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Knowledge Bank of Management Effectiveness

Technical guide

Veronica A.J. Doerr, Micah J. Davies, Erik D. Doerr, Suzanne Prober, Helen Murphy, Heather McGinness, Ben Hoffmann

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1 The Knowledge Bank of Management Effectiveness for NRM

Natural Resource Management (NRM) and Landcare activities are fundamental to the ongoing health and prosperity of Australia's environment. Over the past three decades, many on-ground actions have been implemented to reduce threats to our environment, improve the condition of native systems, and even re-establish native ecosystems where they have been heavily modified.

Through monitoring and research, a growing body of evidence is accumulating regarding the actual observed effectiveness of these on-ground management activities. Yet much of this evidence is published in scientific journals to which government and management practitioners do not have direct access. Internal government reports, public research summaries and factsheets, and unpublished student work are other sources of information that can be difficult to find. As a result, there is a general lack of understanding about how much direct evidence exists and a lack of synthesis to explain what works best.

The Knowledge Bank of Management Effectiveness is an initiative of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Government's Department of Environment and Energy (DoEE) that is intended to fill these gaps. The initiative initially aimed to discover direct studies of the effectiveness of NRM interventions (activities to improve the environment) across Australia, collect them in an updatable repository, and draw initial insights into what we have learned thus far and where key knowledge gaps remain. The intent is for there to be ongoing efforts to add to the Knowledge Bank and more evidence about management effectiveness accumulates.

How to use this report

This report is not intended as the primary source for understanding the Knowledge Bank, nor as a stand-alone document. Rather, it is intended to serve as a companion to the main report on the initiation of and first set of insights from the Bank (Doerr et al. 2017). This companion provides a more complete description of the methods used and results obtained from the initial construction of the Bank. It should be consulted where more detail is required than is provided in the main report, and can be used as a methods guide when future efforts are made to update the Bank using consistent methodology. The Bank itself is a Microsoft Excel database and associated reference library held by DoEE.

What is the Knowledge Bank of Management Effectiveness?

The Knowledge Bank is a repository of existing empirical studies about the effectiveness of NRM interventions (activities to improve the environment) that can be readily accessed by a range of end users across government agencies and the NRM and scientific communities. In the long term, The Bank aims to improve the current state of understanding about environmental management and support improved evidence based decision making by:

- collating knowledge about management effectiveness as well as knowledge gaps
- developing an understanding of the relative confidence in existing management recommendations
- determining how extensively management recommendations can be applied to like-for-like assets or threats, including within the Conservation Management Zones of Australia framework
- revealing strategic monitoring needs to address knowledge gaps
- establishing and linking the Knowledge Bank information architecture with existing tools and resources, such as the Atlas of Living Australia to enable this knowledge to be easily deployed and accessed into the future

Initially developed as an Excel workbook to facilitate the most widespread and immediate use, the intent is that the Bank may in the future be a more complex database with a simpler, more user-friendly web interface.

2 Methods

2.1 Classifying management interventions

There are many different management interventions taken to improve the environment across all of Australia. To determine which interventions to include in the Knowledge Bank, we first examined all interventions described for all of the Conservation Management Zones (CMZs) within Australia. These intervention lists were derived from *Environment Protection and Biodiversity Conservation Act 1999* threatened species and ecological community recovery plans, conservation advices, scientific literature, biodiversity and vegetation management policies, local government environmental planning documents, environmental Non-Governmental Organisations planning and restoration literature (e.g. Greening Australia), as well as Natural Resource Management (NRM) regional plans and national, state and local NRM programs. They are therefore representative of the suite of actions currently invested in by governments and organisations across Australia.

The CMZ profiles group interventions according to 'types'. However, there was a mixture of breadth of types - some describing interventions to address specific threats (such as 'feral animal management') and some to address groups of threats under a broader theme (such as 'rehabilitation'). We made a decision to re-categorise into Themes based on types of damage or threat to natural ecosystems in Australia to enable more logically consistent literature searches and database structures. We then grouped interventions within each Theme that were similar to each other (to make the number of interventions to be included in the Knowledge Bank tractable) and examined each Theme for completeness to create a workable list of 38 different interventions to include in the Knowledge Bank, grouped into 10 Themes based on the problems they are intended to alleviate (Table 1).

Note that it is possible that other interventions have been attempted in Australia and there are often many different specific variations used within a single intervention type. But the broad types of interventions in Table 1 capture the majority of on-ground work that has occurred. The only exception is interventions to manage diseases and fungal infections, which were initially part of searches but search terms could not be targeted enough so the scope of the project was insufficient to allow full filtering of the irrelevant search results.

Table 1. Management interventions included in the Knowledge Bank, organised according to 10 Themes, expressed as types of damage done to natural ecosystems in Australia which interventions are intended to halt or reverse.

