Received: 24 April 2023 | Revised: 13 September 2023 | Accepted: 19 September 2023

DOI: 10.1111/conl.12981

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

PERSPECTIVE

Invasion trends: An interpretable measure of change is needed to support policy targets

Melodie A. McGeoch[1] | **Yehezkel Buba**[2] | **Eduardo Arlé**[2,3] | **Jonathan Belmaker**[2,4] | **David A. Clarke**[1] | **Walter Jetz**[5] | **Richard Li**[5] | **Hanno Seebens**[6] | **Franz Essl**[7] | **Quentin Groom**[8] | **Emili García-Berthou**[9] | **Bernd Lenzner**[10] | **Carsten Meyer**[3] | **Joana R. Vicente**[11] | **John R. U. Wilson**[12,13] | **Marten Winter**[3]

[1]Securing Antarctica's Environmental Future, Department of Environment and Genetics, La Trobe University, Melbourne, Victoria, Australia

[2]School of Zoology, George S. Wise Faculty of Life Sciences, Tel Aviv University, Tel Aviv, Israel

[3]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, sDiv – Synthesis Centre, Leipzig, Germany

[4]The Steinhardt Museum of Natural History, Tel Aviv University, Tel Aviv, Israel

[5]Department of Ecology and Evolutionary Biology, Center for Biodiversity and Global Change, Yale University, New Haven, Connecticut, USA

[6]Senckenberg Biodiversity and Climate Research Centre, Frankfurt, Germany

[7]Division of Bioinvasions, Global Change, Macroecology, Department of Botany and Biodiversity Research, University of Vienna, Vienna, Austria

[8]Biodiversity Informatics, Meise Botanic Garden, Meise, Belgium

[9]GRECO, Institute of Aquatic Ecology, University of Girona, Girona, Spain

[10]Bioinvasions, Global Change, Macroecology Group, Department of Botany and Biodiversity Research, University of Vienna, Vienna, Austria

[11]CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Campus de Vairão, BIOPOLIS Program in Genomics, Biodiversity and Land Planning, Universidade do Porto, Vairão, Portugal

[12]South African National Biodiversity Institute, Kirstenbosch Research Centre, Cape Town, South Africa

[13]Department of Botany and Zoology, Centre for Invasion Biology, Stellenbosch University, Stellenbosch, South Africa

Correspondence
Melodie A. McGeoch, Securing Antarctica's Environmental Future, Department of Environment and Genetics, La Trobe University, Melbourne, Australia. Email: melodie.mcgeoch@monash.edu

Funding information
Synthesis Centre of iDiv, Grant/Award Numbers: DFG FZT 118, 202548816; Spanish Ministry of Science, Grant/Award Numbers: PID2019-103936GB-C21, TED2021-129889B-I00; Research Contract, Grant/Award Number: DL57/2016/CP1440/CT0024; Australian Research Council, Grant/Award Number:

Abstract

The Kunming-Montreal Global Biodiversity Framework (GBF) calls for a 50% reduction in rates of invasive alien species establishment by 2030. However, estimating changes in rates of introduction and establishment is far from straightforward, particularly on a national scale. Variation in survey effort over time, the absence of data on survey effort, and aspects of the invasion process itself interact in ways that make rate estimates from naive models of invasion trends inaccurate. To support progress toward robust global and national reporting against the GBF invasions target, we illustrate this problem using a combination of simulations, and global and national scale case studies. We provide recommendations and a clear set of steps that are needed for progress. These include routine collection of survey effort data as part of surveillance and

SR20010005; Austrian Science Foundation FWF, Grant/Award Number: I 5825-B; iDiv Flexpool; South African Department of Forestry, Fisheries and the Environment; Australian Friends of Tel Aviv University—Monash University Research Collaboration Award

monitoring protocols and working closely with researchers to develop meaningful estimates of change in biological invasions. Better awareness of this challenge and investment in developing robust approaches will be required from Parties if progress on Target 6 of the GBF is to be tracked and achieved.

KEYWORDS
Convention on Biological Diversity, Essential Biodiversity Variables, EU's biodiversity strategy 2030, Global Biodiversity Monitoring Framework, invasive alien species, rate of establishment, species populations data, survey effort, Target 6

1 | WHY A PERSISTENT FOCUS ON INVASION TRENDS?

The documented numbers of alien species in new locations have continued to increase over recent decades (Seebens et al., 2017). Evidence of known drivers, patterns, and pathways of invasion has also grown significantly (e.g., Capinha et al., 2023), adding impetus to the message that this invasion load (numbers of invasive alien species (IAS) (Table 1(1)) and populations) and associated risks of socioeconomic and environmental impacts continue to increase (Diagne et al., 2020). Target 6 of the recently adopted Kunming-Montreal Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD) specifies, inter alia, reducing the rate of introduction and establishment of IAS by at least 50% by 2030 (CBD/COP/DEC/15/4). The associated headline indicator is "Rate of invasive alien species establishment" (CBD/COP/DEC/15/5), pointing to a policy-driven need to quantify and estimate introduction (Table 1(2)) rates. To report on this biodiversity target, authorities need robust indicators that track invasion trends (Table 1(3)), and derived estimates of IAS introduction rate (Table 1(4)).

Trends in the observed number of IAS in an area (expressed per unit time or cumulatively), from which rates of introduction are estimated, are among the most long-standing and frequently referred-to indicators of biological invasions (Butchart et al., 2010; Seebens et al., 2017; Tittensor et al., 2014). Such time series are an intuitive way to visualize and interpret the increase in biological invasions (e.g., Mormul et al., 2022). However, investment in IAS surveillance and monitoring (referred to as "survey effort" here (Table 1(5))) is spatially and temporally variable and the true number of introduced species is different from the observed number, that is, the process by which IAS are introduced is unobservable (Solow & Costello, 2004). Furthermore, the GBF specifically calls for investment in updating and maintaining IAS data, and for better data standards, although it does not refer specifically to data on survey effort. As we demonstrate here, trends of observed numbers of introductions are, on their own, almost certainly misleading. This widely underappreciated problem must be addressed if estimates of introduction rates are to inform the GBF and decision-making on IAS in the coming years.

