Impact of Different Economic Factors on Biological Invasions on the Global Scale

Wen Lin1,2, Xinyue Cheng2, Rumei Xu2*
1 Zhangzhou Entry-Exit Inspection and Quarantine Bureau, Zhangzhou, Fujian, China, 2 State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China

Abstract

Social-economic factors are considered as the key to understand processes contributing to biological invasions. However, there has been few quantified, statistical evidence on the relationship between economic development and biological invasion on a worldwide scale. Herein, using principal factor analysis, we investigated the relationship between biological invasion and economic development together with biodiversity for 91 economies throughout the world. Our result indicates that the prevalence of invasive species in the economies can be well predicted by economic factors ($R^2 = 0.733$). The impact of economic factors on the occurrence of invasive species for low, lower-middle, upper-middle and high income economies are 0%, 34.3%, 46.3% and 80.8% respectively. Greenhouse gas emissions (CO2, Nitrous oxide, Methane and Other greenhouse gases) and also biodiversity have positive relationships with the global occurrence of invasive species in the economies on the global scale. The major social-economic factors that are correlated to biological invasions are different for various economies, and therefore the strategies for biological invasion prevention and control should be different.

Introduction

Invasions by non-indigenous species are a growing global problem [1]. In today’s world, almost all countries suffer similar problems from the effects of invasive species, while they are also exporters of invaders to other countries. Alien invasive plants, animals and pathogens caused serious environmental and economic damages and have altered ecosystems throughout the world. Biological invasions are considered as the second most important threat to biodiversity [2,3]. The intensive global trade and transportation has been blamed to be the major cause of biological invasions [4]. Social-economic factors are considered as the key to understand processes contributing to biological invasions [5–8]. “The causes of the problem of invasive alien species are primarily economic and, as such, require economic solutions” [9].

Lacking from our current theories of human-induced species invasions is the explicit integration of ecological and economic causal pathways [6]. So far, there are few quantified and statistical evidence on the relationship between economic development and biological invasion on the worldwide scale. We had proven that economic developments had accelerated biological invasion in China, and the prevalence of invasive species can be well predicted by the economic development on the provincial scale [10]. Is this rule applicable on the global scale? There is a strong geographical bias in the regions of the globe where research on biological invasions is conducted [11]. These differences in data quality and availability create a challenge in forming global strategies to deal with invasions [8]. If the driving economic factors are not the same for biological invasions in different economies, the strategies for the prevention and control of invasive species should have what differences? These are all important questions for us to explore for a better understanding, prediction and management of invasive species.

Results

Our results indicate that high-income economies have more invasive species. The top 5 economies which have the highest numbers of invasive species are all high-income economies (Table 1).

Based on the invasive species data collected from Global Invasive Species Database (GISD), and economic and biodiversity data collected from The World Factbook and Species 2000, we found that 27 variables have significant associations with the number of invasive species for all economies throughout the world ($p<0.05$). Through principal factor analysis, four principal components were selected; the contribution rate is 59.19%, 11.65%, 10.75% and 9.75% of the total variance respectively (Table 2). The 1st component consists mainly of economic variables in which GDP, imports and services have the highest load (0.971, 0.961 and 0.960, respectively). The 2nd component includes human population and agriculture value. The 3rd principal component reflects biodiversity. The 4th component includes forest area, land area and waterway.

A multiple regression model was established between the number of invasive species and the factor scores of each component. The first three principal components were selected and they accounted for 83.2% of the total variance in the number...
of invasive species, indicating a significant association between biological invasion and those factors ($F_{3, 17} = 143.906, p<0.001$). Economic factors proved most important, influencing the occurrence of invasive species ($R^2 = 0.733$). Biodiversity, population and agriculture constitute the next two most important components ($R^2 = 0.064$ and $0.035$, respectively) (Table 3).

