Pacific Invasive Species
Battler Series

PRIORITISE WIDESPREAD WEEDS TO TARGET WITH NATURAL ENEMIES

PRISMSS

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Cover image: Merremia *Decalobanthus peltatus* smothering all other vegetation. Photo: Jeffline Tasale

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Secretariat of the Pacific Regional Environment Programme

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Our vision: A resilient Pacific environment sustaining our livelihoods and natural heritage in harmony with our cultures.

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Dear Invasive Species Battler

We are a diverse bunch of people in the Pacific region, which spans about one third of the earth's surface and encompasses about half of the global sea surface. We have ~2,000 different languages and ~30,000 islands. The Pacific is so diverse that its ecosystems make up one of the world's **biodiversity** hotspots, with a large number of species found only in the Pacific and nowhere else. In fact, there are 2,189 single-country endemic species recorded to date. Of these species, 5.8 per cent are already extinct or exist only in captivity. A further 45 per cent are at risk of extinction. We face some of the highest extinction rates in the world.

The largest cause of extinction of single-country endemic species in the Pacific is the impact of invasive species. Invasives also severely impact our economies, ability to trade, sustainable development, health, ecosystem services, and the resilience of our ecosystems to respond to natural disasters.

Fortunately, we can do something about it.

Even in our diverse region, we share many things in common. We are island people, we are self-reliant, and we rely heavily on our environment to support our livelihoods. We also share many common invasive species issues as we are ultimately connected. Sharing what we learn regionally makes us and our families benefit economically, culturally, and in our daily lives.

The "Invasive Species Battler" series has been developed to share what we have learned about common invasive species issues in the region. They are not intended to cover each issue in depth but to provide information and case-studies that can assist you to make a decision about what to do next or where to go for further information.

The SPREP Invasive Species Team aims to provide technical, institutional, and financial support to regional invasive species programmes in coordination with other regional bodies. We coordinate the Pacific Regional Invasive Species Management Support Service (PRISMSS), the Pacific Invasive Learning Network (PILN), a network for invasive species practitioners battling invasive species in Pacific countries and territories, and the Pacific Invasives Partnership (PIP), the umbrella regional coordinating body for agencies working on invasive species in more than one Pacific country.

For knowledge resources, please visit the Pacific Battler Resource Base on the SPREP website: www.sprep.org

Thank you for your efforts,

SPREP Invasive Species Team

About This Guide

This Battler Series publication builds understanding about negative impacts of weeds in Pacific island contexts and supports the prioritisation of established, widespread weeds for management. This guide is based on training conducted by PRISMSS NENS Technical Lead Manaaki Whenua – Landcare Research (MWLR), New Zealand. Tiffany Straza prepared the guide text; Lynley Hayes, Chris McGrannachan, and Quentin Paynter provided review.

This publication is part of a collection of Battler guides on managing weeds in the Pacific region. For an introduction to biocontrol, read the Battler publication *Use natural enemies to manage widespread weeds in the Pacific*. For weeds present at low abundance, see *Manage low-incidence priority weeds to conserve Pacific biodiversity*.

What are invasive weeds?

Plants that are growing too well in the wrong place, or weeds, have significant negative impacts on the economy, environment, human health and amenities. There are already hundreds of species with negative impacts in the Pacific islands. For more about what weeds are and why they matter, see *Manage low-incidence priority weeds to conserve Pacific biodiversity*.

Introduced species have a competitive advantage because their natural enemies are absent. All terrestrial and freshwater species are threatened by these invaders.

The situation is expected to worsen with time, as existing introduced species naturalise and spread and as increased travel and movement of goods as well as climate change increase the risks of invasive species being transported and flourishing in new areas. (For more about how climate change affects species invasions, see page 15 and the Battler guide *Clean boats, clean ports*.)

Invasive species arrive, establish themselves and spread — in that order, meaning that the impacts of the invasive species may not be felt until long after a species first arrived. When weeds are only present in small populations, they may be controllable through the use of targeted herbicides or manual removal. But by the time an invasive species becomes a priority for the larger society, its population may be too widespread for eradication or manual control.

What are natural enemies?

Conventional control techniques can be useful when weeds are not yet common and to protect high value sites. However, once weeds become widespread, the only safe, cost-effective, and sustainable way of tackling them is through the use of natural enemies, also known as **biological control** or biocontrol.

Natural enemies can be used to restore the natural balance between weeds and the environment by introducing the enemies where they are needed. Natural enemies tend to be invertebrates (mostly insects and mites) and fungal plant pathogens that eat, take energy from, or disrupt the function of the plant or the reproductive parts of a plant (like the seeds).

The balance between weeds and the environment can be restored through the use of natural enemies of the weeds. Only natural enemies that will not damage other desirable species or cause any other unwanted problems are used.

The Natural Enemies – Natural Solutions (NENS) regional programme aims to lower the impact of widespread invasive plants by reducing their vigour by introducing safe natural enemies from the area where they, and their host plant, originate.

This technique has been used safely and successfully worldwide, including the Pacific islands, to manage weeds for more than 100 years. Safety measures include assessments of the natural enemies, testing whether they will use or interfere with other species native to the potential site of introduction or beneficial introduced species.

Natural enemies have been established on 25 weed species in 17 countries and territories in the Pacific. There are many examples of safe and successful weed control using natural enemies in the Pacific islands, including control of broomweed *Sida acuta*, chromolaena *Chromolaena odorata*, grand balloon vine *Cardiospermum grandiflorum*, ivy gourd *Coccinia grandis*, mile-a-minute *Mikania micrantha*, lantana *Lantana camara*, nail grass *Mimosa diplotricha*, red passionfruit *Passiflora rubra*, water hyacinth *Pontederia crassipes*, and water lettuce *Pistia stratiotes*.

There are many opportunities both for spreading existing natural enemies available in the Pacific to new countries, from introducing species available outside the Pacific, and through developing new options for the Pacific.

This guide supports national managers to assess the viability of using natural enemies, prioritise among target species, and understand how climate change may affect weed populations and the effectiveness of biocontrol approaches. For more about characterising weed populations and selecting a control approach, see *Use natural enemies to manage widespread weeds in the Pacific*.

