species' invasion potential and management. We also discuss challenges of applying iEcology to studying the behaviour of invasive animals and highlight the need for careful validation and complementary methods. Finally, we highlight ways and provide a workflow to maximise the potential of iEcology for advancing the study of invasive species behaviour.
4. We advocate for integrating iEcology into invasion science to advance our understanding of animal behaviours accompanying invasion success and ultimately to support the monitoring, management and mitigation strategies of biological invasions. We argue that iEcology is best viewed as a complementary tool that enriches traditional behavioural ecology and invasion biology, enabling rapid, accessible insights into one of the most urgent ecological issues of our time.

For affiliations refer to page 1028.

KEYWORDS
animal behaviour, behavioural ecology, digital data, ecological monitoring, iEcology, invasive species

1 | BEHAVIOUR AND INVASION SUCCESS

Biological invasions currently represent one of the greatest threats to biodiversity, ecosystems and human livelihoods (Jaureguiberry et al., 2022; Pyšek, Hulme, et al., 2020; Roy et al., 2024). Alien animal invaders have already driven many native species and populations towards extinction through multiple mechanisms such as predation, competition and habitat alteration (Bellard et al., 2016; Doherty et al., 2016; Mack et al., 2000). Successful invasions are driven by a combination of ecological and socioeconomic factors, including propagule pressure, the characteristics of the recipient ecosystems (such as habitat characteristics and climatic suitability) and the invasive species traits (Bates & Bertelsmeier, 2021; Pyšek, Bacher, et al., 2020).

The role of life history, morphology and physiology in driving animal invasion success has been relatively well studied, particularly in vertebrates (Capellini et al., 2015; Hayes & Barry, 2008; Jeschke & Strayer, 2006). Also, the role of animal behaviour is increasingly recognised as an important driver of invasion success (Holway & Suarez, 1999; Sol & Maspons, 2016). Behavioural traits such as aggressiveness, boldness, dominance and cognitive flexibility, as well as naïveté of both native and invasive species, can potentially play an important role in a species' ability to establish and spread in novel environments (Anton et al., 2020; Carere & Gherardi, 2013; Chapple et al., 2012). Invasive alien species also often show rapid behavioural changes that help them survive and spread in novel environments (Yosef et al., 2019), for example, by evading human exploitation (Diquelou & Griffin, 2020). Similarly, native species affected by biological invasions may undergo behavioural shifts in response to novel predation, competition or habitat modification (Ruland & Jeschke, 2020).

Compared to many life history, morphological and physiological traits, animal behaviour is often difficult to define and measure, especially across large spatial and temporal scales. To date, our knowledge of invasive animal behaviour is heavily biased towards some taxa (e.g. birds and mammals) and behavioural traits (Holway & Suarez, 1999; Ruland & Jeschke, 2020; Sol & Maspons, 2016). This limits our ability to fully understand and generalise the influence of behavioural traits on animal invasion success. iEcology ('internet Ecology')—the study of ecological patterns, processes and interactions using digital online data that were originally not generated to address the focal ecological question, and lie outside of peer-reviewed literature, traditional ecological datasets or scientific reports (Jarić et al., 2021; Jarić, Correia, et al., 2020; Jarić, Roll, et al., 2020) (Table 1) can help fill this gap. Here, we highlight the opportunities and limitations, and present a workflow to utilise the potential of iEcology to study invasive species behaviour. The aim of this perspective is not to comprehensively review the behavioural traits influencing invasion success in animals, but to acknowledge the role of behaviour in the invasion process and discuss the current landscape and future potential of iEcology in understanding animal invasions.

