WILDLANKA Vol. 3, No. 2, pp. 107 - 127, 2015.

AN OUT-COME BASED APPROACH TO MANAGING PLANT AND ANIMAL INVASIONS IN THE FACE OF CLIMATE CHANGE

S. JAYAKODY[1], A.C. GRICE[2,*] and I.J. GORDON[3,1]

[1] *Wayamba University of Sri Lanka, Makandura, Gonawila*

[2] *CSIRO Ecosystem Sciences, Australian Tropical Sciences and Innovation Precinct, James Cook University, Building 145, Douglas Campus, 101 Angus Smith Drive, Townsville, Queensland 4811, Australia*

[3] *The James Hutton Institute, Invergowrie, Dundee, DD2 5DA, UK*

**iain.gordon@hutton.ac.uk*

ABSTRACT - It is well established that invasive species are able to disrupt natural ecosystems and affect the ecosystem goods and services that they provide. Though invasion biology is mainly concerned with intentional or accidental species introductions; with increased interest in the effects of climate change, much debate has recently been focused on species' range expansions. In this review we focus on the uncertainty in the responses of present and potential invasive plant and animal species to global climatic change and propose an out-come based approach to the management of invasive species. Range expansions/contractions, due to global climatic change, are reviewed and we conclude that positive and negative impacts of invasives on ecosystems are likely as a result of the interactions between climate changes and other human disturbances. Recognising the need to manage invasives with scientifically informed approaches, an outcome focused management model is proposed which highlights the importance of acquiring understanding, synthesising it at a system level and applying it to management.

KEY WORDS : Containment, Global climate change, Invasives, Outcome based management, Plasticity

INTRODUCTION

The exact definition of invasiveness it still being debated (Colautti and MacIsaac 2004; Colautti 2005; Davis *et al.* 2000)[1] ; however, as (Richardson *et al.* 2000) state the lack of an exact definition has not held back the growing interest in invasion biology (e.g. in year 2011, there were at least eight international conferences where invasive species were the sole topic or a major topic of discussion). Similarly, management of invasive species* is currently being actively pursued in many countries through the development of action plans and policies (e.g. Australian Weed Strategy - Department of the Environment and Water Resources ("Australian Weeds Strategy – A national strategy for weed management in Australia" 2006)) and while invasive alien species have been identified as one of the five main pressures on biodiversity in the Global Biodiversity Outlook report (www.gbo3.cbd.int). Invasion biology is now operating in a world where changes in global climatic conditions are predicted to affect both biotic and

[1] * *For the purpose of this review we define an invasive as a species that possesses the capacity for successful self propagation in a non-native environment that could lead to replacement/extinction of native species, their functions, processes and ecological interactions.*

abiotic factors (Houghton 2007). However, because of the focus on historical issues neither scientists nor managers have fully addressed the question of how the management of invasives will be affected by global climate change.

We review the current understanding of seven key issues in invasion biology (ecogeographical distribution of invasives, effects of human actions on the spread of invasives, time lags (i.e. the time taken for the actual consequences of invasion), aquatic invasives, established invasives, plasticity and responses to climate change) and highlight how our current knowledge could influence the future management of invasive species in a changing world. We then discuss the uncertainty of species responses to climate change and argue for adopting outcome-based management strategies to control invasions.

Issue 1: What types of ecogeographical regions are prone to invasion?

Biological invasions are complex, context specific processes (Andrew and Ustin 2009) that can be caused by both introduced aliens and range expanding natives (Gunaratne et al. 2009). It is well known that invasives can affect biological patterns and processes at multiple ecological scales, influencing community structure, ecosystem processes and functions and the nature and intensity of ecological interactions (Brown et al. 2008). Most research has found that, at small scales, species-rich communities resist invasion (Kennedy et al. 2002; Knops et al. 1999; McGradySteed et al. 1997; Naeem et al. 2000). Several explanations have been proposed for this phenomenon including the presence of a diverse guild of consumers (Naeem and Li 1998), fully occupied niches (Crawley 1987) and the presence of key species that could retard invasion (Levine and D'Antonio 1999). At the regional scale, the relationship becomes less clear and in some cases, high species diversity even appears to promote invasion (PlantyTabacchi et al. 1996; Stohlgren et al. 1999) possibly because the factors that have promoted high native species diversity could also facilitate the invasion process (Rejmanek 1989). Also, despite theoretical support (May 1973) it is not clear whether high diversity necessarily indicates high stability of an ecosystem; in many instances, diverse ecosystems, especially the ones found in temperate and polar regions are dynamic due to fluctuations resulting from normal environmental influences, with species, especially annuals, emerging and disappearing seasonally. Though temperate and polar ecosystems are considered to be stable over the long term, dynamism could create short-term pressures during which resistance to invasions is lowered. Therefore, although diverse, the high turnover rates of species could result in lose biotic and abiotic interactions (Stohlgren et al. 1999), a situation which could potentially be exploited by invasives.

