THE VECTORS OF INVASIONS BY ALIEN SPECIES

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The Achilles Heel of exotic species invasions is the vector by which a non-native species gains access to a distant land, lake, river or sea. If these vectors can be effectively intercepted, alien species invasions will be reduced. Fundamental to this effort is an understanding of the diversity and patterns of the human-assisted transport mechanisms that serve to move organisms across their natural barriers, as well as extensive knowledge of the potential diversity of species transportable by such means.

Provided here is a brief abstract of selected key issues in the understanding and analysis of alien species vectors, derived in part from a book in preparation on Invasion Pathways, multiauthored under the Global Invasive Species Programme (GISP), and based upon a symposium held at the Smithsonian Environmental Research Center in November 1999 in Edgewater, Maryland USA. This note also provides a summary of a slide presentation given at the Best Management Practices for Preventing and Controlling Invasive Alien Species in Cape Town, South Africa in February 2000.

Categorising Vectors

Numerous human-mediated **physical conveyances** move terrestrial, freshwater, and marine (saltwater) species around the world on an hourly and daily basis. We assume that tens of thousands of species are in motion globally at any given moment. These conveyances are:

- On land: automobiles (cars), jeeps, trucks, buses, wagons, carts, wheelbarrows; railroads and associated materials, such as the rail track and bed
- In air: aeroplanes, manned balloons, and other airborne devices
- In water: vessels (ships, boats); sealevel and lock canals.

In turn, each of these conveyances, in terms of introduced species, may have or be characterised by:

- Multiple **routes** (geographic diversity, in terms of intercontinental (transoceanic) as well as intracontinental (interbasin and intrabasin) movements)
- Multiple **political boundaries** (intercountry, intracountry, and within the latter, local, state, or provincial levels)
- Different **motives** (accidental *versus* intentional introductions)
- Multiple **economic or political incentives** (commercial, private, or military enterprises)
- Multiple **goods or products**, some of which may be alive (biotic) and some of which may be inanimate (abiotic). These include individual and bulk products, such as food stuffs, ore, soil, household goods, tiles, cut flowers, wood and wood products, vehicles, boats, tires, machinery, animal and plant products for whatever purpose and in whatever condition (fresh, dry, frozen), personal effects, clothing, and thousands of other articles, objects, items, wares, and commodities.
- Associated **weighting or packing materials** (ballast (whether dry or water), dunnage, containers, chests, crates, cartons, boxes, baggage, luggage, pallets, and internal packaging materials, such as sawdust, styrofoam, newspaper, et cetera)
- **Humans** (emigrants and immigrants; legal, illegal, refugees, and so forth).
- And, pertinent to the latter three categories, **associated life**, in terms of pathogens, parasites, and disease agents (bacteria, viruses, fungi, protists, myxozoa, and other organisms), and other epibionts and endobionts.

In combination, this diversity yields an extraordinary complex matrix. Potential management approaches and strategies will often thus need to be equally complex. Operationally, different vectors will have different strengths in different countries (and different subregions within those countries) for different species. Thus ranking vectors *in general* as either minor or major

may often falsely reduce a very complex state of affairs into a too simple dichotomy, and may lead to management predicaments. Multiple vectors often operate along the same routes at the same time. Vectors are constantly changing over time and space; some aspects of this change may be predictable and other aspects less predictable. Rather than to convey a hopeless web of affairs, these general observations and conclusions are meant to guide and focus management and to underscore that many management regulations may not sufficiently encompass the diversity of vectors now in operation, their growing scale in time and space, and the diversity of living organisms potentially in motion.

Accidental versus Intentional Introductions

Particularly challenging is the dichotomy between **accidental** (also referred to, sometimes for political or euphemistic purposes, as unintentional, inadvertent, unaware, unthinking, escapes, and leakage) and **intentional** (also referred to as planned or deliberate) introductions. Management strategies that address alien species introduction may not clearly distinguish between accidental versus intentional releases. Deliberate but unauthorised introductions may be too quickly categorised as accidental, resulting in, or as a result of, limited quarantine or customs oversight on private, illegal, or smuggling vectors or routes.

Of equal concern is the intentional, authorised release of a non-native species into the wild, which may occur for a variety of reasons. In the 19th century, such practices were common and not only sanctioned but also encouraged through local and national Acclimatisation Societies. Animals and plants were released for food, aesthetic, recreational, or other cultural reasons, to convert landscapes (and sometimes seascapes) to those that appeared to be more similar to the geographic origins of the colonists of a new region at the time, or simply to improve local diversity. In the 21st century, environmental concerns over the release of a novel species, without a thorough understanding of the direct impacts or indirect interactions that such species might have in a new region, have depressed the frequency and scale of the release of such species. However, economic drivers remain strong to introduce species that would be beneficial, with ecological or environmental considerations often thus taking a secondary role. The International Council for the Exploration of the Seas (ICES) has, since the 1970s, provided a Code of Practice, last revised in the 1990s, which reviews the environmental, ecological, genetic, and other considerations required when contemplating the release of a new organism. Minchin (this volume) has provided a copy of that Code.

