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The accidental introduction of invasive animals as hitchhikers through inanimate pathways: a New Zealand perspective

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Summary

Hitchhiker organisms have been known since the earliest days of international travel, but changes in global trade mean that there are more now than ever before. They include a number of serious invasive species and are among the most difficult of quarantine problems to manage. Invasive animals transported as hitchhikers, other than plant pests, fall largely outside the international frameworks for biosecurity risk analysis. However, this is not necessarily a barrier to either risk analysis or effective management. While there are a number of challenges in managing hitchhiker organisms, the risk analysis tools that are needed already exist. However, opening up access to appropriate information, increasing international cooperation and developing new biosecurity treatments suitable for large-volume pathways will enable significant improvements.

Keywords

Biosecurity – Hitchhiker – Inanimate pathway – Invasive animal – New Zealand – Risk analysis.

Introduction

Understanding the vectors or pathways by which invasive animals enter new countries and become established is an important step in developing strategies to lessen the risk from these species (3, 9, 23, 27). Drawing on recent work from New Zealand, the authors review the accidental introduction of new species of invasive terrestrial animals via ships, aircraft, containers, packaging, vehicles, machinery and other commodities, collectively termed 'inanimate' pathways, and identify solutions to the risk management challenges that they present. The paper focuses on the entry component of the introduction process because the factors influencing the likelihood of establishment are generally not specific to this pathway (e.g. 41).

Terms such as pathway, vector, inanimate pathway, hitchhiker and stowaway are used variably in the literature (e.g. 22, 26, 56). In this paper, the terms 'pathway' and 'hitchhiker' are used as defined below:

– pathway: any means that allows the entry or spread of a potential hazard (38)

– hitchhiker organism: an organism that has an opportunistic association with a commodity or item with which it has no biological host relationship (41).

While not always considered hitchhikers, pathogens in contaminants, such as soil or animal faeces, require a similar approach to risk assessment and management and are considered within the definition of a 'hitchhiker organism'. In this paper, the authors focus only on macroscopic organisms.

What are hitchhikers?

A number of important invasive species are transported as hitchhikers on inanimate pathways. The Asian gypsy moth (*Lymantria dispar*), carried on vehicles, sea containers and ships, is one of the most well-known plant pests

transported as a hitchhiker (41). This moth is a major pest of forest and amenity trees. The brown tree snake (*Boiga irregularis*), one of the best-known reptilian hitchhikers, arrived in Guam in the late 1940s or early 1950s, most probably with vehicles or other military cargo (51). The destruction of much of the forest avifauna of Guam and some lizards has been attributed to this snake (50, 54), which also causes power outages and affects tourism (52). Disease-carrying mosquitoes, including *Aedes aegyptii* and *A. albopictus*, have been carried as hitchhikers on used tyres (48). Adult mosquitoes can be transported by aircraft and are associated with 'airport malaria', in which individuals who have never visited a malarious area contract malaria through the arrival of infected mosquitoes (25). The red imported fire ant (*Solenopsis invicta*), an invasive ant of economic and medical significance, is associated with inanimate pathways, particularly where items are contaminated with soil (36) (Fig. 1). Further examples of hitchhiker groups are given in Table I.

Hitchhiker traits

Traits that contribute to the likelihood of successful establishment in a new location have been frequently considered (e.g. 22, 34). Recent risk analyses for hitchhiker organisms (39, 41) show that there are also traits that contribute to the likelihood of species becoming associated with transport pathways and surviving to reach new locations. These traits include:

Fig. 1
The invasive red imported fire ant (*Solenopsis invicta*) is associated with inanimate pathways, particularly when items are contaminated with soil
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– an attraction to habitats modified by humans, e.g. the Asian gypsy moth being attracted to lights; mosquitoes being attracted to water in old tyres

– the ability to complete their entire life cycle in human environments or highly disturbed habitats, e.g. the Asian house gecko (*Hemidactylus frenatus*), widow spiders (*Latrodectus* spp.) and many ant species

– a life stage that seeks sheltered areas to avoid extreme conditions or escape detection, e.g. the brown tree snake, the giant African snail (*Achatina fullica*)

– a life stage or stages with dormancy, which allows them to survive extended periods in transit, e.g. the eggs of the Asian tiger mosquito (*A. albopictus*), the aestivating giant African snail, praying mantis egg masses

– an association with common contaminants of imported goods, such as soil or plant material, e.g. the red imported fire ant.

