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Economic costs of forest pest invasions are under-sampled worldwide but high and increasing outside Europe and North America

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Abstract

Forest pest invasions threaten biodiversity, folkways, and ecosystems. However, an assessment of their costs, which is possible globally using the InvaCost database, is needed to grab the attention of policymakers and decision-makers. Overall costs, damage costs, and management costs for invasive fungi, arthropods, and nematodes were extracted from the InvaCost database, standardized, estimated, and modeled over time. Only costs estimated prior to 2010 were considered due to a lag in reporting, but they could be used to estimate current costs. The overall lack of data in the InvaCost database for forest pest invasions indicated underestimation and under-sampling of their costs. Nonetheless, some key differences in trends were apparent, including in annual costs in 2025 and rate of increase between Europe (US $347M + 1% per year) and North America (1.8B + 2% per year), which were much smaller and increasing more slowly than the rest of the world (i.e., Asia and Global South; 506M + 13% per year). There was another key mismatch in the ratio of cumulative costs of damage vs. management from 1980-2010 in Asia and the Global South (10B vs. 29M), and to a less extent, North America (18 vs. 2.6B) compared to Europe, where investment in management was comparable to costs of damage (12 vs. 12B). Annual global costs are estimated to increase to US $50B by 2050, but with a wide range of uncertainty. The uncertainty of current and future costs of invasive forest pathogens highlights the uncertainty-visibility tradeoff between proactive and reactive approaches to forest pest invasions and provides rationale for increased investment in and integration of research, monitoring, and management.

Keywords: exotic, introduced, fungus, native, natural, pathogen, policy, socioeconomic

Introduction

Biological invasions are among the principal drivers of biodiversity loss worldwide, and they are both environmentally and economically costly. In particular, invasive forest pests (pathogens and insect herbivores that attack trees) reduce productivity and ecosystem services, and in rare cases, have caused functional extinction of entire species across their native range (Ellison et al. 2005; Ward et al. 2021). Although the negative impacts of invasive forest pests range from loss of cultural heritage (Roy et al. 2024), to watershed health, carbon sequestration, and wildlife habitat, it is unfortunately necessary to quantify their impacts in terms of economic costs in order to influence policy and public decision-making (Williams et al. 2023).

Despite recent attempts to standardize and quantify impacts of invasive species worldwide (Diagne et al. 2020; Roy et al. 2023), there have been only a few general studies (continent or global scale) of the economic costs of invasive forest pests (e.g., Aukema et al. 2011). Fortunately, InvaCost, a recent database (Diagne et al. 2020) and an accompanying package in the R programming language (Leroy et al. 2022) provide a standardized framework to quantify costs of invasive forest pests worldwide, as well as the opportunity to evaluate how comprehensive the database’s treatment (and therefore, available literature) may be for invasive forest pests. Ultimately, the availability of long-term data on economic costs could provide a basis to project expected costs into the future, and could facilitate long term financial planning by governments based on previous and current trends.

A standardized dataset also provides the opportunity to compare costs among world regions. There may be an imbalance in documentation of forest pest invasions and their impacts between wealthy and less wealthy, English-speaking and non-English speaking, and/or temperate and tropical countries (Chong et al. 2021; Gougherty and Davies 2022). This imbalance may be due in part to citation bias towards English within English-language scientific literature, and this imbalance extends to quantifying costs of biological invasions (Angulo et al. 2021). In any case, invasion biology, the study of human-aided movements and introductions of organisms to new habitats, is a field where international collaboration is critical. By comparing costs across world regions, it may be possible to highlight areas where such collaboration is needed.

The goals of this study were to use the InvaCost database and R package to b) evaluate the completeness of the data for forest pests, b) quantify costs of forest pest invasions over time, and c) estimate current and project future costs based on previous trends.