When island ecosystems are considered, species poor islands are generally particularly prone to invasion (Vitousek et al. 1996). Is this purely due to low biodiversity on islands that have unutilized resources that can be exploited by invaders? Is it due to the release from natural enemies (DeWalt et al. 2004), possession of novel traits compared with the natives (Vitousek 1990) or the competitive advantages under novel environmental conditions (Daehler 2003)? Similarly, the isolation of islands leads to them having had limited biological interaction with invaders in the past which could leave the biota less resistant to invasion unless they develop mechanisms to avoid/tolerate the impacts of invasive such as developing behavioural plasticity (Hoare et al. 2007). (McKinney 2005) indirectly provides insight into this argument when he reported that species introduced from nearby sources have coexisted while species from far away replaced the natives and changed the ecosystem.

There has been substantial theoretical progress in trying to understand the relationship between species diversity and species invasions; however, most models developed to predict the invasion process assume that communities are in equilibrium prior to (Robinson and Valentine 1979) and after invasion (Goslee et al. 2006). Communities are dynamic and are largely a result of complex non-equilibrium processes and functions

(Kikkawa and Anderson 1986); therefore, developing a unifying theory that links the resistance of native communities and ecosystems to invasion is difficult. As a result it is unlikely that species diversity per se is sufficient as an explanation of how habitats and ecosystems are to invasion (Stohlgren et al. 1999). We will revisit this point below, in an attempt to predict how global climate change will disrupt the dynamic processes that affect local patterns of biota in both biodiversity-rich and -poor habitats and the consequences of such changes for future invasions.

Issue 2: Do human actions make an ecosystem prone to invasion?

Though species ranges have been constantly range shifting due to tectonic movements, climate change and natural disasters (Whittaker 2001), never before in the history of Earth has a single species (*Homo sapiens*) been so influential in the movement of other species. Among all issues in biological invasions, the contribution of humans in making ecosystems more prone to invasion (through pollution, species removal, water and nutrient removal/addition etc.) is unanimously accepted.

TABLE 1: Evidence on impact of human disturbance on increasing ecosystem vulnerability to invasion

Disturbance	Major impacts	Reference
1. Destruction of existing ecological and physical barriers a) by roads, tunnels, bridges, shipping routes and ballast water) b) intentional and unintentional species introductions for agriculture, aquaculture, livestock practises and other economy related activities	Providing access to invasive species	(Brown et al. 2006; Christen and Matlack 2009; Dittel and Epifanio 2009; Gofas and Zenetos 2003; Gruszka and Wozniczka 2008; Jorgensen and Kollmann 2009; Olenin et al. 2000) (Canonico et al. 2005; Karatayev et al. 2009; Mack et al. 2000; Smyth et al. 2009)
2. Habitat destruction, area clearance, fragmentation, and alternation	Creating spatial variability, providing access to invasive species, habitats with transient species	(Hansen and Clevenger 2005; Hawbaker et al. 2006; Minor et al. 2009; With 2002)
3. Pollution and nutrient enrichment	Creating habitats with high species turnover rates	(Piola and Johnston 2008; Saltonstall and Stevenson 2007; Tyler et al. 2007; Zhao et al. 2006)
4. Genetic improvements	Creating transient species with high vigour	(Aikio et al. 2008; Zapiola et al. 2008)
5. Human colonisation, human traffic and population growth	Creating spatial variability, high species turnover rates and habitats with transient species	(Anderson 2009; Limpus et al. 1999; Morton and Britton 2000)

Our understanding of biological invasions is handicapped by the relatively short time over which their impacts have been explored compared with the time taken by an invasive to naturalise, establish and influence ecological interactions in the community it is invading. However, studies indicate that vulnerability of a region to invasion increases with the level of stress-related instability (e.g. tectonic activity, drought, floods, cyclones, anthropogenic action) irrespective of biodiversity (Occhipinti-Ambrogi and Savini 2003). Most studies also agree that human disturbance creates spatial instability, high species turnover rates and habitats with transient species and so contributes to the spread of invasives (Table 1).