2 | HOW INTRODUCTION RATES BASED ON OBSERVATION DATA MISLEAD

High and increasing rates of IAS introduction are a reason for concern at all spatial scales. They suggest that prevention and control measures have not been sufficient. On the contrary, low or declining introduction rates suggest that prevention efforts are succeeding. However, the difficulty of accurately estimating such invasion trends, first raised two decades ago (e.g., Solow & Costello, 2004), remains largely underappreciated in both scientific and indicator selection and development communities. The problem arises from the fact that the observed number of new IAS (Table 1(6)) over time is a function of both (1) the true rates of introduction of new alien species (i.e., the invasion process) and (2) the survey effort. As we show here, temporally and spatially variable survey effort can have a substantial effect on the form and slope of invasion trends and, therefore, on estimates of the introduction rate.

Inferring IAS introduction rates directly from the raw numbers of newly observed introductions neglects the fact that survey effort influences the counts of IAS (Belmaker et al., 2009; Solow & Costello, 2004). Simulating different patterns of variation in the survey effort over time shows how a range of invasion trends result (Figure 1b) even when the true number of introductions per unit time is constant (Figure 1a). Both the true numbers of newly introduced IAS (i.e., all species, observed and not observed) and survey effort are likely to vary over time. Even when species introductions and survey effort are constant over time (Figure 1, black line), the numbers of new species

TABLE 1 Clarifications needed when estimating invasion trends and introduction rates.

	Concept	Application
1	Delimitation of the intended species pool	Here, we use the definition under the Convention of Biological Diversity (https://www.cbd.int/invasive/WhatareIAS.shtml), and do not make a distinction between "alien" species and "invasive alien species" (IAS). The latter represent a subset of alien species and the argument in his paper applies in either instance.
2	Introduced versus established species	Here, the term introduction encompasses the introduction, establishment, and spread stages of the invasion process. These stages of the invasion process are in the main not possible to disaggregate for the purpose of empirical invasion trend modeling.
3	Invasion trend	A time series showing the change in the number of IAS in an ecosystem, country, region, or globally.
4	Introduction rate	The rate at which new species are introduced over a particular time period and for a particular region (subnational to global), calculated from the invasion trend.
5	Survey effort	Investment in surveillance and monitoring activities to observe (and document/report) newly introduced and established species. We assume for argument's sake here that "effort" constitutes effective and efficient surveys. Here, "survey effort" is synonymous with the term "discovery process" in Solow and Costello (2004).
6	Observed IAS	Detected and documented new IAS, recognizing that some IAS go undetected and unrecorded (synonymous with the term "discovery" in Solow and Costello, 2004).

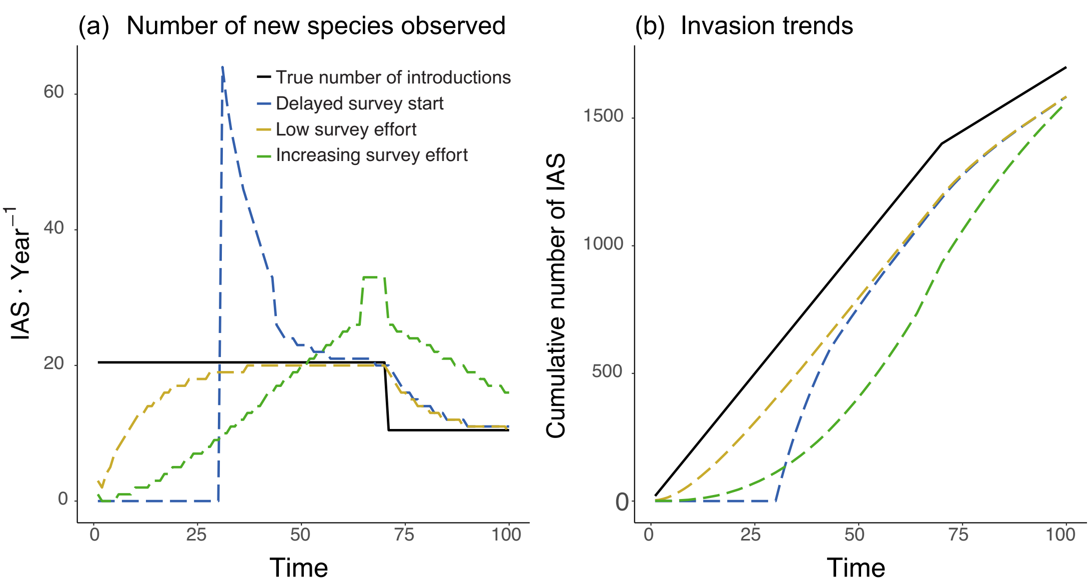

FIGURE 1 Simulation showing how varying survey effort for invasive alien species (IAS) produces different patterns of new species observations (a, number per year), and invasion trends (b, cumulative introductions). All curves in (a) and (b) are based on the same "true," constant introduction rate of 20 species per year until year 75, and a decrease of 50% to 10 species per year over the last 30 years. Curve colors and dash types in (a) correspond to those in (b). The true number of IAS introductions (solid black line) (a) produces the trend in (b) if all IAS are detected as soon as they are introduced (i.e., the survey effort is high enough to achieve this). The dashed-line cases in a and b show scenarios of varying survey effort over time (delayed, low, or increasing): delayed sampling (blue) assumes here that recording of IAS starts 25 years after the first introduction, after which 10% of IAS are detected each year; low sampling effort (gold) assumes that a set portion (e.g., 10%) of IAS are observed each year; increasing sampling effort (green) assumes that survey effort increases with time (the sudden drop with increasing survey effort ~ 75 years results from the sudden 50% drop in the true number of introduced species per year [solid black line]). (b) shows (i) how there is routine underestimation of IAS numbers, particularly during earlier stages of invasion (dashed lines lie below solid black line), and (ii) if observations of new introductions are not complete and instantaneous, the 50% drop in true introduction rate in the final 30 years is not clearly visible from the observation record (i.e., the success of an intervention that reduces introduction rates would not be discernible from trends in observed numbers of IAS). This implies that an indicator based solely on observed numbers of IAS over time can be misleading.