Learn online

Recordings of an online workshop series held in 2022 are available to guide national managers determining the top priority weeds for the Pacific. The workshop was hosted by SPREP and PRISMSS with support from Manaaki Whenua – Landcare Research and the New Zealand Foreign Affairs and Trade Manatū Aorere.

NENS Prioritisation session videos:

Session 1 —Understanding the impacts of weeds: https://youtu.be/smIed4VrYIE

Session 2 — Introducing a prioritisation system: https://youtu.be/jNOZ1UrCXJQ

Session 3 — Considering climate change implications: https://youtu.be/i45KcJyvXQM

Control weeds to build resilience

"Eradication of invasive species is an obvious climate adaptation solution because the natural environment is the first line of defence in any Pacific island country," said Filomena Nelson, Climate Change Advisor for the Secretariat of the Pacific Regional Environment Programme.

Invasive weeds are a serious problem hindering community resilience to climate change. PRISMSS hosted an online showcase of the impacts of tamaligi *Falcataria moluccana* during natural disasters and extreme weather events in Samoa as well as devil's ivy (taro vine *Epipremnum pinnatum* cv *aureum*) on the forest ecosystems of Niue, highlighting the linkage between invasive species management and building climate resilience in the Pacific.

See: https://youtu.be/oSz4dHGJ3PE

What harmful impacts do weeds have?

Weeds can cause both positively received and negatively viewed changes in local environments. Here, we focus on negative impacts considered in two major categories:

- *Ecological impact*, with measurable changes to ecosystem properties by introduced weed species. These changes may affect the lives and survival of native biodiversity, including threatened and/or iconic species, as well as ecosystem services.
- *Socioeconomic impact*, with changes to ecosystems and human-dominated systems that affect economies and human health and wellbeing. Weed invasions may affect food security, incomes and livelihoods, cultural activities, livestock health, and more.

Impacts are not always felt immediately upon the arrival of an invasive species. Some impacts are identified or felt well after the invasive species has arrived, established a population, and spread across a large area or into a high-value ecosystem.

Islands are particularly susceptible to weed invasions, compared to mainland sites (Lonsdale 1999), although the reasons why are varied and not fully understood.

- Propagule pressure is important, and many species of plants have recently been introduced into the Pacific region for varied uses such as crops, forestry, and ornamental uses. For example, 7,866 ornamental plant species have been cultivated in Hawai'i between 1840 and 1999 (Schmidt & Drake 2011), greatly outnumbering the approximately 956 native plant species (Wagner et al. 1990).
- Pacific islands are more affected by natural disasters and storms, such as hurricanes and cyclones. Every year, small island states make up two thirds of the countries globally that suffer the highest losses from disasters (OECD & World Bank 2016). Extreme weather creates conditions favourable for recruitment of invasive plant species (see Murphy & Metcalfe 2016).
- Islands, particularly remote ones, are often dominated by endemic species found nowhere else. For example, over 956 native plants occur in Hawai'i, of which 90 per cent are endemic and the majority evolved from an estimated 280 colonists (Wagner et al. 1990). Such species are often susceptible to outside threats, having spent many years evolving in isolation. For example, until recently, mammalian herbivores such as goats were absent from most Pacific islands and plants did not need defences against browsing, such as sharp thorns or plant secondary compounds that reduce digestibility. Consequently, the introduction of exotic mammalian herbivores can favour invasive species that are adapted to resist grazing and browsing over native species that are not.

- On isolated islands, 'functional groups' of plants may be underrepresented, resulting in niches that are more readily invaded (see Fine 2002). For example, mainland tropical forests may be resistant to invasions because the early successional phase of tropical forests are dominated by fiercely competitive native species. On isolated islands, this functional group is probably less represented, making tropical island forests more easily invaded (Rejmánek & Pitcairn 2002).
- The dynamic equilibrium model of island biogeography (MacArthur & Wilson 1963) postulates that arrival of a new species on an island will be compensated for by the extinction of a species already present, so that the number of species remains constant.

Impacts on native biodiversity

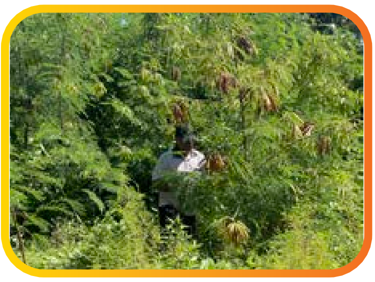
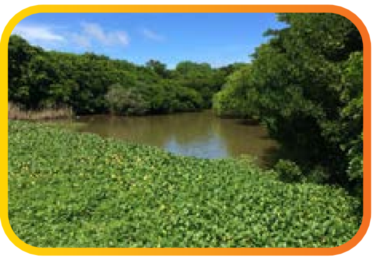
Type of negative impact	Example
Changes to population structure: The weed impacts on the resources, environment and behaviour of native species, leading to changes in the native species' population structure.	*Chromolaena odorata* shades nesting sites of Nile crocodiles in South Africa. This reduces the soil temperatures by 5 to 6°C, likely to cause a female-biased sex ratio or prevent development of eggs (Leslie and Spotila 2001).  Photo: Arturo de Frias Marques via Wikimedia Commons  Photo: Asashathees via Wikipedia
Displacement or population loss: The weed causes a reduction in population or local displacement of native flora and/or fauna.	African tulip trees *Spathodea campanulata* can reproduce by suckering and form dense thickets that outcompete native vegetation, block or interrupting natural succession and reducing biodiversity in countries such as Fiji (Brown and Daigneault 2014).  Photo: Lucidcentral.org
Genetic loss through hybridisation: The weed reproduces with native species, reducing the genetic variation of native species populations and potentially causing negative impacts.	In China, the native *Sphagneticola calendulacea* has hybridised with *S. trilobata* and is suggested to be just as competitive and as invasive as *S. trilobata* (Ni et al. 2014, Li et al. 2016).   Photos: Jkadavoor (Jee) via Useful Tropical Plants Database