Issue 3: Observation time and time lag in eliciting response by invasives

In recent years there has been growing concern that scientists are biased in their assessments of whether invasions are positive or negative (Stromberg et al. 2009). Also studies are mostly confined to species that are perceived to be having major impact/s which has introduced another bias to invasive biology. The majority of views of invasives are negative because of their impacts on biological processes in the short term. Some of these include reductions in local biodiversity (Bos et al. 2008) due to local extinction/decline of native fauna and flora (Sax and Gaines 2008), promotion of opportunistic species (Kappes et al. 2007) and the decline of habitat specialists (Gunaratne et al. 2009) through allelopathy (Callaway et al. 2008; Jarchow and Cook 2009), changes in the reproductive cycle (Pratt and Grason 2007), introduction of new pathagons and diseases to native fauna and flora (Heckmann 2009) and hybridising (Loomis and Fishman 2009), all affecting community (Fisher et al. 2009; Mitchell and Knouft 2009) and landscape (Litton et al. 2006) structure. Ultimately they result in loss of ecological memory (Schaefer 2009).

Invasives have the potential to alter fundamental properties of ecosystems (Mack *et al.* 2000) yet identification of these changes as either positive or negative by humans have been biased by economic and social influences as well as the time lag in eliciting the true impacts of invasives. Today, a new branch of invasive biology is emerging that emphasises the ecological importance of invasives and the ecosystem services they provide (Pejchar and Mooney 2009). With the changes in native diversity, invasives are recognised as important food sources for native species such as Andean condor (*Vultur gryphus*) (Lambertucci *et al.* 2009). Many aquatic invasive flora are valued for their capacity in nutrient removal (Dhote and Dixit 2009) and water retention. Invasives can also create new habitats (Bruschetti *et al.* 2009) and provide protection from predators for native biota (Cristinacce *et al.* 2009). For example, in Australia, dingos are recognised for controlling the impact of other introduced predators on native small mammals (Letnic *et al.* 2009). Invasives could also be valuable as pollinators (Gross 2001). However, none of these impacts either positive or negative, have been observed as net effects across an entire ecosystem.

Ecologically the true impacts of a new species in a novel environment will be dynamic and categorising the impacts into positive and negative outcomes is biased by the conditions prevailing at the time of invasion and afterwards. Realizing that the majority of studies cover only a fraction of the invasion process is important in invasion biology and has resulted in labelling some invasives as noxious, established and naturalised etc, which is determined by the vigour of the species and the prevailing characteristics of the habitat at the time of invasion. This is particularly true for aquatic invasives.

Issue 4: Are aquatic invasives noxious than terrestrials?

No other ecosystems on planet earth have been altered and exploited as wetlands by humans, primarily because civilizations evolved around them. The extent of use is such, virtually untouched wetlands are no more present and as a result, species composition and dynamics of these systems are not pristine. The water movement connects all systems, hence rapid spread of any influence is beyond control in most occasions. Compared to terrestrial ecosystems, few conditions are capable of resulting in rapid turnovers and amongst them, flashy or chronically flooded conditions are pivotal (Kercher and Zedler 2004). Studies have confirmed that species that possess certain traits like morphological plasticity (Bonin and Zedler 2008) withstand the pressures of both presence and absence of water and in most instances such traits are present among aquatic invasives (Daehler 2003; Tao et al. 2009). However, one confounding factor associated with flooding is nutrient flow and interactive effects are little explored and known. Invasives tolerate and thrive under prolonged hydro-periods (Boers et al. 2007) but nutrients and sediments hinder the native plant growth (Maurer and Zedler 2002).

Yet, the fact that native assemblages in aquatic systems are fast changing and are over taken by invasives cannot be attributed only to noxious nature of aquatic invasives as eutrophication, acid rain, increasing atmospheric carbon dioxide concentrations and purposeful human management of aquatic systems are all responsible for changes to systems (Knight and Hauxwell 2009). As such if it is the noxiousness of invasives or the rapidness of the system in responding to changes needs to be clarified. Most changes in shallow aquatic systems, especially in lake systems could be stable state shifts (Scheffer et al. 1993) and as such invasive species becoming dominant for a brief period could be explained. However, if aquatic invasives are noxious than terrestrials largely remains unanswered merely because of the lack of any terrestrial system experiencing similar levels of disturbance.

