Invasive species and climate change

backgrounder

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Living in a warmer, wilder, weedier world

Climate change is expected to cause extinctions when native plants and animals are prevented from migrating out of their hotter or drier habitats to more suitable climates. But for many species a more imminent or serious threat will be the opportunities created by climate change for invasive species to proliferate and cause more harm.

Invasive species have already caused many extinctions and are one of the major causes of decline of native species and ecosystem degradation. The 2009 assessment of the vulnerability of Australia's biodiversity to climate change noted that in many cases the impacts of invasive species benefiting from climate change are likely to exceed the direct impacts of climate change.[1]

The extinction toll of Australian animals due to invasive species[4]

22 mammals[5] (16 species, 6 subspecies) due largely to predation by foxes and/or cats, with rabbits also implicated as a contributing factor in some cases.

Across much of Australia all native mammals weighing between 35 grams and 5.5 kilograms have disappeared.

Nine species survive only on cat- and fox-free islands or inside large fenced enclosures.

13 island birds (3 species, 10 subspecies) due to predation by black rats (*Rattus rattus*), cats and pigs, and competition from introduced birds and honeybees.

4 (but probably 6) frogs due to infection by chytrid fungus (*Batrachochytrium dendrobatidis*) in eastern Australia.

2 endemic rodents on Christmas Island due to infection by a trypanosome blood parasite from introduced black rats.

Pig Footed Bandicoot ((*Chaeropus ecaudatus*).

1. Devastating invaders

Globally, invasive species have been recognised as the most serious threat to biodiversity after habitat loss.[2] Along with habitat loss and climate change, they are one of the top three threats to Australian species.[3]

Australia has lost by far the highest number of mammal species in recent times, with foxes or cats (and rabbits to some degree) implicated in most of these extinctions. Many birds on islands have been wiped out by introduced rats, and an exotic fungus has caused the extinction of at least four frog species (see Box).

The threats are escalating as new species become established and as existing invaders proliferate and spread. Just one exotic pathogen *Phytophthora cinnamomi* threatens hundreds of endemic plant species in Western Australia,[6] and numerous mammal species need protection from foxes and cats. Weeds are increasingly dominating many ecosystems, fundamentally altering their composition and function. More than 80% of federally threatened ecological communities are threatened by weeds.[7] Rabbits have prevented woodland regeneration over vast areas, and goats, pigs and other hard-hoofed feral animals are causing widespread degradation. Marine invaders have transformed coastal ecosystems, becoming dominant predators or filter feeders.

2. Climate change – driving diverse changes

Since 1950, Australian average temperatures have increased by 0.9ºC, and average rainfalls have dropped in coastal eastern Australia, Victoria, and south-west Australia.[8] Climate models suggest these trends will intensify as atmospheric carbon dioxide levels continue to rise (see box next page). Emissions are increasing at a rate currently exceeding the worst-case emissions scenarios of the Intergovernmental Panel on Climate Change.[9]

3. Climate change impacts on species and ecosystems

Different species will respond to climate change in different ways. CSIRO researchers Mike Dunlop and Peter Brown outline three models of response.[11]

The most prevalent model predicts that species will move gradually and at different rates as the climate changes – 'gradual changes in distribution' – to maintain a similar climatic niche. The obvious conservation response is to ensure that species are able to migrate, by removing barriers to movement and creating corridors to potential habitats. However, many species will not move: plants are often constrained by soils rather than climate and other species are constrained by biological factors such as competition or predation. Although the model is "intuitively appealing", and allows for simple, directional predictions, Dunlop and Brown caution that the preference for it may not reflect reality. For invasive species, this model implies their ranges will also gradually change in response to changing climatic conditions.

Another model – "rapid changes in distribution"[12] – predicts range expansion for some species that can take advantage of changing conditions. Fire pioneers, for example, will benefit from more fires; wind- and water-dispersed species may benefit from more cyclones and floods; and higher CO_2 levels will give some plant species a competitive edge. This model is particularly pertinent for those invasive species likely to benefit from more extreme events or more CO_2. The impact of these climate change "winners" may be detrimental to some native species. In some cases, native species that benefit from the changes may also become invasive. Conservation responses to this model include addressing the threats caused by climate change "winners".