Theme	Interventions
Excessive Grazing	• Manage timing of grazing • Reduce total grazing pressure (livestock, feral herbivores, natives)
Clearing of Native Vegetation (whether recent or legacy)	• Encourage natural regeneration • Revegetate, matching local composition • Revegetate, engineering new composition • Revegetate, engineering new structure • Manage fire regimes to restore native system
Changed Hydrological Conditions	• Create structures that reduce erosion • Manage release of water from dams & weirs

	• Manage water for floodplains & wetlands via regulators • Reduce extraction of surface and ground waters • Reduce populations of predatory, parasitic & competing pests (fish)
Changed Fire Regimes	• Change fire extent and/or intensity • Change fire intervals and/or seasonality • Protect sensitive habitats from fire
Proliferation of Weeds	• Control weeds in revegetation & remnants • Control outlying populations of weeds • Reduce weed presence and density next to native vegetation and waterways • Control transformer weed species (including flammable grasses) • Clean vehicles & footwear between sites
Predation/Damage by Feral Vertebrates	• Kill introduced predators & pigs • Remove habitat for introduced predators & pigs • Control access by domestic/introduced predators & pigs • Support natives that compete with introduced predators
Damage by Pest Invertebrates	• Reduce populations of plant-feeding pests • Reduce populations of predatory, parasitic & competing pest invertebrates
Excessive Nutrients and Pollutants	• Avoid chemicals in and next to native vegetation • Plant or maintain densely rooted vegetation next to native vegetation and waterways • Plant or maintain scattered trees next to wooded native vegetation • Reduce movement of livestock into native vegetation
Loss of Keystone Species	• Reintroduce keystone species (animals, plants, micro-organisms) (captive breed if necessary) • Revegetate, engineering composition to cater for a keystone sp. • Revegetate, engineering structure to cater for a keystone sp.
Loss of Key Structures and Functions	• Create and/or manage movement 'corridors' • Especially protect and manage refugia • Protect, manage & restore keystone habitat structures (mature trees, logs, snags in water, etc.) • Control overabundant native species

The interventions themselves are deliberately referred to as 'interventions' rather than 'actions', as actions would be so specific (e.g. poison weeds with spraying of glyphosate on foliage) that the list to include in the Knowledge Bank would be too long to be tractable. Instead, 'interventions' essentially represent the immediate outputs intended from on-ground activities which could be done in a range of different detailed ways. For example, revegetate (matching local composition) could be done by planting or direct seeding using a variety of soil pre-treatments. We considered the revegetation itself to be the intervention, and the details of how it was done are additional sources of variation Similarly, some interventions can be quite broad in terms of the actions they encompass – reduce total grazing pressure may involve management of livestock, feral herbivores, and/or overabundant native species – while others may be much narrower. The same action may also be used in different interventions depending on the goal (e.g. controlling a particular weed may be done to reduce the proliferation of weeds but could also be done as part of a targeted effort to restore a keystone grass species it is competing with).

2.2 Classifying outcomes to define 'effective'

To assess effectiveness, the aim of the intervention must be clear – there must be a desired outcome to measure. To ensure comparability across the Knowledge Bank dataset, we needed to have a consistent way to express desired outcomes. This is because the same general outcome might be measured differently in different studies and classifying them differently in the database could lead to fragmentation of evidence that could otherwise be synthesised. Thus, to collect information on effectiveness at achieving desired outcomes in a consistent way across studies, we needed to specify which outcomes would be expected from an intervention if it were achieving the high-level vision of protecting and conserving the environment for all Australians.

To do this, we developed a series of 'Program Logics' that clarify the relationship between management interventions and their desired outcomes at a variety of levels. Developed to assist monitoring and reporting, the program logic approach articulates expectations of what interventions will achieve based on ecological theory and prior knowledge (for a simple example, see Figure 1). They trace the relationship between an intervention and its expected immediate outcomes, as well as what intermediate and ultimate outcomes might be expected to follow-on over time due to ongoing ecological processes.