Methods

The InvaCost database was last updated in 2022 (version 4.1). I filtered organisms that belong to major pest groups (fungi, oomycetes, arthropods, and nematodes) and forest and horticultural habitats (forests, woodlands, scrub, and nonagricultural human-modified landscapes), filtered out non-pest species, and divided the data by region (North America, Europe, and the rest of the world i.e., Asia & Global South), as well as by cost type (all, damage, and management). Next, annual costs were estimated and summarized using the *expandYearlyCosts* and *summarizeCosts* functions. To control quality, prior to estimating yearly costs, I used the adjusted probable start and end date and cleaned the data by removing records with dubious probable start and end dates. Due to the fact that cost assessment reports tend to accumulate slowly over time, costs decreased after 2010 in the database, so we only considered the time span 1980-2010. To assess the comprehensiveness of the database for invasive forest pathogens, I calculated number of unique sources (papers, reports, communications) and tabulated the major forest pest species represented in the database for each region and cost type. To explore long-term trends, I conducted linear and quadratic ordinary least square (OLS) regressions with *modelCosts2* because of the simplicity of OLS and for sake of brevity of presentation.

Results and Discussion

There was a paucity of information in the database to provide reliable projections of future costs of forest pest invasions in Europe and North America relative to the rest of the world (Table 1). Across regions, references referred to 39 unique species and were dominated by 8 organisms: one nematode, one fungal, one chromist, and five insect species (Table 1). The sparsity of the dataset is reflected in a wide range of projections and cost growth rate error (Fig. 1, Table 2), including some that decreased in quadratic regressions due to the time lag when approaching 2010 (*i.e.*, Figs. 1B, F). The lag in accounting after 2010 resulted in major recent pest invasions going unaccounted for, such as beech leaf disease caused by the nematode *Litylenchus crenatae mccannii*, spotted lantern fly *Lycorma delicatula*, vascular streak dieback, *Fusarium* dieback and its shothole borer vectors *Euwallacea* spp., laurel wilt caused by *Harringtonia lauricola* and its ambrosia beetle vectors, etc. Estimates were sparse prior to 1980, particularly for damage, but also for management in North America (Table 3).

Conceding obvious data limitations, there was nevertheless a notable discrepancy between damage and management outside of Europe and North America (26 vs. <1 % of global costs), while Europe invested six times more in management than North America in relation to damage costs (Table 2)—partly due to the fact that damages weren't quantified in Europe prior to 2000 (Table 3). Nevertheless, these differences derive from the difficulty of coordinating pest management in North America and China across large continental land areas and ranging levels and provenances of governments and institutions. In Europe, small nations can mobilize substantial resources relative to their size on local scales while benefitting from collaborative governance entities (*e.g.*, EPPO). Clearly, pooling resources, knowledge, and expertise on a global scale is needed to reduce costs through investment in management, monitoring, and prevention.

Costs of invasions are also increasing fastest outside Europe and North America (Table 2, Fig. 1). Given a lack of saturation in pest invasions (Seebens et al. 2017) and increased travel and interest in biosecurity, continued exponential increases in costs of forest pest invasions is expected. Future costs, which depend in part on management and policy decisions, could be limited by adoption of proactive policy or nearshoring of global trade in the future, but may continue to increase outside Europe and North America as economies emerge and become more integrated in global supply chains and/or as trade networks "re-shore" across the world.

It is likely that the estimates reflected in the database fall far short of accounting for costs of invasive forest pests. Based on World Bank figures (data.worldbank.org), invasive forest pests, which cost US $ 4.3 billion annually in the decade 2000-2010 (Table 3), accounting for 0.004% of global GDP (~US$100T). This global figure accounts for only ~1% of the annual estimate for the cost of all types of invasive organisms (Roy et al. 2023), or 0.4% of GDP. Given

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that invasions of plants, animals, non-herbivore arthropods like wasps, and crop pests are better quantified and recognized by policymakers compared to pests that impact natural systems, this discrepancy is unsurprising and likely due to the predominantly market-focused paradigm of risk assessment (Williams et al. 2023).