A third model – "changes in abundance" – predicts that climate change will affect the abundance of some species rather than their distribution. Some species will decline and others will proliferate, and that in turn will affect ecosystem structure and function. Species vulnerable to climate change may retract to climate refuges, such as cooler or wetter locations in their range. Some invasive species are likely to become more abundant and increase pressure on declining species. Conservation responses to this model include protection of refugia for declining species and control of threats deriving from more-abundant species.

All three models are likely to account for some changes,[13] and under each, it is likely that invasive species will strongly affect how native species and ecosystems fare under climate change.

Climate change predictions for Australia

By 2050, annual warming in Australia is predicted to range from 1.5 to 2.8ºC for the highest emissions scenario, increasing to 2.2 to 5.0ºC by 2070.

Reduced average rainfall is predicted over most of Australia.

By 2070, for the highest emissions scenario the predicted range of change in southern areas is from a 30% decrease to a 5% increase, little change in the far north and from -30% to +20% in other areas.

More droughts are expected over most of Australia: by 2070 up to 40% more droughts in eastern Australia and up to 80% more in south-western Australia.

There is a substantially increased fire risk in south-eastern Australia; the risk has not been assessed elsewhere.

Source: CSIRO and the Bureau of Meteorology[10]

4. Invasive species – overall winners under climate change

Under climate change, some species will decline and others will thrive. Winners and losers will include invasive species. The cane toad, for example, is expected to expand its range further south,[14] but rising temperatures would constrain rabbit breeding.[15] Some invasive species will benefit in some places and decline in others.

This does not mean there will be an overall balancing out: for a variety of reasons invasive species are overall likely to cause more harm under climate change.

One reason is that many invasive species are generalists and highly adaptable, able to tolerate or take advantage of change and disturbance.[16] Many weeds are weedy because they thrive over a wide range of climatic conditions.

An increase in extreme events in particular will offer new opportunities for invasive species to proliferate and spread – weeds colonise bare patches after droughts, fires and cyclones; and foxes and cats prey on animals whose shelter is destroyed by those events.[17] We know from past experience that extreme events promote invasions: floods in the 1970s spread carp (*Cyprinus carpio*) throughout the Murray-Darling system[18] and athel pine (*Tamarix aphylla*) along hundreds of kilometres of the Finke River in central Australia.[19] Carp are now the most abundant big fish in the Murray-Darling and athel pine is a weed of national significance.

Native species and ecosystems stressed by climate change will be less competitive and more vulnerable to threats by invasive species. Stressed plants, for example, would be more vulnerable to diseases like phytopthora dieback or displacement by weeds.

Human responses to climate change are likely to provide new invasive opportunities – with the introduction of weedy biofuel crops or the spread of weeds in fodder after droughts and other extreme events – and less control of existing invaders. If farmers are under economic stress due to extreme weather events and governments have other climate-related budgetary demands, we can expect less focus on weed and pest control. In addition, some herbicides and biological control agents may be rendered less effective under climate change.

5. Interactions between climate change and invasive species

Climate affects the distribution, abundance and behaviours of invasive species. It also affects native species and ecosystems, and human behaviours with invasive species (see Figure 1). Conversely, some invasive species exacerbate climate change (see section 5.5). There are uncertainties with all these factors – climate, its impacts on native and non-native species, and future human actions – which make predicting interactions very difficult.[20] Invasive species can initiate complex, unpredictable cascades of change. High levels of uncertainty are unavoidable, and policies therefore should make allowances for inevitable "ignorance, imprecision, stochasticity, and surprise".[21]

However, we can identify likely trends and patterns of change, which is essential to developing strategies to prevent the interacting threats. Here we give examples of likely changes in three interactive categories: the interactions of invasive species with climate factors (abiotic interactions), with other species affected by climate change (biotic interactions) and with human actions in response to climate change (anthropogenic interactions). Table 1 (page 6) also exemplifies the variety of predicted interactions that are likely to lead to increased weed, pest and disease threats.