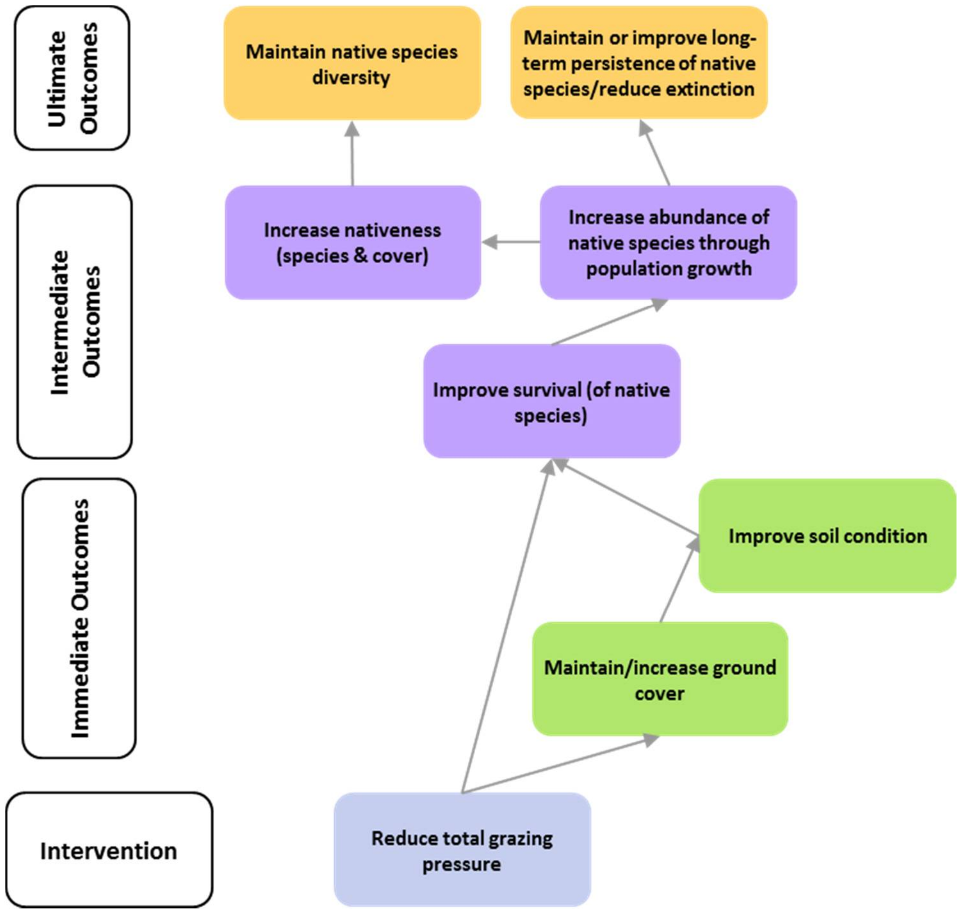

Figure 1. Example of a short program logic in which an intervention, reducing total grazing pressure, is expected to have the immediate outcomes of maintaining or increasing ground cover and through that improved cover, improving soil condition. Both directly and indirectly, through improved soil condition, the plants themselves are then expected to have improved longer-term survival. Improved survival should then lead to increased abundance through population growth, which should then increase the nativeness of the system. Assuming those processes of survival, growth and reproduction proceed as expected, the ultimate outcome should be improved long-term persistence of the species that were grazed and maintenance of native species diversity in the system.

Empirical studies might attempt to measure outcomes at any of these levels. For example, in Figure 1, a study about the effectiveness of reducing total grazing pressure might measure any of the seven outcomes shown. Arguably, evidence of effectiveness is stronger if there is evidence that ultimate outcomes are achieved, and weaker if there is only evidence that immediate outcomes are achieved, though the latter are often easier to measure and ascribe to a specific intervention.

We constructed a program logic for each of our 10 Themes, starting with the interventions in that Theme and then specifying the desired immediate, intermediate and ultimate outcomes that ecological theory suggests could result. We combined all outcomes from these Theme-based program logics to create one consistent set of desired outcomes that could potentially be measured in empirical studies.

Figure 2. Set of potential outcomes searched for in studies to assess effectiveness of NRM interventions, organised according to three outcome levels in Program Logic.

2.3 Using a Systematic Map approach

The approach used to construct the Bank – to find direct empirical studies of the effect of the above interventions (Section 2.1) on the above desired outcomes (Section 0) and extract consistent, comparable data from them – is known as 'systematic mapping'. The technique is related to 'systematic review', which was originally developed in the medical research field to synthesise overall conclusions about effectiveness of medical treatments across many individual studies in a transparent, consistent, and rigorous way. The systematic review approach has been successfully extended to environmental management interventions.

In recent years, systematic maps have become particularly useful as precursors to detailed reviews. Systematic maps use the same transparent and consistent methods to search for relevant studies and describe the total volume and nature of the evidence available across a suite of interventions. The difference is that systematic maps are broader explorations of where there might be sufficient information for synthesis but stop short of doing formal meta-analysis of data and drawing deep inference. Systematic maps are thus particularly suitable for the initial stages of addressing broad questions (like the effectiveness of NRM interventions). They enable identification of more specific questions where sufficient evidence might be available to perform a deeper, quantitative synthesis across studies (like the effectiveness of restoring ecosystems through revegetation).

For the Knowledge Bank of Management Effectiveness in NRM, a systematic map protocol was developed and executed, and then some initial inference was draw from examination of patterns in the volume of studies discovered, study characteristics, and the conclusions of study authors about effectiveness. The intent is that this can support more quantitative cross-study analyses of specific interventions in the future where sufficient volume of evidence exists.

Appropriate interpretation of the results depends on a basic understanding of the systematic map process. While more detail can be found in the following sections, here are the key steps that were used:

- **Detailed search strings drafted** for each Theme to perform search but with as high a relevance as possible to the Theme while still remaining very broad to try to capture *all* sources that might possibly be relevant to the Theme
- **Test papers identified** – papers the expert team already knew about in each Theme that we expected searches to identify
- **Search strings modified** to ensure they picked up test papers but didn't greatly expand the total number of sources found that were irrelevant – done iteratively until search strategy was successful for all Themes
- **Final searches performed** separately for each Theme using
    - Web of Science Core Collection (where there is greatest search functionality)
    - Web of Science All Databases, restricted to key journals not indexed in the Core Collection
    - NRM Knowledge Online (using shortened search strings)
    - Trove (using shortened search strings)
    - Google (using shortened search strings)