The Scale of Invasions

One method to judge the importance of a given vector is the number of invasions occurring per unit area (typically but artificially within a political jurisdiction) and per unit time (typically per year or per decade). This can be expressed by a number of both theoretical and empirical mathematical formulas, but generating robust and accurate numbers for a given formula remains a significant challenge. In general, *the number of invasions is always underestimated*, thus resulting in a lower-than-actual vector signal. In all environments -- terrestrial, freshwater, and marine -- recorded invasions are usually restricted to either charismatic megainvasions (very large or very abundant species) and to invaders that are of clear, obvious, and immediate economic or human health-related concerns.

With declining work in biogeography, natural history, and systematics (including taxonomy), this leaves unrecorded the majority of invaders -- ranging from bacteria, viruses and protists to worms, small crustaceans, insects, other arthropods, and in the marine environment additional organisms such as bryozoans, sponges, and ascidians (sea squirts). Assumptions and presumptions about this unrecorded invasion element are often that such invasions must be of less importance. Frequently, however, these other invaders may either (1) have immediate and profound environmental impacts, but delayed economic or human-health impacts, or (2) become abundant at some later time, awaiting altered climatic conditions, of particular concern relative to global climate change predictions. It is thus of critical importance to keep a sensitive finger on the pulse of regional biodiversity change, both in order to understand the scale of inflow of alien species, but also to detect invasions at an early stage.

A Relationship Between Vectors and Increasing Population Dispersion of Alien Species

A further critical consideration -- a "red flag" in the invasions framework -- is that as the number of scattered populations of an alien species increases (either through post-introduction range expansion, even by natural means, or simply through the widespread inoculation of disparate populations around the world by human-mediated vectors), the potential of such species to interface with a greater number of vector episodes and incidents and vector types also increases.

Thus, Population "A" of Species "H" at Site "S" can be dispersed by (n) vectors from that site. But when Species H is introduced to Site T, forming what may be a distinct metapopulation, vector diversity (Vd) may change, such that Species H may now be dispersible by not only an increasing number or frequency of vectors, but also be transportable to regions to which Site T but not Site S is connected by certain vectors. When Species H is introduced to Site U, Vd may again change, and so on.

The rationale for limiting a species' spread is thus not only to reduce its economic or environmental impact, but also to limit its abilities to interface with an increased number or diversity of conveyor belts. It is thus not surprising that when some species enter a new continent, they may spread rapidly across the land or water, not simply because it is being carried by one conveyance (trucks or boats), but because each newly established population has the potential to interface with one or more new vectors.

Vector Research Needs and Public Information Needs

In order to provide scientific data that of necessity underlie management strategies, vector research agendas are now required for most regions. Little to no information is available for most regions relative to the total diversity of transport vectors now serving to transport species to a given region, nor the diversity of species moved with and along such vectors. In contrast, a great deal of speculation, assumption, estimation, and conjecture is often available, leading, not surprisingly, to diffuse and unfocused strategies that permit numerous invasion windows to remain open.

Coupled with this is the need to have in place sufficient and adequate public information campaigns that describe in direct, simple terms what the concerns are relative to exotic species invasions -- and thus why new invasions must be curtailed.

Relative to this, challenges abound as to the quality and quantity of an understanding of exotic species invasions and vectors among the public, government, the press, and indeed scientists as well. Commonly expressed beliefs, for example, are that (1) invasions happen all the time anyway, and that humans are "simply" or "merely" speeding up a process that would happen anyway, (2) that humans have moved species around the world for hundreds or thousands of years, such that everything that could be moved would be moved by now, and (3) that the scale of people and goods moving around the world paint a picture of hopelessness in trying to affect any real control.

Fortunately, each of these common beliefs are easily addressed and erroneous information rectified, but correct information must reach what are now referred to as "stakeholders" in this process -- those who are at the heart of the vectors. Many invasions, of course, would simply never "happen anyway", as the majority of organisms are highly bounded by continental or oceanic barriers. Despite the continued operation of many vectors for many years, invasions continue to happen, underscoring the fact that not all species that could be successfully introduced to new regions have been introduced -- indeed, the opposite is the case. *Why* this is so is the subject of much speculation, but clearly both the donor regions, the vector itself, and the recipient region are in a constant state of change and flux, permitting many new opportunities for species to become established. Finally, numerous quarantine, control, and management efforts now in place paint a clear picture that the situation is anything but hopeless. Indeed, the public and political awareness of the importance of exotic species invasions is, at the beginning of the 21st century, unparalleled, suggesting that we are on the threshold of increased pressure on reducing invasion flow to an invasion drip, if powerful and dynamic vector management strategies are implemented.

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