observations can still appear to be accelerating (e.g., Figure 1, green dashed line). This is because with inadequate survey effort, the number of unobserved IAS accumulates through time, and as a result, even a constant survey effort over time with the same baseline introduction rate will appear to show an increasing number of IAS (Wonham & Pachepsky, 2006). Therefore, variation in survey effort alone can produce strongly positive invasion trends and thus apparently positive invasion rates (Belmaker et al., 2009) (Figure 1; Solow & Costello, 2004; Wonham & Pachepsky, 2006). This means that percentage reductions in introduction rate, such as the 50% called for by GBF Target 6, cannot naively be estimated from IAS observations alone, and the inferences from trends in IAS observations are likely to be wrong if survey effort is not considered.

Many different potential scenarios exist for: (1) the impact of survey effort on observed invasion trends; (2) the implication of each of these scenarios for understanding how the invasion is changing; and (3) levels of certainty about national and multinational policy success (Figure 2). Interpretations range from a high risk of underestimating new introductions (left column, scenarios 1, 4, and 7, Figure 2), to high and increasingly certain evidence that the success of prevention efforts is being accurately evaluated (right column, scenarios 3 and 6, Figure 2). However, there are currently no available and comparable data on survey effort at national scales.

The simulated example (Figure 1), and the alternative possible scenarios for the impact of survey effort on interpreting invasion trends (Figure 2), demonstrate the challenge of using IAS introduction rates as indicators for biodiversity policy reporting. Below, we outline data solutions and analytical options for countries to address this challenge. We also outline the research needs for enabling confident reporting on progress to achieve Target 6 of the GBF, supported by an up-to-date and sustainable flow of necessary information on IAS (sensu McGeoch & Jetz, 2019).

3 | DATA SOLUTIONS

The most powerful and instrumental solution to this challenge is to invest in collecting data on explicit measurement of IAS survey effort, the identities, timing of introductions, and distributions of IAS. These data provide the information critical for estimating robust invasion rates (Figure 3). Significant progress has been made in making IAS occurrence data available for countries over the last decade, for example, through the Alien Species First Records Database (Seebens, 2021). Baseline, multi-taxon, and openly available country checklists are also available (Pagad et al., 2022). Efficient and pragmatic approaches to improving this essential IAS data have been proposed (Latombe et al., 2017; van Rees et al., 2022), and potential financial benefits of doing so have also been shown (Cheney et al., 2018). This suggests advances on the collection and delivery of survey effort data are similarly possible.

Data on survey effort are nonetheless much less readily available than data on IAS per se. Standard approaches and tools for measuring and recording survey effort are currently not developed, and harmonized guidelines will be needed. Examples of relevant data on the survey effort include measures, such as hectares surveyed for IAS per assessment period (Cheney et al., 2018), numbers of inspections of high-risk establishment sites (Lovell et al., 2021), volume of cargo inspected (Miralles et al., 2021), time spent searching for a specific species (Mehta et al., 2007), number of high conservation value areas surveyed for IAS (Keet et al., 2022), and proportion of cells with expected presences that have relevant observations, the metric underpinning the Species Information Index (Oliver et al., 2021). New monitoring technologies are increasingly available, such as remotely sensed products (e.g., unmanned aerial vehicle (UAV), satellite, and camera traps) or eDNA approaches, which through fixed elements of deployment protocols (e.g., area surveyed and number of traps or samples) provide quantifiable, efficient, and effective ways to survey a subset of IAS for rapid and systematic observations (van Rees et al., 2022). These methods could in the future provide repeatable quantification and reporting on survey effort. We strongly suggest collecting data on survey effort and routinely incorporating this into species monitoring protocols.

Without comparable information on survey effort for IAS, more readily available proxies could be used. For example, we used the number of IAS occurrences in the Global Biodiversity Information Facility (GBIF) database as a proxy for survey effort (for eight countries, recorded over the last ~ 50 years), to show how the scenarios in Figure 2 are plausible (Methods S1 and Figure S1). Although biases in such data are well recognized, approaches to reducing these biases are increasingly available (Arlé et al., 2021; Meyer et al., 2016), and the steps outlined in this Perspective will improve the quality of information required for assessment and reporting (Figure 3). Other possible proxies of survey effort include the number of new biodiversity occurrence records per area per reporting period, correlations between the number of native and nonnative occurrence records, numbers of publications on IAS for a region, effort invested in monitoring for other environmental purposes, as well as the respective survey effort for those species, and qualitative scoring of how proactive countries are perceived to be with