- **Additional grey literature solicited** by writing to the heads of all ecology-related departments or institutes at all Australian universities, asking department staff to share any relevant but unpublished sources of empirical evidence of effectiveness
- **Filtering based on titles** of all search results from Web of Science for each Theme, the first 100 hits from the online databases for each Theme, and all sources sent to us following additional grey literature solicitation to exclude studies clearly not relevant to the Knowledge Bank based on pre-determined inclusion and exclusion criteria
- **Filtering based on abstracts** of all search results that passed title filtering based on the inclusion and exclusion criteria
- **Filtering based on full text** of all search results that passed abstract filtering based on the inclusion and exclusion criteria
- **Extracting data** for each empirical study and existing review included through all the filtering stages

2.4 Search strings

As noted in Section 2.3, search strings were developed and tested to see if they adequately captured studies we already knew about ('test papers'). Changes were made iteratively until all search strings adequately captured test papers but did not pick up too many irrelevant studies. This was assessed by scanning the first 50 hits of each search as well as examining the total number of references found relative to previous iterations of the search string. In systematic maps and reviews, searches are intended to be as broad as possible, so many irrelevant studies are initially identified in order to ensure that as many relevant ones as possible are actually discovered. Given the unusual breadth of this systematic map, we needed to carefully balance the desired comprehensiveness of systematic reviews with constraining searches to yield more targeted results in order to manage a tractable scope of work. We largely did this through many iterations and testing of search strings.

Search strings were constructed separately for each Theme (**Error! Reference source not found.**). Each string consisted of intervention terms specific to the Theme and subject terms specific to the Theme if appropriate (i.e. if the interventions were specifically applied to certain species or ecosystems, like feral predators). Search strings for all Themes then included a consistent (i.e. not specific to each Theme) set of additional terms: a long list of potential outcomes terms, geographic terms to restrict the searches to studies in Australia, subject area terms to restrict the searches to the NRM domain, and a set of NOT terms to exclude broad types of irrelevant studies commonly identified using the previous sets of terms. The Boolean operators AND, OR and NOT were used appropriately within and between these different elements of the search strings. Note that subject terms generally included both broad terms and species-specific ones to capture as much breadth as possible while still targeting the search. For example, Excessive Grazing mentions a variety of species of feral herbivores as well as livestock but also uses 'grazing' as a more general term. This was more effective than mentioning cattle, sheep, and kangaroos specifically as inclusion of those subject terms generated many more non-relevant sources without making it any more likely that relevant sources would be found.

Search strings were developed and tested in Web of Science Core Collection and then modified for application to Web of Science All Databases to search specific relevant journals not indexed in the Core Collection. Further modification was made to enable searches to be conducted of three grey literature databases – Google, Trove, and NRM Knowledge Online (hosted by the Australian Government).

All searches capture sources available through 2016. Any updates should repeat these searches from 2017 onwards.

Table 2. Final search strings implemented in Web of Science Core Collection (modified versions were used for Web of Science All Databases and for Google, Trove and NRM Knowledge Online grey literature searches). The full string used for each Theme is shown and the number of different drafts of that string that were explored until test papers were adequately captured is given.

Theme	Search String	# drafts
Excessive Grazing	TS=(spelling or rest or resting or rotational or timing or season* or "grazing pressure" or exclu*) and TS=(livestock or "feral herbivor*" or rabbit* or camel* or deer or goat* or "water buffalo" or grazing or grazed or pasture or rangeland*) and TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "non-native" or "vegetation health" or refug* or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or manage* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "water quality") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	15
Clearing of Native Vegetation	TS=(revegetat* or regenerat* or fenc* or "seed provenance" or restor*) AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south Australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Environmental Sciences OR Environmental Studies OR Ornithology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable) NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patient* or regulatory or traffic or tumour)	11

Theme	Search String	# drafts
Changed Hydrological Conditions	TS=("environmental water*" or "environmental flow*" or diversion or dam or dams or weir* or regulator or regulators or "artificial water*" or "flow management" or "fishway" or "carp screen" or "fish ladder" or "fish-ladder" or "re-snagging" or resnagging or "carp removal") AND TS=(river* or stream* or riparian or wetland* or groundwater or artesian or flood*) AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Fisheries OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or manage* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "water quality") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	18
Changed Fire Regimes	TS=(regime* or intensity or frequency or interval or extent or control* or "time since fire" or "prescribed") AND TS=(fire or fires or burn*) AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology OR Forestry) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "non-native" or "vegetation health" or refug* or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or manage* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "water quality") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	3
Proliferation of Weeds	TS=(spray* or mow* or slash* or control* or remov*) AND TS=(weed* or invasi* or exotic) AND TS=(plant or plants or annual* or perennial*) AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Plant Sciences OR Soil Science OR Forestry) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable) NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	15

Theme	Search String	# drafts
Predation by Feral Vertebrates	TS=(cull* or shoot* or poison* or bait* or trap* or control*) AND TS=(fox* or cat or cats or pig or pigs or "wild dog*" or pest* or "feral predator*" or "cane toad*") AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland) AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "non-native" or "refug*" or abundance or alien or biodiversity or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or manage* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "water quality") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	17
Damage by Pest Invertebrates	TS=(insecticid* or pesticid* or "bio-control" or "biological control" or "leaf damage" or "flower damage" or eradicat* or control* or bait* or poison*) AND TS=(insect* or inverteb* or arthropod* or mite* or pest* or "pest ant*") AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable) NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	16

