Biological Invasions, Biological Diversity of Trade

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BESTNet/DIVERSITAS ecoSERVICES Workshop
Global Institute of Sustainability
Arizona State University,
29-31 October 2007

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“And in this section it appears that you have not only alienated voters but actually infected them, too” (New Yorker, Dec 17, 2005).
Globalization and invasive species

- The growth and development of the world trade system (globalization) has increased the number and volume of species introductions.
  - as the objects of trade,
  - as ‘passengers’ on traded goods, packaging or the vehicles of trade.

- Globalization has also increased the homogenization of host systems with consequences for:
  - their vulnerability to invasions
  - the correlation in risks across systems/countries

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The risks from aid are higher than the risks from trade because it is subject to lower sanitary and phytosanitary standards.

- Grey leaf spot was first reported in South Africa in 1988 and has now spread into all the main maize-growing areas of Africa (Rangi, 2004). It was introduced in US food aid shipments of maize in during the 1980s drought (Ward et al., 1999).

- Parthenium weed from Mexico was first detected in Ethiopia in 1988 near food-aid distribution centers. It had accompanied wheat grain distributed as food aid during the same drought (GISP, 2004).


Trade and species introductions in the literature

Two foci of economic research:

- The link between specialization under trade, habitat conversion, and species loss (e.g. Barbier and Schultz, 1997; Polasky et al, 2003).

- The biological invasions as an externality of trade (e.g. Perrings et al, 2002; Costello and McAusland, 2003).


Market presence accounts for introductions, but not establishment


- Of 534 non-native ornamentals on sale in Britain in the 1900s, 27% casuals and 30% were established.

- While market presence helped distinguish escaping from non-escaping species, other factors explained establishment.

Tariffs and inspections

- Costello and McAusland (2003), and McAusland and Costello (2004) consider trade growth which increases species introductions and hence the risk of biological invasions.
  
  - tariffs and inspections/exclusions reduce the volume of trade and the probability that trade will introduce new species.

- McAusland and Costello (2004) find tariffs equivalent to the shadow value of the change in trade-related invasion risks can reduce the level of imports to the socially optimal level.


# The cost of invasive species

(USD billion % pa)

- A parallel literature has focused on the costs of invasions.

<table>
<thead>
<tr>
<th>Introduced pest</th>
<th>United States</th>
<th>United Kingdom</th>
<th>Australia</th>
<th>South Africa</th>
<th>India</th>
<th>Brazil</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td>0.148</td>
<td>–</td>
<td>–</td>
<td>0.095</td>
<td>–</td>
<td>–</td>
<td>0.178</td>
</tr>
<tr>
<td>Mammals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rats</td>
<td>19.000</td>
<td>4.100</td>
<td>1.200</td>
<td>2.700</td>
<td>25.000</td>
<td>4.400</td>
<td>56.400</td>
</tr>
<tr>
<td>Other</td>
<td>18.106</td>
<td>1.200</td>
<td>4.655</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>23.961</td>
</tr>
<tr>
<td>Birds</td>
<td>1.100</td>
<td>0.270</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.370</td>
</tr>
<tr>
<td>Reptiles/Amph.</td>
<td>0.006</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.006</td>
</tr>
<tr>
<td>Fishes</td>
<td>1.000</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.000</td>
</tr>
<tr>
<td>Arthropods</td>
<td>2.137</td>
<td>–</td>
<td>0.228</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>2.365</td>
</tr>
<tr>
<td>Mollusks</td>
<td>1.305</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.305</td>
</tr>
<tr>
<td>Livestock Diseases</td>
<td>9.000</td>
<td>–</td>
<td>0.249</td>
<td>0.100</td>
<td>–</td>
<td>–</td>
<td>9.349</td>
</tr>
<tr>
<td>Human Diseases</td>
<td>0.566</td>
<td>1.000</td>
<td>0.534</td>
<td>0.118</td>
<td>–</td>
<td>2.333</td>
<td>10.467</td>
</tr>
<tr>
<td>Total</td>
<td>58.299</td>
<td>6.570</td>
<td>6.866</td>
<td>3.013</td>
<td>25.000</td>
<td>6.733</td>
<td>106.481</td>
</tr>
</tbody>
</table>

Source: Pimentel et al (2001)

Trade, invasiveness and invasibility

- The likelihood that an introduced species will competitively exclude native species depends on a range of factors including
  - the invasiveness of the species (a property of species traits, including plasticity, but also of propagule pressure, a function of trade),
  - the vulnerability of the host system to invasion (a property of disturbance, including fragmentation and species loss),
  - the bioclimatic similarity between the source and host countries.