Habitat loss: The weed reduces the availability of required habitat for native species, causing their displacement.	On Hawai'i's Midway and Kure Atoll, *Verbesina encelioides* reduces habitat quality for seabirds by creating a physical barrier to nesting birds, lowering nest density and shading out native plants (Feenstra and Clements 2008).  A field of *Verbesina encelioides* on Midway Atoll with black-footed albatross and Laysan albatross. Photo: Forest and Kim Starr, 1999
Local extinction: The weed causes the local or total extinction of native endangered flora and/or fauna.	Endemic *Abutilon pitcairnense* went extinct on Pitcairn Island from being outcompeted by *Syzigium jambos* and other weeds such as *Lantana camara* (The National Botanic Gardens of Ireland 2023).  *Abutilon pitcairnense.* Photo: Salix via Wikipedia  *Syzigium jambos*. Photo: B. Navez via Wikipedia  *Lantana camara*. Photo: CABI

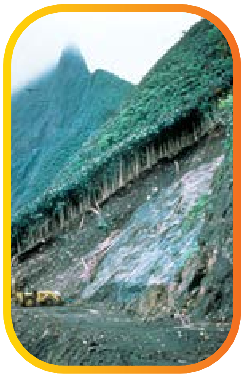
Facilitation of non-native species

Type of negative impact	Example
Changes to soil microbial and chemical composition: The weed changes soil microbial communities and the chemical composition of soils, to the benefit of other non-native plants, microbes, or soil fauna.	Singapore daisy changes soil fungal communities and soil pH. This changes community structure of soil microbial communities which leads to further invasion by Singapore daisy, as well as other weeds (Si et al. 2013).  Photo: Chantal Probst
Alteration of habitat structure: The weed changes the habitat structure of natural environments, to the benefit of other non-native species.	In the lower Potomac River, Washington DC, yellow flag iris has changed riparian marshes used by native *Salix* species to forest dominated by introduced *Fraxinus* species (Crawford 2000).  Photo: Dennis Kramb via SIGNA
Facilitation of crop pests: The weed is a host of non-native pests that can be damaging to crops and food sources.	In Hawai'i, invasive strawberry guava *Psidium cattleianum* is a reservoir host of invasive fruit flies such as medfly or Mediterranean fruit fly *Ceratitis capitata* (Vargas et al. 1990).  Photo: Forest and Kim Starr via Wikipedia

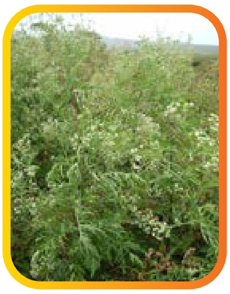
Alteration of ecosystem processes

Type of negative impact	Example
Chemical changes to ecosystem: The weed alters the chemical composition of the environment, potentially disrupting natural chemical cycles and ecosystem processes.	*Myrica faya* increases soil nitrogen through nitrogen fixation in Hawai'i Volcanoes National Park, resulting in the invasion by other weeds that take advantage of the increased nitrogen (Vitousek and Walker 1989).  Photo: Forest and Kim Starr via Wikimedia Commons
Changes to disturbance regimes: The weed alters the type and strength of disturbance in a local ecosystem impacting on natural processes and cycles.	Invasion of *Anisantha tectorum* into the bush-steppe communities of the Great Basin (Idaho, Utah), changed fire occurrence from every 60 to 110 years to every 3 to 5 years, and native species are replaced by the weed (Pimentel et al. 2005).  Photo: Theodore Roosevelt Conservation Partnership
Disruption of natural succession: The weed alters landscapes and ecosystems by disrupting the natural order of plant succession.	Leucaena *Leucaena leucocephela* forms dense monocultures which suppress other vegetation in some Pacific Islands like Niue and Tuvalu.  Photo: MWLR
Changes to hydrological regimes: The weed reduces the flow and quality of freshwater.	Water hyacinth infestations can change water flows and increase the build-up of silt in rivers, leading to wider, ecosystem impacts (Ministry for Primary Industries 2020).  Photo: EPPO Global Database

Natural disasters

Type of negative impact	Example
Increases in wildfires: The weed increases the number and intensity of wildfires.	Gamba grass *Andropogon gayanus* increases fuel loads in the Northern Territory, Australia, posing a significant fire risk to human settlements and wildlife (Whelan et al. 2006).  Photo: Invasive Species Council, Australia
Increases in flooding: The weed causes flooding and flooding damage by blocking water ways.	In Samoa, storms cause *Falcataria moluccana* trees/branches to clog waterways. This can lead to further risk of flooding and flood damage (SPREP 2020).  Photo: Government of Samoa
Increases in invasions: Cyclones and hurricanes can carry weeds great distances, allowing it to spread to other locations.	Cyclone Heta in 2004 created new infestations of taro vine all over Niue, after it spread plant fragments (FAO 2016).  Photo: Pacific Community (SPC)
Increases in landslides: Some weeds can be less adapted to storms and cyclones, increasing the risk of landslides and soil erosion.	*Miconia calvescens* on Tahiti reduces ground cover species under it through shading. Their large leaves increase "throughfall" rain drops that break up the soil underneath, leading to landslides (Giambelluca 2012).  Photo: The Nature Conservancy

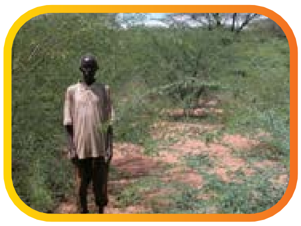
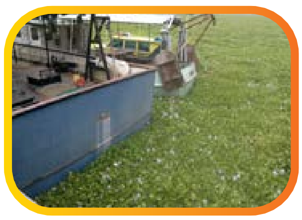
Harm to human and animal health

Type of negative impact	Example
Allergic reactions and poisoning of humans: The weed is allergenic or toxic to humans, leading to poor health or death.	*Parthenium hysterophorus* dust and pollen can cause skin inflammation, eczema, asthma, hay fever, burning, and blisters around eyes in humans (Patel 2011).  Reaction to *Parthenium.* Photo: Sharma and Verma (2012)  *Parthenium hysterophorus.* Photo: Forest and Kim Starr, CC BY 3.0
Facilitation and spread of diseases: The weed may introduce or increase species that carry diseases, increasing the risk of spread to domestic and wild species and humans.	Aquatic weeds, such as water lettuce and water hyacinth, can increase numbers of mosquitos that carry diseases dangerous to wildlife and humans by reducing water flow (Stone et al. 2018). Photo: iNaturalist; Wikipedia 
Allergenic and poisonous to pets, wildlife and livestock: The weed is toxic or allergenic to animals, leading to poor health or death.	*Lantana camara* poisoning results in 1,000 to 1,500 cattle deaths per year in Queensland, Australia. Poisoning results in liver disorders and sensitivity to light (Day et al. 2003). Photo: Texas A&M Veterinary Diagnostic Laboratory 
	Taro vine is toxic to cats and dogs, with symptoms such as oral irritation, vomiting, eye pain, and mouth swelling (Meshram and Srivastava 2015). Taro vine. Photo: backyardgardenlover.com 