Theme	Search String	# drafts
Excessive Nutrients and Pollutants	TS=(buffer* or "chemical drift" or "buffer zone*" or "edge effect*" or wind or "sediment transfer" or "sediment export*" or "sediment transport" or "nutrient transfer" or "nutrient export*" or "nutrient transport" or "sediment movement" or "nutrient movement") AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or manage* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "water quality") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	23
Loss of Keystone Species	TS=("*introduc*" or "re-establish*" or translocat* or assisted colonisation or assisted colonization) AND TS=("umbrella species" or "foundation species" or engineer* or keystone) AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "northern territory" or "south australia*" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable or "vegetation health") NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	14

Theme	Search String	# drafts
Loss of Key Structures and Functions	TS=("cat curfew" or "pet curfew" or "mosaic burn*" or "wildlife crossing*" or "fallen timber" or hollow* or "habitat supplement*" or "habitat enrichment" or "wildlife specific manage*" or refugia or "wildlife refugia" or "wildlife corridor*" or "stepping stone*" or "nest box*" or "coarse woody debris" or "landscape connectivity" or "kangaroo cull*" or "kangaroo control") AND TS=(australia* or "new south wales" or victoria* or "western australia*" or "south australia*" or "northern territory" or tasmania* or queensland or "australian capital territory") AND WC=(Biodiversity Conservation OR Ecology OR Entomology OR Environmental Sciences OR Environmental Studies OR Evolutionary Biology OR Marine & Freshwater Biology OR Ornithology OR Plant Sciences OR Soil Science OR Water Resources OR Zoology) AND TS=("algal bloom" or "ecosystem dynamics" or "ecosystem services" or "fire regime" or "ground cover" or "Non-native" or "refug*" or abundance or alien or biodiversity or blackwater or compaction or competition or condition or contain* or control* or damage or degrad* or destroy or distribution* or divers* or eliminat* or endangered or endemic or eradicat* or erode* or erosion or establish* or exotic or growth or habitat* or health or herbivory or invasi* or native* or nutrient* or persist* or pest* or pollutant* or population* or predation or prevent* or recover* or recruitment or reduc* or re-establish or regen* or remnant* or remov* or reproduction or resilien* or restor* or richness or sediment or shelter or survival or threatened or understorey or viability or viable) NOT TS=(aquaculture or bacteria* or biomedical or blood or cancer or cell* or child* or clinic* or diabetes or econom* or educat* or financ* or geochemical or hormone or horticultur* or medic* or marine or neuro* or patholog* or patient* or regulatory or traffic or tumour)	14

2.5 Inclusion and Exclusion Criteria

A standard part of systematic review and systematic map methods involves specifying clear a priori criteria for which studies will be included and which will be excluded. The standard structure for doing this is based on the PICO framework, referring to Population, Intervention, Comparator, and Outcome (Collaboration for Environmental Evidence 2013). In other words, to be included, studies must be of the population of interest (e.g., empirical studies of NRM in Australia), must report on an intervention of interest, must have some sort of comparator – a baseline measure or control site or even site with a lower level of intervention, and must measure some sort of outcome of interest and compare that outcome between intervention and comparator sites or time periods. In addition to the PICO criteria, potential sources of heterogeneity are often specified a priori. These are additional variables that might the relationship between interventions and outcomes – the sorts of things that effectiveness might also depend on. These are specified because they can often be turned into additional variables about studies, data can be extracted, and additional questions about what effectiveness depends on can thus be explored. The PICO criteria and sources of heterogeneity used in the Knowledge Bank systematic map are shown in Table 3.

Table 3. PICO criteria (Population, Intervention, Comparator, Outcome) used to include/exclude studies from the Knowledge Bank, as well as sources of heterogeneity aimed to be represented in the data extraction process.

PICO Element	Inclusion/Exclusion Criteria
Population	• Terrestrial or inland freshwater natural ecosystems in Australia (i.e., not production-only systems and not brackish, saline, intertidal, etc. systems) • Empirical studies only – reviews will be excluded from full data extraction but noted and included in drawing inference
Intervention	• Any application of an on-ground management action *or set of actions* intended to improve the ecological/biodiversity condition of the site where implemented or the broader landscape for the purposes of conservation of nature/natural resources • 'Interventions' expressed as the immediate intent rather than the details of the actions (e.g. manage timing of grazing, control riparian weeds, etc.) • Biophysical actions only are included, so different types of social processes, market-based instruments or other socioeconomic mechanisms are excluded
Comparator	• Studies must compare the same sites or landscapes before and after the intervention, or sites/landscapes with and without intervention (space for time substitution) • Studies that have at least one intervention/control comparison will be included even if there is a lack of replication and thus formal statistical analysis, though differences in the quality of the experimental design (study quality) will be noted • Studies that compare degraded vs. reference sites (i.e. with no actual intervention) will be excluded but noted as 'reverse' indirect evidence
Outcome	• Any measure of the consequences of the intervention related to ecological condition, environmental improvement, or biodiversity conservation • Program Logics developed for each broad theme of actions/outputs may be used as a guide to try to recognise where similar measures have been used and can be categorised as the same • Outcomes intended for directly improving agricultural production or human well-being will be excluded
Sources of Heterogeneity	Effectiveness is highly like to vary between: • Ecosystem types • Sets of actions, or additional actions used • Time after intervention that outcomes were assessed • Degree to which intervention was used repeatedly vs. once • Seasonality including ENSO Other factors of interest include: • Effectiveness under climate change • Study quality/experimental design • Level of the Program Logic where outcomes were assessed (i.e., are immediate outcomes easier to achieve than ultimate outcomes?)