### Table 1. Top 5 economies ranked by the number of invasive species.

| Ranked by Number of Invasive Species | Country’s Name | Number of Invasive Species | Country’s Type | Ranked by GDP |
|--------------------------------------|----------------|---------------------------|----------------|--------------|
| 1                                    | United States  | 447                       | H              | 1            |
| 2                                    | Australia      | 247                       | H              | 15           |
| 3                                    | Canada         | 137                       | H              | 8            |
| 4                                    | France         | 100                       | H              | 5            |
| 5                                    | United Kingdom | 89                        | H              | 4            |

H: High-income Economies.

doi:10.1371/journal.pone.0018797.t001

### Table 2. Result of the principal factor analysis for 91 economies.

| Variables                                                                 | Factor loadings¹ |        |        |        |
|---------------------------------------------------------------------------|------------------|--------|--------|--------|
|                                                                           | 1                | 2      | 3      | 4      |
| Gross domestic product                                                    | 0.971            | −0.113 | 0.023  | −0.133 |
| Imports of goods and services                                            | 0.961            | −0.048 | −0.052 | −0.162 |
| Services, etc., value added                                              | 0.960            | −0.167 | 0.013  | −0.138 |
| Industry, value added                                                     | 0.956            | 0.023  | 0.042  | −0.144 |
| Energy use                                                                | 0.945            | 0.244  | 0.065  | 0.145  |
| Railway                                                                   | 0.922            | 0.050  | 0.072  | 0.309  |
| International tourism, receipts                                          | 0.917            | −0.116 | −0.038 | −0.130 |
| International migrant stock, total                                       | 0.917            | −0.202 | −0.079 | 0.172  |
| CO₂ emissions                                                             | 0.908            | 0.337  | 0.068  | 0.140  |
| Exports of goods and services                                            | 0.898            | 0.039  | −0.075 | −0.169 |
| Railway                                                                   | 0.889            | 0.081  | 0.218  | 0.084  |
| International tourism, expenditures                                      | 0.885            | −0.091 | −0.103 | −0.186 |
| Other greenhouse gas emissions, HFC, PFC and SF₆                          | 0.874            | 0.331  | −0.022 | 0.116  |
| Airports                                                                  | 0.856            | −0.265 | 0.194  | 0.186  |
| Energy production                                                         | 0.803            | 0.319  | 0.091  | 0.430  |
| Net migration                                                             | 0.742            | −0.482 | −0.260 | 0.122  |
| Nitrous oxide emissions                                                   | 0.705            | 0.526  | 0.363  | 0.150  |
| Methane emissions                                                         | 0.681            | 0.542  | 0.273  | 0.350  |
| Agricultural land                                                         | 0.569            | 0.380  | 0.413  | 0.396  |
| Population, total                                                         | 0.392            | 0.852  | 0.223  | 0.091  |
| Agriculture, value added                                                  | 0.677            | 0.691  | 0.211  | 0.017  |
| Plant species (higher); total known                                       | 0.204            | 0.132  | 0.872  | 0.185  |
| GEF benefits index for biodiversity                                       | 0.465            | 0.080  | 0.817  | 0.213  |
| Species, total known                                                      | 0.410            | 0.341  | 0.795  | 0.074  |
| Forest area                                                               | 0.410            | −0.021 | 0.245  | 0.828  |
| Land area                                                                 | 0.508            | 0.147  | 0.253  | 0.772  |
| Waterway                                                                  | 0.461            | 0.512  | 0.204  | 0.610  |

Rotated sums of squared loadings²

| Eigenvales                                                               |        |        |        |
|-------------------------------------------------------------------------|--------|--------|--------|
| % of variance                                                            | 59.190 | 11.649 | 10.748 |
| Cumulative %                                                             | 59.190 | 70.839 | 81.587 |

---

¹Refer to Table S2 for details and units.

²Extraction method was Principal component analysis.