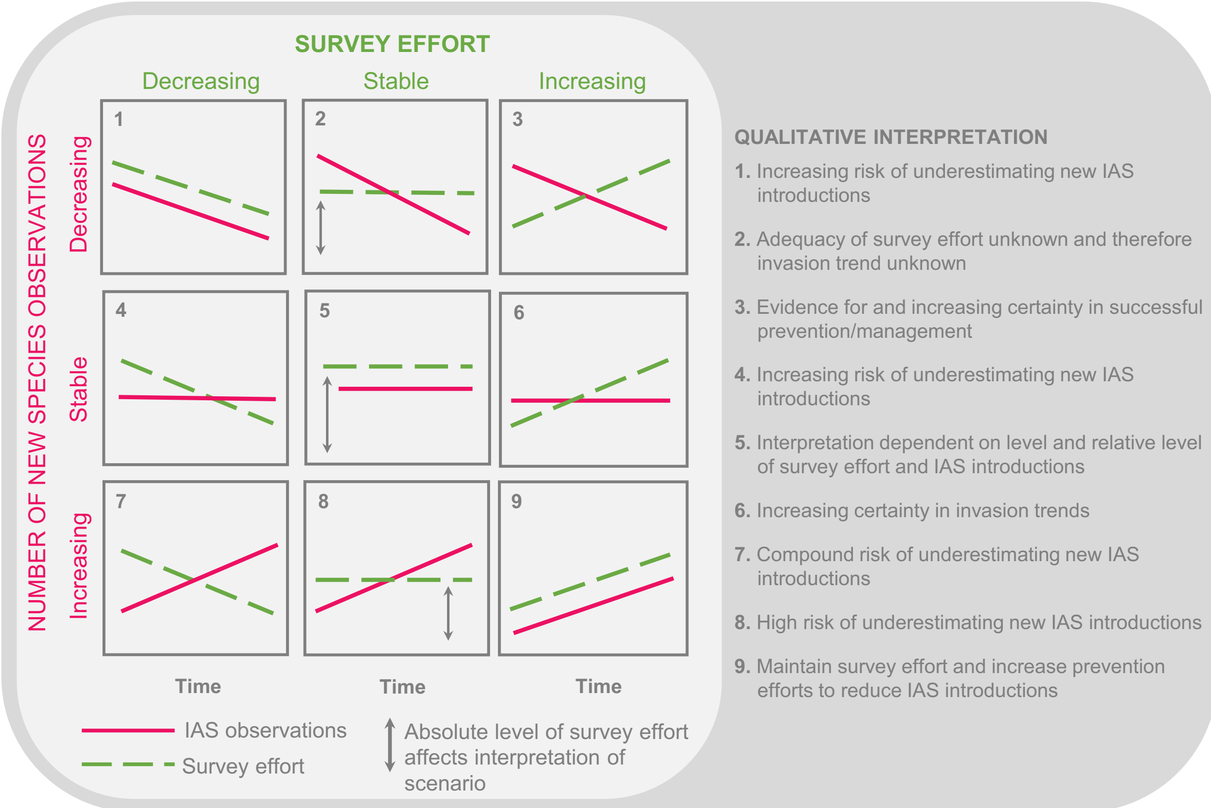

FIGURE 2 Introduction-survey effort scenarios showing how different combinations of trends in survey effort (dashed line, green) and observed numbers of new invasive alien species (IAS) (solid line, dark pink) have different implications. Each of these scenarios has a different potential interpretation and associated relative level of confidence (see "Qualitative Interpretation" to right). For example, in scenario 1, both the survey effort and numbers of new IAS observed are declining. With the decline in survey effort, it is not possible to tell if the true numbers of new IAS are actually declining or simply not being observed because of declining survey effort. By contrast, in scenario 6, even though survey effort is increasing over time, the number of new species being observed is constant. Over time, there is, therefore, increasing confidence that the number of new species observed is an accurate reflection of the true number of new introductions. Note (i) that the range of scenarios shown are simplified and relative for illustration, and (ii) that the initial and absolute levels of survey effort and IAS observations will affect the interpretation (see also Supporting Information, Figure S1 that uses country examples and proxy survey effort data to demonstrate the plausibility of these scenarios).

recording early invasions (e.g., Capinha et al., 2023; Larson et al., 2020; Visser et al., 2016). Such proxies are commonly used (e.g., Bonnamour et al., 2021) and provide a useful independent assessment that can indirectly inform on IAS observation probability based on the assumption that during the collection of general occurrence records, IAS are likely to be observed.

An alternative that could be useful, especially in cases of geographic progression of invasions over larger land masses rather than "jump" introductions, would be model-based, Essential Biodiversity Variable (EBV) style predictions (McGeoch & Jetz, 2019). Integration of varied, relevant data types and sources (e.g., individual occurrences, inventory, and expert elicitation on IAS distributions) can reduce data gaps, along with environmental information and appropriate modeling, and increase the resolution of information on the redistribution of IAS (McGeoch & Jetz, 2019). Species population EBVs, along with increasing and ongoing data collection on IAS (e.g., including government, research, and citizen science contributions), and on survey effort, can begin to provide reliable predictions of IAS in near real-time and at spatial resolutions useful for management and reporting. Drawing on and contributing to occurrence records in GBIF, maintaining the Global Register of Introduced and Invasive Species (GRIIS) country checklists (see Pagad et al., 2022), and investing in EBV production are the backbone of this process (McGeoch & Jetz, 2019).

The steps to build the information needed to adequately estimate invasion trends and inform on the success of policy interventions are clear (Figure 3 and Table S1). Importantly, the information benefits of such data are wide-ranging and relevant beyond the estimation of introduction trends (right-hand text in Figure 3). Temporally

