Standardising and Structuring Pathways and Impacts of Invasive Species

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James Russell

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Executive Summary

A standardised system for managing pathways and impacts of invasive species is vital for the long-term management and prevention of invasions. Little work has addressed such a framework though, and some groups believe it is foolish to classify invasive species by pathways and impacts. This report reviews current literature and summarises discussions held with staff of the Invasive Species Specialist Group on devising an appropriate framework. The final standardised structure is immediately for use within the Global Invasive Species Database (GISD), however it may have wider application.

The framework for invasive species pathway management is an adaptation of work by Jim Carlton, focusing on human-aided dispersal (cause, routes and vectors), with additional input on self-regulated dispersal. The largest distinction is between human-aided and self-regulated dispersal. Other conflicts in devising a framework are also resolved. Some clarification and re-definition of terminology is also suggested.

The framework for invasive species impacts management recognises the distinction between mechanism and outcomes of impacts. It builds upon current structures and links mechanisms to outcomes with a many-to-many relationship. Absence of information in impacts is incorporated into this framework. Standardisation based on literature is recommended, accounting for difficult to classify impacts such as those of pathogens.

The appendices provide preliminary draft lists of standardised terms to be used. These lists are not intended to be exhaustive at this stage, and should only be considered complete once consultation with a wider panel of invasive species experts has taken place.

Background

The Invasive Species Specialist Group (ISSG) manages a Global Invasive Species Database (GISD). The primary purpose of this database is to provide information to managers on invasive species, with a global and environmental focus. This information is largely delivered at the species level via an ecology 'factsheet' page, and a global distribution page.

Pathways and impacts of invasive species are a fundamental part of their description and management. Knowledge of pathways allows for prevention of invasions, while knowledge of impacts empowers managers seeking support. Unfortunately, there have been very few attempts to develop structures which would allow categorical classification of the pathways and impacts of invasive species. This can in large part be attributed to the lack of knowledge on the diversity of all invasive species, and the appropriate reactionary attitude of eradication towards invasive species. This is compounded by the relative youth of the discipline. This has been reflected in the GISD, where in the past procedures for classifying pathways and impacts have generally been made in an *ad hoc* manner.

If managers are to be truly empowered to address the issue of invasive species from a collective non-specific approach (i.e. not species based) then a standardised structure (which can be applied within the GISD) which allows invasive species to be classified according to their pathways and impacts must be developed. This report builds on previous work that was available and discussion with ISSG staff to develop such a standardised structure.

Pathways

Currently

Pathways in the database are currently loosely defined by a number of 'new location' and 'local' dispersal mechanisms. In the past, new categories have had to be added as they are detected, generally as a result of a species-specific mechanism. Although this method conveys the key components of dispersal to managers, it lacks the ability to properly classify by mechanism (c.f. collecting mechanisms within a species). It also does not allow for rigorous qualification of pathways and their components.

Invasion pathways to new locations	*Local dispersal methods*
Acclimatisation Societies	Acclimatisation Societies (local)
Agriculture	Agriculture (local)
Aircraft	Aquaculture (local)
Aquaculture	Boat
Aquarium trade	Digestion/excretion
Biological control	Escape from confinement
Floating vegetation/debris	For ornamental purposes (local)
For ornamental purposes	Forestry (local)
Forestry	Garden escape/garden waste
Ignorant possession	Hikers' clothes/boots
Internet sales/postal services	Mud on birds (local)
Landscape/fauna "improvement"	Off-road vehicles
Live food trade	On animals
Military	Other (local)
Mud on birds	People foraging
Nursery trade	People sharing resources (local)
Other	Road vehicles
People sharing resources	Self-propelled (local)
Road vehicles (long distance)	Translocation of machinery (local)
Seafreight (container/bulk)	Transportation of habitat material (local)
Self-propelled	Water currents
Ship	Wind
Ship ballast water	
Ship/boat hull fouling	
Smuggling	
Taken to botanical garden/zoo	
Translocation of machinery	
Transportation of domesticated animals	
Transportation of habitat material	

Table 1: Current GISD pathways classification (note some overlap in terms)

James Carlton of the Maritime Studies Program, Williams College, Connecticut has given the most thorough treatment to pathways prior to this report[1]. His framework is notable for being pathways based (c.f. species

[1] Carlton, J. T. and Ruiz, G. M. (*in press*) *Principles of Vector Science and Integrated Vector Management.* in H. Mooney *et al.* (eds), *Best Practices for the Prevention and Management of Alien Invasive Species.* Island Press.

based) and is described here, as an adaptation building upon it and incorporating elements from other systems appears to be the best way to progress towards pathway classification for invasive species.

The Carlton framework is based on a tri-level classification

- CAUSE – Why a species is transferred
- ROUTE – The geographical passage of transfer
- VECTOR – The agent of transfer

Cause can be further divided into 'accidental' or 'deliberate'. Deliberate introductions have 'purposes'

- PURPOSE – Why a species is introduced

ROUTES also have associated 'corridors'

- CORRIDOR – The physical conduit of transfer

VECTORS also have associated summary statistics – 'tempo', 'biota' and 'strength'. A synopsis of the Carlton framework is provided in Appendix A, with associated terminology and glossary.

The Carlton framework can be diagrammatically represented (Table 2).

CAUSE			ROUTE		VECTOR
ACCIDENT	DELIBERATE	=>	CORRIDOR	=>	
	PURPOSE				
	~				
	~				
	~				
	~				

Table 2: Summary of Jim Carlton's framework.

Conflicts

There are a number of potential 'conflicts' in pathway derivation and classification that need to be resolved before and during creation of an appropriate system. These are

- Long / Short distance
- Intentional / Unintentional
- Human-aided / Self-regulated
- Terrestrial / Marine

It should be noted here that long and short distance are misnomers to some extent. 'Long' and 'short' are entirely defined within the context of the species and regions they are being applied to. They have some equivalence to the terms currently used in the GISD ('new location' and 'local'). They are considered to equate to 'inter' and 'intra' regional dispersal (e.g between countries as compared to within countries). This is most readily applied to island systems. When considered within the context of continental systems, they make less sense (e.g. dispersal along a single river system crossing many regions). 'Long' and 'short' are also arbitrary, given that distance itself is a continuous function. This once again emphasises the human conceptualisation of this distinction. This largely preempts the exclusion of the distance distinction from the proposed structure.

Intentional and unintentional are introduced here as an alternative to deliberate and accidental. This is because the latter pair of words are more connotatively loaded (accident in particular implies an absence of responsibility). Intentional releases may also be authorised or unauthorised by governing bodies, however such distinction is largely historical, and would not particularly aid managers of prevention or eradication.

Similarly, human-aided and self-regulated are introduced here as an alternative to human and natural dispersal. Natural dispersal implies a sense of 'naturalness' and that humans are not responsible. This is not the case, as the original introduction of any invasive species is through the error of humans, and so humans are no less responsible for any subsequent actions as they are for the original introduction (whether it be intentional or unintentional).

The terrestrial and marine distinction is included largely due to the division of these two disciplines ecologically. Often, standard terms in one discipline do not readily cross-over to the other. This would only serve to confuse managers with no knowledge of either discipline. Any standardised structure created for classifying pathways would need to be transferable between both disciplines. These conflicts shall also be resolved during the creation of the proposed structure, through testing within the context of it.

Proposal

In addressing the conflicts outlined earlier in relation to the Carlton framework, it becomes apparent that the Carlton framework is 'human-aided' and 'long distance' focused (though the framework can be effectively applied to short distance, human-aided dispersal). It accounts for intentional and unintentional introductions under the headings of deliberate and accidental. Cursorily assessing the framework for both terrestrial and marine species suggests it works equally well. Because the vector characteristics (tempo, biota and strength) are summary statistics (with a regional focus), they have been disregarded here, and so no further reference will be made to them. This simplifies the proposed system, hopefully making it more accessible to lay-people. Similarly the concept of 'routes' is not appropriate for a globally focused database. Although identification of geographic routes is vital to invasive species management, they become intractable at the global scale (the number of possibilities tends towards infinite). Similarly corridors can be identified from vectors, and generally any corridor can be a possible route (e.g. transporting contaminated machinery). Purposes and vectors are generally finite lists which can be standardised (although as new forms of transport are identified, new vectors may warrant addition). Vector terms may have specific information attached to them in a notes section for a species (e.g. if mud is the vector, it may be noted that for one species the mud is distributed on birds' feet).

In light of the conflicts, the apparent approach to structuring the new system is either by distinguishing between long and short distance dispersal (as the GISD currently does, though without standardisation), or by distinguishing between human-aided and self-regulated dispersal. Because of the associated problems with distinguishing between long and short distance dispersal that largely dictated the need for this report (see earlier discussion), that option was abandoned early on. The remaining option is to distinguish pathways of invasion as either human-aided or self-regulated (Table 3).

What remains now is to adapt a framework for self-regulated dispersal of invasive species. The key here is that such self-regulated dispersal will be species dependent (c.f. human-aided dispersal which is for the most part species independent).

SELF-REGULATED	HUMAN-AIDED
?	Adapted Carlton
(SHORT)	(LONG + SHORT)

Table 3: Distinguishing between self-regulated and human-aided dispersal. The Carlton framework applies to human-aided dispersal, over both long and short distances.

The Carlton framework does not apply in its entirety to natural dispersal.

- CAUSES = biological cues for dispersal
- ROUTES = do not exist (corridors however may)
- VECTOR = species dependent modes of locomotion

Self-regulated dispersal methods can also include a statistical component of rates such as breeding and migration, as vector summary statistics do.

It is immediately clear that dispersal cues can not be managed, as these are intrinsic to species. These will be of little interest to managers of invasive species. Knowledge of the expansion process through natural dispersal mechanisms is the only remaining approach managers can take (and do) to managing invasive species. Here the term ‘locomotion’ is introduced as a surrogate for ‘mechanism’ which is already used in impacts. Hence the best framework for managing self-regulated dispersal of invasive species is by describing their species dependent modes of locomotion, and making these available to managers. These modes could be further divided by taxa groupings (e.g. animals, plants, etc).

SELF-REGULATED
LOCOMOTION
~
~
~
~
~
~

Table 4: Proposed framework for categorising self-regulated dispersal in invasive species

The implementation of these frameworks within the GISD would see each species categorised by values from a standardised list (e.g. Appendix B) for its

- SELF-REGULATED: LOCOMOTION
- HUMAN-AIDED: CAUSE (PURPOSE) & VECTOR

With the appropriate search queries defined managers could then obtain lists of invasive species by each of the above categorisations.

Impacts

Currently

Impacts in the database are currently loosely defined by a number of *ad hoc* terms. Note in particular the inclusion of 'other' and 'unknown' which characterise the non-finite nature of the list, and lack of information. In the past, new terms have had to be added as they are detected in a species-specific manner. Although this method conveys some idea of impacts to managers, it is not particularly robust. It also does not allow for rigorous qualification of impacts (being either too general or too specific).

Impacts
Agricultural
Competition
Disease transmission
Economic
Fouling
Habitat alteration
Herbivory
Human nuisance
Hybridisation
Interaction with other invasive species
Modification of fire regime
Modification of hydrology
Modification of natural benthic communities
Modification of nutrient regime
Modification of successional patterns
Other
Parasitism
Pathogenic
Physical disturbance
Predation
Unknown

Table 5: Current GISD impacts classification (note unknown/other terms)

Little work has been done addressing the impacts of invasive species from a non-species (or at best taxa) specific approach. Most impact classification has been done following multiple studies each on single invasive species, and then coercing those impacts to fit within a similar framework. This is what has been done in the GISD. The key to a successful framework is for impact terms to be unrelated to any specific species (though not taxa) and independent of locations. Following definition they can then be linked to species or locations and appropriate lists compiled. This is also important as niche shift can occur in some invading species, and hence new impacts revealed.

Impacts can also be classified as either 'mechanisms' or 'outcomes'. Currently the GISD makes no distinction, which has contributed to confusion during the *ad hoc* process of impact definition.

Proposal

The current impacts classification framework appears appropriate, however it needs proper standardisation, and to incorporate the distinction of mechanisms of impacts (e.g. herbivory) versus outcomes of impacts (e.g. altered fire regime). Outcomes are logically the product of mechanisms (this would be a many-to-many relationship) though there may be cases when mechanism or outcomes are not known. This would have to be considered during implementation of the framework.

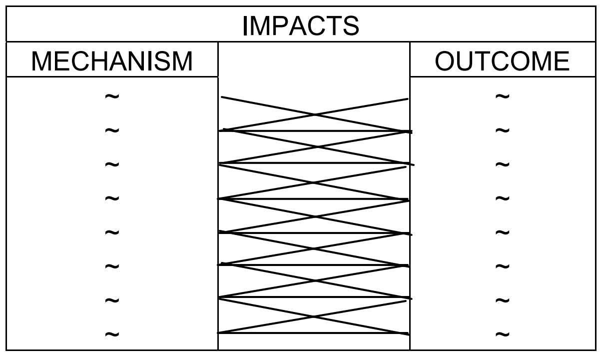

Table 6: Proposed framework for categorising impacts of invasive species

Because mechanisms are species specific, it would fit to list and group mechanisms by taxa. Outcomes may overlap between taxa (e.g. ‘human nuisance’), but the many-to-many relationship (Table 6) would allow for this. The distinction between overlapping outcomes would be the differing taxa-specific mechanisms by which the same outcome is generated.

Standardisation of the two lists is seen as the fundamental component of re-structuring the impacts framework. If a list is too general, new, more specific, terms would warrant inclusion. If a list is too specific, the framework would devolve into a non-useful species specific system once again. Impact notes can be attached to species in locations. It is important to note that impacts occur at the species-location level. To say a species has a certain suite of impacts is incorrect without specifying in which locations (e.g. niche shift), although this does occur and may require incorporation into the framework. The goal is to provide broad but definitive lists of mechanisms and outcomes which are useful to managers and can be classified by either species, location or impact type.

Outcomes can have a ‘cascade’ effect on ecosystems whereby invasive species can alter one component of an ecosystem, which will in turn reverberate into other components of ecosystems. Although recognising this effect is important, it could become intractable within a framework. Outcomes are thus recognised as the result of a mechanism, whether known or not. Additional notes should draw attention to cascading effects.

By recognising the relationship between impacts and taxa groups, it is also possible to embrace the literature, which often only operates at the species or taxa scale. In particular some problematical species may be encountered, which require careful consideration when standardising the list of impact mechanisms and outcomes (e.g. Appendix C). Examples include whether the species is an invasive pathogen, or the species transmits a pathogen (and this is the impact).

Acknowledgments

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Appendix A: A Framework for Vector Science

Figure 1

A Framework for Vector Science:

Cause, Route, Corridor, and Vector Components

CAUSE

why a species is transported, that is, whether *accidentally* or *deliberately* (if the latter, see *Purpose* below)

Examples: The European shore crab *Carcinus maenas* was accidentally introduced through shipping operations to eastern North America and elsewhere.

Synonyms: pathway, enterprise, activity, trade, endeavor, commerce, motive, rationale, incentive, reason

of <u>accidental:</u> unintentional, inadvertent, escape, chance

of <u>deliberate:</u> intentional, planned, purposeful, premeditated, planted, direct

- ***PURPOSE***:

why a species is *deliberately* introduced

Examples: food resource, ornamentation (aesthetics), biocontrol, pets, medicine

Synonyms: as above

ROUTE

the geographic path over which a species is transported from the origin (*donor area*) to the destination (*target area*)

Examples: " A route is from Rio de Janeiro (Brazil) to Le Havre (France)"

Synonyms: pathway, path, passageway, course, corridor

- ***CORRIDOR***:

the physical conduit over or through which the vector moves (i.e., within the route)

Examples: footpaths, roads, highways, canals, shipping lanes, trails, railroad beds

Synonyms: pathway, conduit, path

VECTOR

how a species is transported, that is, the physical means or agent

Examples: ballast, ships' hulls, movement of commercial oysters, clothing, animal feeds, vehicles

Synonyms: pathway, mode, dispersal mechanism, transport mechanism, manner, carrier, bearer, method

[VECTOR]

- ***CRYPTOVECTIC AND POLYVECTIC SPECIES***:

Species for which the vector of introduction is not known are *cryptovectic*, a term introduced here (from the Greek *crypt-,* secret and*vect*-, Latin,*vectus*, past participle of *vehere*, to carry).

Species having two or more means of being transported are *polyvectic,* a term introduced by Cohen (1997); etymology not given, but from the Greek *polys*, much, many; *vect*-, Latin (as above). Cohen defined polyvectic as "having many vectors or means of being transported".

Figure 2

A Framework for Vector Science:

Vector Tempo, Vector Biota, and Strength Components

VECTOR TEMPO **how a given vector operates through time, in terms of size and rate, speed, and timing**

- ***SIZE and RATE***

the frequency with which the vector operates to deliver propagules to the target, measured as the quantity of the vector (in units appropriate to the vector) expressed per unit time
Examples: the gallons of ballast water/hour, the number of container boxes/hour, the number of logs/day

- ***DURATION***

the length of time it takes for the vector to move species from the donor area to the target area

- ***TIMING***

the period (such as time of day, season, or other intervals) when the vector is active and delivers propagules to the target area

VECTOR BIOTA

description of the biota (the propagules) transferred by a given vector, in terms of diversity, density, and condition
Synonyms: propagule pressure, inoculant

- ***DIVERSITY***

the species richness, or number of different organism types, associated with the vector

- ***DENSITY***

the concentration or abundance of organisms, often expressed per taxon

- ***CONDITION***

the physiological condition or quality of propagules upon delivery to target area

VECTOR STRENGTH

the relative number or rate of established invasions that result within a specified time period from a given vector in a particular geographic region
Synonyms: magnitude, importance

James T. Carlton and Gregory M. Ruiz (*in press*) *Principles of Vector Science and Integrated Vector Management.* in H. Mooney *et al.* (eds), *Best Practices for the Prevention and Management of Alien Invasive Species*. Island Press.

Appendix B: Pathways Examples

MONGOOSE (*Herpestes javanicus*)

CAUSE
INTENTIONAL
PURPOSE Biological Control
Introduced for biological control of rats and snakes in agricultural habitats, from which the animals spread throughout local areas within decades
VECTOR
Cargo
Spread to neighbouring islands by cane planters
LOCOMOTION
Walking

ZEBRA MUSSEL (*Dreissena polymorpha*)

CAUSE
UNINTENTIONAL

VECTOR
Ship hulls
Water stores
Including ballast water, fish stocking and aquarium water
Equipment
Attached to scuba diving gear, scientific equipment, anchors, etc
LOCOMOTION
Currents
Range expansion within North America has been very rapid due to downstream transport of planktonic larvae and on vegetation debris and animals

VELVET TREE (*Miconia calvescens*)

CAUSE
INTENTIONAL
PURPOSE Captive population
Papeari botanical garden (Tahiti, 1937).
VECTOR
Mud
Including machinery, hikers and equipment.
LOCOMOTION
Animal transport
Digested in animal or in mud on hooves or in hair. This is how it has escaped from captivity

Appendix C: Impacts Examples

MONGOOSE (*Herpestes javanicus*)

LOCATION
Pacific
MECHANISM
Predation
OUTCOME
Species extinctions
Mongooses are known to eat the young of the endangered Hawai'ian crow (Giffen 1983 in Stone 1984) and both eggs and incubating females of the nene goose (Banko 1982).
Human nuisance
Predates on domestic fowl, can attack humans

LOCATION
Caribbean
MECHANISM
Predation
OUTCOME
Species extinctions
Mongooses caused the near-extinction of the ground-nesting quail dove (Geotrygon mystacea) (Nellis and Everard 1983)
Human nuisance
Predates on domestic fowl, can attack humans

ZEBRA MUSSEL (*Dreissena polymorpha*)

LOCATION
North America
MECHANISM
Fouling
OUTCOME
Economic
Loss of revenues from industries during closure for cleanout of intake pipes; cost of control in municipal water treatment plants and power plants; local cost of removal from docks, boat hulls
Human nuisance
Fouls water intake pipes, beaches, boat hulls, docks, may sink navigation buoys, clogs condenser pipes
Ecosystem alteration
Fouls shells of native molluscs, and spawning grounds of benthically spawning fishes
MECHANISM
Competition

OUTCOME

Trophic level alteration

Competes with native planktivores for food

MECHANISM

Predation

OUTCOME

Trophic level alteration

Consumes plankton species

VELVET TREE (*Miconia calvescens*)

LOCATION

Pacific

MECHANISM

Competition

Unknown

Forms dense monocultures, though the effect of this is unknown

OUTCOME

Ecosystem alteration