³Rotation method was Quartimax with Kaizer Normalization.

doi:10.1371/journal.pone.0018797.t002
Discussion

Economic development has heavier impact on the distribution of invasive species in the economies with higher levels of economic development (Figure 1) (Table 4, 5, 6, 7, Table S3, S4, S5, S6). In low-income economies, there is no significant relationship between economic development and the number of invasive species, but mainly determined by international population flow ($R^2 = 0.752$, $F_{1, 8} = 24.214$, $p < 0.002$). In low-income, lower-middle-income, upper-middle-income and high-income economies, economic impacts are increasing ($R^2 = 0.343, 0.463$ and $0.808$, respectively). Biological invasion is a complex chain process [1,12]. Accompanying economic developments, economic activities promote the occurrence and success for the invader in each step of the invasion process (Figure 2). Economic and other human factors enhance international trade, travel and economic-purposed introduction that transport alien species to new areas. They accelerate industrialization and urbanization that are responsible for disturbances of nature habitats that allow invasive species to establish, intensifies the loss of resistance from the local communities to invasions. They are also influence the domestic transportation and travel, and thus enhance the spread of invasive species. Thus, when the rate of success increases in each step of the chain process, the total probability of a successful invasion will be highly promoted according to the tens rule of Williamson [12].

All of the 4 greenhouse gases emission variables (CO2, Nitrous oxide, Methane and Other greenhouse gas emissions) have positive relationships ($p < 0.001$) with the number of invasive species for all economies throughout the world. Especially, CO2 emission has a rather high load in the economic component for high-income and lower-middle-income economies (ranked 2nd and 4th respectively) (Table 4 and Table 6). Recent studies have indicated that increase in atmospheric CO2 concentration may facilitate biological invasions [13–16]. The response of invasive species and native species are different to elevated CO2 [17] and invasive species showed a greater increase in energy-use efficiency under elevated CO2 [18]. Increased soil N availability may often facilitate plant invasions [13,19–22].

Also, our results indicated that biodiversity has a strong positive relationship with the number of invasive species on the global scale ($p < 0.001$). The relationship between biodiversity and biological invasions has been in debate for many decades since the publication of Elton [23]. The relationships are often negative on a small scale, but positive on a large scale [24–27]. At community-wide scales, the effects of ecological factors spatially co-varying with diversity, make the most diverse communities

### Table 3. Stepwise regression between number of invasive species and factor scores of the principal components for 91 economies.

| Variable entered by stepwise order | Regression | Analysis of variance (ANOVA) |
|------------------------------------|------------|------------------------------|
| Factor Score 1                     | 47.152     | 0.733                        |
| Factor Score 3                     | 14.012     | 0.797                        |
| Factor Score 2                     | -10.307    | 0.832                        |

1Step by step cumulative $R^2$.
2Factor Score 1, Factor Score 3 and Factor Score 2 correspond to Principal components 1, 3 and 2 in Table 2.

doi:10.1371/journal.pone.0018797.t003

Figure 1. The impact of economic components ($R^2$) on the number of invasive species for different income-groups.
doi:10.1371/journal.pone.0018797.g001
The major social-economic factors that are correlated to biological invasions are different for various economies, and therefore the strategies for biological invasion prevention and control should be different:

1. High-income Economies

The 1st component consists of economic factors (contribution rate = 80.8% of the total variance). Energy use, CO₂ emissions, services, international migrant stock and railway have the highest load (0.992, 0.988, 0.981, 0.981 and 0.981, respectively) (Table 4). The 1st component accounted for 80.8% of the total variance in the number of invasive species (F₁, 24 = 263.532, p < 0.001) (Table S3). High-income economies, with just 15 percent of world population, use almost half of global energy [30]. Therefore, for these economies, reducing energy use and greenhouse gas emissions are important actions for obtaining a greener GDP, but often being overlooked by the public for reducing the risk of biological invasions.

2. Low-income Economies

The only component consists of international migrant stock, international tourism expenditures, energy use and international tourism receipts (contribution rate = 63.08% of the total variance). They have the load of 0.936, 0.820, 0.819 and 0.683, respectively (Table 5). The component accounted for 75.2% of the total variance in number of invasive species (F₁, 8 = 24.214, p < 0.002) (Table S3). For these economies, monitor international migrant stock and improve airport inspection is the most important action to prevent biological invasions.