In practice, during the filtering process noted above, each potential source is evaluated according to the PICO criteria. If any one of the criteria are not met, the source is excluded from the map or review. If there is doubt, the source is included for the next round of filtering or data extraction if all other filtering has been complete. Thus, while PICO criteria are usually specified according to the characteristics studies need to have to be *included* in a map/review, the criteria are actually used to *exclude* studies until only those relevant remain. It can thus be useful to supplement PICO criteria with some specific statements about what types of studies will be excluded. The following were additional notes developed on exclusion prior to filtering sources:

Reasons for exclusion (to be noted during abstract and full-text filtering (not title filtering) to compare # of sources excluded for different reasons):

P - Not the right population (not in Australia, modelling work not empirical, a discussion paper only, etc.)

I - Intervention not sufficiently clear/no intervention/not a relevant intervention (i.e. for purpose of conservation)

C - Lack of comparator (i.e. no control – no place where intervention NOT applied)

O - Outcomes not measured

Detail for exclusion criteria:

- The above PICO characteristics mean that theoretical studies, modelling (other than statistical analysis of empirical data) and review studies will all be excluded, though reviews will be noted and taken into account in drawing inference.
- Non-English studies will be excluded, though we don't anticipate there will be any given the nature of the population.
- Studies that do not involve a management intervention intended to improve or maintain some aspect of ecological/resource condition will be excluded. This means that studies which look at a gradient of threat (e.g. increased intensity of livestock grazing (rather than removal or changed timing of livestock grazing)) will be excluded. While these studies demonstrate threat and are often used to *infer* that management to remove the threat will lead to a recovery of condition, threats are not necessarily directly reversible. Thus, this type of evidence is not actually direct evidence of the effectiveness of management intervention.
- Studies in which interventions were intended exclusively for the purpose of improving human use of the land (e.g. improving agricultural yields, increasing retention of water in reservoirs, providing urban shade or amenity value, etc.) will be excluded. While these types of interventions are sometimes included in a broader definition of 'natural resource management' (NRM), the focus in this review is on the aspects of NRM that relate to nature conservation and overall environmental health and condition (albeit often with the ultimate aim of long-term sustainability for humans).
- Outcomes must be measured in some way, so studies that describe a project or suggest intended outcomes but do nothing to quantify them will be excluded.

Key Note on Scope

Note that the inclusion and exclusion criteria set a consistent scope for the Knowledge Bank across Themes – a scope that is strongly focused on Australian empirical studies of NRM interventions that have been implemented at intended scales, in real natural ecosystems. The focus is also on outcomes related to actual biodiversity improvement not just the immediate efficacy of the mechanics. Thus, controlled trials in laboratory conditions or at small experimental scales in field conditions are excluded. Similarly, studies of fox or weed control that only assess effectiveness at killing foxes or weeds are excluded.

These excluded studies can sometimes make valuable contributions to drawing inference on effectiveness, and can often give critical insights into the underlying processes involved (particularly experimental and robust theoretical work). However, they rely on assumptions to infer that actions will still be effective when implemented in the real world, at scale. The purpose of the Knowledge Bank is to understand what we know from direct empirical studies of actual on-ground intervention.

2.6 Data Extraction and Synthesis

A database was constructed to capture basic meta-data about each included study, meta-data related to the sources of heterogeneity of interest specified above, basic information on the intervention(s) applied, the type of comparator, and the authors' conclusions about effectiveness. Specific instructions were developed about how to extract and record data to ensure consistency across project team members, who each handled different Themes. The resulting data were then summarised within and across Themes to draw conclusions about confidence when investing in different interventions and to enable identification of knowledge gaps and support development of recommendations for targeting scientific monitoring and future research. Gaps were identified if there is a paucity of evidence available as well as if available evidence is inconclusive. We have also indicated the situations in which evidence is sufficient enough to formally synthesise in a meta-analysis and complete systematic review.

The CSIRO team that performed the work included six scientists each with expertise in at least two Themes. Each Theme thus had one key science lead who developed the Theme program logic, advised on search methods, made final decisions about which studies to include in the Bank, and extracted the data. Two of these team members were also experts in systematic review, and they developed the methods, tested and adjusted the searches, performed initial filtering, helped to draw insights within Themes, drew insights across Themes, and guided the entire process in a consistent and comparable way.

3 Special Considerations for Government Use

To ensure the results and the precise form of delivery would be most useful to the Department of the Environment and Energy, the research team engaged in a number of scoping and framing discussions to provide clarity about the boundaries of the systematic map and the structure of the database to be produced. Many of these discussions have been held with various members of the Working Group within the Department of the Environment and Energy, established and informally led by Fiona Dickson to help guide the project. These discussions have particularly focused on what is required to ensure the Knowledge Bank can serve its purpose long into the future, which includes the ability to:

- be easily updated (accommodate deposits)
- readily extract information not just on actions but on regions, vegetation types, etc. (accommodate withdrawals)
- incorporate new management actions and new ways of categorising nature in the future
- eventually link to other sources of evidence like direct monitoring data and expert opinion
- sit within existing government IT platforms
- consider effectiveness of management actions in the context of a changing climate
- be achievable, given that this is the broadest systematic map yet attempted in the world

The sub-sections below describe some key decisions made in consultation with the Working Group to keep the Knowledge Bank achievable while still relevant and user-friendly.