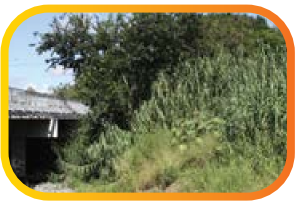
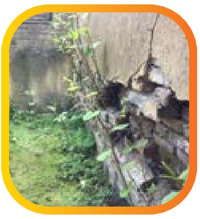
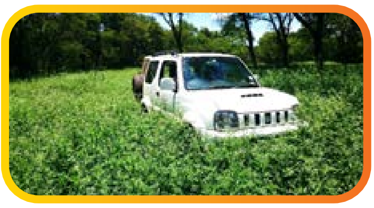
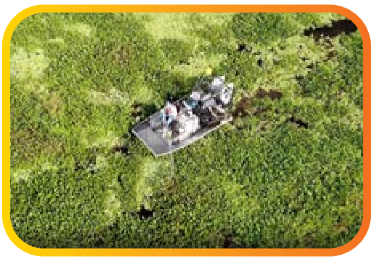
Control costs

Type of negative impact	Example
Time, labour, chemical, and equipment costs: Control of the weed causes economic costs in the form of labour, time, chemicals, and equipment for its management and control, especially when repeated control activities are needed.	The safe removal of a single mature *Falctaria moluccana* tree was estimated to cost between USD 2,000 and USD 10,000 in Hawai'i, making its management extremely costly (MWLR 2021).  Photo: Big Island Invasive Species Council  Photo: Wiki.nu
Disturbance from control costs: Efforts to control the weed lead to detrimental secondary impacts, including to non-target native species and the environment (terrestrial and aquatic).	Taro vine control in Niue involves full foliar spray with herbicide. Because the vine attaches itself to trees, the tree is sacrificed in order to kill the vine, as the herbicide travels into the tree trunk via the vine's penetrating roots (David Moverley, SPREP, pers. comm.).  Photo: Niue Department of Environment

Primary production

Type of negative impact	Example
Production loss of commercial arable crops/food: The weed causes a reduction in crop or food yield.	In Papua New Guinea, *Mikania micrantha* was observed smothering crop plants, such as taro, banana and papaya, which resulted in poorer crop quality (Day et al. 2012).  Photos: Michael Day
Production loss of pastureland: The weed causes a reduction in the yield of pasturelands needed to raise livestock.	In Vanuatu, approximately 90 per cent of beef farmers have a problem with weeds such as *Solanum torvum*, *Urena lobata*, and *Senna tora* out-competing more desirable pasture species (MFAT 2018).  Photo: Michael Day
Loss of income from commercial enterprises: The weed reduces the economic gain of commercial enterprises and businesses, through disruption to services or products.	In 2005, the economic impact of weeds in Australian winter cropping systems was estimated to be a loss of AUD1.3 billion. This loss represented 17 per cent of the value of Australian grain and oilseed production in 1998 to 1999 (Jones 2005).  Photo: Department of Primary Industries and Regional Development, WA, Australia
Production loss for small-hold and subsistence living: The weed causes food loss of individuals and communities living day-to-day, potentially leading to food shortages and famine.	Imperata grass *Imperata cylindrica* produces chemicals that inhibit the growth of other plants and the underground stems can actually grow through root crops, such as cassava and sweet potatoes (SPREP 2020).  Imperata grass invasion in Palau. Photo: David Moverley, SPREP
Loss of income from natural resources: The weed causes a reduction in the yield of natural resources that results in a loss of income for industry (such as forestry or fisheries).	Water hyacinth mats reduced access to fishing grounds on Lake Victoria, East Africa, resulting in decreased fishing rates, delayed access to markets and increased costs of fishing (Kateregga and Sterner 2009).  Photo: Ocean Scientific International Limited

Infrastructure, lifestyle, and cultural values

Type of negative impact	Example
Damage to infrastructure: Damage to roads, building, power lines, and water/sewage infrastructure are caused by the target weed.	Giant reed *Arundo donax* is known to cause damage to bridges when uplifted by floodwaters (University of California, Riverside 2023).  Photo: Steve Csurhes via The Queensland Government
	The emerging shoots of Japanese knotweed *Fallopia japonica* are known to damage roads and building walls (Ainsworth & Weiss 2002).  Photo: Environet Invasive Plant Specialists
Restriction to aquatic and terrestrial movement: The target weed reduces movement of vehicles on aquatic waterways, land, and by foot.	Water hyacinth reduces mobility on lakes and rivers in Africa and the Pacific (Gebregiorgis 2017).  Photo: Blair Cowie via Centre for Invasion Biology, Stellenbosch University  Photo: The Standard
Reduction in recreational activities: Aquatic and land recreational activities are restricted due to the target weed and any hazards this may cause.	Aquatic weeds such as water lettuce and water hyacinth can reduce or halt leisure activities such as swimming, fishing, and boating (Centre for Invasive Species Solutions 2021).   Photos: Julia Evans via Daily Maverick; Delwyn Verasamy via Mail & Guardian
Reduction in tourism: Certain tourism activities are restricted due to the proliferation of the target weed and any hazards it may cause.	Invasive weeds reduce ecotourism activities in Florida's public parks and privately owned natural areas, which have an estimated economic impact of USD 8.1 billion per year, with USD 3.1 billion per year from wildlife viewing alone (Adams et al. 2010).  Photo: Mike Knepper via CNN

Type of negative impact	Example
Loss of aesthetic value: The weed may dominate in a landscape, decreasing its aesthetic appeal/beauty to individuals.	Smothering vines like merremia *Decalobanthus peltatus* obscure and reduce native vegetation decreasing aesthetic values.  Photo: MWLR
Loss of cultural value: Reductions or loss of traditional and cultural activities and resources leads to a loss of cultural significance, value, or pride.	Singapore daisy *Sphagneticola trilobata* invasion of coastal areas in Nauru threatens the locally endangered medicinal plant *Triumfetta procumbens* (Thaman 1999).  Photo: Christian Moliné via POWO

Managing invasive species to preserve cultural heritage

In French Polynesia, on the island of Raiatea, one hour's flight west of Tahiti, invasive plant species are threatening a globally unique site: the Taputapuātea marae.