3. Middle-income Economies

These two categories of economies have more similarities, though economic factors have more impact for the upper-middle-income economies. For the lower-middle-income economies, the

**Table 4.** Result of the principal factor analysis for high-income economies.

| Variables                                      | Factor loadings¹ |
|------------------------------------------------|------------------|
|                                                | 1         | 2         | 3         |
| Energy use                                     | 0.992    | −0.020   | 0.033     |
| CO₂ emissions                                  | 0.988    | −0.006   | 0.046     |
| Services, etc., value added                    | 0.981    | −0.033   | −0.120    |
| International migrant stock, total             | 0.981    | −0.013   | 0.129     |
| Railway                                        | 0.981    | 0.107    | 0.138     |
| Gross domestic product                         | 0.980    | −0.035   | −0.143    |
| Roadway                                        | 0.979    | 0.092    | 0.127     |
| Nitrous oxide emissions                        | 0.971    | 0.125    | 0.140     |
| Population, total                              | 0.971    | −0.038   | −0.211    |
| Methane emissions                              | 0.969    | 0.083    | 0.202     |
| Net migration                                  | 0.957    | −0.012   | 0.163     |
| Imports of goods and services                  | 0.956    | −0.138   | −0.156    |
| Energy production                              | 0.952    | 0.088    | 0.246     |
| Waterway                                       | 0.950    | −0.009   | 0.149     |
| Airports                                       | 0.949    | −0.015   | 0.268     |
| Industry, value added                          | 0.943    | −0.016   | −0.266    |
| Agriculture, value added                       | 0.927    | 0.050    | −0.273    |
| International tourism, receipts                | 0.924    | −0.055   | −0.002    |
| Other greenhouse gas emissions, HFC, PFC and SF₆ | 0.920    | −0.039   | −0.342    |
| Exports of goods and services                  | 0.862    | −0.166   | −0.322    |
| International tourism, expenditures           | 0.848    | −0.144   | −0.344    |
| Plant species (higher); total known            | 0.747    | 0.562    | 0.039     |
| Forest area                                    | 0.692    | 0.432    | 0.362     |
| Land area                                      | 0.646    | 0.575    | 0.341     |
| Species, total known                           | 0.555    | 0.795    | −0.225    |
| GEF benefits index for biodiversity            | 0.690    | 0.711    | −0.032    |
| Agricultural land                              | 0.674    | 0.679    | 0.163     |
| Rotated sums of squared loadings²              |          | 21.733   | 2.562     |
| % of variance                                  | 80.491   | 9.489    | 4.487     |
| Cumulative %                                   | 80.491   | 89.980   | 94.468    |

¹Refer to Table S2 for details and units.
²Extraction method was Principal component analysis.

**Table 5.** Result of the principal factor analysis for upper-middle-income economies.

| Variables                                      | Factor loadings¹ |
|------------------------------------------------|------------------|
|                                                | 1         | 2         |
| Gross domestic product                         | 0.989    | −0.012   |
| Industry, value added                          | 0.982    | −0.091   |
| Services, etc., value added                    | 0.980    | −0.005   |
| Population, total                              | 0.942    | 0.137    |
| Agriculture, value added                       | 0.920    | 0.037    |
| Exports of goods and services                  | 0.883    | −0.388   |
| Imports of goods and services                  | 0.875    | −0.377   |
| Airports                                       | 0.865    | 0.358    |
| GEF benefits index for biodiversity            | 0.827    | 0.489    |
| International tourism, expenditures           | 0.781    | −0.382   |
| Nitrous oxide emissions of CO₂                 | 0.760    | 0.525    |
| Species, total known                           | 0.720    | 0.596    |
| International tourism, receipts                | 0.641    | −0.589   |
| Plant species (higher); total known            | 0.633    | 0.637    |
| Rotated sums of squared loadings²              |          | 10.131   | 2.218     |
| % of variance                                  | 72.366   | 15.845   |
| Cumulative %                                   | 72.366   | 88.212   |

¹Refer to Table S2 for details and units.
²Extraction method was Principal component analysis.
³Rotation method was Quartimax with Kaiser Normalization.

doi:10.1371/journal.pone.0018797.t005

...
Table 6. Result of the principal factor analysis for lower-middle-income economies.