The lack of data on costs of forest invasive pest also reflects a fundamental tradeoff between proactive and reactive approaches to mitigate the impacts of forest pest invasions (Williams et al. 2023): landscape-scale management of spreading invasive pests is costly to intractable; but uncertainty regarding incipient and future invasions consistently precludes effective prevention. For example, scientists are still learning the basic biology of *L. crenatae mccannii*, the foliar-feeding nematode, an understudied life history in forest pathology that causes Beech leaf disease and kills young and mature *Fagus grandifolia*, which has spread rapidly in twelve years since its discovery (Ewing et al. 2019; Carta et al. 2020; Marra and LaMondia 2020; Kantor et al. 2022; Vieira et al. 2023). In addition to costs and biology, uncertainty of eventual ecological and social impacts persists for many pests many years after their establishment. The shortcomings of our understanding of something as basic as economic cost of forest pest invasions underscores a need for integrative approaches that span value systems, management modes, and prevention and management.

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Competing Interests

The author has declared that no competing interests exist

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Data Resources

The InvaCost R package is available at www.github.com/Farewe/invacost. The code used to produce this analysis is available at github.com/usfsipsentinelnetwork/neobiota_invacost_IFPs

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Table 1. Summary of publications relevant to forest pests in InvaCost database 1980-2010

Global Region	Number of pubs			Main Organisms in Records	
	All Costs	Damage	Management	Organism(s)	% of records
Europe	12	6	11	*H. fraxineus* (ash dieback)	77%
				Monochamus spp. (longhorn beetles)	12%
				Total	**89%**
North America	8	5	5	*Adelges* spp. (balsam/hemlock wooly adelgids)	18%
				L. dispar (spongy moth)	18%
				P. ramorum (sudden oak death)	14%
				Total	**50%**
Asia & Global South	25	11	14	*B. xylophilus* (pine-wilt nematode)	20%
				Sirex noctilio (woodwasp)	50%
				Total	**70%**
Worldwide	45	22	30	**All above, percent of all records**	**64%**

Table 2. Estimated costs (2023 $US)

Global Region	Damage		Management		All Costs				
	Total*	% global	Total	% global	Total	% global	Annual costs**		
							Δ/y (± 1.96SE)	2025	2050
Europe	12B	30%	12B	82%	24B	36%	1 (-51, 200)%	347M	480M
North America	18B	44%	2.6B	18%	33B	49%	2 (-51, 206)%	1.8B	3.2B
Asia & Global South	10B	26%	29M	< 1%	20B	15%	13 (-57, 245)%	506M	11B
Worldwide	40B		15B		68B		7 (-54, 212)%	8.5B	50B

† cumulative 1980-2010

‡ based on linear ordinary least squares regression

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Table 3. Annual average costs of invasive forest pests from InvaCost database by decade (2023 $US 1 Millions)

Global Region	Worldwide			North America			Europe			Global South and Asia		
Type of Cost	All	Damage	Mgmnt.	All	Damage	Mgmnt.	All	Damage	Mgmnt.	All	Damage	Mgmnt.
Period												
1960-69	181.5	-	181.5	-	-	-	181.1	-	181.1	0.4	-	0.4
1970-79	181.5	-	181.5	-	-	-	181.1	-	181.1	0.4	-	0.4
1980-89	374.5	117.6	181.5	173.2	97.8	-	181.1	-	181.1	20.2	19.8	0.4
1990-99	1,265.5	672.2	213.5	853.6	451.6	31.9	181.1	-	181.1	230.8	220.6	0.5
2000-10	4,346.6	2,943.9	634.2	2,081.4	1,115.9	205.2	1,538.8	1,110.8	427.9	726.4	717.2	1.0
Cumulative	67,845.0	40,281.4	14,557.5	33,164.4	17,768.7	2,576.2	24,171.5	12,218.9	11,952.6	10,509.2	10,293.8	28.8