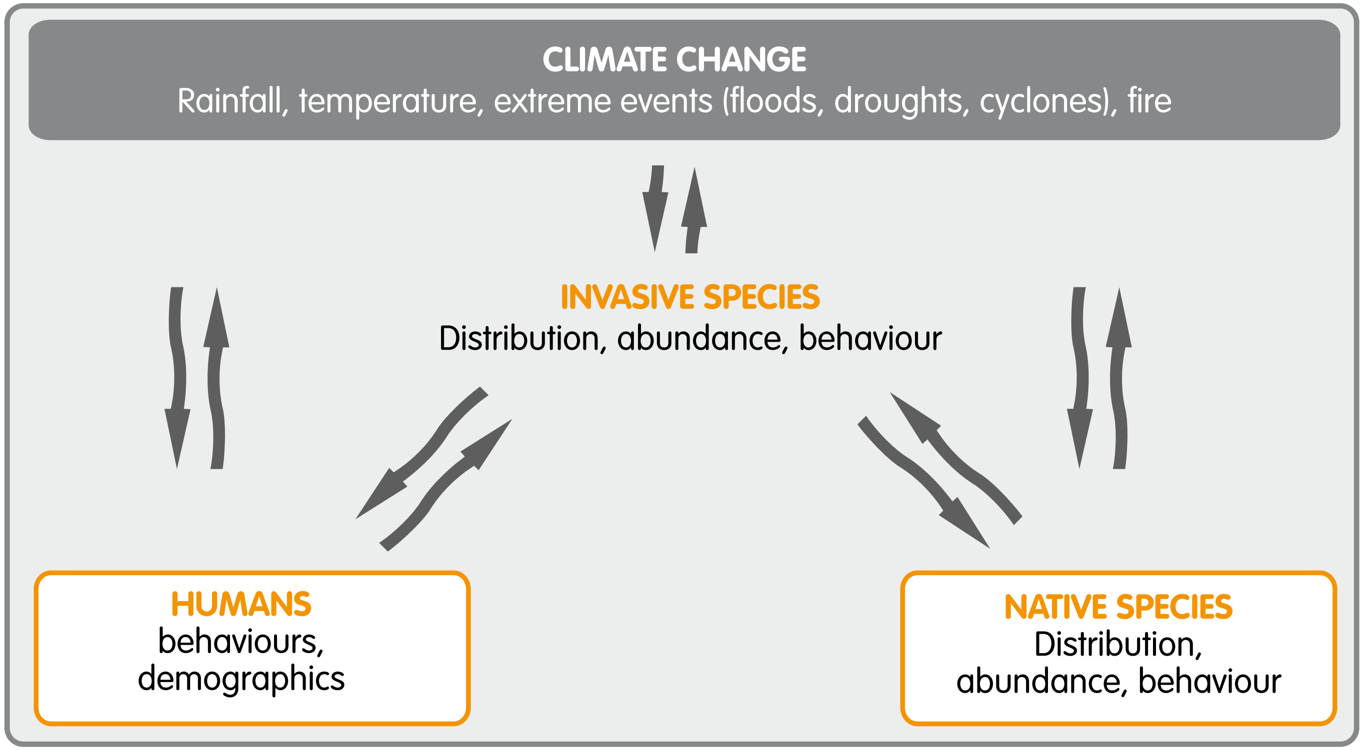

Figure 1. Complexity of interactions between climate change and invasive species.

5.1 Interactions with abiotic changes – temperature, rainfall, CO_2, extreme events, fire

Following are a few examples of invasive species expected to directly benefit from future climate patterns, such as higher average temperatures and more extreme events. They are predictable to some extent based on current patterns of invasion.