2 | BEHAVIOURAL iECOLOGY OF INVASIVE SPECIES

iEcology presents a unique opportunity to investigate behaviour of invasive species at an unprecedented spatial and temporal scale. iEcology primarily leverages online data sources—such as photos, videos, sounds, texts and online activity from user-driven non-specialist online platforms (e.g. social media). However, it can also repurpose digital data generated initially for scientific purposes (e.g. from citizen science databases) unrelated to the specific questions being addressed. By doing so, iEcology complements conventional time-consuming and small-scale field and experimental ecological research with a potential for minimising costs and effort (Jarić, Correia, et al., 2020; Jarić, Roll, et al., 2020; Pernat et al., 2024; Vardi et al., 2024). Additionally, iEcology can provide insights into regions where traditional ecological monitoring is underdeveloped due to financial or logistical constraints, especially where human activities such as tourism frequently generate relevant digital data (Hart et al., 2025). However, online data has so far been rarely used to study animal behaviour, representing only ~5% of available iEcology studies by 2020 (Jarić, Correia, et al., 2020), with only a recent increase (Vardi et al., 2024).

iEcology allows analyses of foraging, feeding, movement patterns and dynamics of intraspecific (e.g. social and sexual behaviour) and interspecific interactions (e.g. competition, predation and interactions with humans) in animals across broad geographic ranges (Vardi et al., 2024), a facet that we refer to as behavioural iEcology (Table 1). Particularly, online photos and videos have already been used to document previously unknown or rare behaviours and interactions between and within species. Examples include tool use in parrots (Psittaciformes) (Bastos et al., 2025), predator–prey interactions between diurnal birds and bats (Mikula et al., 2016), cleaning of sika deer (*Cervus nippon*) by large-billed crows (*Corvus macrorhynchos*) (Tomita & Matsuyama, 2025), the use of plastic shells by terrestrial hermit crabs (Coenobitidae) (Jagiello et al., 2024) and thanatological (death-related) behaviour in Asian elephants (*Elephas maximus*) (Pokharel et al., 2022). Such insights may be particularly valuable for identifying potential mechanisms and impacts of animal invasions, highlighting the importance of identifying tools that enable early detection of invasion-related behaviours to support effective and timely management.

TABLE 1 A glossary of key terms used or contextually relevant to this article.

Term	Definition
iEcology	A discipline focused on studying ecological patterns, processes and interactions using digital online content and activity (e.g. photos, videos, sounds, text and user interactions) that were not originally collected to address the focal ecological question, and lie outside of peer-reviewed literature, traditional ecological datasets or scientific reports (Jarić, Correia, et al., 2020)
Invasive iEcology	A subdiscipline of iEcology focused on the ecological patterns, processes and impacts associated with invasive non-native species across their native and introduced ranges, using iEcology data (Jarić et al., 2021)
Behavioural iEcology	A subdiscipline of iEcology focused on studying animal behavioural patterns, adaptations and interactions (or lack thereof) across ecological contexts, using iEcology data
Invasive behavioural iEcology	A subdiscipline of behavioural iEcology focused on the behavioural patterns, adaptations and interactions of invasive species in both native and non-native ranges, as well as the behavioural responses of native species to invasive species
Biological invasion	The human-driven introduction of a species from its original range to a new location where it reproduces rapidly and causes harm to local ecosystems and communities (Richardson et al., 2000)
Alien species	Species introduced by humans, intentionally or unintentionally, into areas outside their native distribution (Pyšek et al., 2004).
Invasive alien species	Alien species that establish self-sustaining populations, spread widely and cause ecological, economic or social harm (Pyšek, Bacher, et al., 2020; Richardson et al., 2000)
Non-invasive alien species	Alien species that do not spread widely and therefore typically do not cause significant ecological impact (Pyšek et al., 2004)

Indeed, online data has proven to be useful for monitoring the spread and distribution of invasive species, studying their life history and phenology and identifying novel biotic interactions (Jarić et al., 2021). Despite the increasing availability of online data, we lack studies that have directly applied iEcology to examine behavioural patterns of invasive species in their native and non-native ranges, or compared invasive species behaviours to their native counterparts—an approach we refer to as invasive behavioural iEcology (Table 1; Methods S1). Two exceptions are the analysis of YouTube videos on behavioural differences between native red (*Sciurus vulgaris*) and invasive grey (*S. carolinensis*) squirrels in Europe (Jagiello et al., 2019) and invasive walking catfish (*Clarias batrachus*) in Florida (US) (Bressman et al., 2020) (Figure 1). Grey squirrels displayed more aggressive behaviour, were more vocal, and interacted more frequently with humans than red squirrels. Walking catfish—known for its ability to breathe atmospheric air and move on land—showed amphibious behaviour most frequently during or after heavy summer rains.