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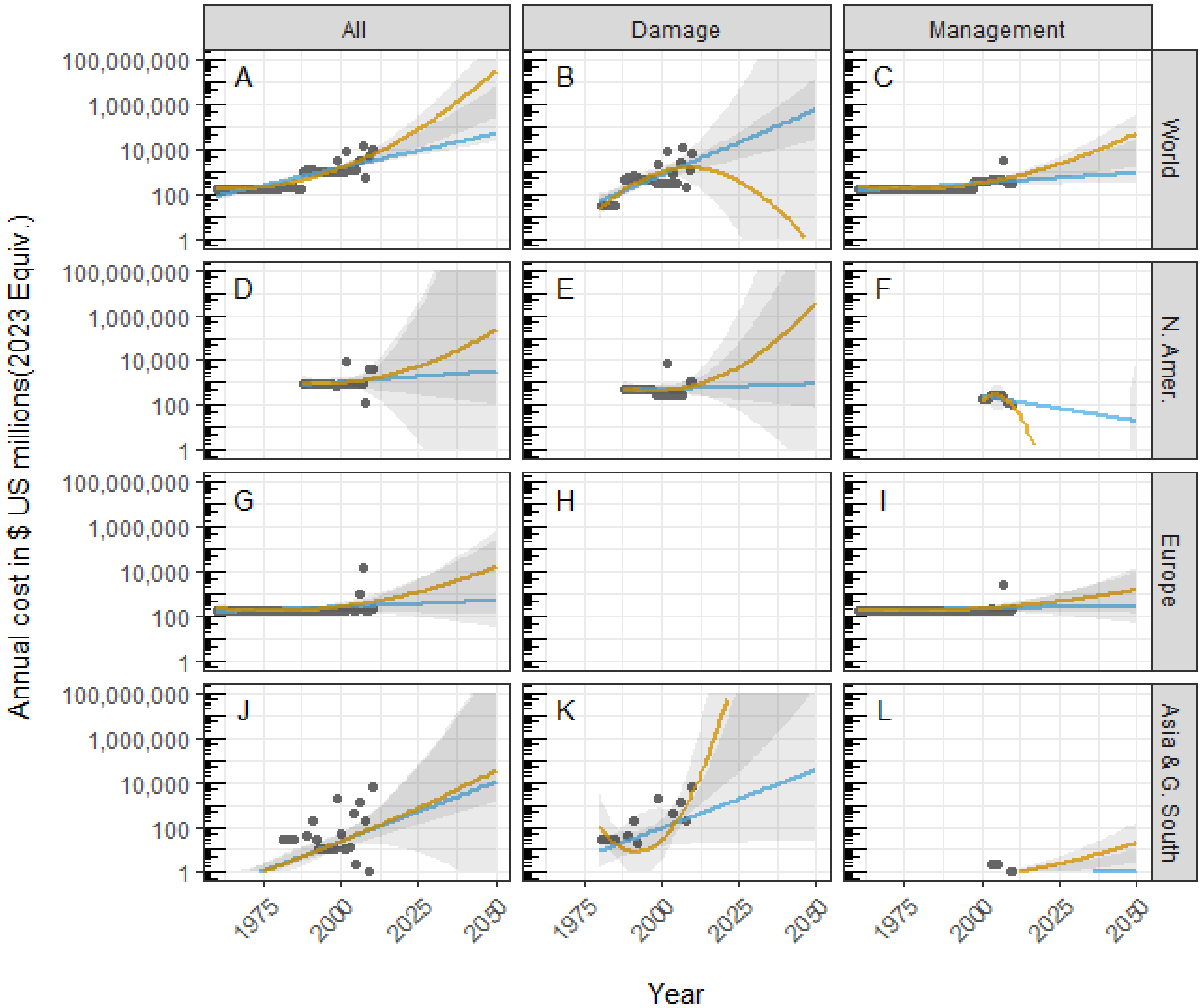
Figure 1. Ordinary least squares linear (blue lines) and quadratic (orange lines) projections of costs ($US 1 Million, 2023 equivalent) of invasive forest pests (nematodes, fungi, and athropods in forest systems) from the InvaCost database based on data from 1980-2010. Observed data, binned and annualized across decades, are depicted as points on the plots.



Works Cited

Angulo E, Diagne C, Ballesteros-Mejia L, Adamjy T, Ahmed DA, Akulov E, Banerjee AK, Capinha C, Dia CA, Dobigny G (2021) Non-English languages enrich scientific knowledge: the example of economic costs of biological invasions. Science of the Total Environment 775: 144441.