Inanimate pathways

Both commodities and methods of transportation, as well as associated material, such as packaging, need to be considered as pathways for hitchhiker organisms. All commodities of non-biological origin, as well as some of biological origin (e.g. timber products), come within the definition of inanimate pathways.

Although hitchhiker organisms do not have a biological host association with inanimate commodities and conveyances, there are some well-documented associations between specific pathways and particular hitchhiker groups. For example, mosquitoes are associated with used tyres (48) and snails with tiles (49). Not all inanimate pathways are equally likely to have hitchhikers; scrap metal and used vehicles are associated with a large number of different hitchhiker groups (11, 39), while air containers have few associated hitchhikers (18, 68). A common factor among the most important commodities for the transport of hitchhiker organisms is the conditions in which they are used and stored before exportation (41).

The types of inanimate pathways that are important in the international transport of hitchhikers vary between countries. As New Zealand has no land borders, air and sea transport are important while road and rail are only relevant internally. New Zealand has no domestic vehicle-manufacturing industry; so both new and used vehicles are imported. Examples of inanimate pathways are given in Table II. Many of these pathways have been identified by the Conference of the Parties under the Convention on Biological Diversity (13).

Table I
Examples of invasive animals transported as hitchhiker organisms and associated pathways

Group	Example species	Example pathways	Notes	References
Reptiles	Asian house gecko (*Hemidactylus frenatus*)	Cargo. Increasing numbers of interceptions as trade patterns change	Cryptic and have parthenogenetic reproduction. Vectors of parasites	(19)
Mosquitoes	Asian rock pool mosquito (*Aedes japonicus*)	Tyres, anything that carries water	Breed in natural and artificial containers. Associated with human-modified habitats. Dessication-resistant eggs. Disease vectors	(4)
Molluscs	Giant African snail (*Achatina fullica*)	Sea containers, some cargo such as tiles, also plants	Historically spread deliberately, now a hitchhiker. Aestivation allows snails to survive transport. Primarily plant pests, also disease vectors	(49)
Spiders	Widow spiders (*Latrodectus* spp.)	Vehicles, household goods, also fresh produce	Venomous, threat to New Zealand native *Latrodectus katipo* via hybridisation	(11, 30, 39, 47)
Ants	Yellow crazy ant (*Anoplolepis gracilipes*)	Sea containers, machinery, freight, baggage, nests associated with soil	Like many ant species, these are common hitchhikers. Associated with declines in crab, skink, bird and insect populations	(1)
Wasps	European and German wasps (*Vespula vulgaris, V. germanica*)	Cargo, possibly entered New Zealand on aircraft parts	Transported as hibernating queens. Compete with native birds and invertebrates for food, especially honeydew. Affect nutrient cycling	(6, 17)
Mantids	South African mantid (*Miomantis caffra*)	Likely hitchhiker on inanimate pathways. Egg cases of other mantids intercepted on vehicles	Arrival in New Zealand coincides with decline in native *Orthodera novae-zealandiae*, uncertain whether there is a causal relationship	(39, 46)
Flies	Old World screw-worm fly (*Chrysomya bezziana*)	Ships, aircraft	Detected on a ship in Darwin Harbour in 1988, uncertain how frequently this species is a hitchhiker	(8)
Beetles	Harlequin ladybird (*Harmonia axyridis*)	Fresh produce; likely hitchhiker on inanimate pathways due to winter aggregation behaviour	Generalist predators, widely introduced as biological control agents, but becoming invasive	(31, 43)

Biosecurity risk analysis frameworks

There is growing evidence that many species which have eluded border controls are hitchhikers (e.g. 5, 29, 41). Increased trade and travel are predicted to increase the importance of hitchhiker pathways (24). Despite increasing concern, relatively little effort has been made to manage the risk of invasions via inanimate pathways, in comparison with biological commodities. This may reflect the absence of a clear international risk analysis framework for inanimate pathways (14) or other factors, as discussed in the next section, 'Hitchhikers: challenges'.