3 | THE POTENTIAL OF iECOLOGY IN UNDERSTANDING THE INVASION PROCESS

Three particular aspects of invasion biology can benefit from iEcology: (1) comparing invasive alien species' behaviour between their native and invasive populations, (2) tracking behavioural shifts throughout the invasion process and (3) documenting interspecific interactions to identify behavioural traits that give invasive species an advantage over native ones, thereby predisposing certain taxa to invasion success (Holway & Suarez, 1999; Sol & Maspons, 2016). Below, we discuss these major points in greater detail.

1. One of the key advantages of iEcology is the opportunity to compare invasive species behaviour in their native and non-native ranges. Online records could allow researchers to track population changes in behavioural traits across different geographical contexts. This approach helps to identify behavioural traits facilitating invasion success and whether behavioural patterns

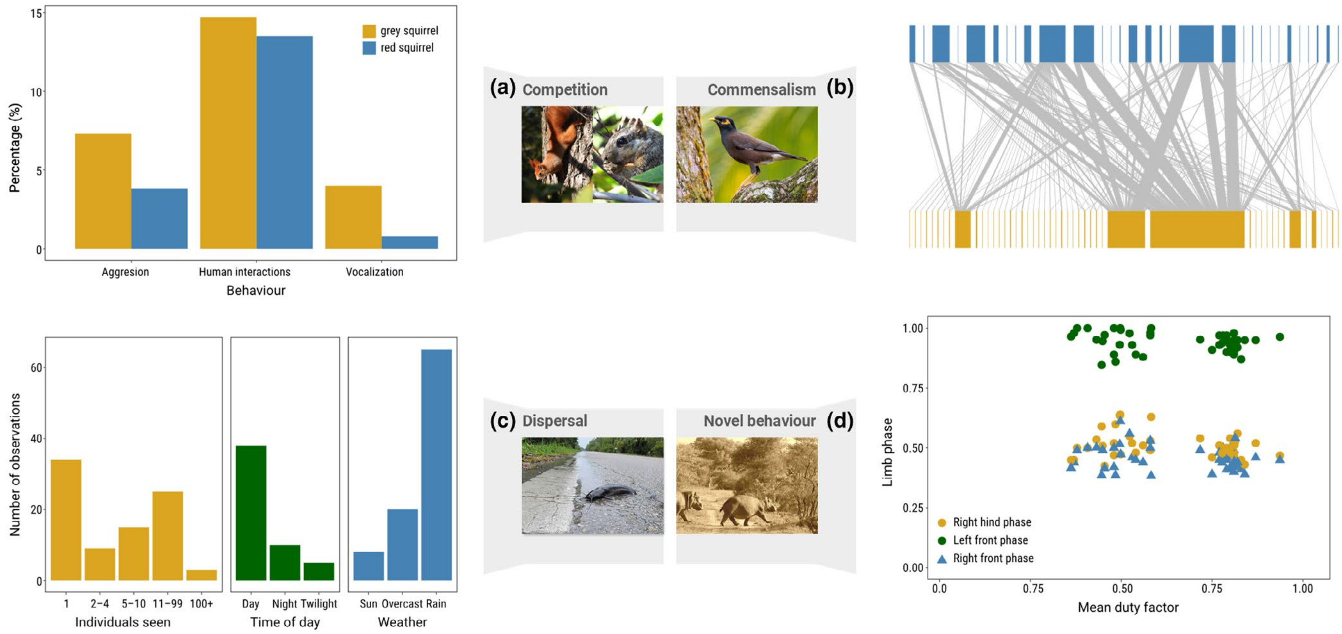

FIGURE 1 Examples of studies using digital data to document behaviours of invasive animal species, either directly or incidentally. (a) Invasive grey squirrels (*Sciurus carolinensis*) were more aggressive, more vocal and interacted more often with humans than native red squirrels (*S. vulgaris*; photo) in urban settings, based on YouTube videos (photo credit: Peter Mikula; side panel adapted from Jagiello et al., 2019). (b) A study on African bird–mammal associations using online photographs from Google Images found an invasive common myna (*Acridotheres tristis*) (on photo) perching on a native blue wildebeest (*Connochaetes taurinus*), an incidental but previously undocumented interactions (photo credit: Jan Grünwald; adapted from Mikula et al., 2018). (c) Online videos of invasive walking catfish (*Clarias batrachus*) captured previously unknown terrestrial movements of both solitary individuals and large groups, primarily after floods, in urban areas during the rainy season, that may facilitate this species spread (photo credit: Shawn Clem/Audubon Florida; adapted from Bressman et al., 2020). (d) Online video analysis revealed short aerial phases during fast locomotion in common hippopotamus (*Hippopotamus amphibius*)—a novel finding in this African species now invasive in Colombia (photo under CC0 Public Domain Dedication; original photo available at https://pixabay.com/de/photos/nilpferde-afrika-safari-tier-277432/; adapted from Hutchinson & Pringle, 2024).

in the non-native range result from species evolutionary history (i.e. if they 'pre-existed'), phenotypic plasticity or evolutionary change in response to new environments (Carere & Gherardi, 2013; Chapple et al., 2012; Holway & Suarez, 1999).