| Variables                               | Factor loadings¹ | 1     | 2     | 3     |
|-----------------------------------------|------------------|-------|-------|-------|
| Gross domestic product                  | 0.997            | 0.031 | -0.032|
| Energy use                              | 0.995            | 0.036 | -0.055|
| Services, etc., value added             | 0.993            | 0.085 | -0.029|
| CO₂ emissions                           | 0.993            | -0.023| -0.079|
| Industry, value added                   | 0.987            | -0.113| -0.033|
| Agriculture, value added                | 0.984            | 0.153 | -0.029|
| Imports of goods and services           | 0.984            | -0.078| -0.035|
| Energy production                       | 0.983            | -0.037| -0.004|
| Nitrous oxide emissions                 | 0.983            | 0.131 | -0.040|
| International tourism, expenditures     | 0.982            | -0.043| 0.026 |
| Exports of goods and services           | 0.980            | -0.117| -0.024|
| Waterway                                | 0.969            | -0.188| 0.032 |
| Land area                               | 0.964            | -0.101| 0.002 |
| Other greenhouse gas emissions, HFC     | 0.957            | -0.193| -0.127|
| PFC and SF₆                              | 0.957            | -0.193| -0.127|
| Agricultural land                       | 0.951            | -0.082| -0.097|
| Methane emissions                       | 0.951            | 0.273 | 0.037 |
| Species, total known                    | 0.943            | 0.093 | 0.205 |
| Population, total                       | 0.926            | 0.344 | -0.002|
| International tourism, receipts         | 0.896            | -0.137| -0.022|
| Railway                                 | 0.889            | 0.359 | -0.088|
| Forest area                             | 0.886            | -0.141| 0.306 |
| Plant species (higher); total known     | 0.723            | -0.008| 0.643 |
| Net migration                           | -0.721           | -0.426| -0.234|
| Population density                      | 0.273            | 0.830 | 0.018 |
| Roadway                                 | 0.661            | 0.670 | 0.034 |
| GEF benefits index for biodiversity     | 0.648            | 0.140 | 0.727 |
| Rotated sums of squared loadings        |                  |       |       |       |
| Eigenvalues                             | 21.382           | 1.884 | 1.187 |
| % of variance                           | 82.239           | 7.244 | 4.565 |
| Cumulative %                            | 82.239           | 89.483| 94.048|

1st component consists of economic factors (contribution rate = 82.24% of the total variance). GDP, energy use, services, CO₂ emissions have the highest load (0.997, 0.995, 0.993 and 0.993 respectively) (Table 6). The 1st component accounted for 34.3% of the total variance in number of invasive species. The 2nd component (population and roadway) and the 3rd component (biodiversity) accounted for 13.9% and 29.2% (F₁, 22 = 28.597, p<0.001) (Table S5). For the upper-middle-income economies, the 1st component consists of economic factors (contribution rate = 72.37% of the total variance). GDP, industry, services have the highest load (0.989, 0.982 and 0.980 respectively) (Table 5). The 1st component accounted for 46.3% of the total variance in number of invasive species (F₁, 22 = 19.002, p<0.001) (Table S4).

As could be seen, these economies are in a more complex situation. The factors are more diverse. For these economies, the strategies suggested for developed economies are not enough, and those for the low-income economies are too simple. Fortunately, we have investigated a case study using China as a model [10]. We demonstrated that the increase in biological invasion was coincident with the rapid economic development that had occurred in China over the past three decades. Economic impact (R² = 0.379) is similar, if not more important than climatic factors (R² = 0.345). We unexpectedly found that residential construction had the strongest positive effect on the occurrence of invasive species. However, it is not hard to explain. From 1995 to 2004, residential construction in China increased at the average rate of 15.3% per year [31]. It is reported that nearly half of the world’s buildings under construction are located in China [32]. Such rapid increase in residential construction and expansion of small towns facilitates timber transportation, urbanization, the degradation and fragmentation of habitats, and therefore, the actions needed (e.g., ecological city construction) to block out these pathways can also be clarified and be taken to reduce invasions. The implement of ecological city planning, sustainable industry and the augmentation of inter-province inspection and quarantine should also be further stressed for restricting the spread of invasive species in China. The China investigation can be used here as a sample. Various economies have different ways of economic developments, and maybe this is the reason why the factors influencing biological invasions are so diverse. We suggest, for each different economy, investigations are required to pin point their specific economic factors and their specific impact on biological invasion, and thus, to obtain a better strategy for management and control.