3.1 Ability to update

The Knowledge Bank will only be useful in the long term if it can be updated – if 'deposits' can be made as new studies are conducted and new information comes to light. The Department of Environment and Energy, in consultation with the CSIRO team, will make recommendations for the ongoing maintenance and governance of the Knowledge Bank. This may involve establishment of an advisory committee or similar governance arrangements to regularly assess new evidence or consider adaptations to management actions that may need to occur within the context of a changing climate. Precise mechanisms are not yet confirmed and it is beyond the scope and agency of this project to put them in place. In addition, if the Knowledge Bank is a long-lived resource as intended, the mechanisms for updating it may need to evolve and change. Thus, within this project, the primary goals are to design a database that is relatively easy to update once mechanisms to do so are in place, including full documentation of any data 'codes' or abbreviations used. The project team will also provide some recommendations for the frequency and process of updating that might be most cost-effective yet still consistent with the principles and methodology of systematic maps and reviews.

3.2 Types of meta-data to extract

The 'meta-data' is the information extracted from each source included in the Knowledge Bank about how and where the study was conducted. The meta-data are what make it possible to query the Knowledge Bank to find out if management actions/approaches are only effective in certain contexts – in particular environments or vegetation types, in combination with other management actions, or when implemented only in particular detailed ways (for example). The project team anticipated that the volume of evidence currently available would be insufficient to examine many of these types of contextual differences (and indeed, that was the case – see results sections below). However, extracting these meta-data now paves the way for future exploration of context-dependence as more information becomes available.

Thus, the project team focused on extracting meta-data related to the most important current questions about the contexts in which actions are most effective. In particular, types of meta-data that allow other sources of data to be integrated were prioritised. For example, each study was geo-referenced so that studies will be able to be linked with any type of spatial classification that may be developed.

In the interests of not exceeding the scope of the current project, meta-data extraction was not fully exhaustive of all types of context-relevance that may one day be considered important. Instead, was agreed the focus should be on the most important current questions and advice is provided on how to add meta-data fields to the Knowledge Bank if and when such additions are deemed necessary.

3.3 Considering climate change

Not only may the effectiveness of management actions change under climate change, but the way in which effectiveness is viewed (i.e. the types of outcomes expected and desired) may need to change. Some management actions may be likely to achieve current desired outcomes despite the ways in which species and ecosystems will respond to climate change, while others may not. Especially given the long life intended for a resource like the Knowledge Bank, it becomes critical to consider how climate change will be incorporated.

The project team anticipated that there would be very little to no evidence one way or the other that management actions are effective despite (or in the context of) climate change. This is due to the length of time that climate change has been on the research agenda for on-ground NRM actions as well as the challenges involved in collecting empirical data given the time scales of climate impacts. Nonetheless, the team included meta-data on whether each source included in the Knowledge Bank considered climate change or not. This provides an overall understanding of where some key gaps may lie in terms of ongoing learning about management effectiveness as climate change begins to have larger and more noticeable impacts.

3.4 Database architecture

'Database architecture' refers to the specific software and/or IT platform on which the Knowledge Bank sits along with the relative organisation of the data within the software. The architecture can play a significant role in enabling or providing barriers to use of the Bank for both deposits and withdrawals (asking questions of the data and getting answers). Ultimately, it was the view of the Working Group that a user-friendly web interface (certainly for withdrawals but possibly also for deposits) would be desirable in the long term. This is increasingly how a variety of users expect to interact with information. However, it is beyond the scope of the current project to develop any kind of web interface, which would need to be additional to the work involved in creating the database itself.

The decision was thus made that this project needed to focus on creating a database that will be capable of interacting with others and having a web interface built in the future. A variety of options were explored, including building the database using the same techniques used by the Atlas of Living Australia and the MERIT tool. However, there were two key barriers to using more sophisticated software to create the database. First, as funds are not currently available to create a web interface and it may be some time before one is developed, it was deemed important to create a simple database that many types of users could interact with immediately. Many users (withdrawers) would not have access to the more sophisticated software or the training on how to use it. Second, the Department indicated that their own internal IT platforms could be changing in the near future but there was little certainty around the possibilities. More sophisticated software or platforms for the database could thus become difficult for the Department to host once its platforms change.

As a result, the key decision was made to build a very simple database in Microsoft Excel with some built-in codes to partially address any risks from data entry error when future deposits are made. The intention is that an Excel database could more readily be converted into something more sophisticated like a relational database or shifted onto a different IT platform in the future as required.

4 Overall Results

The search process resulted in a total of 15,653 peer-reviewed and grey literature sources across the 10 Themes, 1972 of which were considered potentially relevant after title/abstract filtering. Only 308 studies were still considered relevant after full-text filtering (detailed in 299 source references). Total numbers at each stage are depicted in Figure 3. Note that the numbers do not perfectly align because at data extraction stage, one source could end up representing more than one study or multiple sources included in the Bank could be describing the same study. Thus, final numbers represent studies but numbers during the filtering stages represent individual sources.