2. The ability to detect the impact of invasive species behaviour throughout the invasion process, especially at an early stage, is another potential key application of iEcology. By analysing online data, researchers can identify within-species changes in sexual and breeding behaviours, including shifts in mating strategies and reproductive potential, which may facilitate population growth and spread, eventually aggravating their impacts. iEcology may also reveal how invasive species adjust their foraging techniques, including shifts in opportunistic feeding, food hoarding or scavenging, monopolising resources, displacing native competitors and disrupting invaded ecosystems. iEcology approaches can also be leveraged to document rare or previously undocumented behaviours of invasive species that would otherwise be difficult to detect through traditional approaches. Such rarities include unexpected predation events, unusual habitat use and novel escape and dispersal mechanisms. To illustrate, in New Zealand, it was unknown that brush-tailed possums (*Trichosurus vulpecula*) were preying on native birds' nests until the 1990s, that is more than 100 years after the first introduction. This discovery was made through time-lapse video cameras (Brown et al., 1993). Nowadays, a large part of the human population carries smartphones equipped with cameras and can easily share photos and videos across online platforms, making these discoveries much more accessible.
3. iEcology can also shed light on interspecific interactions involving invasive species, including interactions with native fauna, other invasive species and humans. These interactions may involve reduced fear responses towards humans, such as increased tolerance of urban environments (Jagiello et al., 2019), use of anthropogenic resources (Le Louarn et al., 2016) and active feeding by humans (Fidino et al., 2018) or behavioural mechanisms that contribute to ecological dominance over the native species, such as greater aggression, boldness or learning capabilities (Bensky & Bell, 2022; Chapple et al., 2012; Sol et al., 2002). Understanding such interactions can help identify behavioural traits that give invasive species a competitive advantage over native ones and predisposing certain taxa to invasion success. Although such interactions may initially appear benign, they can foreshadow further spread and emerging conflicts, including dominance over native species, disease transmission to native wildlife and humans, hybridisation, traffic collisions (Ballari & Barrios-García, 2022; Medina et al., 2014) and nuisance behaviours such as crop raiding and competition with domestic animals. This knowledge also

enables risk assessment of currently non-invasive species with high invasive potential, particularly under ongoing global environmental change and increased human-mediated species introductions, providing critical information for wildlife management. Interestingly, some of the most impactful invasive species, including cats, rats, mice and pigs, remain underrepresented in iEcology studies. This may reflect the fact that they are already well studied through traditional approaches. Yet their widespread online presence offers underused opportunities to explore behavioural patterns and interactions at broader spatial and temporal scales.

Importantly, the iEcology approach is best viewed as complementary to, rather than a replacement of traditional ecological methods, enriching rather than substituting the foundations built by conventional research.