- Vulnerability to invasion depends on the way the host system is exploited, specifically on the effect of exploitation on the patchiness or *environmental heterogeneity* of the host system.

Modelling invasions and heterogeneity

- Heterogeneity on the landscape allows different species dominate in different patches.
- The equation of motion for the $i^{th}$ of $m$ species is:

$$\frac{ds_i}{dt} = s_i \left[ r_i \left( 1 - \left( \frac{es_i}{K/\phi_i(e, m)} + \left( \frac{(1 - e)S}{K} \right) \right) \right) \right] - d_i - a_i \ell_i$$

- $s_i =$ Species $i$ gets a share of carrying capacity defined by $K/\phi_i$, but only if $e > 0$
- $r_i =$
- $d_i =$
- $a_i \ell_i =$ the rate of ‘harvest’ or depletion due to exploitation,
- $K =$ maximum carrying capacity of the ecosystem in terms of biomass,
- $e =$ an index of environmental heterogeneity,
- $\phi_i(e(L), m)$ allocates carrying capacity between species

If $e = 0$, reverts to standard logistic for competitive dominant
Environmental heterogeneity and biodiversity

- Let the m species in the system be labeled such that 
  \( g_1 > g_2 > ... > g_m \), i.e. species are competitively ranked by their equilibrium abundance (they are K-selected).

- A necessary condition for the existence of the \( i^{th} \) species is that \( g_i > 0 \).

- A sufficient condition is that:

\[
g_i > (1-e)K \left( i - \sum_{j=1}^{i} \frac{d_i + a_i \ell}{r_i} \right) \frac{\phi_i(e, m)e - i(1-e)}{\phi_i(e, m)e - 1(1-e)}
\]
Biodiversity and heterogeneity in autarkic systems

- We take the case where future consumption is not discounted, and the optimal steady state solution solves:

$$\max_L U(H, Q) = U(H, 1 - L(x))$$

subject to:

$$0 = s_i \left[ r_i \left( 1 - \left( \frac{e(L)^2 ms_i + (1 - e(L))S}{K} \right) \right) - d_i - a_i \ell_i \right]$$
Optimal stock size and harvest effort: autarkic heterogeneous systems

- In an extremely heterogeneous exploited autarkic system, \((e = 1, L > 0)\):

\[
s_i = \frac{K}{m} \left( r_i - d_i - \frac{a_i \ell_i}{r_i} \right)
\]

\(s_i\) is decreasing in the technical efficiency of harvest, harvest effort, and the number of species that coexist in the system

and:

\[
\ell_i = \frac{1}{a_i} \left( r_i \left( 1 - \frac{ms_i}{K} \right) - d_i \right)
\]

\(\ell_i\) is increasing in \(r_i\), the natural regeneration rate of the \(i^{th}\) species and decreasing in \(a_i\), the technical efficiency of harvest
**Optimal stock size and harvest effort: autarkic homogeneous systems**

- In a homogeneous exploited autarkic system, \((e = 0, L > 0)\):

\[
s_i = \begin{cases} 
K \left( \frac{r_i - d_i - a_i \ell_i}{r_i} \right), & g(s_i) = g_m \\
0, & g(s_i) \neq g_m 
\end{cases}
\]

and:

\[
\ell_i = \begin{cases} 
\frac{1}{a_i} \left( r_i \left(1 - \frac{S}{K}\right) - d_i \right), & g(s_i) = g_m \\
0, & g(s_i) \neq g_m 
\end{cases}
\]