The risk analysis chapter of the *Terrestrial Animal Health Code* of the World Organisation for Animal Health (OIE) covers the introduction of organisms that may have negative consequences for animals, humans and the environment through the importation of animals and animal products (73). The International Standards for Phytosanitary Measures (ISPMs) numbers 5 and 11, developed by the International Plant Protection Convention (IPPC), encompass the risks to plant health from pests or diseases associated with plants, plant materials and other regulated articles, including inanimate objects (55, 56). However, organisms that can be carried by plant products or inanimate objects and which affect human and animal health are not covered by either framework (59). The Conference of the Parties under the Convention on Biological Diversity (1992) has noted these gaps in the existing international regulatory framework (14). The gaps are linked to the different approaches of the two organisations: the OIE approach is pathway-based (animals and animal products), while the IPPC approach is based on the type of impact (plant health).

Despite these gaps, the World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement) (1995) allows mitigation measures to be developed in the absence of international standards, to protect human, animal and plant life or health, as long as they are consistent with the other provisions of the SPS Agreement (74). On this basis, national biosecurity frameworks can be developed to encompass hitchhiker organisms and inanimate pathways. An example is the biosecurity risk analysis framework (38) used in New Zealand for animal products, plant products and inanimate pathways. Some analyses conducted within this framework are discussed below.

Hitchhikers: challenges

A number of serious invasive species, as well as poorly known species with an unknown potential to cause problems, can be transported as hitchhikers. While hitchhikers are a serious problem, there are a number of barriers and challenges to more effective management of hitchhiker organisms. The New Zealand experience has highlighted some of these challenges.

Recognising the significance of hitchhiker organisms

Hitchhiker organisms such as Norway rats (*Rattus norvegicus*) have been documented since the earliest days of European colonisation of New Zealand (35). Other well-known invasive species in New Zealand, such as the introduced social wasps *Vespula germanica* and *V. vulgaris*, were also most likely to have been introduced as hitchhikers (17). However, since, historically, there have been so many deliberately introduced animals that became invasive (e.g. 28), and since these species include some of the most well-known invasive animals in New Zealand, such as the brushtail possum (*Trichosurus vulpecula*), the deliberately introduced species have perhaps eclipsed the hitchhikers.

There are relatively few analyses of the pathways by which invasive species, particularly hitchhikers, arrive in a new area. Kiritani and Yamamura (29) reviewed entry pathways for exotic insects in Japan, and were unable to identify probable entry pathways in 76% of cases. Among the examples where the likely entry pathways could be determined, 13 (of 98) were associated with inanimate pathways. Ten of these were associated with military transport, while the remaining three were listed as hitchhikers but the pathway was not specified further. The difficulty in determining the introduction pathway for hitchhikers, especially when compared to deliberate introductions, contributes to a lack of awareness of the need to manage hitchhiker organisms, even when their significance is accepted.

Evidence of association with pathways

The opportunistic nature of hitchhikers means that it can be difficult to understand their association with pathways. For organisms associated with biological commodities, such as live animals or meat products, sources of evidence include the scientific literature and the *Terrestrial Animal Health Code* (73). These sources are rarely useful as evidence for the association of hitchhiker organisms with pathways. The most useful information is records of organisms being intercepted during routine entry or targeted surveys (collectively termed 'interception records'). This approach has been used both for pathways – for example: sea containers in Australia (62), cargo aircraft in the United States (10) and vehicles in New Zealand (39) – and for groups of organisms, for example: non-marine gastropods (49), wood-boring Coleoptera (21), reptiles and amphibians (19), and ants (63, 69).

While interception records provide direct evidence of an association between a hitchhiker organism and a pathway, they have a number of limitations. In particular, they do not provide a complete list of potential hazards. Moreover, they can only rarely be used quantitatively (39, 41, 62), because:

– entry pathways have different levels of quarantine inspection, identification and recording

– interceptions recorded over a short period reflect only that season or set of import conditions

– many interceptions are not identified taxonomically, by species (27)

– post/border interceptions generally rely on public reporting (39)

– there may be biases in the collection of data according to national detection priorities (15, 27).

Impact of propagule pressure and pathway volume

Species that are introduced in larger numbers, or more frequently, are more likely to become established than those that are introduced in smaller numbers or less frequently (33). The effect of propagule pressure has been observed in a wide range of organisms, including birds (20, 65), insects (2) and plants (67). Hitchhikers typically occur at low frequencies on pathways. For example, while the likelihood of a used vehicle being infested with live Asian gypsy moth egg masses is less than 0.1% (41), the high volume of the imported vehicle pathway (see Table II) translates this 'low frequency' infestation into a high likelihood of entry. The Asian gypsy moth is also associated with other high-volume pathways, such as sea containers and ships, further increasing the likelihood of entry. The large number of potential hitchhiker species also increases the risk. For example, at least 15 high-consequence organisms have a demonstrated association with the used vehicle pathway (39). In the context of hitchhiker species, low frequency for any one species does not necessarily mean a low likelihood of incursions on that pathway.

Difficulty of visual detection

Work *et al.* (72) estimated that even rigorous quarantine inspections probably only detect 19% to 50% of associated species, depending on the pathway. The use of a

Table II
Examples of inanimate pathways relevant to New Zealand

Pathway	Volume entering New Zealand in 2007 to 2008 (42)	Notes
Sea containers	631,000	Different types of organisms associated with the interior and exterior of sea containers. Containers can be a pathway for hitchhiker organisms independent of cargo or packaging (37, 41)
Used vehicles and machinery	128,000	Important pathway for New Zealand. Complex structures conceal a wide range of organisms. New vehicles and machinery are less commonly associated with hitchhikers (39)
Personal effects	33,000 consignments	Many different types of item from multiple countries of origin. Ants and spiders are frequent hitchhikers (12)
Packaging	90% of sea containers in a recent survey contained wood packaging	Most organisms associated with wood packaging are not hitchhikers, but species associated with live trees or recently cut wood. These are managed through the international standard for the regulation of wood packaging material. In contrast, hitchhikers are not managed through the implementation of the wood packaging standard, but can be associated with both wood packaging and non-wood packaging, such as metal and plastic (16, 41, 44, 57)
Bulk cargo (non-containerised)	No figures available	Outdoor storage means that this cargo is often a greater risk than containerised cargo (41)
Ships	3,000	Associated with a wide range of terrestrial hitchhiker organisms, but not all organisms are likely to get off a ship in port (41, MAFBNZ unpublished data)
Air containers	221,000 (Auckland only)	Handled differently from sea containers and much less commonly associated with hitchhikers. However, shorter transport time increases the likelihood that organisms will survive transport (18, 41, 68)
Military	Figures not available	Military vehicles and equipment are internationally recognised as a pathway for hitchhikers; there is no evidence that this is a significant pathway for New Zealand (29, 41)
Aircraft	30,000	Short transport time increases the likelihood of organisms surviving transport. Higher contamination on night-loaded flights. Risk depends on cargo type. Implicated as entry pathway for *Anopheles gambiae* into Brazil (10, 53, 61)

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videoscope to inspect 541 randomly selected, imported used vehicles entering New Zealand found that 48% had biosecurity contamination that was not detectable by visual inspection conducted without specialist equipment (70). Sea containers are more likely to have contaminants on the underside than any other part of the container, but this is also the most difficult area to inspect (71). Certain hitchhiker groups, such as reptiles and spiders, are particularly difficult to detect visually because they include very mobile organisms that actively hide. The complex structure of some inanimate commodities, such as vehicles and machinery, also makes it difficult to detect associated organisms.

Based on a statistical analysis of interception records, Ward *et al.* (69) concluded that inspection is of limited efficacy for detecting ants entering New Zealand in maritime cargo. Detection rates depend on a range of factors, including the nature of the commodities, the commodities that are focused on by border authorities and the traits of the taxa, e.g. cryptic behaviour and body size (69). The sampling protocols used are also influential (66).

Difficulty of prediction

Many inanimate pathways are high volume and, for practical purposes, there is a need to focus risk management effort on the areas of highest risk. However, there are serious difficulties in predicting which imported items are most likely to carry hitchhikers and even grouping them on the basis of risk is difficult. For example, one important indicator that goods will carry hitchhiker organisms is that they have been used and stored outdoors (36, 41). Knowing where they have been stored outside can also be helpful. For instance, for some caterpillar species, storage close to a host plant, when full-grown caterpillars are seeking sites to pupate, enables the association to occur. This type of information is so rarely available that it currently has no practical use in risk assessment.

Lessons for managing hitchhiker organisms on inanimate pathways

Information for analysing biosecurity risks

While the management of hitchhiker organisms poses a number of challenges, one key to improving risk management is obtaining the appropriate information to conduct more accurate risk analyses.

Interception records

Despite their limitations, the value of interception records in understanding invasive hitchhiker species, such as ants, means that maintaining accessible databases of intercepted specimens is a wise investment (63). The Ministry of Agriculture and Forestry Biosecurity of New Zealand (MAFBNZ) maintains a database of organisms intercepted on incoming goods at the border and post border, including records from both routine inspections and surveys. Records from this database have been used to inform recent hitchhiker risk analyses. A pest risk assessment of six species of moth looked at a range of pathways (41), while an import risk analysis for imported vehicles and machinery assessed the risks from a range of organisms on a single pathway (39).

Surveys to identify hitchhiker pathways

When the resources required for comprehensively identifying and recording interceptions are not available, surveys can be used to give a picture of the overall rate of contamination and the main hitchhiker groups. In New Zealand, there is a continuing programme of detailed surveys to detect and measure the amount of biosecurity risk material entering on different pathways, in order to monitor changes over time and inform the biosecurity system. Recent surveys of biosecurity contaminants on inanimate pathways in New Zealand have confirmed that these are important for the entry of hitchhikers. Pathways surveyed include:

– imported used vehicles (70)
– scrap metal (11)
– sea containers (71)
– personal effects (12).

However, surveys are unlikely to produce a comprehensive species list or to detect lower frequency organisms, unless the survey has a very large sample size.

Basic biological data

Analysis of the biology and life cycle of a range of hitchhiker organisms suggests that there are characteristics which predispose species to an association with transport pathways and the ability to survive to enter a new location (41). Information on these traits enables hitchhiker organisms and pathways to be identified, but there is a paucity of ecological information, relevant to risk analysis, on many hitchhiker species.

Longer-term requirements

As well as highlighting the challenges associated with managing invasive animals transported as hitchhikers through inanimate pathways, the New Zealand experience has identified areas that offer substantial opportunities for improvement (41). Four such areas are outlined below.

International cooperation

Concerted action at a global or regional level is necessary to manage the risks on many pathways that enable invasions of hitchhikers to occur. Since both the causes and consequences of invasions are shared, they can only be effectively addressed by cooperative action (60). Practical areas for cooperation include information sharing and the development of joint management programmes. More accessible data, and data exchanges between relevant organisations, are also needed (45).

Alternatives to visual inspection

In addition to the limited efficacy of visual inspection, the scale of many inanimate pathways means that the resources required for inspection are excessive. Thus, there is a need to focus efforts on those pathways that are most likely to be infested (49, 64) or on those by which the organisms most likely to become established can enter (69). The proportion of organisms that can be detected on high-volume pathways, such as sea containers, can only ever be a small proportion of those that are actually imported (62).

However, if the factors that increase the likelihood of association with a particular pathway are known, and the right information is collected, a greater degree of targeting is possible. For example, the well-documented link between the Asian gypsy moth and specific ports in far-eastern Russia, combined with information on the most likely place in which Asian gypsy moths will be found on a sea container, justifies the inspection at the New Zealand border of the undersides of sea containers that are known to have been in these ports. This has resulted in the interception of a number of Asian gypsy moth egg masses that would otherwise have entered New Zealand undetected (41).