4 | iECOLOGY DATA AND METHODS FOR INVASIVE SPECIES BEHAVIOUR

By integrating large-scale, potentially near real-time, online data into invasion science, iEcology offers a powerful, cost-effective tool for detecting, monitoring and managing invasive species, including their behaviour. For example, iEcology enables the capture of behavioural changes and patterns, interaction dynamics and novel interactions through, for example, (i) photographs where behaviour can be inferred from posture or prey presence, (ii) online videos that display aggression, foraging or breeding and (iii) accompanied text cues (e.g. author captions and comments) enhanced through social media data mining (e.g. recording captions and forum posts), photo- and video-platforms analytics, text-based web-search queries and open data repositories scraping (Jarić, Correia, et al., 2020; Pernat et al., 2024).

Overlooked yet ecologically relevant information unintentionally captured in photos, videos, audio recordings or texts (Pernat et al., 2024) appears in user-driven non-specialist online platforms such as social media (e.g. Instagram, Facebook, TikTok, X), content-sharing services (e.g. YouTube and Flickr), publicly accessible surveillance feeds (e.g. live-streaming wildlife cameras), web forums, news portals, citizen science repositories (e.g. eBird or iNaturalist) and their observation-linked media. Such sources could be potentially harvested automatically with emerging computer vision tools, recently able to parse also video (Chan et al., 2025). We found several examples where authors mined these data sources to investigate the behaviour of species that are invasive in parts of their range, but without explicitly framing their analyses within an invasion context, including studies on opportunistic feeding strategies (Hernandez et al., 2019; Miranda et al., 2016), novel commensal associations in non-native ecosystems (Mikula et al., 2018), unexpected locomotor modes or physical activity levels (Hutchinson & Pringle, 2024) and human–wildlife conflict (Miranda et al., 2016) (Figure 1).

To support researchers aiming to adopt iEcology approaches for behavioural invasion studies, we outline a schematic workflow illustrating key steps in extracting, processing and applying digital data (Figure 2; Table S1). We move from general steps such as defining research goals, selecting relevant data sources and harvesting digital content via searches, scraping or API access to stages involving data cleaning and filtering, standardising metadata and annotating behaviours, either manually or using automated tools. These steps feed into downstream behavioural analysis, interpretation and integration of results into broader ecological models or management actions. While simplified, this workflow provides practical guidance for navigating the use of diverse digital data types in invasive behavioural iEcology. This flexible framework is applicable across multiple data types and taxa, and we encourage readers to consult complementary protocols for data mining, secondary data processing, automated classification or good practice to tackle privacy issues and ethical use (Chan et al., 2025; Ghermandi & Sinclair, 2019; Jarić, Roll, et al., 2020; Pernat et al., 2024).

5 | CHALLENGES

Despite the enormous potential of iEcology in studying invasive animal behaviour, we highlight four key challenges of using this approach.

1. Like any other biodiversity data, digital data can be severely biased (Kosmala et al., 2016). Certain invasive species are more frequently recorded due to their visibility, appeal or cultural relevance, and records could be concentrated in urban areas, wealthier regions and daylight hours (La Sorte et al., 2024; Thomsen et al., 2014). Highly visible or dramatic behaviours—such as predation or courtship—also tend to be overrepresented (Nanni et al., 2020). In the invasion context, for example, a taxon that is novel, charismatic or perceived as problematic can attract disproportionate online attention in its invaded range, whereas the same species may be underreported in its native range.
2. Cultural and linguistic differences further shape the types of behaviours and species represented and accessible in online space, influencing both data availability and synthesis (Amano & Berdejo-Espinola, 2025; Qiao et al., 2023). Such biases can be especially pronounced when a species' native range lies in regions with different dominant languages, social media platforms or levels of internet access than its invaded range, complicating cross-range comparisons.
3. Variable image and video quality, along with incomplete metadata (e.g. timestamps, geolocations, species ID and user-provided context), complicate large-scale behavioural analyses (Crandall et al., 2023; Lürig et al., 2021), although the quality of publicly available recording tools (e.g. smartphones and cameras) is continuously improving. Careful interpretation of online content is essential to minimise the risk of misclassification and false positives when identifying invasive species and their behaviours. If supported by robust data curation and validated analytical pipelines (Figure 2; Table S1), it may have the potential to deliver solid