Aukema JE, Leung B, Kovacs K, Chivers C, Britton KO, Englin J, Frankel SJ, Haight RG, Holmes TP, Liebhold AM (2011) Economic impacts of non-native forest insects in the continental United States. PLoS One 6: e24587.

Carta LK, Handoo ZA, Li S, Kantor M, Bauchan G, McCann D, Gabriel CK, Yu Q, Reed S, Koch J, Martin D, Burke DJ, Woodward S (2020) Beech leaf disease symptoms caused by newly recognized nematode subspecies Litylenchus crenatae mccannii (Anguinata) described from Fagus grandifolia in North America. Forest Pathology 50: doi:10.1111/efp.12580.

Chong KY, Corlett RT, Nuñez MA, Chiu JH, Courchamp F, Dawson W, Kuebbing S, Liebhold AM, Padmanaba M, Souza L, Andersen KM, Fei S, Lee BPY-H, Lum S, Luskin MS, Ngo KM, Wardle DA (2021) Are Terrestrial Biological Invasions Different in the Tropics? Annual Review of Ecology, Evolution, and Systematics 52: 291-314. doi:10.1146/annurev-ecolsys-012021-095454.

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.

Ellison AM, Bank MS, Clinton BD, Colburn EA, Elliott K, Ford CR, Foster DR, Kloeppel BD, Knoepp JD, Lovett GM (2005) Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3: 479-486.

Ewing CJ, Hausman CE, Pogacnik J, Slot J, Bonello P (2019) Beech leaf disease: An emerging forest epidemic. Forest Pathology 49: e12488.

Gougherty AV, Davies TJ (2022) Most countries are vulnerable to novel pest invasions and under-report the diversity of tree pests. Global Ecology and Biogeography 31: 2314-2322. doi:https://doi.org/10.1111/geb.13580.

Kantor M, Handoo Z, Carta L, Li S (2022) First report of beech leaf disease, caused by Litylenchus crenatae mccannii, on american beech (Fagus grandifolia) in Virginia. Plant disease 106: 1764.

Leroy B, Kramer AM, Vaissière Ac, Kourantidou M, Courchamp F, Diagne C (2022) Analysing economic costs of invasive alien species with the invacost R package. Methods in Ecology and Evolution 13: 1930-1937.

Marra R, LaMondia J (2020) First Report of beech leaf disease, caused by the foliar nematode, Litylenchus crenatae mccannii, on American Beech (Fagus grandifolia) in Connecticut. Plant disease 104: 2527.

Roy HE, Pauchard A, Stoett P, Truong TR, Bacher S, Galil BS, Hulme PE, Ikeda T, Sankaran K, McGeoch MA (2023) IPBES Invasive Alien Species Assessment: Summary for Policymakers. IPBES:

Roy K, Frankel SJ, Oakes LE, Francisco KS, Kealiʻikanakaʻoleohaililani K, Sitz RA, Huff ES, Schelhas J (2024) Perceptions of Tree Diseases in Indigenous Communities: Native Alaskan and Hawaiian Insights. Journal of Forestry: doi:10.1093/jofore/fvad053.

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M (2017) No saturation in the accumulation of alien species worldwide. Nature communications 8: 14435.

Vieira P, Kantor MR, Medina-Mora CM, Sakalidis ML, Handoo ZA (2023) First report of the beech leaf disease nematode Litylenchus crenatae mccannii (Nematoda: Anguinidae) in Michigan. Plant disease 107: 2266.

Ward SF, Liebhold AM, Morin RS, Fei S (2021) Population dynamics of ash across the eastern USA following invasion by emerald ash borer. Forest Ecology and Management 479: 118574.

Williams GM, Ginzel MD, Ma Z, Adams DC, Campbell F, Lovett GM, Pildain MB, Raffa KF, Gandhi KJ, Santini A (2023) The global forest health crisis: A public-good social dilemma in need of international collective action. Annual Review of Phytopathology 61: