Determining the relationship between invasive alien species density and a country's socio-economic status

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ABSTRACT

We explored the relationships between various socio-economic variables and the prevalence and density of invasive alien species (IAS) on a global scale using country-level data sets. We did this by testing the hypothesis that the abundance and distribution of populations of IAS are correlated with various socio-economic indicators, with the direction of causality being that the state of IAS is determined by socio-economic conditions. We found a positive and statistically significant relationship between the prevalence and density of IAS and the human development index (HDI), the satisfaction with life index and the gross domestic product (GDP) among all the countries tested. Additionally, the density of IAS increased significantly with human-population density, total geographic area, GDP and HDI. We also found a positive relationship between the density of IAS and the top 10 road networks of the world. This provides some insight into the development of renewed policies and management strategies for invasive species across both continents and countries. We do caution, however, that the results are likely to be influenced by the sampling factor, whereby affluent countries have more resources to measure and monitor IAS than poorer countries and hence have better records of such, which then indicates a stronger relationship with the level of development.

INTRODUCTION

The introduction and spread of invasive alien species (IAS) have been predicted from land-use and socio-economic factors. While links between these factors have been made on certain scales (within-country, regional and limited-country comparisons), a geographically comprehensive comparison has not yet been attempted. Therefore, we report on an evaluation of the hypothesis that the prevalence and density of IAS at country level are correlated with the state and rate of change in the economic development of that country. We did this to determine whether or not there is a link between the prevalence, density and distribution of IAS and the level of economic development.

Higher trade volumes and the increased movement of people are inextricably linked to increased levels of affluence and improved transportation networks, both the result of economic growth. These levels of affluence and networks open the door to an increased movement in both plant and animal species, which jump borders and continents in ways and at rates that would not have been possible without this level and extent of trade and transport. It has been established that, for China, fast economic growth accelerates invasion by exotic species.[1] Furthermore, the relationships between the number of invasive alien plant species and some socio-economic factors in China have been compared to those of the United States of America (USA), leading to the conclusion that Chinese provinces are likely to become more invaded as economic development progresses, since international commerce will bring new invaders.[2] Economic trade has also been implicated in the spread of IAS on a global scale.[3] Furthermore, it has been shown that, at a regional level, disturbed and anthropogenically induced transformed environments are invaded more than pristine areas.[4]

Land-use and socio-economic factors apparently influence the introduction and spread of IAS directly.[5] This conclusion was reached after the exploration of the predictive power of land-use and socio-economic parameters on the density of alien plants in European and North African countries. There is also a general notion that development and progress increase the number of IAS.[6] An analysis of the relative influence of several economic variables on the share of IAS in terms of the density or intensity of invasion has suggested that disturbances associated with human activities and gross domestic product (GDP) per capita are important determinants of a given country's vulnerability to invasions.[7]

Economic development is associated with infrastructure expansion and it has been shown that road networks and their development do indeed act as corridors and conduits for the spread of IAS.[8,9] In developed countries, road networks extend over large areas and are particularly dense in highly populated regions.[8,9] In contrast, road networks in developing countries are often less extensive in rural areas.[10] Roads and activities surrounding their development and maintenance also provide suitable conditions for the establishment, growth and spread of IAS.[11,12,13]

While much work has been done on the relationship between the state of and change in country- and area-specific economic activity and the prevalence and spread of IAS, to our knowledge, no global comparative analysis has been done using country-level data. To bridge this knowledge gap, we assumed, firstly, that high human densities occur in areas where there is high(er) economic productivity and, secondly, that areas with potentially high and positive economic growth are measured as changes in the GDP. While GDP is an extremely weak indicator of human welfare and economic development, it is a uniform measure of income and changes in income and of the income gap between and among nations; levels of environmental transformation, including invasion, are linked to economic growth.

A variety of primary and secondary driving forces of invasion operates within and across national and international boundaries. Primary driving forces (Table 1),[14] such as the arrival of new propagules and disturbance regimes, are inextricably linked and can operate individually or together to facilitate or hinder invasions. Secondary driving forces, such as human-population growth and movement and global climate change, are likely to have a direct effect on the primary driving forces of propagule arrival and changes in limiting factors, respectively. From the perspective of first principles therefore, it is the secondary driving forces that affect, influence and contribute to the primary driving forces

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TABLE 1
Primary and secondary driving forces of invasion that operate within and across national and international boundaries

Primary driving force	Secondary driving force
Arrival of new propagules	Human-population growth
Disturbance regime	Expanding network of international trade and travel links
Changes in limiting factors	Increasing magnitude of international trade
Fragmentation of landscape	Globalisation of economies
–	Global economic trends, globalisation of forestry/agro-forestry enterprise
–	Improved communication methods
–	Growth and maturation of invasion ecology into a robust, predictive science
–	Global climate change
–	International treaties

Source: compiled from Le Maitre et al.[14]

and not the other way around. It is self-evident that IAS do not cause economic growth or the movement of people or economic trade; they are a consequence thereof. The causal relationship is therefore unidirectional.

The question, and the focus of this study, centres on the strength of this relationship and whether there is a meaningful and statistically significant difference among countries with different levels of economic development.

Given that levels of environmental transformation are linked to economic growth and the need for resources and given the established links between environmental transformation and the prevalence and spread of IAS, one can accept that measures such as GDP per capita and human-population density can be considered as conduits or even drivers for both propagule pressure and ecological disturbance, which facilitates the establishment and spread of alien species.[4,15] One can therefore anticipate that developed countries are likely to have more IAS than developing countries.

We tested these assumptions against various indicators of the level and change in socio-economic well-being, such as population density, GDP, the happy planet index (HPI), the satisfaction with life (SWL) index and the human development index (HDI) (Table 2). We assumed that the indicators of social well-being, such as the HPI and SWL indices, also provide insight into the ecological dimension of human well-being, in other words there is more to happiness than economic prosperity alone. The latter can be achieved only when ecosystem services, defined as the end products of nature that benefit humans,[16] are optimal and without the hindrance of IAS.

Emerging correlations from this study may provide insight regarding the renewal of policies and management strategies for invasive species across continents and countries.

METHODS

We used the International Union for Conservation of Nature (IUCN, or World Conservation Union) definition of IAS as 'an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity'.[17] Ultimately, the degree to which IAS impact biodiversity is the most important consideration; we thus did not take the broader approach of including all alien species in a country. Instead, we used the IAS database of the Invasive Species Specialist Group of the IUCN, which is the most geographically comprehensive database on invasive species worldwide.[17] It includes 227 countries and profiles on 357 IAS across all taxa that are significant threats to native biodiversity.[17] We used the density of invasive aliens (i.e. the number of IAS divided by the $\log_{10}$ area of the country concerned) and not the number of invasive aliens per se to avoid confounding effects with area.[4,18]

The HDI was retrieved from the *Human development report 2007/2008* of the United Nations (UN) Development Programme[19] and GDP was retrieved from the *World economic outlook database*[20] and the International Monetary Fund.[21] Human population was compiled from UN estimates and from the population clock for each country on 3 December 2007.[22] Area for countries was retrieved from *Wikipedia*[23], as was the SWL index[24] and the HPI was obtained from the New Economics Foundation and *Wikipedia*[25,26]. A list of the top 10 countries with the longest road networks, together with the extent of these networks, was compiled from maps of the world.[27] The FTSE index of the *Financial Times* and the London Stock Exchange groups countries into developed, advanced-emerging and secondary-emerging (comprising largely developing or poorer) countries.[28] We assumed that these groups provide an indication of emerging international trade and therefore more opportunity for invasion, which is why we used the FTSE classification and because it is the leading world index provider in terms of countries that are emerging financially in economic investment and international trade. We used all the above-mentioned indicators of socio-economic well-being and economic development as they are arguably the best predictors of the social and economic well-being of countries (Table 2).

Correlations were performed among the various socio-economic variables and regression analysis was conducted for human population, total geographic area, HDI and GDP for the 172 countries under investigation. Residual regressions were performed between GDP and the density of IAS, with the successive removal of the top invaded countries using the SPSS (SPSS Inc., Chicago, USA) statistical package.[29] We used non-parametric correlations (Spearman's correlation) to investigate the relationships among various socio-economic factors and IAS.

RESULTS

Significant relationships between the density of IAS and the indicators of socio-economic well-being were obtained across the world (Table 3). There was a positive and significant

TABLE 2
Explanations of the socio-economic indicators used in the study

Indicator	Description
HDI[19]	The human development index (HDI) is a summary measure of human development. It measures the average achievements in a country in three basic dimensions of human development: long and healthy life, knowledge, and decent standard of living.
HPI[26]	The happy planet index (HPI) is an innovative measure that shows the ecological efficiency with which human well-being is delivered around the world. This index combines environmental impact with well-being to measure the environmental efficiency with which country by country, people live long and happy lives.
SWL[49]	Satisfaction with life (SWL) is a measure of an individual's perceived level of well-being and happiness which is related to health, wealth, and access to basic education.
GDP[50]	Gross domestic product (GDP) is defined as the total market value of all final goods and services produced within a country in a given period of time. GDP is considered as the best indicator for a country's economic development.
FTSE[28]	FTSE (The *Financial Times* and the London Stock Exchange) Global Equity classification index is based on the ease, cost and security of underlying investment transactions by international investors in all countries. This classification groups countries into developed, advanced-emerging, and secondary-emerging (which largely comprise developing or poorer) countries.
Human population[22]	Total population of a country accessed on 3 December 2007.
Geographic area[23]	Total geographic area of a country in km^2.

Sources for data are shown with the relevant indicators.

relationship between the density of IAS and the HDI ($r^2 = 0.509$; $p < 0.01$), the SWL index ($r^2 = 0.298$; $p < 0.01$) and the GDP ($r^2 = 0.680$; $p < 0.01$).

When all the countries ($n = 172$) were included in the regression analysis between GDP and IAS, we found that the USA was the driving factor for the significance of the data. Residual-regression analysis revealed that significance values decreased as the top invaded countries (and, correspondingly, those with the highest GDP) were removed from the analysis (the outliers in the datasets) (Table 4).

More affluent countries have more potential for species cataloguing, which could explain the relationship between GDP and IAS. There was a significant increase in invasive-species numbers with increasing GDP, total geographic area and human population (Figure 1). GDP showed a significant positive correlation with the HDI and SWL index but was not related to the HPI. Although the density of IAS was significantly positively related to the HDI, SWL index and GDP, no significant relationship was found between the HPI and the density of IAS. Results clearly illustrated a positive relationship between the number of IAS and the top 10 road networks of the world ($r^2 = 0.61$; $p < 0.05$) (Figure 2a). A change in pattern was observed when the density of alien species was related to the density (km/km^2) of the top 10 road networks, although the significance value increased ($r^2 = 0.90$; $p < 0.001$) (Figure 2b).

DISCUSSION

A key point emerging from our study is that a country's economic strength and socio-economic status, according to the most commonly used indices, are excellent predictors of IAS density. This association is due mainly to three reasons. Firstly, more funds are likely to be available for the research, surveying and cataloguing of IAS. Secondly, if GDP is high, there is greater potential for more imports and therefore probably for more opportunities for the introduction of IAS. Thirdly, greater affluence means improved road networks and, therefore, more opportunities for the introduction and spread of IAS. It is important to understand these drivers and to interpret which plays a more important driving role.

Research agendas are more directly influenced by economic priorities and practical limitations than by geographic and socio-political barriers.[30] The economic status of a region affects research efforts not only directly, by more resources being spent on the problems of biological invasions in developed states than in developing ones, but also historically because developed states have more advanced systems of science and education and therefore greater resources to survey and catalogue the presence of IAS. The surveying and cataloguing of IAS in the USA, for example, are extensive due to the higher funding of research, thus revealing a potential source of error in the IAS data set.

Due to the growing number of databases of alien plants and animals,[31] reliable and balanced data for the unbiased comparison of research effort with levels of invasion are likely to be difficult to obtain and the issue of circular reasoning in exploring relationships with these data has been raised.[32] Major global databases are selective because they are not aimed at providing a complete overview of global invaders but rather at documenting those with a serious impact. Moreover, the inclusion of species in these databases is based largely on published information, most of which comes from case studies; the databases thus reflect what is recorded in scientific literature rather than the real state of affairs. The number of IAS in most databases and check-lists is furthermore affected by sampling effort.[33]

The results presented in this study should, therefore, be interpreted with caution. Our study approach is statistically exploratory but it does highlight the strong potential links between plant invasions and human economic activities. We argue that, for a broader picture of the current scenario, such data sets can lead to some reliable conclusions with implications.

Our results suggest that human population, total geographic area and HDI have less of an influence on invasive alien spread and that GDP plays a more prominent role. GDP could be a surrogate measure for the total imports and exports of a country.[34] There is positive feedback between the degree of wealth and invasions because developed countries with high GDP and large trade volumes are also those that receive the most alien species as an inescapable by-product of trade in commodities.[4,32,35] In a study from the continental USA, GDP was positively related to the establishment rates of alien species.[35] The results suggested that the more developed countries (with a high GDP) are rich in IAS possibly due to the above reasons. In most developing countries, however, the primary goal of government is GDP growth and not necessarily environmental protection; invasive species are thus largely ignored.[36]

Economic practices and related incentives could, therefore, be a powerful policy tool to reduce future invasions.[13] The concept of 'the rich get richer' has been subjected to theoretical debate for several decades;[18,37,38,39,40,41,42,43] and here we demonstrate a situation in which economically richer countries are becoming richer in IAS. We were unable, however, to detect a significant trend in the number of IAS in the developed, advanced-emerging and secondary-emerging countries of the FTSE classification, due to the high variability among the countries (Figure 3).

Road networks are the backbone of a country's economic development. The significant positive relationship between the countries with the top 10 road networks and road density and the number and density of IAS also indicates that road development could facilitate the spread of IAS in these countries (Figures 2a and 2b). Turbulence created by passing vehicles, for example, enhances plant dispersal.[44] The recent construction of transport networks (such as highways and railways) also enhances the immigration rates of new species and the spread of existing species.[44,45] A similar relationship has been found with road

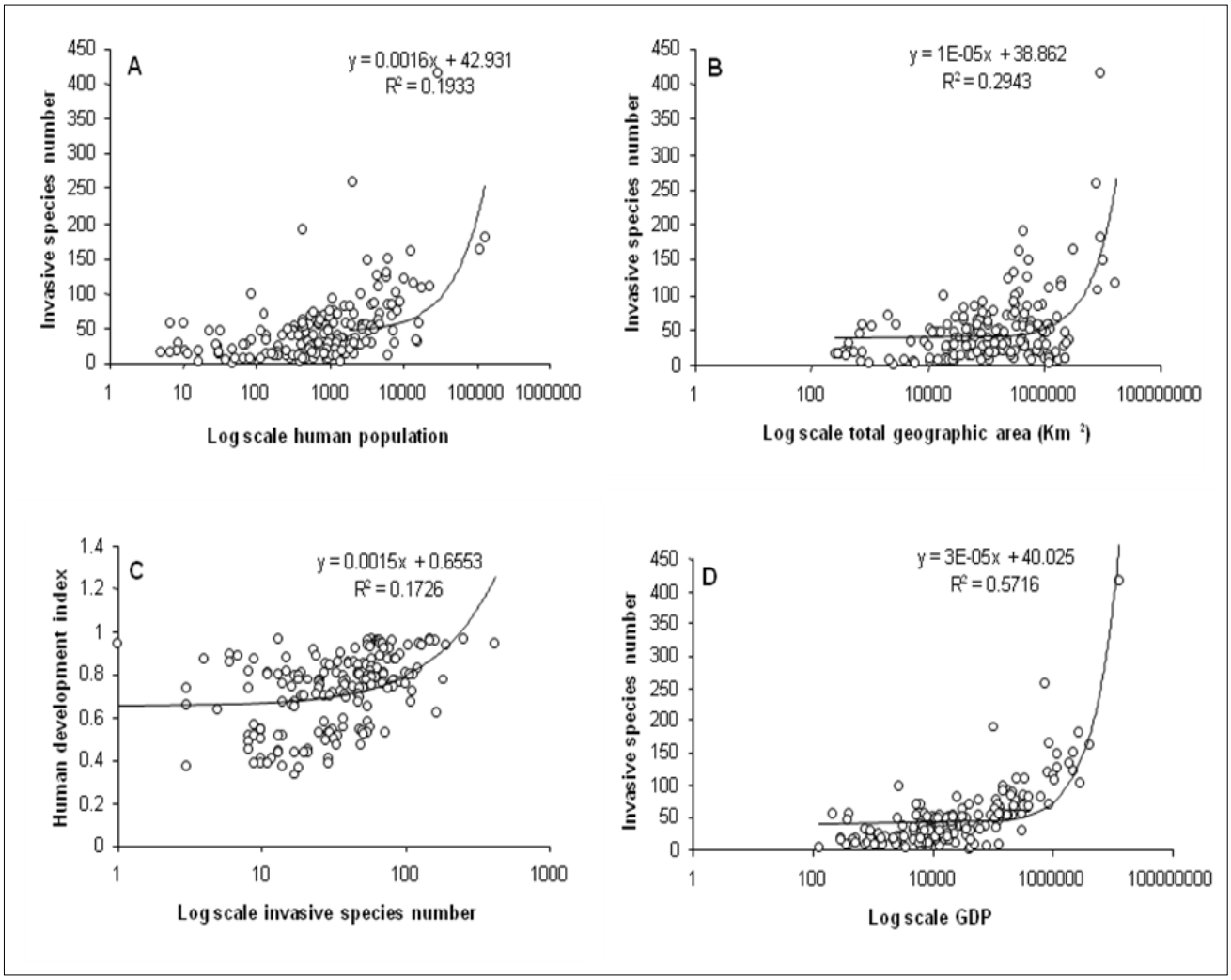
TABLE 3
Correlation matrix among various indicators of socio-economic well-being and the density of invasive alien species