Table 7. Result of the principal factor analysis for low-income economies.

| Variables                              | Factor loadings¹ | 1     |
|----------------------------------------|------------------|-------|
| International migrant stock, total     | 0.936            |
| International tourism, expenditures    | 0.819            |
| Energy use                             | 0.749            |
| International tourism, receipts        | 0.645            |
| Sums of squared loadings               |                  |
| Eigenvalues                            | 2.523            |
| % of variance                          | 63.083           |
| Cumulative %                           | 63.083           |

¹Refer to Table S2 for details and units.
²Extraction method was Principal component analysis.
doi:10.1371/journal.pone.0018797.t007
control of invasive species. Therefore, the task of investigating and prevention of invasive species is not only the task for biologists.

Materials and Methods

Data collection

We collected the number of invasive species from Global Invasive Species Database (GISD). Economic and biodiversity data was collected from 2000 to 2006 from The World Development Indicators (WDI), The World Factbook and Species 2000. Because of the lacking of data, only 91 economies were selected, which were divided into 4 groups (Table S1) according to 2008 GNI per capita, calculated using the World Bank Atlas method. Based on linear regressions between economic variables and the number of invasive species in each economy, 28 variables were selected (Table S2). The mean values of these variables were used for data analysis.

Data analysis

Principal factor analysis was carried out on these economic and diversity variables. The number of principal components we selected is based on Kaiser criteria. After analysis using Quartimax with Kaiser normalization rotation, we further removed those variables with absolute load < 0.5. The remaining variables were subject to final principal factor analysis and a factor score for each economy was given accordingly. A multiple regression model was established between the number of invasive species and the factor scores of each economies, through stepwise selection method with p = 0.10 entering and p = 0.05 removing criteria.

Supporting Information

Table S1 The list of 4 income-groups of 91 economies. (DOC)
Table S2 List of variables used for analysis. (DOC)
Table S3 Stepwise regression between number of invasive species and factor scores of the principal components for high-income economies. (DOC)
Table S4 Stepwise regression between number of invasive species and factor scores of the principal components for upper-middle-income economies. (DOC)
Table S5 Stepwise regression between number of invasive species and factor scores of the principal components for lower-middle-income economies. (DOC)
Table S6 Stepwise regression between number of invasive species and factor scores of the principal components for low-income economies. (DOC)

Author Contributions

Conceived and designed the experiments: RX WL XC. Performed the experiments: WL. Analyzed the data: WL. Contributed reagents/materials/analysis tools: WL. Wrote the paper: RX WL XC. Did the data collection, analysis and statistics: WL. Supervised the research: RX.