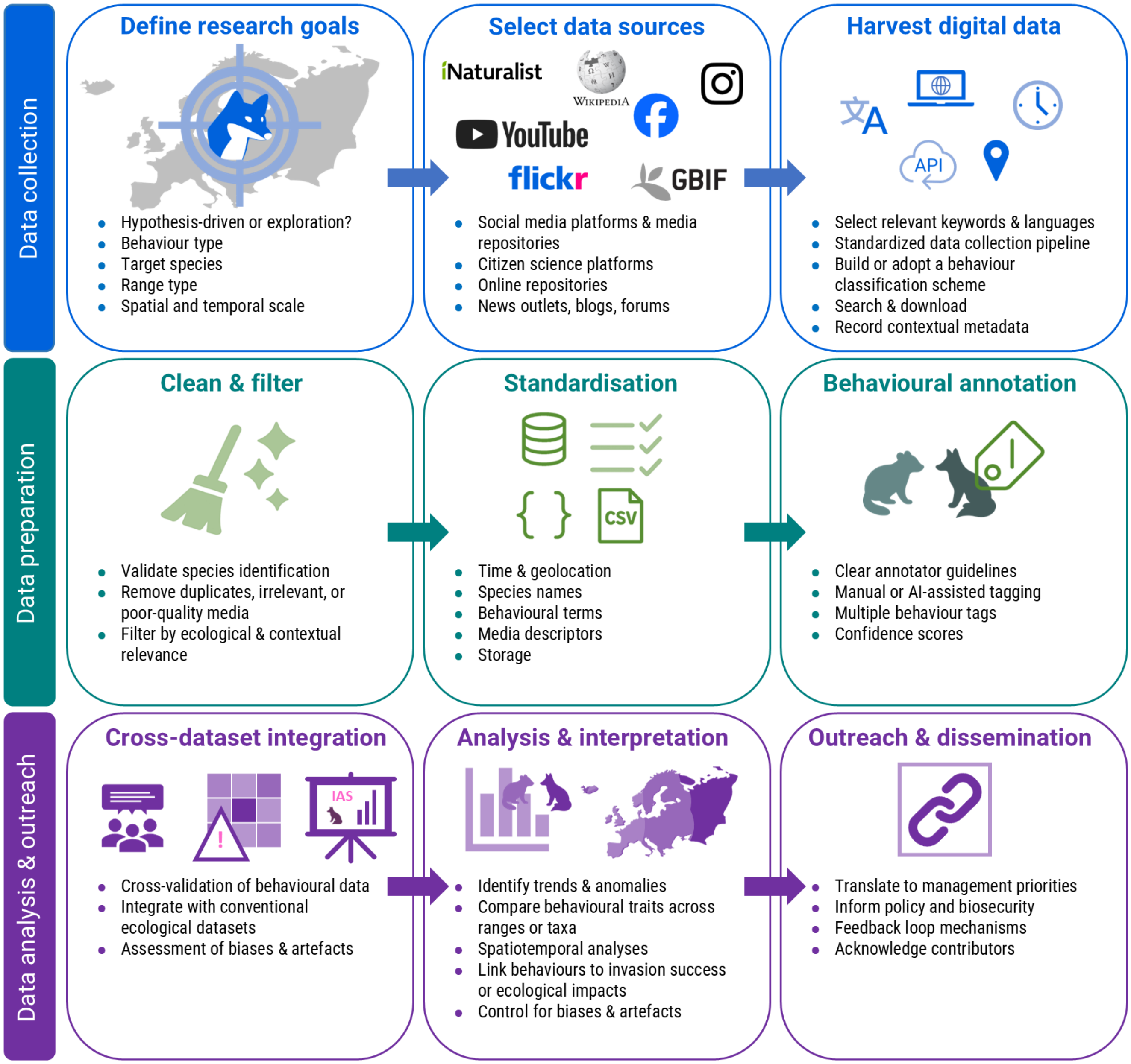

FIGURE 2 A generalised workflow for applying iEcology to studying invasive species behaviour. The diagram outlines key steps and decisions needed in using online-derived data to extract behavioural insights. For details, see Table S1.

sample sizes across broad spatial and temporal scales and contribute to more effective, evidence-based conservation, management and policy interventions.