This special place has been listed as a UNESCO World Heritage site since 2017. It is a cultural site and also an ancient political site which is in fact the cradle of Maohi civilisation. This marae is considered a sacred place for the reunification of the Polynesian peoples.

Invasive weeds threaten part of site's 5,500 hectares. Invasive trees threaten the archaeological integrity of the marae, requiring urgent management action. Via PRISMSS, the SPREP PROTEGE team is working with the Department of Culture and Heritage and Department of Environment of French Polynesia to control weedy species.

Management action has multiple cross-cutting benefits: controlling invasive species also protects cultural heritage, benefits native biodiversity, and supports local farmers.
A partnership with the Taputapuātea commune seedling nursery provides economic benefits while sourcing healthy native plants to rebuild the site's ecosystem.

See: https://youtu.be/FDSjIbcBQVo

How do weeds relate to climate resilience?

The average global temperature is increasing. This planetary warming affects global, regional, and local climate patterns, including extreme events.

Warming is caused by increased levels of greenhouse gases released by burning fossil fuels: the most important of these is carbon dioxide (CO_2) which contributes to 76 per cent of the total greenhouse gas emissions from human activity (IPCC 2014).

Climate change, its drivers, and resulting extreme events affect species invasions:

- Tropical cyclone intensity will increase under climate change with profound implications for the long-term sustainability of ecosystems (Turton 2012). According to Turton (2012), "There is a real risk of a phase shift to vegetation types dominated by disturbance species, including weeds, at the expense of cyclone-intolerant species."
- Intense storms facilitate plant invasion (particularly invasive vines and lianas) by increasing resource availability, reducing competition and increasing opportunities for dispersal (Murphy & Metcalfe 2016, Camarero 2019).
- In a 2017 study, invasive weeds tended to have a stronger positive response to increased rainfall than do native plants, but this difference was not statistically significant, perhaps because impacts of changes in rainfall are inconsistent (Liu et al. 2017).
- Invasive weeds may also be effectively 'fertilised' by carbon dioxide.

How do carbon dioxide emissions affect invasive weeds?

Plants use CO_2 during photosynthesis. Carbon dioxide is the sole source of carbon for plants, necessary for their production of living matter (biomass). As well as changing the climate, increased levels of CO_2 can affect plant growth through an increased rate of photosynthesis: this is called the 'CO_2 fertilisation effect' or 'carbon fertilisation effect'.

The specific impacts of increasing CO_2 levels may vary according to plant metabolism. The vast majority of plants will be positively affected by elevated CO_2.

The CO_2 fertilisation effect varies depending on the plant species, temperature, availability of water and nutrients, and other factors. There is much uncertainty about the specific extent, timing, and results of such CO_2 fertilisation.

Despite this uncertainty, reviews clearly indicate that invasive weeds exhibit larger growth increases by comparison to other plant species (Ziska & George 2004, Liu et al. 2017). In other words, invasive weeds stand to benefit even more from climate change.

For example, three invasive species in China (*Mikania micrantha, Sphagneticola (=Wedelia) trilobata*, and *Ipomoea cairica*) showed significantly greater increases in photosynthetic rate (67.1 per cent vs. 24.8 per cent) and total biomass (70.3 per cent vs. 30.5 per cent) compared to similar or congeneric native species (*Paederia scandens, Sphagneticola calendulacea [= Wedelia chinensis],* and *Ipomoea pescaprae*) at elevated CO_2 (Song et al. 2009).

Rising CO_2 can favour invasive weeds within plant communities, but the mechanism is not well understood (Liu et al. 2017). Invasive weeds may simply have a broader environmental tolerance and be more adaptable than most plants.

How does climate change affect biocontrol?

Biocontrol systems as living systems can be altered by a changing climate, either by effects on the target species or the natural enemy.

To our knowledge, there is only one experimental example from the biocontrol literature (Reeves et al. 2015): In a field experiment, elevated CO_2 levels increased the fitness of an invasive plant *Centaurea diffusa*. However, the population density of its biocontrol agent *Larinus minutus* also increased. This increase in the natural enemy balanced out the positive effects of CO_2 on the weed.

There is more information on what might happen to plant/natural enemy interactions due to climate change from the crop and pest literature. This is potentially relevant to invasive weeds, if we think of weeds as a 'crop' and natural enemies as their 'pests'.

The effects may be difficult to predict. For example, based on a study of insect pests in forests (Jactel et al. 2019):

Effect of climate change	Implication for NENS programmes
Responses of forest insect herbivores to climate change are expected to be mostly positive, with shorter generation time, higher fecundity, and greater survival, leading to increased range expansion and outbreaks.	Positive
Negative effects are also likely, such as lethal effects of heat waves, less palatable host tissues, or more abundant parasitoids and predators.	Negative
The complex interplay between abiotic stressors, host trees, insect herbivores, and their natural enemies makes it very difficult to predict overall consequences of climate change on forest health.	Uncertain

Some predictions have been made about the effects of warming on insect populations (see Figure 1). Most of the predictions are probably not highly relevant to NENS in the Pacific region, except for the increased number of generations. This change is potentially good news for NENS because more generations should result in larger populations and more damage to the target weed.