Issue 5: What are the ecological concerns regarding "established" invasives?

Established invasives are problematic for scientists as well as managers as most species have spread beyond the spatial scales at which ecologically meaningful research and management can be conducted without huge financial and man power inputs. They typically occupy large areas and many sites and are transformers of ecosystems. On the one hand some established invasives have "naturalised" (species that are capable of establishing in a novel locality and species at the current observational time). On the other hand, the same naturalised invasives could pave the way for the local extinction of natives when they interact with other invasives; this is known as invasion meltdown. This was recently demonstrated in a study involving naturalised European rabbit, (*Oryctolagus cuniculus*), native water vole (*Arvicola terrestris*) and the recent invasive, American mink (*Neovison vison*) in Scotland (Oliver *et al.* 2009) where unexpected interactions between rabbit and voles indicated that in large-scale natural landscapes there is spatial asynchrony, enabling coexistence between apparent competitive native and invasive species, impacts. Trophic interactions and the various spatial scales at which these interactions occur, are rather obscure, making it difficult to manage established invasives without there being perverse outcomes for the ecosystem. The removal of an established invasive could be catastrophic and management decisions should be based in an understanding of the elements of the ecosystem that have been replaced or suppressed by the invasive (species as well as their functions) and the current role of the established invasive in the system. This applies to the case of removal of dingo from arid regions of Australia, which has resulted in increased activity an invasive mesopredator, the red fox (*Vulpes vulpes*) and of herbivores leading to loss of grass cover and severe decline of many populations of native small mammals (Letnic *et al.* 2009). Similarly, despite the eradication of cats (*Felis catus*) from sub-Antarctic Macquarie Island being part of an integrated pest management programme it resulted in an array of landscape-wide changes to ecosystems including an increase in introduced herbivores with substantial impacts on the native flora (Bergstrom *et al.* 2009a). Both of these cases targeted the removal of invasive top predators and resulted in short-term increases in the activity of other species that affected prey species directly or indirectly.

Another concern arises due to the presence of multiple invaders in ecosystems. Most ecosystems have been invaded by more than one invasive either at the same time or at different time periods, and these multiple invasives could have additive or synergistic effects on the ecosystem (Levin *et al.* 2002), making it difficult to determine the actual impacts or to quantify any benefits of control measures of the invasive that is under control. Table 2 outlines some potential ecological concerns of controlling established invasive primary producers, primary consumers, meso-predators and top predators.

Established invasives have been known to be facilitated by other anthropogenic activities, some having synergistic effects. For example, evidence is mounting that invasives spread more easily in fragmented landscapes (Minor et al. 2009), polluted areas where nutrient levels of nitrogen and phosphorus are high (Loo et al. 2009), landscapes in which physical barriers have been disrupted resulting in increased connectivity (Leuven et al. 2009), habitats subjected to deforestation (Veldman et al. 2009) and constant utilisation (King and Tschinkel 2008). Focusing only on controlling populations of invasives does not deal with these underlying facilitative factors.

Many of thet anthropogenic activities mentioned above are point activities i.e. invasives being facilitated at the point of activity, although allochthonous inputs such as nutrients to aquatic systems can be non-point. Among non-point sources there is a growing awareness of the potential effects of climate, a

TABLE 2: Potential ecological concerns of controlling established invasives of different trophic levels

Trophic status of the established invasive	Potential ecological concerns of control
Primary producers	- Loss of habitats and/or habitat heterogeneity - Decline in primary production - Natives unable to re-establish due to existing allelopathic effects, soil characteristics including water retention, seed bank composition etc. - Loss of any habitat specialists that depended on invasive (Cristinacce et al. 2009) - Spatio-temporal changes in the availability of resources such as nectar, fruits etc. for consumers (Severns and Warren 2008)
Primary consumers	- Niche shifts in other primary consumers - Increased spread of flora previously consumed by the primary consumer altering the community structure (both spatially and temporally) - Increased pressure on native primary consumers by their prey
Meso-predator	- Immigration of other invasive meso-predators to the ecosystem - Increased grazing/browsing by primary consumers and changes in their group size and population dynamics (which can be a positive change as prey species could recover to their natural levels with time) - Changes in the populations of other exotic species previously controlled by meso-predator (Banks et al. 1998) - Increased predation on primary consumers by top predators (Risbey et al. 2000)
Top predator	- Increased meso-predator activities and abundance (Letnic et al. 2009) - Increased primary consumers (Bergstrom et al. 2009b) - Population booms in other predatory invertebrates in islands (Feare 1999)