\(s_i = S\) if the \(i^{th}\) species is the competitive dominant species, and is zero otherwise

\(= L\) if the \(i^{th}\) species is the competitive dominant species, and is zero otherwise
The set of living species, $A^*$

(a) $g(i)$ linear, $A^*$ is the interval $[0,m]$
The set of living species, $A^*$

(b) $g(i)$ non-linear, $A^*$ is the union of disjoint intervals $[0,i]$ and $[j,m]$
Managing invasive species risks

- In the open economy case the problem is:

\[
\max_{L,X,M_I} \left( F^M \right) U((H - X), 1 - L + M) + \left( 1 - F^M \right) U(M_I, 1 - X_I)
\]

subject to:

- \( F^M \) is the probability that imports will not result in an invasion

\[
0 = s_i \left[ r_i \left( 1 - \left( e^* \phi(1, m^*) s_i + (1 - e(L)), S \right) \right) - d_i - a_i c_i \right]
\]

\[ p^*X = M \text{ (if an invasion does not occur)} \]

\[ p^*M_I = X \text{ (if an invasion does occur)} \]
Effect of species introductions

- The introduction of species through trade affects species richness ($m^*$) and abundance through the impact on interspecific competition ($g_i^* i \in \{1, \ldots, m^*\}$).

- If trade introduces species with ‘$g$’ values that dominate the ‘$g$’ values of the $i^{th}$ existing species, it will reduce the likelihood that species will survive in the steady state.
Managing invasive species risks

- We show that

\[ L^*(F = 1) > L^*(F < 1) \]

If there is a positive invasion risk associated with imports, \( F^M < 1 \), and if the system is perfectly homogeneous, then the socially optimal level of harvest effort is strictly less than the socially optimal level of harvest effort where there is zero invasion risk, \( F^M = 1 \), and tends to zero as the invasion risk tends to one.
Trade growth exceeds output growth

The volume of world trade has increased significantly relative to world output due to:

- share of world output (-);
- GDP per head (+);
- transport costs (-);
- tariff rates (-);
- exchange rate volatility (-);
- price of tradable relative to non-tradable goods (-).

Trade and invasive species

Number of invasive species in relation to current import volumes

WTO International Trade Statistics. NEOBANIS data on invasive species in the Baltic Region
Import volumes and invasive species: Japan

WTO International Trade Statistics. apasd-niaes.dc.affrc.go.jp/menu/news.php, apasd asian pacific alien species database
Trade and vulnerability

- Trade growth increases the risks of AIS, but economic development which reduces vulnerability may have the opposite effect.

- Costello and McAusland (2003) argue that freer trade may reduce the damage due to exotic species if it leads to changes in production that make a host country less vulnerable (through, e.g. reallocation of resources from agriculture to manufacturing).

Openness to trade

Ratio of exports and imports of goods and commercial services to GDP, 2003

Trade patterns and species introductions

- Trade between bioclimatically similar regions increases the likelihood that introduced species will become invasive.

- Regional Trade Agreements open up new trading opportunities between countries which:
  - brings closer linkages between ecosystems in which bioclimatic conditions are broadly similar.
  - consequently increases the risk that introduced species will establish, naturalize and spread.

- Example: NAFTA has encouraged spread of species within North America of species introduced to one NAFTA country from some other country (Perrault et al, 2003).

Koppen-Geiger bioclimatic zones
Growth of Regional Trade Agreements

- The number of Regional Trade Agreements grew rapidly during the 1990s, as did the importance of intra-regional trade.

Intra-regional imports increased as a proportion of total imports from the early 1980s.
RTAs in the Americas and Asia/Pacific

Koppen-Geiger bioclimatic zones

Distribution of merchandise exports from China, 2005

[Map and chart showing merchandise export distribution across different continents and regions.]
The paradox of globalization

- Trade liberalization that increases import volumes, also increases the rate at which new species are introduced, establish and become invasive.

- If this affects ecosystem productivity through its impact on biodiversity, it imposes a cost on society.

- If this cost is increasing in the volume of imports, the higher the volume of imports, the higher is the optimal tariff.