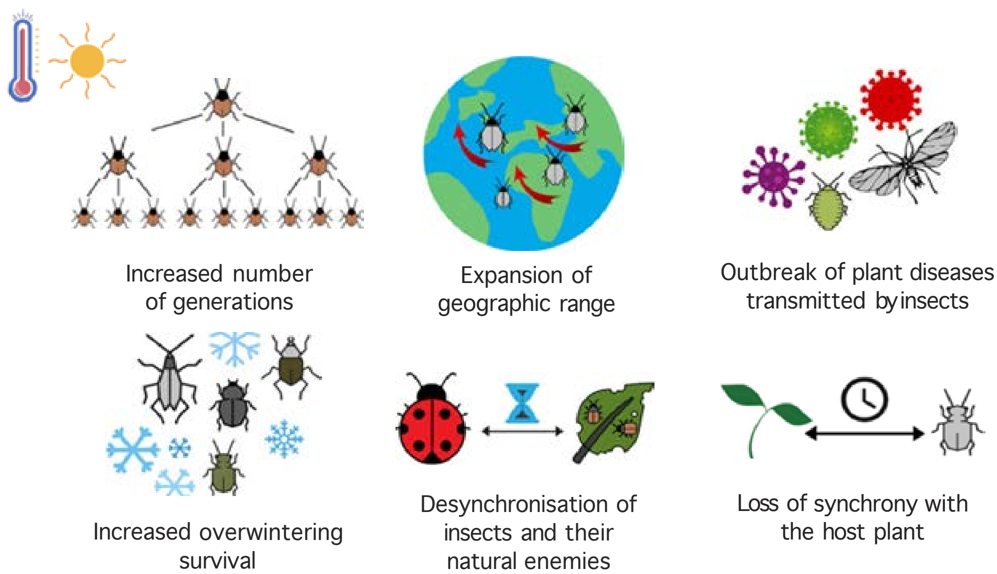


FIGURE 1. Effects of temperature rise on agricultural insect pests.
Figure reproduced from Skendžić et al. (2021), under the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

The CO_2 fertiliser effect may have implications not only for plants but also for species that eat plants. The CO_2 fertiliser effect can reduce palatability by altering the C (carbon) to N (nitrogen) ratio. N is a key element for insect development. If the C:N ratio increases, insects must eat more of the plant to get the same amount of N, causing more damage to plants. However, if the insect's development time increases, there may be fewer generations per year, resulting in lower natural enemy populations.

The findings to date are mixed. For example, rust fungi are a group of plant pathogens commonly used in NENS programmes. There is evidence that increased CO_2 concentrations could enhance rust diseases of cereal crops, but a study on leaf rust *Melampsora medusae* f. sp. *tremuloidae* on aspen found that elevated levels of CO_2 had no effect on rust incidence (Eastburn et al. 2011).

In summary, there is conflicting information on the potential effect of climate change on NENS programmes:

- Increasing temperature may increase natural enemy populations.
- Increased CO_2 may indirectly have negative impacts on natural enemies, but the overall effect may depend on the natural enemy and host weed.

The overall impact of climate change on NENS programmes is very hard to predict. That said, the problem of weeds is clearly predicted to become worse due to climate change. There is emerging evidence that natural enemies might mitigate the impact of climate change on invasive weeds. Based on the best knowledge today, weeds without natural enemies will benefit more from climate change than weeds with them.

> *"Ongoing global change is predicted to alter the impacts of invasive plants on native and managed ecosystems and will generally increase the risk of invasion due to the direct effects of increasing greenhouse gases and the consequences of these increases on the global climate."*
>
> **Bradley et al. (2010)**

How do I decide whether to use natural enemies to control a weed?

Using natural enemies (biocontrol) is often the most cost-effective means of reducing the impacts of invasive weeds, but:

- it is not possible at present to tackle all invasive weed species in the Pacific region; and
- not all invasive weeds make good targets.

First, understanding the potential target species and site characteristics is essential. For a set of factors to consider, see 'What do I need to know about this weed?' in *Manage low-incidence priority weeds to conserve Pacific biodiversity*.

Is the release of natural enemies appropriate?

Some weedy species are native to the region. For example, *Decalobanthus peltatus* (= *Merremia peltata*) causes problems as a pest even though it is native to the region. In New Zealand, regulations state that the introduction of any natural enemy that would affect a native species cannot be approved. However, the growing impacts of climate change may require a change of policy in the future, allowing native species to be controlled if they are having significant harmful impacts.

Is the use of natural enemies appropriate?

Some plants were introduced deliberately because they had the potential to provide desired benefits. Some of these introduced species became invasive but are still considered 'weeds with benefits'. It is not unusual for a plant species to be both invasive and have beneficial properties. In such cases, control measures may not be desired or popular because the benefits will decline as the invasive population is controlled. However, because weeds are not eradicated through the use of natural enemies, it can be possible to reduce their harmful impacts and still use their beneficial properties.

Societal perception and biological description of the introduced species	Suitability for control using natural enemies
Regarded as useful without causing weed problems	Unsuitable
Regarded as weedy with no reported use	Potentially suitable
Useful in some situations but causing weed problems in other situations	Potential conflict

When a weed is valued, conflicts must be resolved before natural enemies can be released. A cost-benefit analysis might be required to determine if the benefits of controlling a weed outweigh the costs.

If biocontrol is a valid way forward, see *Use natural enemies to manage widespread weeds in the Pacific* for a step by step approach.

How do I prioritise weeds to control using biocontrol?

Usually there are more potential targets than can be addressed at once. Managers must select priorities. This process can be made quicker and more objective by assigning scores to the both the use of natural enemies and potential target weeds. As part of the PRISMSS programmes, support is available for Pacific islands staff to prioritise weeds and biocontrol systems: PRISMSS Support Request Form | PRISMSS Navigator System (sprep.org)

Rank natural enemies

The NENS prioritisation tool scores and ranks potential NENS agents and weed targets according to:

1. Predicted efficacy/impacts of natural enemies on the target weed (*it is best to identify targets that are likely to be susceptible to natural enemies*)
2. The cost of implementing NENS (*to help identify which target represents the best 'return' on investment*)
3. Weed impacts/importance (*it's best to identify and target the most important weeds*)

A pre-generated worksheet is available as an electronic supplement to this guide: *4.Plant importance score calculator for NENS for Battler.xlsx* allows users to select among options for plant abundance and other factors, automatically assigning the appropriate scoring from a table of reference values.

Two components are used to generate the overall NENS score.

$$\text{Total NENS score} = \frac{\text{Efficacy (impact) of NENS score}}{\text{Cost of developing and releasing NENS score}}$$

Predicting efficacy of natural enemies

Repeat target weeds.

For target weeds where natural enemies have already been used in other countries, the impact of the initial 'pioneer' programmes generally predicts the impact of 'repeat programmes'; for example:

- *Puccinia spegazzinii* reduced *Mikania* populations in PNG by 50 per cent. It was subsequently released with similar impacts in the Cook Islands, Fiji, Taiwan, and Vanuatu (although failed to establish in Guam or Palau).
- Natural enemies have been released against *Cyperus rotundus* in multiple countries without success.

Understand new targets.

For novel targets, the potential impact can be predicted, to a degree, because natural enemy impacts are linked to plant traits (Paynter et al. 2012).

Is the plant a weed in its native range? Weeds which are not weedy in their native range are more likely to be successfully controlled using natural enemies.

What is the mode of reproduction of the target weed? Impacts against asexual weeds are generally higher vs. weeds that reproduce sexually. Genetic diversity is connected to mode of reproduction (asexual weeds may be just one clone). The more genetic diversity, the more chance there will be phenotypes that are resistant to natural enemy attack

What is the ecosystem of the target weed? Aquatic/wetland weeds are easier targets than terrestrial weeds.

The use of natural enemies may still be an option even if all the traits are not ideal. Biocontrol has succeeded against plants with the worst combination of traits (such as *Mimosa diplotricha*).

Scoring

Natural enemy efficacy/impact scored on a scale of 0-100 according to:

- Observed per cent reductions in target weed (for repeat programmes) or
- Predicted per cent reductions based on plant traits (for novel targets)

Predicting the cost of developing and releasing natural enemies

A review of New Zealand programmes found that the average cost of programmes against novel targets is approximately 3.8 times more than repeat programmes. The cost is lower if some work is already done overseas or if the work is shared among agencies. The cost is greater if the target weed is a closely related (belongs to the same genus) to a valued plant (such as a native plant or a crop), in part because more complex and costly host specificity testing may be required to demonstrate safety.

The cost of developing and releasing a natural enemy is scored on a scale of 0 to 50 according to (1) the novelty of the programme and (2) the presence of valued (such as native species or an exotic crop) congeneric plants.

Scoring basics:

Programme type	Score
Novel programme	38
Novel shared programme: overseas exploration stage	28
Novel shared programme: overseas exploration has already been conducted; agents testing stage	18
Repeat programme (agents have already been released overseas and could be imported)	10
Presence of a valued congeneric plant: if present, more testing is required	12

Assess weed importance

Measures of weed importance generally take into account:

- weed distribution and abundance
- weed impacts
- ease of control

Ranking is built from the weed importance score, which is the sum of scores for weed distribution and impact, divided by a score for ease of control of the weed:

$$\text{Weed importance score} = \frac{\Sigma \text{ Weed distribution scores} \times \Sigma \text{ Weed impact scores}}{\text{Ease of control scores}}$$

Scoring weed distribution and abundance

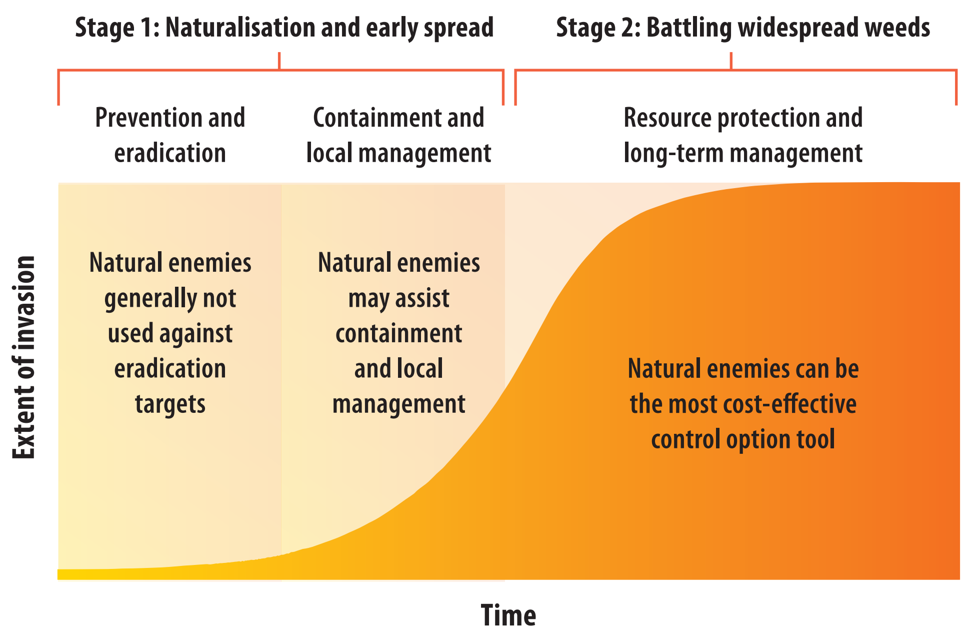


FIGURE 2. Weed distribution and abundance: NENS and the invasion curve

Weed distribution and abundance are very different at different stages of invasion (Figure 2).

Due to high development costs, NENS usually released against the most widespread weeds, so weed distribution and abundance is categorised and scored as:

- absent = 0
- few infestations = 1
- locally common = 5
- widespread & abundant = 10

Scoring weed impacts

The impacts of weeds are divided into two broad categories.

1. Socio-economic impacts

- Human and animal health
- Primary production (food crops, pasture, forestry, and so on)
- Impacts on Infrastructure, mobility, access to leisure activities, lifestyle, or cultural values
- Natural disasters (weed exacerbates fires, floods, landslides, and so on)

2. Ecosystem impacts

- Biodiversity
- Facilitation of other non-native species
- Transformation of ecosystems

Scoring of each sub-category is ranged from zero (no impact) to 10 (major impacts) and then summed.

Scoring ease of control

Ease of control is scored according to two factors: efficacy and cost of the current control measures in use.

The **efficacy score** of the current control is measured as:

- Highly effective = 2
- Moderately effective = 1.5
- Ineffective = 1

The **cost score** of the current control is measured as:

- Relatively cheap = 2
- Moderately expensive = 1.5
- Prohibitively expensive = 1

These efficacy and cost scores are summed. For example, if the current control options are ineffective and prohibitively expensive, the resulting score = 1 + 1 = 2.

Final ranking

		Weed importance	
		HIGH	LOW
NENS score Impact	HIGH	BEST	INTERMEDIATE
	LOW	INTERMEDIATE	WORST

FIGURE 3. Overall score = Weed importance score × Total NENS Score

How do we decide on action to take for intermediate scores?