disturbance that has the potential to interact with global invasions across all ecosystems. Since climate change is a non-point effect it is difficult to determine whether range shifts are due to climate changes or other factors. Hence the impacts of global climate change on established invasives will set new challenges for their management. However, it is essential that climate change effects on the invasion process and the effects of anthropogenic factors are understood so that, at the practical level, value judgements are not made which lead to unexpected outcomes of management interventions. Similarly, we need to be able to predict whether species with expanding ranges are invasives or not. Since it has been shown that anthropogenic activities have resulted in climate change, any range shifts of a species due to climate change should be considered to be mediated by humans and are, therefore, invasive. Yet, the distinction would then be that range shifts due to climate change would be for both of natives and invasives already present in an ecosystem. We will, however, consider only the fate of invasives in the presence of global climate change in this review as opposed to range expanding natives.

Issue 6: Warming world: a free ticket for invasives?

As with other issues involving climate change, opinion is divided on its impact on invasives (Bradley et al. 2009; (Wang and Mohan 2008). Assessments of the likely impacts of climate change on invasives should be based on predictions of climate change itself. According to the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report "Climate Change 2007: The Physical Science Basis" future projections could be summarised as:

1. Warming over many land areas is greater than global annual mean warming.
2. A reduction in rainfall in the subtropics and an increase at higher latitudes and in parts of the tropics.
3. A reduction in precipitation at the pole ward edges of the subtropics.
4. Monsoonal circulations to result in increased precipitation.

One of the challenges faced by invasion biologists is the anticipated disappearance of certain ecosystems and creation of new ecosystems (Barnard and Midgley 2010) . For some parts of the world, the lack of analogous climates in current ecogeographical regions makes it difficult to predict the behaviour of invasives (Fitzpatrick and Hargrove 2009). Most invasive flora are associated with cropping systems and the recent review by (Wang and Mohan 2008) highlighted the complexity of responses as these species belong to a variety of growth forms as well as C3 and C4 photosynthetic pathways. However, reduced effects of above and below ground pathogens, herbivores and other pests are anticipated for species that are likely to expand their range (Engelkes et al. 2008). Although a number of studies have looked into the physiological, behavioural and population dynamics responses of major crop species and threatened fauna in relation to elevated temperatures, CO2 and O3 and variations in precipitation (Booker et al. 2009; Laidre et al. 2008; Leakey 2009; Vors and Boyce 2009), no systematic studies have been conducted into the physiological and behavioural changes that are likely to affect invasives due to global warming. Table 3 summarises our current understanding regarding the effects of global warming on some invasives of different geographical regions. These can be evaluated with the generalisations of Figure 1 in mind. In summary, the outcomes are in agreement with the concept of biotic homogenization, the process of increasing similarity between bioregions, a well known outcome of invasions involving changes in community structure resulting from the gradual replacement of the natives by non-native species (Lockwood and McKinney 2001; Vergara et al. 2011).

The review reveals rising temperatures, precipitation and humidity as the three key variables that have influenced most projections. The current survival of invasives in the areas they invade is partly due to their broad ecological amplitudes and ecological tolerance (Williamson 1996) and one important issue would then be the role of phenotypic plasticity in pre-adapting invasives for conditions that develop as a result of global warming.

Issue 7: Plasticity of invasives and future climate projections

Most predicted range expansions/contractions in Table 3 assume no changes in a species' current physiological endurance and behaviour. However, invasives are known to tolerate different conditions through phenotypic plasticity (Chun et al. 2007; Geng et al. 2006; Lardies and Bozinovic 2008) whereby individual organisms can alter their development, physiology and life history, depending on environmental conditions. This leads to a greater breadth of environmental conditions under which a species can maintain positive population growth and increase the likelihood of invasiveness (Hulme 2008) These environmental responses can be both trait and resource specific, and could represent evolved characteristics that vary among genotypes, populations and species (Sultan 2000). Two strategies, namely local adaptation and phenotypic plasticity in heterogeneous environments, have been known to benefit invaders (Cordell et al. 1998; Lehmann and Rebele 2005). Hence, future range expansions as well as contractions anticipated for invasives will depend on how invasives adapt to varying environmental conditions.

The effects of different water regimes on certain invasives such as Alligator weed (*Alternanthera philoxeroides*) (Geng *et al.* 2006; Tao et al. 2009) and purple loosestrife (*Lythrum salicaria*) (Chun *et al.* 2007), have been tested and the species' adaptation to variation in water availability has been confirmed. Similarly, differential physiological responses under drought conditions have been attributed for the better performance of invasive spring tails (Insecta: Collembola) (Chown *et al.* 2007), suggesting that certain invasives could be able to cope with a changing environment. If invasives adopt ecologically relevant behavioural, physiological, morphological life history traits and demography in response to climate change, they would gain a foot hold in new areas whilst persisting in their previous ranges. This is also true for native species. However, it is also known that the lag between the induction time of a plastic response and the timing of environmental change can strongly influence whether plasticity stabilizes a population (Padilla and Adolph 1996). The uncertainty and high variability associated with precipitation and temperature, therefore, might hinder the establishment of some invasives in novel environments.

Treading the ground amidst chaos: roles, responsibilities and solutions

The six issues raised in this review demonstrate the complexity associated with global invasions and our limited knowledge regarding the basics of the response mechanisms (Courchamp et al. 2003; Mack et al. 2000). Although not all of the issues raised above are associated with global climate change, they are all interconnected. Some of the areas requiring further research are outlined below with some recommendations for managers on how to operate in an "information poor" environment. Finally, we propose an outcome-based model which is a tool that links research and management by firstly deciding what is expected (i.e. outcomes) from a given research/management activity along with ways to measure the outcome (assessment) at the outset. Such an approach will help in the design of experiments and the field implementation of management interventions underpinning effective action to counter invasions in the face of climate change (Figure 1). It is evident from the proposed model that research should provide a back bone for management and should range from knowledge (eg: identification of species that are likely to spread due to elevated temperatures) to evaluation and synthesis (eg: (a) quantification of types and extent of native species that can be replaced by new invaders or (b) effectiveness of the use of controlled burning to limit the spread of a new invader). Research will assist with decisions about appropriate management tools (e.g. uprooting, burning, poisoning, sterilising) which should then be aligned with the Intended Invasive Management Outcomes (IIMOs) and

TABLE 3: Predicted changes in the distributions of invasives

Type of invasive species	Ecogeographical region	Anticipated climate changes	Predicted effects on invasive
Fauna			
Insecta	Temperate terrestrial ecosystems including agricultural land	Increased temperature	Shifts in Tb paving access to higher altitudes(Huey and Pascual 2009) Northward spread (Tougou et al. 2009) Range expansions towards polar areas and contractions in currently favourable areas (Mika et al. 2008), Range expansions (Estay et al. 2009) Northward range expansion (Gutierrez et al. 2008) Increased risk of establishment of invasive insects from tropics (Evans et al. 2002)
Crustacea	Temperate lentic and lotic	Increased winter temperatures	Increased distribution and range expansion (Pockl 2009)
	Polar marine	Increased temperature	Increased invasion (Aronson et al. 2007)
Pisces	Temperate lotic	Increased temperature	Range expansion leading to competition with native fish (Sapna et al. 2009)
	Temperate marine	Increased winter temperatures	Disappearance of natives due to range expansion of captive bread counterparts (McGinnity et al. 2009)
	Mediterranean marine	Increased temperature	Enhanced invasive and native congruence(Lasram and Mouillot 2009)
Amphibia	Tropical continental and island terrestrial ecosystems	Increased temperature	Range expansion (Rodder and Weinsheimer 2009) and invasion towards higher elevations (Roedder 2009)
Reptilia	Tropical wetlands	Increased temperature	Range contraction (Pyron et al. 2008)
Aves	Mediterranean terrestrial	Increased temperature	Increased invasions (Reino et al. 2009)

Type of invasive species	Ecogeographical region	Anticipated climate changes	Predicted effects on invasive
Flora			
Myrtaceae	Tropical and subtropical terrestrial	Increased temperature	Current range contraction but pole ward movement (Watt et al. 2009)
Gramineae	South African Fynbos shrublands	Increased temperature	Hinder current spread but range expansions to higher altitudes (Parker-Allie et al. 2009)
Poaseae	Sub tropical and Temperate agricultural ecosystems	Increased temperature Decreased precipitation	Northward movements (McDonald et al. 2009) Shift in range with range contractions (Bradley 2009)
Euphorbiaceae	Sub tropical and Temperate terrestrial	Decreased precipitation and increased winter temperature	Shift in range with range contraction (Bradley et al. 2009)
Balsaminaceae	Temperate woodlands	Increased temp and water availability	Northward range expansion (Beerling and Woodward 1994)
Tamaricaceae	Sub tropical and Temperate terrestrial	Decreased precipitation and increased winter temperature	Range expansion (Bradley et al. 2009)
Asteraceae	Sub tropical and Temperate terrestrial	Decreased precipitation and increased winter temperature	Range expansion (Bradley et al. 2009)
Verbenaceae	Tropical terrestrial	Elevated CO_2	Increased growth (Raizada et al. 2009)
Lamiaceae	Tropical terrestrial	Elevated CO_2	Increased growth (Raizada et al. 2009)

assessment. Similarly, outcomes from management interventions help to validate the effectiveness of the model for that particular system and can help refine the model and guide further research. Such an approach will equip managers and scientists with knowledge, will and political patronage to deal with invasives.

What is the role of invasion biologists in developing the outcome-based model approach to the management of invasives?

1. Although the relationship between biological diversity and invasion is certainly important, future research should explore the role of other ecological controls such as competition, above ground and below ground mutualism and resource availability, recognising that when a species has invaded it has become a part of the system. This emphasises the need to move away from a phenomenological approach to a process based understanding of invasiveness. Such an approach demands long term research that would be greatly assisted by adoption of common terminology and an understanding between plant and animal invasive biologists. Similarly, research should cover both aquatic and terrestrial habitats. Currently, there is a gap in our knowledge about the ecology of invasives in Asia and Africa (Pysek *et al.* 2008) which is critical, as many invasives spreading in other parts of the world have their roots in these two continents.
2. Research that unravels the interdependencies between biotic and abiotic factors relating to established invasives will not only provide insights into ecological relationships of a particular invasive, but will also assist in their management. It is important to understand the socioeconomic influences contributing to the spread and establishment of invasives and ecologists must address the biophysical evidence rather than rely on prevailing dogma or prejudice (Stromberg *et al.* 2009).
3. The questions of when and how to remove an invasive species, if it has well established links within the food web of an ecosystem, has drawn much attention in invasion biology (Burnett *et al.* 2007; Gunaratne *et al.* 2009; Kaiser and Burnett 2010). Although the answers to this question are highly context specific, models developed by (Tompkins and Veltman 2006) highlight two important concerns, (a) indirect effects of the control and (b) thresholds in the strength of control; both of which have the potential to trigger negative impacts of controlling an established invasive. Accordingly, scientific research is vital in identifying (a) which species are available to play the role previously played by the removed invasive, (b) if the species that replace the removed invasive is a native and (c) anticipated time taken for its establishment.
Despite the wealth of information on plasticity, ecological impacts of plasticity are not well studied. In the case of fauna, behavioural plasticity is just as important as morphological and physiological plasticities, as it can affect all levels of ecological organization through effects on demographic parameters and direct and indirect species interactions (Fordyce 2006). Since plasticity could be viewed as the primary means whereby invasives are likely to respond to climate change in the short- to medium-term, future studies need to understand the impacts of floral and faunal plasticity. Some important effects on flora could involve changes in plant morphology and chemical composition on herbivores, other flora and soil microbes. Similarly it is important to know about the effect of changes in flowering, fruiting and propogule production on other fauna and flora as well as changes in resistance to current control measures. For fauna, changes in herbivory, predation, reproduction and migration could be expected.
4. Finally tying together the current concepts and theoretical developments in invasion biology is undoubtedly the most urgently needed advancement. It would bring together a wealth of knowledge which is currently scattered across the disciplines and develop general concepts in invasion

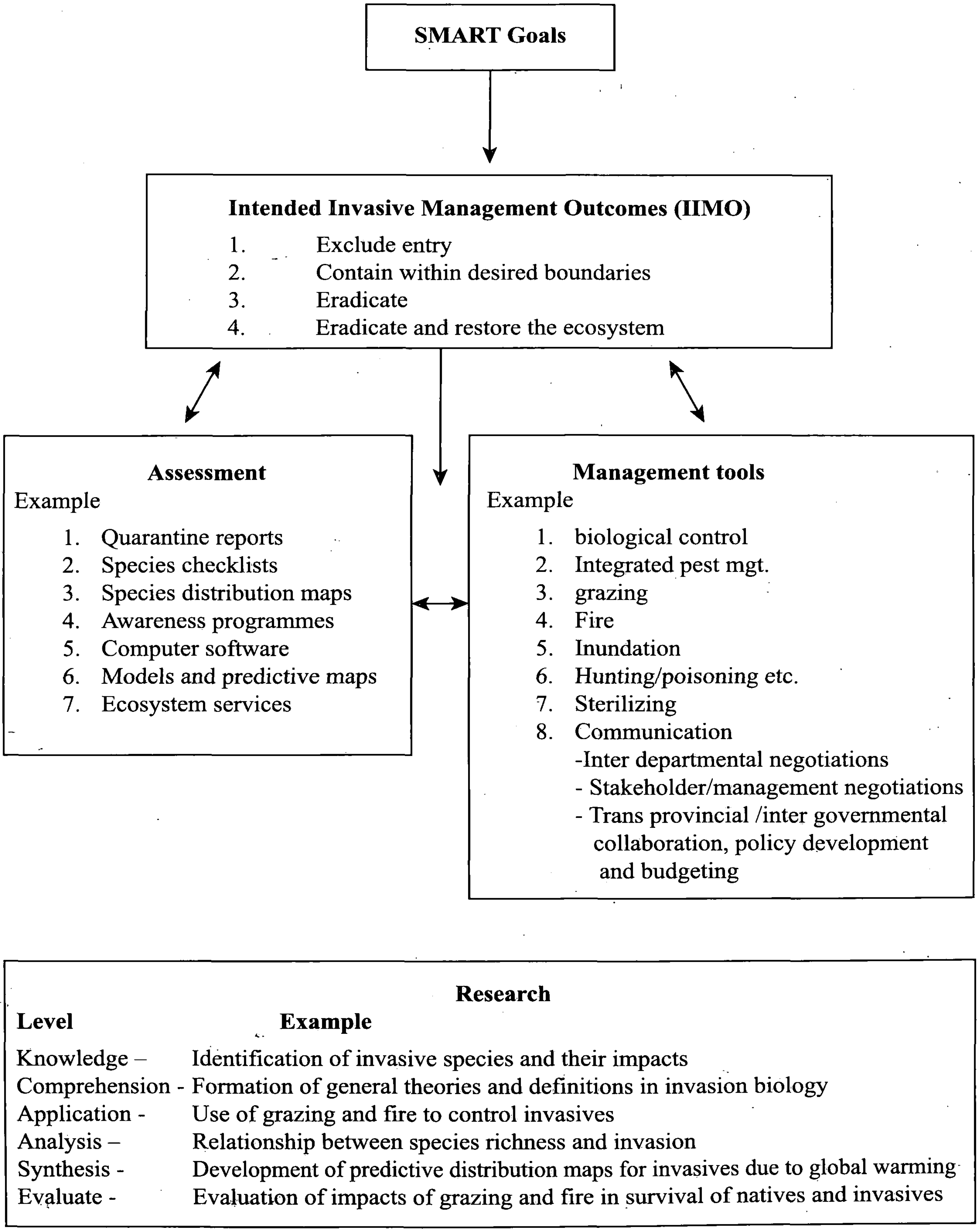

FIGURE 1: Intended Invasive Management Outcomes (IIMO) based model

biology (Courchamp *et al.* 2003) as well as facilitate interdisciplinary research of practical significance.

Today, management of invasives is not just about routine identification, range mapping and control. It has also become a part of restoration biology, a branch of applied science which could itself lead to environmental and social degradation unless handled appropriately.

Human beings through their occupation of the globe have created challenges to the survival of themselves and the species with which they share the planet. Some of these challenges are well understood while others are complicated enough to demand prolonged investigations; invasives fall into later category especially when coupled with more complicated issues such as global climate change. This paper paves the way for an approach which is both self sustaining and outcomes-oriented calling for action now even though there is still much to find out.

ACKNOWLEDGEMENTS

Authors acknowledge the Endeavour Executive Award of Australia for financial support which enabled the preparation of this manuscript.

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Received: 5 April 2015
Accepted: 30 April 2015