- **Changed rainfall patterns:** Southwest Western Australia is in the grip of a plant disease – phytophthora dieback – that has infected a million hectares of native bush, threatening dozens of species found nowhere else.[22] Climate change is expected to bring more rain during summer, which would spread the disease more rapidly because the spores travel with flowing rainwater. This could result in plant extinctions and ecosystem collapse.[23] The

Why invasive species will be overall winners under climate change

- Many invasive species are highly adaptable, tolerant of a wide range of conditions and advantaged by disturbance.
- Extreme events often facilitate biological invasions.
- Native species under stress are less competitive with and more vulnerable to invasive species.
- Human responses are likely to provide more invasive opportunities and may result in less effective control.

disease could also worsen in south-eastern Australia if there are wetter summers and warmer winters under climate change.[24]

- **More-intense cyclones:** Lurking in many gardens in the Wet Tropics are exotic plants that have not yet had the right conditions to spread beyond the garden fence. More-intense cyclones under climate change bringing forest damage and flooding could provide opportunities for their spread. Many of them are rainforest plants that could colonise clearings in rainforest.[25]
- **Warmer temperatures:** Foxes are already increasing their numbers at higher altitudes in the Australian Alps as the climate warms. Vulnerable native animals include the endangered mountain pygmy possum and broad-toothed rat. Weeds too will spread further up the slopes, pushing out less competitive native species.[26]

  Most aquarium fish are from tropical waters, so increases in average water temperatures will provide more habitat for released or escaped fish.[27]
- **More fire:** Exotic pasture grasses in northern Australia up to 4 metres tall fuel fires so intense they can kill trees. In a damaging cycle that can turn native woodlands into exotic grasslands, such fires promote yet more grass invasion.[28] Climate change could increase the frequency of fires, facilitating the further invasion of exotic grasses.

5.2 Interactions with biotic changes

Following are examples of how invasive species may benefit from changes to other organisms caused by climate change. They are much harder to predict because they involve a sequence of interactions.

- **Reduced competitiveness and increased vulnerability of native species:** Plants and animals stressed by climate change-induced drought are likely to be more susceptible to disease – during drought southern hairy-nosed wombats are more susceptible to mange caused by an exotic mite, for example.[29] (Conversely, native animals under stress due to predation by foxes or cats or habitat degradation by goats or deer are likely to be more vulnerable to stress caused by a changing climate and less able to adapt.)

  When plants die due to drought and other climate stresses, their place is likely to be taken by weeds such as serrated tussock (*Nasella trichotoma*), which are often rapid colonisers.[30]

  More fires under climate change can lead to less vegetation cover for native species, such as endangered eastern bristlebirds,[31] exposing them to more predation by foxes and cats.
- **Less effective control of invaders:** Some biological control agents may become less effective under climate change. Under experimental conditions of high CO_2 and temperature, a leaf-miner (*Dialectica scalariella*) introduced as biocontrol for Paterson's curse (*Echium plantagineum*) became less effective because of reduced nutritional quality of leaves.[32] (Conversely, some biocontrol agents are likely to become more effective.) Glyphosate, the most important herbicide, is also likely to become less effective under climate change.[33]
- **Compromised dispersal of native species:** Many native plants that need to migrate southwards in response to higher temperatures rely on birds to

spread their seeds. But in many areas fruit-eating birds, including currawongs, figbirds and silvereyes, now live largely upon the fruits of weedy garden plants, and the seeds of weedy camphor laurel, privet and others are more likely to be dispersed than the seeds of native plants. Weedy shrubs and trees can produce larger crops of fruit than native plants because they are not attacked by insects or diseases that control them in their countries of origin.[34]

5.3 Interactions with anthropogenic changes

Following are examples of how invasive species may benefit from human responses to climate change.

- **New agricultural and horticultural products:** There are plans to grow vast areas of biofuels such as giant reed (*Arundo donax*) and jatropha (*Jatropha curcas*) in Australia. Giant reed is a catastrophic riparian weed in the US, costing millions of dollars to control, and jatropha is also a significant weed.[35]

  Breeders are developing new drought-tolerant and hardier plant varieties for gardens and pastures. Many of the species are already weedy, and hardier cultivars could increase their invasion into natural areas.[36] With an increased potential for hybridisation and genetic recombination, some could become super-invaders.[37] New drought-hardy breeds of goats could breed with feral goats, exacerbating their impacts.

- **Introductions in new areas:** There is considerable talk of agriculture moving north as conditions become drier in southern Australia under climate change. This would inevitably result in the introduction of new potentially invasive species.

- **Less control effort:** A recent NSW survey found that feral animal numbers did not decline during a drought, attributed to fewer control efforts by farmers under economic stress.[38] The challenge of coping with climate change events may compromise the control of pests and weeds. Governments may have less money to direct to such efforts.

See Table 1 (next page) for further examples of potential interactions between climate change and invasive species, with more detailed interaction categories.

5.4 Native invaders under climate change

Some native species are likely to do much better than others under climate change – surviving extreme events, migrating into new areas, or flourishing under new weather patterns – and the more successful species could become so dominant they suppress biodiversity, and effectively become native weeds or pests.

Australia already has many native plants considered weeds[39], either because they have spread from cultivation into new areas or because they have multiplied from human impacts and outcompete other native species. Because of this we need to think carefully about what “invasive” may mean in the future. Is a newly arriving native plant or animal an invader or something responding as it should?

Laughing kookaburras are an example. They have moved higher in the Australian Alps and are hunting alpine skinks, which have not previously been subject to bird predation and are highly vulnerable because they are live-bearers and need to bask in the sun for incubation.[40]

Climate change is likely to result in more invasions by native species when they shift or are shifted due to climate change. Some of the worst weeds – eg. pittosporum (*Pittosporum undulatum*) and cootamundra wattle (*Acacia baileyana*) – are Australian. Native species threatened by climate change may be deliberately shifted to new locations with more suitable climates, running the risk that they will become invasive.[41]

5.5 Invasions that increase greenhouse gas emissions

Some invasive species can exacerbate climate change by increasing greenhouse gas emissions (and some have the opposite effect[42]). But this has not yet received much research focus.

Weeds can change rates of carbon sequestration and decomposition and promote fire. Flammable weeds such as gamba grass and mission grass promote more and higher intensity fires that kill sapling trees and sometimes adult trees and promote grass invasion – a positive feedback loop (see Box 3).[43] Lower tree density reduces carbon storage in woodlands. Many of Australia’s major weeds are large flammable grasses: molasses grass (*Melinis minutiflora*), para grass (*Urochloa mutica*), veldt grass (*Ehrhata calycina*), buffel grass (*Pennisetum ciliare*), and African lovegrass (*Eragrostis curvula*) and the proposed biofuel giant reed (*Arundo donax*) as a potential major weed).

Weeds can increase emissions by stimulating higher rates of soil carbon decomposition and reducing carbon stores.[44] Some weeds that invade wetlands – willows (*Salix spp*.), for example – release methane, which they

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Changed conditions	Introduction & naturalisation of invasive species	Spread & proliferation of invasive species	Other potential advantages for invasive species
ABIOTIC CONDITIONS (climate, fire & CO_2)			
Altered temperature and rainfall patterns	A warmer Antarctic peninsula is more favourable for establishment of seeds, insects or spores transported by visitors or blown by wind or stuck to birds. Alpine areas become suitable for more garden plants to establish. Warmer temperatures create more favourable habitats for released tropical aquarium fish.	*Phytophthora cinnamomi* spreads in south-western WA due to a greater coincidence of warmer and wetter conditions. Weeds and feral animals (eg. foxes) move higher into alpine areas. Warmer temperatures accelerate the life cycle of invasive pathogens and insects.	
More droughts	More drought tolerant plant species/varieties are introduced.	Weeds (eg. serrated tussock) colonise bare patches, replacing native plants killed by drought. Some invasive animals increase populations more quickly after droughts.	Invasive plants and animals are able to dominate resources and refuges during drought and recover more quickly.
More/more-intense cyclones & floods	Exotic fish are washed out of ponds into wetlands. Weed seeds are washed/ blown from gardens and paddocks into bushland.	Weeds spread with flood waters, eg. athel pine, lippia, and they may be able to colonise faster than native species.	Violent weather destroys competing native vegetation.
Intensifying fire regimes		Flammable pasture grasses spread with more fire and promote fire. Weeds spread along fire tracks.	Wildlife is more exposed to foxes and cats due to loss of vegetation cover.
Higher CO_2 levels		Weeds that become more water efficient under higher CO_2 levels spread into drier areas. Increased asexual reproduction of weeds due to greater below-ground growth of rhizomes and roots.	Some biocontrol agents and herbicides become less effective. Some native species benefit less from CO_2 fertilisation than competing weed species.
BIOTIC CONDITIONS (other species affected by climate change)			
Native species moving	Some native species moving to new ranges become invasive.	Hosts or vectors (eg. mosquitoes) of invasive pathogens move into new areas. Changed migration patterns of frugivores spread weeds into new areas.	Movement of native species provide more resources for invasive species, eg. prey for predators.
Native species & ecosystems stressed		Plant death creates spaces for colonisation by weeds. Animal deaths create more resources for some invaders.	Stressed organisms are more vulnerable to invasive pathogens, eg. wombats to mange and plants to phytophthora dieback.
ANTHROPOGENIC CONDITIONS (human responses to climate change)			
New products & industries, relocations	Agriculture shifts north, and new weed, pest and disease species are introduced. Climate refugees inadvertently or deliberately introduce new invasive species into the country.	Disturbance/clearing in new areas for agriculture provides opportunities for invasive species to spread.	
Climate change mitigation & adaptation, response to extreme events	Weedy biofuel plants are cultivated. Invasive trees are cultivated for carbon credits. New drought-hardy plants are introduced for gardens and pastures. Some native species shifted into new areas to save them from climate change become invasive.	Fodder distributed in response to droughts and floods spreads weed seeds.	Due to economic stress, there is less control of feral animals by landowners and governments. Governments reduce budgets for control programs.

Table 1 Examples of potential interactions between climate change and invasive species.

extract from the mud they grow in.[45]

Below-ground invaders such as earthworms can increase decomposition rates and reduce soil carbon stores – by making conditions favourable for more-rapid decomposers (eg. bacteria over fungi) and for low-biomass tree species, for example.[46]

Worldwide, emissions from livestock are estimated to account for about 14% of greenhouse gas emissions.[47] Most feral animals in Australia – pigs, goats, deer, donkeys, horses, cattle, buffalo, rabbits – emit methane and nitrous oxide (as byproducts of bacterial fermentation of cellulose) and therefore contribute to greenhouse gas emissions. Feral animals are responsible for an estimated 4-5% of the Northern Territory's emissions.[48]

These herbivores can also contribute to climate change by changing the structure and composition of the ecosystems they invade. The most profound impacts occur when herbivory both damages trees and prevents subsequent recovery of forests.[49]

Invasive leaf-eating insects and plant pathogens can also substantially reduce carbon uptake by forests. Large-scale disease and herbivory is turning some northern hemisphere forests from carbon sinks into carbon sources.[50] Longer-term impacts on carbon uptake depend on which species replace trees killed.

Predators can also affect the carbon dynamics of forests. Invasive yellow crazy ants (*Anoplolepis gracilipes*) are changing the structure and composition of forests on Christmas Island. By preying on the red crabs that process leaf litter, they reduce the decomposition of forest litter (which would reduce emissions). But by protecting honeydew-secreting scale insects from predators, they increase the growth of sooty mould, which reduces photosynthesis and leads to canopy dieback and sometimes tree death (which is likely to increase emissions).[51]

6. Responding to the double trouble of climate change and invasives

Worldwide, climate mitigation efforts so far have failed dismally and trends in greenhouse gas emissions exceed worst-case IPCC scenarios.[54] Attention is turning increasingly to how native species and ecological communities can be supported to survive the inevitable changes.

Invasive species are already a major threat to biodiversity, and likely to cause more extinctions in Australia even without climate change. Climate change strengthens the imperative for addressing such threats.

Climate adaptation measures should address invasive species threats in three ways:

(1) Reduce existing invasive species threats to increase the capacity of native species and ecosystems to adapt to climate change;

(2) Control invaders or potential invaders likely to benefit under climate change; and

(3) Prevent new introductions, ensuring that responses to climate change do not create new invasive species problems.

Climate mitigation measures should also include addressing invasive species threats:

(4) Control invasive species that contribute to greenhouse gas emissions.

Reduce invasive threats to increase capacity for adaptation

Extinctions are often the result of multiple, cumulative threats. Reducing other threats is essential to providing species with the best prospects of surviving and adapting to climate change. With invasive species one of the top three threats to biodiversity, they should be a very high priority in efforts to facilitate adaptation to climate change.

Some species have survived past climate change by retracting to refuges. Identification and protection of refuges from invasive species and other threats should be a high priority. Fire refuges, for example, need protection from invasion by flammable weeds and drought refuges from predation by cats and foxes and exotic competitors for resources.

Control invaders likely to benefit under climate change

Climate change will change priorities for managing invasive species, with new threats emerging, some existing threats increasing and others declining. It is prudent to substantially reduce the number of potential invasive species (eg. eradicate sleeper weeds) and control species likely to exert the most serious threats. For example, there should be programs to eradicate garden plants that could spread into the Wet Tropics after cyclones or invade warming alpine areas. A national priority should be fighting the dieback disease *Phytophthora cinnamomi*, as it is a major threat that could get much worse in some areas under climate change.

Prevent new harmful introductions

While Australia has a good risk assessment process for introductions of new species from overseas, most species imported prior to 1997 (when risk assessment was introduced) have never been assessed and can be freely imported. Most states and territories regulate the use of only a very small proportion of invasive species, allowing new introductions without risk assessment. For example, the highly invasive riparian weed giant reed (*Arundo donax*) that costs millions of dollars annually to control in California can be grown for biofuels in Australia without risk assessment. New hardier varieties of existing weedy garden plants or pasture plants that could greatly exacerbate their threats can also be introduced without assessment.

It is also important to ensure that any translocation of native plants and animals to more suitable habitats under climate change does not lead to them becoming invasive.

Reduce greenhouse gas emissions by reducing invasive threats

Some invasive species threats could be addressed as part of efforts to reduce Australia's greenhouse gas emissions. A high priority should be to limit the spread of flammable weeds that both increase fuel loads well beyond natural levels and increase emissions due to more fires and in some cases the death of trees.

There would be both biodiversity and mitigation benefits in reducing the numbers of feral animals in many areas.

It is also very important to ensure that climate mitigation efforts do not increase invasive species threats. For example, trees planted as carbon sinks should not be invasive species.

Positive feedback loops of invasive species and climate change

Some interactions between invasive species and climate change are particularly worrisome because they exacerbate positive feedback loops – problems cyclicly begetting worse problems.

Flammable invasive pasture grasses such as gamba grass (*Andropogon gayanus*) and mission grass (*Pennisetum polystachion*) promote fire by providing very high levels of dry fuel for fire.[52] They also benefit from fire by increasing in its wake. Climate change is likely to intensify fire regimes, which in turn will promote more exotic grass invasion, tree death and higher greenhouse gas emissions.

The damage that cyclones cause to rainforests promotes invasion by exotic vines such as blue thunbergia (*Thunbergia grandiflora*) and turbina (*Turbina corymbosa*). Vine invasion prevents canopy recovery, rendering forests more vulnerable to future cyclone damage and vine invasion. Climate change is predicted to increase the intensity of cyclones, exacerbating this cycle.[53]

Tree pathogens that benefit under climate change – *Phytophthora cinnamomi* in southwest Australia, for instance – can render trees more vulnerable to the impacts of climate change (eg. drought or fire) and contribute to greenhouse gas emissions when trees are killed. Weeds may take the place of trees killed.

There are human-based feedback loops as well. The more invasive species that establish, the less many people are inclined to do about it – due to the feeling that the problem is too big and hopeless. Climate change will exacerbate this trend by driving even more environmental problems. Promoting motivation to avert invasive species threats is a key climate change challenge.

7. Conclusion

The already dire impacts of invasive species are likely to be exacerbated under climate change. That invaders are increasing most where temperatures have risen the most – the Australian Alps – is an early warning of potentially momentous changes. More frequent or severe extreme events are of particular concern as previous experience shows they can dramatically boost weed and pest invasions.

Invasive species management should be a major part of adapting to climate change. Some of the new spending for climate change adaptations should go to understanding and reducing climate-boosted invasive species threats. There needs to much greater public support for action on invasive species. And as well as taking public transport and using low-energy lightbulbs, householders should remove potential invaders from their environment as part of their own climate change response.

Summary of recommendations

Reduce invasive threats to increase capacity for adaptation

- Reduce invasive species and other threats to native species and ecological communities likely to decline under climate change.
- Protect likely climate change refuges from threats, including those due to invasive species.

Control invaders likely to benefit under climate change

- Develop programs to prevent potential invasive species threats under climate change, including eradicating potential weeds from gardens in the Wet Tropics and alpine areas.
- Direct strong research and control efforts to invasive species likely to exert the highest threats to biodiversity under climate change, eg. *Phytophthora cinnamomi* and flammable invasive pasture grasses.

Prevent new harmful introductions

- Adopt a permitted list approach to exotic species at the state level that permits release only if they pose low invasive risks.
- Ensure that all new cultivars or breeds of existing weedy or pest species undergo risk assessment and are permitted for import or release only if they pose low risk.
- Subject biofuel crop species and other species proposed for widespread cultivation to risk assessment, permitting cultivation only for low-risk species.
- Develop a national policy on translocation of native plants and animals that requires rigorous risk assessment of the invasive threat.

Reduce greenhouse gas emissions by reducing invasive threats

- Develop programs to limit the spread of flammable weeds to limit the risk of intensified fire regimes and increased greenhouse gas emissions.
- Fund control programs for feral animals as a mitigation measure.
- Ensure that climate change mitigation programs do not increase invasives species threats, eg. ensure that plants used for carbon sinks and biofuels are non-invasive.

Endnotes

1 Steffen et al. (2009).

2 Sandlund et al. (2001); Walker and Steffen (1997); World Resources Institute et al. (1992).

3 Booth (2009a), and references therein.

4 Booth (2009a)

5 The 23rd extinction of an Australian mammal species due to invasive species is likely to have occurred in 2009 with the loss of the Christmas Island pipistrelle (Pipistrellus murrayi) (see Low 2009).

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37 Wilson et al. (2009); Booth (2009b).

38 West and Saunders (2007).

39 According to Randall (2007), more than 600 of about 11,000 Australian native plant species in cultivation are invasive.

40 Low (2008b).

41 Ricciardi and Simberloff (2009).

42 Wolkovich et al. (2009), for example, found that exotic grass invasion of a shrubland in the US turned it from a carbon source to a sink by increasing carbon storage 1.4 times.

43 Rossiter et al. (2003); Peltzer et al. (2009).

44 Strickland et al. (2009) found that an exotic grass invading many US forests, Japanese stiltgrass (Microstegium vimineum), stimulates higher rates of decomposition in the soil and reduces soil carbon stores.

45 Jamie Smialek et al. (2000).

46 Peltzer et al. (2009); McLean and Parkinson (2000)

47 Goodhand and Anlang (2009)

48 Northern Territory Government (2008), citing Price et al. (2007).

49 Peltzer et al. (2009).

50 Clark et al. (2010); Kurz et al. (2008).

51 O'Dowd et al. (2003)

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