	HDI	HPI	SWL	GDP	Density IAS	Human-population density
HDI	1	0.283**	0.557**	0.252**	0.509**	-0.006$^{n.s.}$
HPI		1	0.622**	-0.72$^{n.s.}$	0.126$^{n.s.}$	0.079$^{n.s.}$
SWL			1	0.161*	0.298**	-0.020$^{n.s.}$
GDP				1	0.680**	0.333**
Density IAS					1	0.367**
Human-population density						1

$n = 172$.
HDI, human development index; HPI, happy planet index; SWL, satisfaction with life index; GDP, gross domestic product; IAS, invasive alien species.
$^{n.s.}$non-significant.
*correlation significant at $p < 0.05$.
**correlation significant at $p < 0.01$.

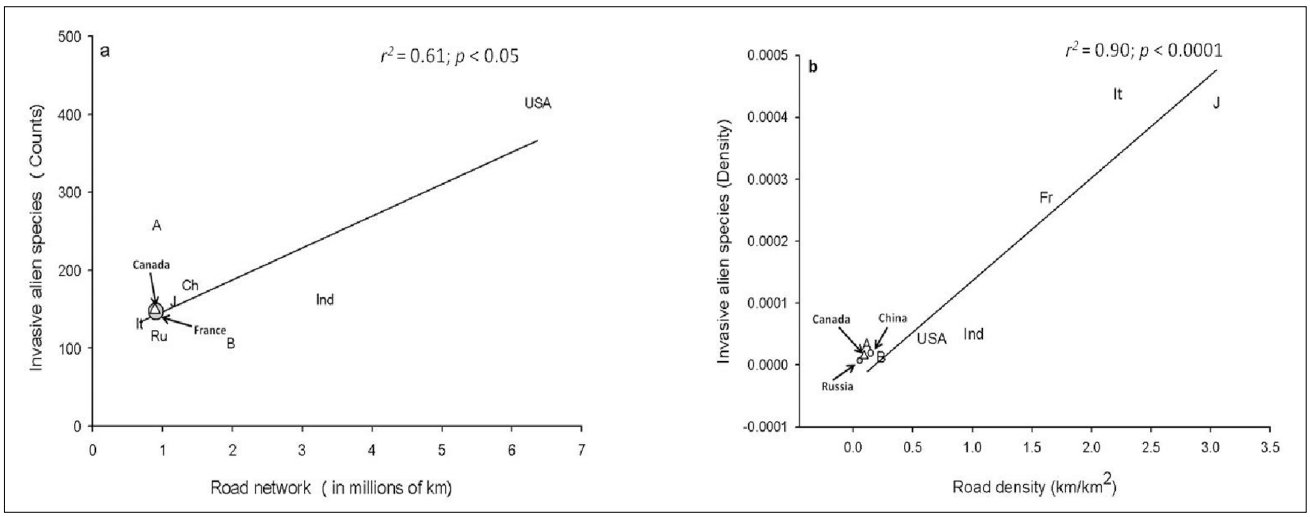
TABLE 4
Countrywide residual regression relationship ($Y = a + bX$) between GDP and density of invasive alien species

Results after the successive removal of:	*a*	*b*	r^2	*p*	*n*
United States	7.6412	0.000007	0.3524	0.0014	171
Australia	7.5524	0.000007	0.3619	0.0090	170
New Zealand	7.3945	0.000007	0.4009	0.0011	169
Japan	7.2502	0.000008	0.3847	0.0050	168
France	7.2513	0.000008	0.3531	0.0020	167
India	7.2305	0.000008	0.3409	0.0010	166
China	7.2055	0.000008	0.3042	0.0010	165
Italy	7.2133	0.000008	0.2702	0.0400	164
All Countries	**8.1095**	**0.000005**	**0.4624**	**<0.0001**	**172**



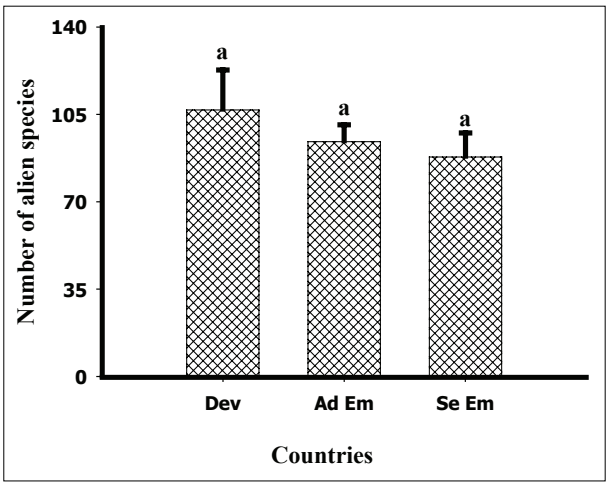
Linear analyses were conducted but we portray the data using a log scale on the x-axis, hence the non-linear shape of the curve.
n = 172.
GDP, gross domestic product.

FIGURE 1
Regression analysis showing the relationship between socio-economic variables and invasive alien species numbers of the countries



Density represents the number of IAS divided by $\log_{10}$ area of the country.
Symbol names marked separately to avoid overlapping.
A, Australia; B, Brazil; Ch, China; Fr, France; J, Japan; Ind, India; It, Italy; Ru, Russia.

FIGURE 2
Relationship between (a) the number of invasive alien species (IAS) and the top 10 road networks and (b) the density of invasive alien species and road density of the top 10 road networks of the world (km/km²)



Error bars represent ± s.e.
Dev, developed; Ad Em, advanced-emerging; Se Em, secondary-emerging.

FIGURE 3
The number of invasive alien species in developed, advanced-emerging and secondary-emerging countries, as per the FTSE index

density and the density of invasive alien plants in provinces of China and in states of the USA,[2] suggesting that international cooperation and trans-boundary collaboration could reduce the risk of new invasions into continents and into countries. The percentage of IAS has also been observed to increase with an increasing number of visitors in protected areas.[46] Positive relationships with IAS, land-use variables (the length of traffic routes and protected land cover) and socio-economic variables (imports and HDI) have been established for Europe and North African countries.[5] The length of terrestrial traffic routes is also related to the number of tourists who visit a country.[5] Inevitable road development with the revival of an economy is therefore also a major concern regarding the spread of invasive species. The message here is that precise policies and management practices need to be in place during road construction and management to minimise the propagule pressure of invasives.

CONCLUSION

We tested the relationship between changes in the population of invasive alien species and level of economic activity, finding positive and statistically significant correlations. We further argued that, in terms of causality, it is the secondary driving forces (economic growth, infrastructure development and population growth) that influence the primary driving forces (such as the arrival of new propagules and disturbance regimes) of changes in IAS and not the other way around. Causality is therefore unidirectional. While it may be possible for specific countries spending a considerable amount of resources on the control of IAS to see a reverse trend (in other words, succeeding in controlling invasions, resulting in the level of economic growth and IAS being negatively correlated), macro-statistics, at least in the short term, are unlikely to pick up such trends.

We suggest that a new agenda of research in modelling and analysing the economic impacts of biological invasions should be explored through interdisciplinary collaboration between ecologists and economists.[47,48] We propose that countries with emerging economies should dedicate funds for invasive species research and management to reduce future costs associated with the management of these species. Resources should be used to support intercontinental cooperation with properly designed research strategies, addressing issues of invasions where current biases can limit our understanding of biological invasions.[32] A comprehensive interdisciplinary study investigating the economic and ecological variables of biological invasion would be a way forward in understanding this scenario in totality.

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Author Note

At the time of proofreading this article, the authors became aware of the following paper that addresses similar issues: McGeoch et al. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Diversity Distrib. 2010;16:95–108.

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