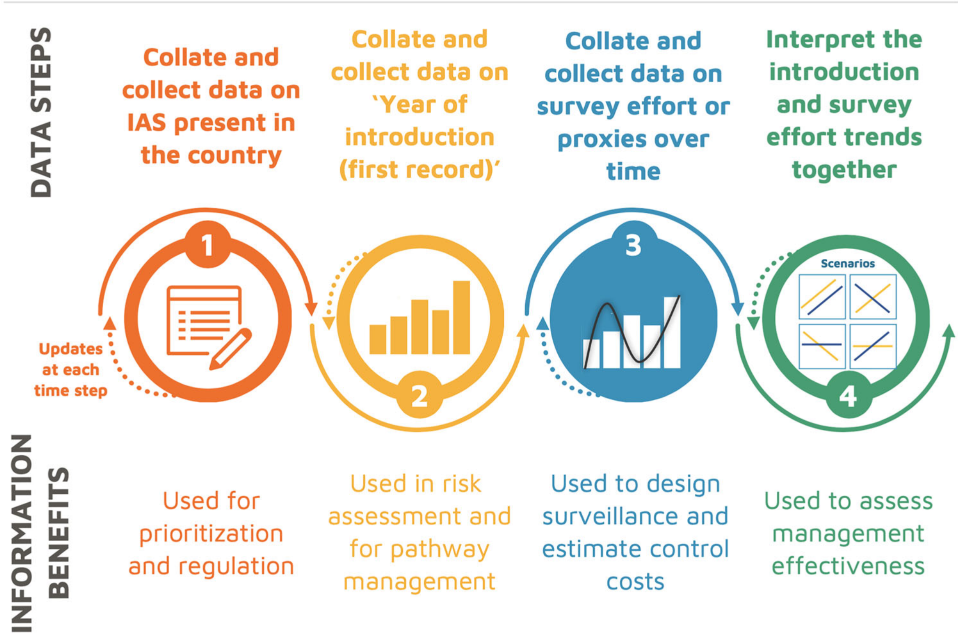

FIGURE 3 Governments and institutions responsible for assessing invasive alien species at the national level can follow steps (1–4) to build the data needed to estimate rates of invasive alien species (IAS) introductions (above) (for recommendation details, see Supporting Information, Table S1). These data contribute to building an indicator of trends in IAS within and across countries, and importantly include the collection of data on survey effort. These steps also deliver several other key information benefits (below) for policy and management.

explicit data on the identity and distribution of IAS populations provide the evidence base for species, site, and pathway prioritization and management, risk assessment, resource allocation planning, and evaluations of management effectiveness (Cheney et al., 2018; van Rees et al., 2022). There is, therefore, a strong incentive for sustained investment in keeping such data up-to-date. Although proxies can provide an interim solution, survey effort data are so foundational for assessing, maintaining, and interpreting information on IAS that we recommend collecting and collating such data as a strategic priority for countries and researchers (Figure 3 and Table S1) (OECD, 2019; Leadley et al., 2022; Vicente et al., 2022).

Building a sustainable pipeline of ongoing new data from which introduction rates can be estimated and reported based on ongoing updates of IAS observations is essential (Figure 3 and Table S1). Where countries lack national information platforms to support these data, GBIF and GRIIS (Pagad et al., 2022) provide tools to collate and publish IAS occurrences, first record, and checklist information (data steps 1 and 2, Figure 3). Some countries could substantially enhance their data by digitizing relevant information from gray literature (e.g., government reports) (Groom, 2015). Importantly, routine and timely capture of information on new introductions is key to ongoing reporting on invasion trends.

4 | ANALYTICAL SOLUTIONS

Analytical methods exist for modeling invasion trends without data on survey effort. As outlined above, estimates of introduction rates should account for the effects of underlying survey effort on IAS observation probabilities. Observation probabilities vary over time and space because of both survey effort and properties of the invasion process (e.g., increase in abundance after introduction; Solow & Smith, 2005). Modeling solutions can bridge the gaps in data availability to arrive at estimates of underlying introduction rates, with associated measures of confidence, and thus survey effort-informed estimates of species introduction rates.

One simple method that accounts for IAS observation probability (in other words assuming that observations are affected by survey effort) is the Solow and Costello (2004) model (SC model). The SC model is based on a time series that describes the number of observed species in each time period, and estimates the rate of introduction of new species from these IAS observations (see Supporting Information, Methods S1). The observed number of IAS is the product of the number of introductions and the observation probability of the introduced species. Observation probability is allowed to change over time, as might happen with increasing survey effort or growing IAS

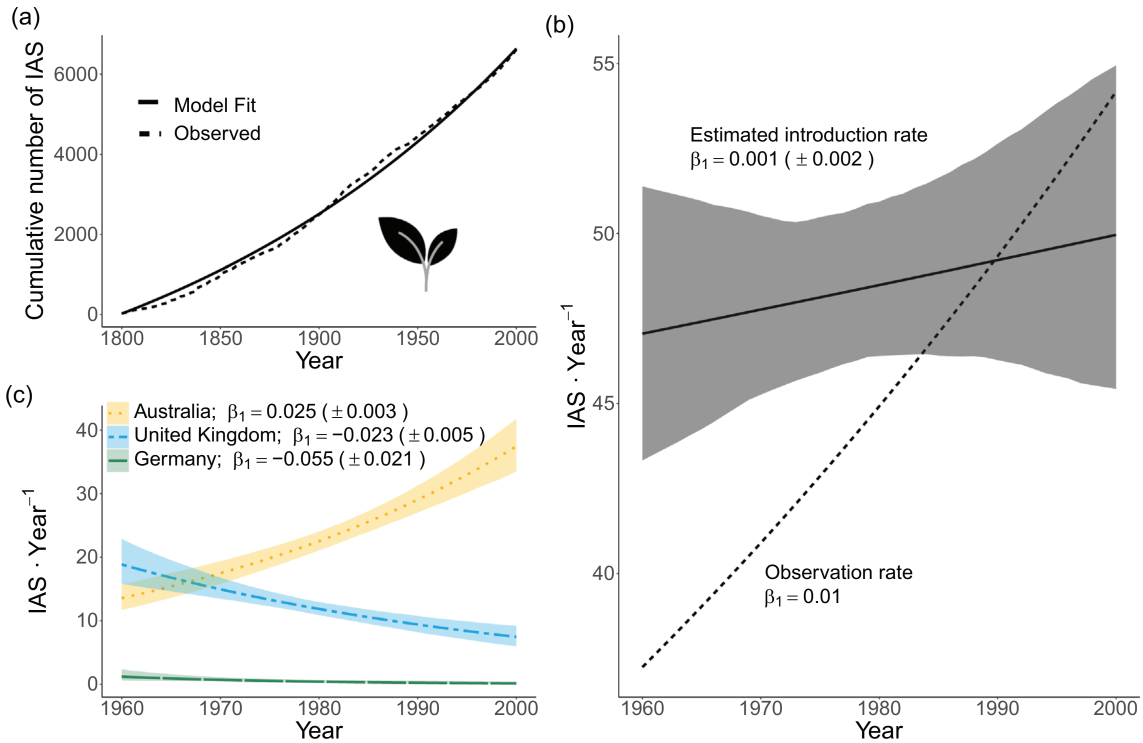

FIGURE 4 Case study examples of estimating alien species introduction rates. (a) Vascular plant species at a global scale: cumulative observed number of new invasive alien plants globally (records of species in new localities) since 1800 (dashed line) and the fit of the Solow and Costello (2004) model (SC model, solid line). (b) Comparison between the observed (naïve, dashed line) and estimated (SC model, solid line) introduction rates from (a). The rates are estimated for the period 1960–2000; shaded area denotes 95% confidence intervals. The annual change in rate parameter ($\beta_1 \pm$ s.e.) represents the rate of change in IAS introductions; and the two β_1 values are clearly very different for the observed (naive) versus modeled with an assumption about survey effort (SC model). Both show that the rate of global plant invasions is increasing (positive β_1 values), but at a slower rate when modeled to consider survey effort. (c) Country case studies used to show that the generally expected increase in introduction rates does not always hold. Using the SC model, the rate of change in invasive alien plant introductions (β_1) for Australia (orange; dotted), United Kingdom (blue; dash-dotted), and Germany (gray, dashed) are shown with 95% confidence intervals. Australia has an accelerating introduction rate of invasive alien plants (β_1 is positive), whereas the rate in the United Kingdom is slowing (β_1 is negative). Germany has a comparatively low number of IAS introductions per year and a largely stable, yet slowing, rate of invasive alien species introductions (β_1 is negative).

populations. Once the model has been applied, the key indicator is the parameter of the model that estimates the (exponential) change in the introduction rate over time (β_1). Positive values indicate accelerating introduction rates, while negative values indicate decelerating rates (Figure 4). The SC model has the advantage that it does not require data on survey effort and uses data commonly available, that is, IAS observations and first records (although more complex versions of the model are possible, e.g., Belmaker et al., 2009).

We applied the Solow and Costello model (Solow & Costello, 2004) to a global data set of first country-level records of invasive alien plants (Methods S1). The SC model of the cumulative number of invasive alien plants at new locations between 1800 and 2000 fits the empirical data well (Figure 4a). However, the comparison of the rates calculated from observations (new species records per year, 1970–2014) with the SC model estimates of introduction rates shows clearly that accounting for survey effort (in this case through the model structure) influences the introduction rate (Figure 4b). For example, this analysis suggests that in the year 2000, the global rate of plant introductions is lower than the observed rate (Figure 4b). Conversely, in 1960, the introduction rates were likely higher than the observation rate suggests. This example demonstrates the importance of considering survey effort before inferring and reporting on IAS introduction rates. Applying this SC model to data for a selection of individual countries also shows that, rather than increasing across the board, introduction rates are likely to vary as either accelerating, stable, or decelerating (Figure 4c).

While a model like this that compensates for survey effort has clear advantages, its usefulness depends on the degree to which the model assumptions are met. For example, the SC model assumes that the underlying IAS introduction rate increases or decreases exponentially with time, and that the survey effort changes monotonically with time. Neither assumption holds across the board, deviations from them are hard to estimate, and violations will affect the estimated introduction rate. More complex models can be used to account for survey effort when additional information on survey processes is available, such as models with an additional term that relies on independent data to estimate survey effort (e.g., Belmaker et al., 2009). However, currently, all available models need rigorous quantification of their data requirements, performance, and sensitivity to deviation from model assumptions. In the interim, we recommend making information available on both observed trends and modeled estimates of introduction rate that consider observation probabilities when reporting on introduction rates (as in Figure 4). Despite their drawbacks, with no or limited direct data on survey effort, modeling approaches represent a best-practice solution to estimate robust IAS introduction rates. Further research is needed on modeling methods that accommodate observation probability and/or survey effort data when estimating introduction rates.

5 | CONCLUSION

Is it possible to estimate the rate of change in establishment for a 50% reduction to be met, as called for by Target 6 of the GBF? This is a question that all countries must answer soon. As shown here, the 50% target value aimed for could assume very different, and not necessarily meaningful, numbers under different scenarios of survey effort. Confident comparisons in percentage-reduction targets are difficult to achieve at present because IAS survey effort data are not available, have varied over time, and between taxa, countries, and regions; and because the effects of survey effort are largely unaccounted for in existing trend estimations. However, within individual countries, it is both possible and valuable to identify locally relevant introduction-survey effort scenarios and to build the data needed to provide robust and meaningful estimates. The steps to do so are outlined here (Figure 3 and Table S1), provide clear direction, and will deliver multiple information benefits for IAS management and international reporting obligations. These steps will bring about significant progress on several of the recommendations agreed to at the 15th Conference of Parties of the Convention on Biological Diversity. Strong international partnerships and data infrastructures, including the Global Biodiversity Information Facility, Group on Earth Observations Biodiversity Observation Network, and the Invasive Species Specialist Group of the IUCN, are in place to support countries as they progress toward 2030 reporting on this foundational element of Target 6. Close collaboration between researchers and implementation and reporting agencies will be necessary.

AUTHOR CONTRIBUTIONS

All authors designed the general idea, led by M.A.M., and M.W. Y.B., and J.B. built the model and simulated the scenarios. E.A. built the country-level scenarios. M.A.M., Y.B., and J.B. wrote the first manuscript draft. All authors contributed to the writing.

ACKNOWLEDGMENTS

sTWIST is supported by sDiv, the iDiv Synthesis Centre (DFG FZT 118, 202548816). The work was further supported by an Australian Friends of Tel Aviv University—Monash University Research Collaboration Award to J.B. and M.M. This work is a contribution to the GEO BON Species Populations Working Group (https://geobon.org/ebvs/working-groups/species-populations). We thank M.V. Henriksen and S.L. Chown for the discussion. M.M. and D.A.C. acknowledge the support of ARC SRIEAS Grant SR200100005 Securing Antarctica's Environmental Future. F.E. and B.L. appreciate funding by the Austrian Science Foundation FWF (grant no. I 5825-B). E.A., F.E., C.M., and M.W. acknowledge funding for this work through iDiv's Flexpool mechanism. E.A. acknowledges funding granted by the Azrieli Foundation. J.R.V. acknowledges research contract DL57/2016/CP1440/CT0024. E.G.-B. acknowledges funding from the Spanish Ministry of Science (PID2019-103936GB-C21 and TED2021-129889B-I00). J.R.U.W. thanks the South African Department of Forestry, Fisheries, and the Environment (DFFE) for funding, noting that this publication does not necessarily represent the views or opinions of DFFE or its employees. The authors thank Rachel Leihy and Steven Chown for presubmission comments on the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Details of the data used to illustrate the points made in this perspective are available in the Supporting Information of this article.

ORCID

Melodie A. McGeoch https://orcid.org/0000-0003-3388-2241
David A. Clarke https://orcid.org/0000-0003-3529-1162
Quentin Groom https://orcid.org/0000-0002-0596-5376
Emili García-Berthou https://orcid.org/0000-0001-8412-741X

Joana R. Vicente https://orcid.org/0000-0003-0382-0189
John R. U. Wilson https://orcid.org/0000-0003-0174-3239

REFERENCES

Arlé, E., Zizka, A., Keil, P., Winter, M., Essl, F., Knight, T., Weigelt, P., Jiménez-Muñoz, M., & Meyer, C. (2021). bRacatus: A method to estimate the accuracy and biogeographical status of georeferenced biological data. *Methods in Ecology and Evolution*, *12*, 1609–1619. https://doi.org/10.1111/2041-210X.13629

Belmaker, J., Brokovich, E., China, V., Golani, D., & Kiflawi, M. (2009). Estimating the rate of biological introductions: Lessepsian fishes in the Mediterranean. *Ecology*, *90*, 1134–1141. https://doi.org/10.1890/07-1

Bonnamour, A., Gippet, J. M. W., & Bertelsmeier, C. (2021). Insect and plant invasions follow two waves of globalisation. *Ecology Letters*, *24*, 2418–2426. https://doi.org/10.1111/ele.13863

Butchart, S. H. M., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., … Watson, R. (2010). Global biodiversity: Indicators of recent declines. *Science*, *328*, 1164–1168. https://doi.org/10.1126/science.1187512

Capinha, C., Essl, F., Porto, M., & Seebens, H. (2023). The worldwide networks of spread of recorded alien species. *Proceedings of the National Academy of Sciences*, *120*, e2201911120. https://doi.org/10.1073/pnas.2201911120

Cheney, C., Esler, K. J., Foxcroft, L. C., Van Wilgen, N. J., & McGeoch, M. A. (2018). The impact of data precision on the effectiveness of alien plant control programmes: A case study from a protected area. *Biological Invasions*, *20*, 3227–3243. https://doi.org/10.1007/s10530-018-1770-8

Diagne, C., Leroy, B., Gozlan, R., Vaissière, A.-C., Assailly, C., Nuninger, L., Roiz, D., Jourdain, F., Jarić, I., & Courchamp, F. (2020). InvaCost, a public database of the economic costs of biological invasions worldwide. *Scientific Data*, *7*, 277. https://doi.org/10.6084/m9.figshare.11627406

Groom, Q. J. (2015). Using legacy botanical literature as a source of phytogeographical data. *Plant Ecology and Evolution*, *148*, 256–266. https://doi.org/10.5091/plecevo.2015.1048

Keet, J.-H., Datta, A., Foxcroft, L. C., Kumschick, S., Nichols, G. R., Richardson, D. M., & Wilson, J. R. U. (2022). Assessing the level of compliance with alien plant regulations in a large African protected area. *Biological Invasions*, *24*, 3831–38441. https://doi.org/10.1007/s10530-022-02883-7

Larson, E. R., Graham, B. M., Achury, R., Coon, J. J., Daniels, M. K., Gambrell, D. K., Jonasen, K. L., King, G. D., Laracuente, N., Perrin-Stowe, T. I., Reed, E. M., Rice, C. J., Ruzi, S. A., Thairu, M. W., Wilson, J. C., & Suarez, A. V. (2020). From eDNA to citizen science: Emerging tools for the early detection of invasive species. *Frontiers in Ecology and the Environment*, *18*, 194–202. https://doi.org/10.1002/fee.2162

Latombe, G., Pyšek, P., Jeschke, J. M., Blackburn, T. M., Bacher, S., Capinha, C., Costello, M. J., Fernández, M., Gregory, R. D., Hobern, D., Hui, C., Jetz, W., Kumschick, S., Mcgrannachan, C., Pergl, J., Roy, H. E., Scalera, R., Squires, Z. E., Wilson, J. R. U., & McGeoch, M. A. (2017). A vision for global monitoring of biological invasions. *Biological Conservation*, *213*, 295–308. https://doi.org/10.1016/j.biocon.2016.06.013

Leadley, P., Gonzalez, A., Obura, D., Krug, C. B., Londoño-Murcia, M. C., Millette, K. L., Radulovici, A., Rankovic, A., Shannon, L. J., Archer, E., Armah, F. A., Bax, N., Chaudhari, K., Costello, M. J., Dávalos, L. M., Roque, F. D. O., Declerck, F., Dee, L. E., Essl, F., … Xu, J. (2022). Achieving global biodiversity goals by 2050 requires urgent and integrated actions. *One Earth*, *5*, 597–603. https://doi.org/10.1016/j.oneear.2022.05.009

Lovell, J. T., Macqueen, A. H., Mamidi, S., Bonnette, J., Jenkins, J., Napier, J. D., Sreedasyam, A., Healey, A., Session, A., Shu, S., Barry, K., Bonos, S., Boston, L., Daum, C., Deshpande, S., Ewing, A., Grabowski, P. P., Haque, T., Harrison, M., & Schmutz, J. (2021). Genomic mechanisms of climate adaptation in polyploid bioenergy switchgrass. *Nature*, *590*, 438–444. https://doi.org/10.1038/s41586-020-03127-1

McGeoch, M., & Jetz, W. (2019). Measure and reduce the harm caused by biological invasions. *One Earth*, *1*, 171–174. https://doi.org/10.1016/j.oneear.2019.10.003

Mehta, S. V., Haight, R. G., Homans, F. R., Polasky, S., & Venette, R. C. (2007). Optimal detection and control strategies for invasive species management. *Ecological Economics*, *61*, 237–245. https://doi.org/10.1016/j.ecolecon.2006.10.024

Meyer, C., Weigelt, P., & Kreft, H. (2016). Multidimensional biases, gaps and uncertainties in global plant occurrence information. *Ecology Letters*, *19*, 992–1006. https://doi.org/10.1111/ele.12624

Miralles, L., Ibabe, A., González, M., García-Vázquez, E., & Borrell, Y. J. (2021). "If you know the enemy and know yourself": Addressing the problem of biological invasions in ports through a new NIS invasion threat score, routine monitoring, and preventive action plans. *Frontiers in Marine Science*, *8*, 633118. https://doi.org/10.3389/fmars.2021.633118

Mormul, R. P., Vieira, D. S., Bailly, D., Fidanza, K., Da Silva, V. F. B., Da Graça, W. J., Pontara, V., Bueno, M. L., Thomaz, S. M., & Mendes, R. S. (2022). Invasive alien species records are exponentially rising across the Earth. *Biological Invasions*, *24*, 3249–3261. https://doi.org/10.1007/s10530-022-02843-1

OECD. (2019). The Post-2020 Biodiversity Framework: Targets, indicators and measurability implications at global and national level. https://www.oecd.org/environment/resources/biodiversity/post-2020-biodiversity-framework.htm

Oliver, R. Y., Meyer, C., Ranipeta, A., Winner, K., & Jetz, W. (2021). Global and national trends, gaps, and opportunities in documenting and monitoring species distributions. *PLoS Biology*, *19*, e3001336. https://doi.org/10.1371/journal.pbio.3001336

Pagad, S., Bisset, S., Genovesi, P., Groom, Q., Hirsch, T., Jetz, W., Ranipeta, A., Schigel, D., Sica, Y. V., & McGeoch, M. A. (2022). Country compendium of the global register of introduced and invasive species. *Scientific Data*, *9*, 391. https://doi.org/10.1038/s41597-022-01514-z

Seebens, H. (2021). Alien Species First Records Database. https://doi.org/10.5281/zenodo.4632335

Solow, A. R., & Costello, C. J. (2004). Estimating the rate of species introductions from the discovery record. *Ecology*, *85*, 1822–1825. https://doi.org/10.1890/03-3102

Solow, A. R., & Smith, W. K. (2005). On estimating the number of species from the discovery record. *Proceedings of the Royal Society B: Biological Sciences*, *272*, 285–287. https://doi.org/10.1098/rspb.2004.2955

Tennen, R. I., Bua, D. J., Wright, W. E., & Chua, K. F. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications*, *8*, 14435. https://doi.org/10.1038/ncomms1443

Tittensor, D. P., Walpole, M., Hill, S. L. L., Boyce, D. G., Britten, G. L., Burgess, N. D., Butchart, S. H. M., Leadley, P. W., Regan, E. C., Alkemade, R., Baumung, R., Bellard, C., Bouwman, L., Bowles-Newark, N. J., Chenery, A. M., Cheung, W. W. L., Christensen, V., Cooper, H. D., Crowther, A. R., & Ye, Y. (2014). A mid-term analysis of progress toward international biodiversity targets. *Science*, *346*, 241–244. https://doi.org/10.1126/science.1257484

Van Rees, C. B., Hand, B. K., Carter, S. C., Bargeron, C., Cline, T. J., Daniel, W., Ferrante, J. A., Gaddis, K., Hunter, M. E., Jarnevich, C. S., McGeoch, M. A., Morisette, J. T., Neilson, M. E., Roy, H. E., Rozance, M. A., Sepulveda, A., Wallace, R. D., Whited, D., Wilcox, T., & Luikart, G. (2022). A framework to integrate innovations in invasion science for proactive management. *Biological Reviews*, *97*, 1712–1735. https://doi.org/10.1111/brv.12859

Vicente, J. R., Vaz, A. S., Roige, M., Winter, M., Lenzner, B., Clarke, D. A., & McGeoch, M. A. (2022). Existing indicators do not adequately monitor progress toward meeting invasive alien species targets. *Conservation Letters*, *15*, e12918. https://doi.org/10.1111/conl.12918

Visser, V., Wilson, J. R. U., Fish, L., Brown, C., Cook, G. D., & Richardson, D. M. (2016). Much more give than take: South Africa as a major donor but infrequent recipient of invasive non-native grasses. *Global Ecology and Biogeography*, *25*, 679–692. https://doi.org/10.1111/geb.12445

Wonham, M. J., & Pachepsky, E. (2006). A null model of temporal trends in biological invasion records. *Ecology Letters*, *9*, 663–672. https://doi.org/10.1111/j.1461-0248.2006.00913.x

SUPPORTING INFORMATION

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

How to cite this article: McGeoch, M. A., Buba, Y., Arlé, E., Belmaker, J., Clarke, D. A., Jetz, W., Li, R., Seebens, H., Essl, F., Groom, Q., García-Berthou, E., Lenzner, B., Meyer, C., Vicente, J. R., Wilson, J. R. U., & Winter, M. (2023). Invasion trends: An interpretable measure of change is needed to support policy targets. *Conservation Letters*, *16,* e12981. https://doi.org/10.1111/conl.12981