Safe and effective treatments

Another approach is the development of broad-spectrum treatments and management approaches that can be applied to high-volume pathways. This is the approach taken by the IPPC to wood packaging material, in ISPM 15 (57). Further use of such treatments and approaches is limited by the available technology. The most widely used treatment for hitchhiker organisms on inanimate pathways is fumigation with methyl bromide. While effective on a wide range of organisms and commodities (7), this is an ozone-depleting gas. Under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (58), the production and consumption of such substances will be phased out. While the use of methyl bromide as a quarantine treatment has been

exempt from these requirements, all countries are urged to reduce its use and find appropriate alternatives.

In New Zealand, the sea container hygiene programme for empty containers returning from some Pacific Islands is another useful approach. Frequent interceptions of ants and other hitchhikers prompted a government-industry partnership to improve the hygiene of these containers. This programme involves cleaning the containers, taking steps to prevent reinfestation and modifying the habitat at participating source ports to reduce ant populations (32). For example, measures might include paving the container storage area and maintaining a buffer zone cleared of vegetation. As well as reducing the number of dirty sea containers arriving in New Zealand, this programme has reduced compliance costs (40), demonstrating that there can be multiple benefits to improved biosecurity.

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L'introduction accidentelle d'animaux envahissants « autostoppeurs » via des vecteurs inanimés : le point de vue de la Nouvelle-Zélande

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Résumé

Le phénomène des organismes « autostoppeurs » est connu depuis le début des voyages internationaux, mais il a récemment pris une ampleur inégalée du fait de la mondialisation des échanges. Certains de ces organismes appartiennent à des espèces envahissantes jugées très préoccupantes ; ils posent aussi des problèmes de quarantaine parmi les plus difficiles à résoudre. En dehors des espèces nuisibles pour les plantes, les espèces animales envahissantes transportées accidentellement ne sont guère prises en compte dans les procédures d'analyse du risque pour la biosécurité appliquées à l'échelle internationale. Néanmoins, cela ne constitue pas nécessairement un obstacle à la conduite d'analyses des risques ni à une gestion efficace de ce problème. Malgré les nombreux défis liés à la gestion des organismes « autostoppeurs », des outils d'analyse du risque adaptés sont disponibles et peuvent être utilisés. Cependant, pour une avancée significative dans ce domaine, il sera nécessaire d'assurer l'accès aux informations, de renforcer la coopération internationale et de mettre au point de nouveaux protocoles de biosécurité adaptés à ces voies d'introduction, qui concernent de grandes quantités d'organismes.

Mots-clés

Analyse du risque – Biosécurité – Espèce animale envahissante – Nouvelle-Zélande – Organisme « autostoppeur » – Voie d'entrée via un vecteur inanimé.

Introducción accidental de animales invasores "autoestopistas" por rutas inanimadas: perspectiva neozelandesa

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Resumen

Aunque se sabe de la existencia de organismos "autoestopistas" desde los primeros tiempos de los viajes internacionales, hoy en día son más numerosos que nunca debido a la evolución del comercio mundial. Entre ellos hay una serie de importantes especies invasoras, que plantean problemas de cuarentena especialmente difíciles de manejar. Aparte de las plagas que afectan a las plantas, la mayoría de los animales invasores transportados como "autoestopistas" quedan fuera de los sistemas internacionales de análisis del riesgo de bioseguridad, aunque ello no impide necesariamente analizar el riesgo y gestionarlo con eficacia. Luchar contra la presencia de "autoestopistas" no deja de plantear una serie de dificultades, pero ya existen para ello las herramientas de análisis del riesgo necesarias. Con todo, la total apertura del acceso a información apropiada, la intensificación de la cooperación internacional y la definición de nuevos tratamientos de seguridad biológica adaptados a las rutas de transporte en grandes cantidades harán posibles nuevos e importantes avances.

Palabras clave

Análisis del riesgo – Animal invasor – Nueva Zelanda – Autoestopista – Ruta inanimada – Seguridad biológica.

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