References

1. Lodge DM, Williams S, Machaca HJ, Hayes KR, Leung B, et al. (2006) Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16: 2035–2054.
2. Witloof DS, Rothstein D, Dubois J, Phillips A, Losos E (1998) Quantifying threats to imperiled species in the United States. Bioscience 48: 607–615.
3. Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, et al. (2000) Biodiversity - Global biodiversity scenarios for the year 2100. Science 287: 1770–1774.
4. Meyerson LA, Mooney HA (2007) Invasive alien species in an era of globalization. Frontiers in Ecology and the Environment 5: 199–208.
5. Levine JM, D’Antonio CM (2003) Forecasting biological invasions with increasing international trade. Conservation Biology 17: 322–326.
6. Taylor BW, Irwin RE (2004) Linking economic activities to the distribution of exotic plants. Proceedings of the National Academy of Sciences of the United States of America 101: 17725–17730.
7. Williamson M (2000) Explaining and predicting the success of invading species at different stages of invasion. Biological Invasions 8: 1561–1568.
8. Nunez MA, Pauchard A (2010) Biological invasions in developing and developed countries: does one model fit all? Biological Invasions 12: 707–714.
9. Perrings C, Williamson M, Barbier EB, Delfino D, Dalmazzone S, et al. (2002) Biological invasion risks and the public good: an economic perspective. Conservation Biology 6: 1. Available: http://www.consecol.org/vol6/iss1/art1/. Accessed 2011 Mar 24.
10. Lin W, Zhou G, Cheng X, Xu R (2007) Fast economic development accelerates biological invasions in China. Plos One 2: Article No.: e1208.
11. Pysek P, Richardson DM, Pergl J, Jarosik V, Sixtova Z, et al. (2008) Geographical and taxonomic biases in invasion ecology. Trends in Ecology & Evolution 23: 237–244.
12. Williamson M (1996) Biological invasions. London: Chapman & Hall. 244 p.
13. Dukes JS, Mooney HA (1999) Does global change increase the success of biological invaders? Trends in Ecology & Evolution 14: 135–139.
14. Welter FF, Belote RT, Sanders NJ (2003) Biological invasions in a greenhouse world: will elevated CO2 fuel plant invasions? Frontiers in Ecology and the Environment 1: 146–155.
15. Nagel JM, Hausman TE, Griffin KL, Smith SD (2004) CO2 enrichment reduces the energetic cost of biomass construction in an invasive desert grass. Ecology 85: 100–106.
16. Hall-Spencer JM, Rodolfo-Metalpa R, Martin S, Ransome E, Fine M, et al. (2008) Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature 454: 96–99.
17. Hungate BA, Canadell J, Chapin FS, III (1996) Plant species mediate changes in soil microbial N in response to elevated CO2. Ecology 77: 2505–2515.
18. Song LY, Li CH, Peng SL (2010) Elevated CO2 increases energy-use efficiency of invasive Wedelia trilobata over its indigenous congener. Biological Invasions 12: 1221–1230.
19. Milchunas DG, Lauenroth WK (1995) Inertia in plant community structure: state changes after cessation of nutrient-enrichment stress. Ecological Applications 5: 432–440.
20. Maron JL, Connors PG (1996) A native nitrogen-fixing shrub facilitates weed invasion. Oecologia 105: 302–312.
21. Rao LE, Allen EB (2010) Combined effects of precipitation and nitrogen deposition on native and invasive winter annual production in California deserts. Oecologia 162: 1035–1046.
22. Perry LG, Blumenthal DM, Monaco TA, Paschke MW, Redente EF (2010) Immobilizing nitrogen to control plant invasion. Oecologia 163: 13–24.
23. Elton CS (1958) The ecology of invasions by animal and plants. London: Chapman & Hall. 181 p.
24. Kennedy TA, Naem S, Howe KM, Knops JMH, Tilman D, et al. (2002) Biodiversity as a barrier to ecological invasion. Nature 417: 636–638.
25. Levine JM, Adler PB, Yelenik SG (2004) A meta-analysis of biotic resistance to exotic plant invasions. Ecology Letters 7: 975–989.
26. Tilman D (1997) Community invasibility, recruitment limitation, and grassland biodiversity. Ecology 78: 81–92.
27. Lonsdale WM (1999) Global patterns of plant invasions and the concept of invasibility. Ecology 80: 1522–1536.
28. Levine JM (2005) Species diversity and biological invasions: Relating local process to community pattern. Science 288: 832–834.
29. Byers JE, Noonburg EG (2005) Scale dependent effects of biotic resistance to biological invasion. Ecology 84: 1428–1433.
30. The World Bank (2009) World development indicators 2009. Washington, D.C.: The World Bank. 434 p.
31. National Bureau of Statistics of China (1996) Chinese National Statistic Yearbook. Beijing: China Statistics Press.
32. Xinhua News Agency (2007) Available: http://www.sh.xinhuanet.com/2007-08/24/content_10953578.htm. Accessed 2011 Mar 24.
33. Xu RM, Ye WH (2003) Biological Invasion-Theory and Practice. Beijing: Science Press. 250 p.