The prioritisation system is good at determining the best and the worst targets. Choosing intermediate targets might require further discussion, focusing on the Weed Importance vs. NENS score and taking into account the local context, including societal priorities and resource availability.

Putting natural solutions into action

The Natural Enemies – Natural Solutions programme is a Pacific Regional Invasive Species Management Support Service (PRISMSS) initiative to enable countries to lower the impact of widespread invasive plants by reducing their vigour by introducing safe natural enemies from the area where they, and their host plant, originate. Please reach out if you require assistance to determine which weeds might be appropriate to target with natural enemies in your country and/or to learn more about available options.

The spreadsheet provided does not have weeds for which agents are widespread in the Pacific because the focus of the prioritisation work was figuring out where new natural enemies would need to be developed. Countries that do not have the widespread agents already may need more species included on their spreadsheet to score to determine country priorities.

Workbook exercises

Exercise 1: What weeds matter in your country today, and tomorrow?

Think about weed impacts, including those you may have just learned.

Think about the invasion curve (Figure 4). What plants considered minor weeds now in your country could be serious in the future?

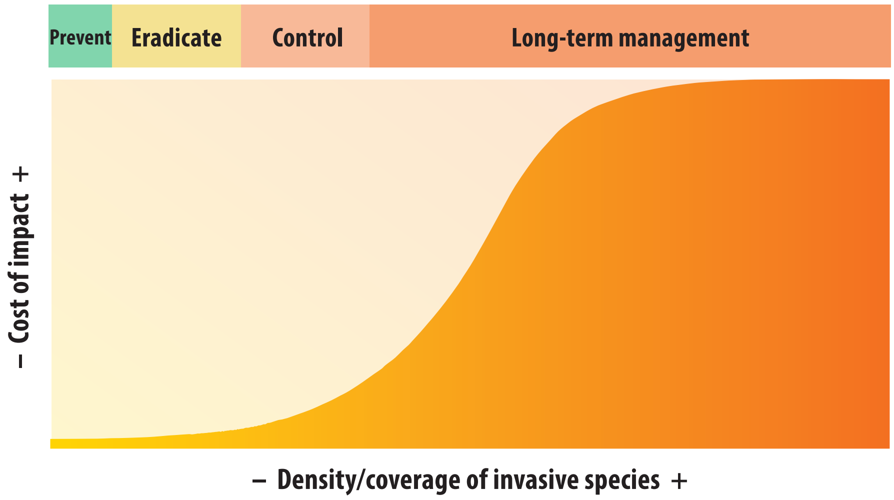


FIGURE 4. Invasion curve

Open the Excel file (*4.Plant importance score calculator for NENS for Battler.xlsx*) with 35 weeds listed in it.

- This list excludes weeds for which NENS are already readily available and widespread in the Pacific, such as lantana.
- Score at least 5 to 10 weeds, and feel free to do more if you wish.
- If weeds of interest to you are not on the list, please add up to 5 species and score them.

Exercise 2: How might climate change affect weeds?

Think about how climate change might affect weeds in your country. What might this mean for the impacts of weeds in your country?

Think about the invasion curve. Are plants considered minor weeds going to be more problematic?

- Use the Excel file with 35 weeds listed in it.
- Make a new copy of this file with a new name to indicate climate change scoring.
- Score the weeds again while considering climate change.
- Score 5 to 10 weeds, or more if you wish.
- If weeds of interest to you are not on the list, please add up to 5 species and score them.

Some scores might be the same for both exercises 1 and 2. Which scores changed?

Any queries on these exercises should be submitted using the PRISMSS Support Request Form | PRISMSS Navigator System (sprep.org)

For more information

Information on invasive species management in the Pacific can be found on the SPREP Battler Resource Base (https://brb.sprep.org) and by request directly to PRISMSS.

The PRISMSS Natural Enemies – Natural Solutions programme aims to lower the impact of widespread invasive plants by reducing their vigour by introducing safe natural enemies from the area where they, and their host plant, originate. There are many opportunities for spreading existing agents available in the Pacific to new countries, introducing agents available outside the Pacific, and developing new options for the Pacific. See: https://www.sprep.org/prismss/natural-enemies-natural-solutions

The Natural Enemies – Natural Solutions programme has created a web resource to help inform decisions about NENS activities and biocontrol for Pacific weeds: NENS Option, https://nensoption.com

Key concepts

Biocontrol or biological control
Controlling an invasive species by introducing a natural enemy, such as an insect or fungus, that specifically attacks the target species and does not attack other native or economically important species.

Biodiversity
The variety of living organisms on Earth or within a defined system, including the variability within and between species and within and between ecosystems.

Host
The plant or plant species that is attacked or eaten by a natural enemy.

Host-specific
A specialist natural enemy that can only attack one, or a limited number of closely related, host species.

Introduced species
Plants, animals, and other organisms taken beyond their natural range by people, deliberately or unintentionally.

Invasive species
Introduced species that become destructive to the environment or human interests; can also include some native species that proliferate and become destructive following environmental changes caused by human activities.

Native species
Plants, animals, and other organisms that occur naturally on an island or in a specified area, having either evolved there or arrived without human intervention.

Natural enemy
An organism, often a fungus, an insect, or a mite, that is used to control a host weed.

Non-native species
Non-native species are those species that have been introduced by people. Non-native species include both harmful (that is, invasive) and beneficial species.

Pacific Regional Invasive Species Support Service
Pacific Regional Invasive Species Support Service (PRISMSS) is a collaboration of leading organisations supporting invasive species management for biodiversity protection in the Pacific islands region. PRISMSS currently provides technical support across five regional programmes: Natural Enemies – Natural Solutions (NENS); Predator Free Pacific (PFP); Protect our Islands (POI); Resilient Ecosystems, Resilient Communities (RERC); War on Weeds (WOW).

Pathogen
Anything that can cause a disease, such as fungi, bacteria, or viruses.

Region
When not otherwise qualified, means the Pacific Ocean with specific reference to the island states and territories members of Pacific Community and SPREP.

Weed
A plant growing too well in the wrong place. Often, 'weedy' invasive species grow very quickly and out-compete desired and/or native plants.

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