4. Emerging technologies such as artificial intelligence (AI) and machine learning can help infer missing metadata and classify behaviours, yet they also risk propagating errors due to biased training data or misclassification. The growing prevalence of AI-generated content on social media further complicates data validation, as synthetic media—such as fabricated wildlife interactions—can be challenging to detect. Safeguarding iEcology from such misinformation may, however, require time-consuming expert reviews and data curation, plausibility assessments based on known species behaviour and tools for detecting synthetic media.

We acknowledge that bias correction methods are still underdeveloped in iEcology. However, we can draw on well-established bias correction methods in citizen science and species distribution modelling: reporting bias can be mitigated by quantifying sampling effort, applying spatial and environmental filtering, incorporating bias-aware modelling strategies such as effort covariates and being transparent in reporting. For example, the use of spatially explicit covariates such as the number of active users as proxies for sampling effort is frequently used (Fithian et al., 2015), although it may not be available for all platforms (e.g. YouTube). Another common framework is the target-group approach, where background or pseudo-absence samples are drawn from the same observer effort distribution as the target species (Ranc et al., 2017). More integrative techniques jointly model presence-only and presence-absence data across species to estimate and subtract shared sampling bias components (Pili et al., 2025). These strategies are directly transferable to iEcology of invasive species—by incorporating regional user activity, platform usage metrics or accessibility proxies as sampling effort covariates, we can statistically adjust for wealth- or accessibility-based sampling biases. Applying such approaches would strengthen inference from opportunistic records, aligning iEcology with best practices in ecological modelling.

6 | FUTURE DIRECTIONS FOR INVASIVE BEHAVIOURAL iECOLOGY

To maximise the potential of iEcology in studying invasive species behaviour, four strategies need to be considered. (1) Standardising metadata collection across online data records and platforms would enhance data reliability and comparability, but most importantly, would allow researchers to prefilter datasets to look for secondary data (Bowser et al., 2020; Pernat et al., 2024). (2) The integration of AI and machine learning techniques could significantly improve the efficiency of behavioural analyses by enabling automated detection and classification of behavioural traits across vast datasets. Leveraging online data sources—such as Instagram, TikTok, Facebook photos, YouTube videos and footage from non-scientific camera traps—with novel analytical tools could provide near real-time evidence of invasive alien species behaviour. Data mining could be scaled from hashtag or object-detection filters to full-stream scraping according to the focal research question, available computing resources and the desired balance between sample size and processing cost. However, this strategy may be constrained by the pay-per-use nature of many social media APIs, potentially limiting access to those with sufficient resources and thereby raising important equity considerations. (3) Increased collaboration between ecologists, data scientists and conservation practitioners is essential for developing best practices for iEcology research, ensuring that methodologies remain robust and reproducible. (4) Additionally, efforts should be made to expand iEcology applications beyond well-documented vertebrate species to include invertebrates and other less-studied taxa, many of which are also invasive species.

Beyond basic research, behavioural insights obtained through iEcology can directly inform conservation science, that is management and control of invasive species. For example, identifying behavioural traits related to mating strategies, breeding patterns or site fidelity can help design temporally and spatially targeted interventions such as trapping, fertility control or habitat modifications. Similarly, understanding foraging behaviour and human–wildlife interactions may guide the spatial and temporal optimisation of attractant-based control measures and deterrent systems and inform public education campaigns.

The future of animal invasion biology will benefit greatly from integrating digital behavioural data. By using iEcology to study invasive animals' behaviour, researchers can obtain a more comprehensive and timely understanding of the mechanisms driving invasion success, leading to improved predictive models and more effective management strategies. As digital technologies continue to evolve, the role of behavioural iEcology in understanding and mitigating biological invasions will become increasingly significant, offering an innovative, cost-effective and scalable approach to addressing one of the most pressing ecological challenges of our time.

AUTHOR CONTRIBUTIONS

Peter Mikula raised the initial idea and all authors developed the rationale of the paper at a workshop. Peter Mikula, Pavel Pipek, Nadja Pernat and Shawan Chowdhury prepared visualisations. Peter Mikula led the writing and manuscript development, and all authors contributed to the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Details for each step of the iEcology workflow (Figure 2), with tailored recommendations for extracting and analysing behavioural data from five digital content types: images, videos, sounds, text, and online activity.

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