Many studies found during the searches were still considered relevant after title filtering but were subsequently excluded. Of these studies, the majority were rejected from inclusion in the Knowledge Bank because they lacked an appropriate intervention (Figure 4). Many studies were available demonstrating a threat or testing an intervention in a controlled trial situation. Yet relatively few empirical studies were available of the outcomes resulting from actual on-ground interventions to address NRM problems.

There were only four Themes with a substantial number of studies to include in the Knowledge Bank – Excessive Grazing, Clearing of Native Vegetation, Changed Hydrological Conditions and to a lesser extent Changed Fire Regimes. Only small numbers of studies were discovered in our searches for the other Themes (Figure 5). The paucity of studies directly assessing clear environmental outcomes as a result of NRM interventions was particularly extreme and surprising for some themes, like Proliferation of Weeds. While overall evidence suggests that most interventions are at least partially effective at delivering environmental outcomes, results were mixed across all the Themes for which there were more than a handful of studies to review, suggesting that results need to be explored further within Themes.

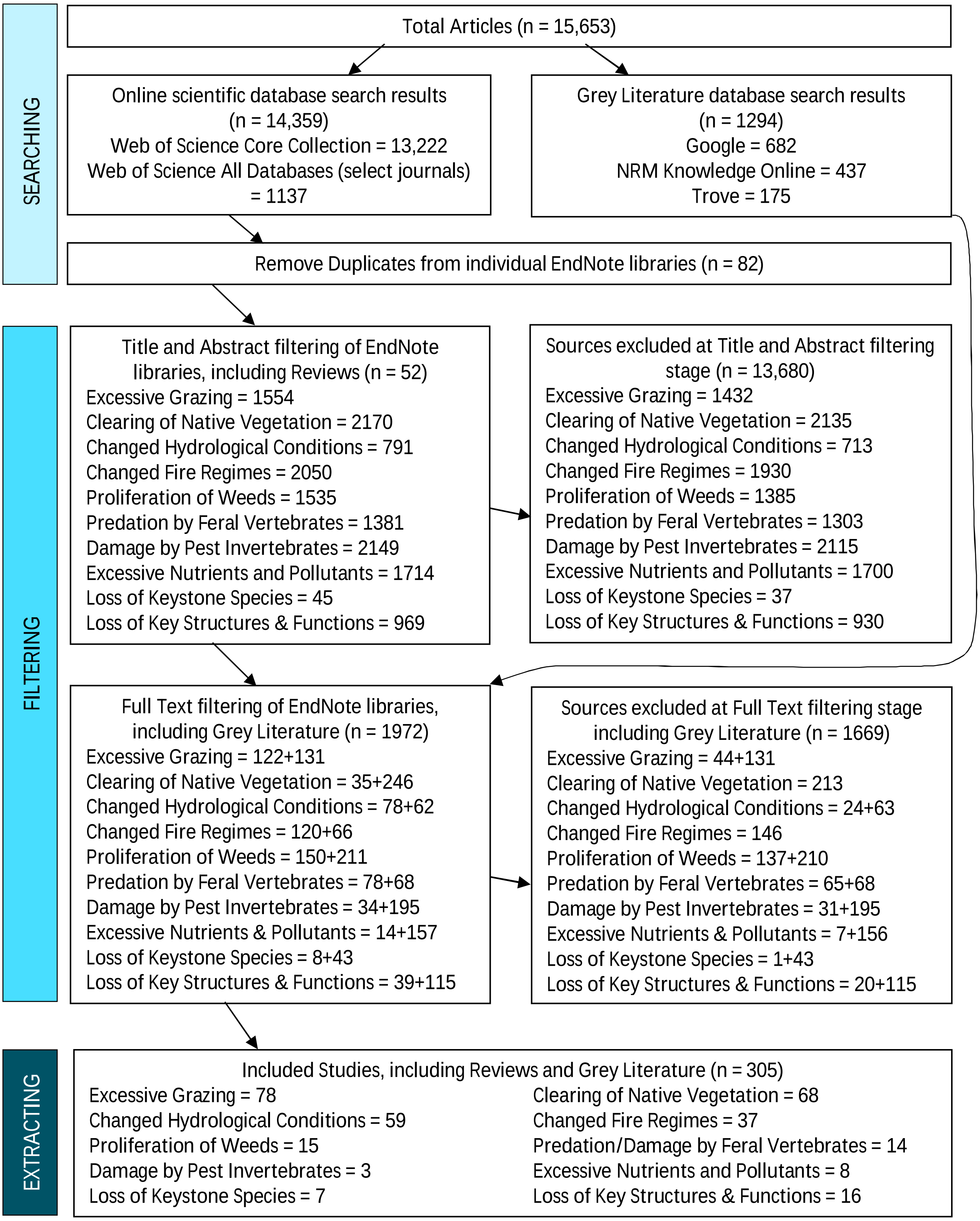

Figure 3. Flow chart showing numbers of sources identified as relevant at each stage of the filtering process and final number of studies included, organised by the 10 different Themes where relevant.

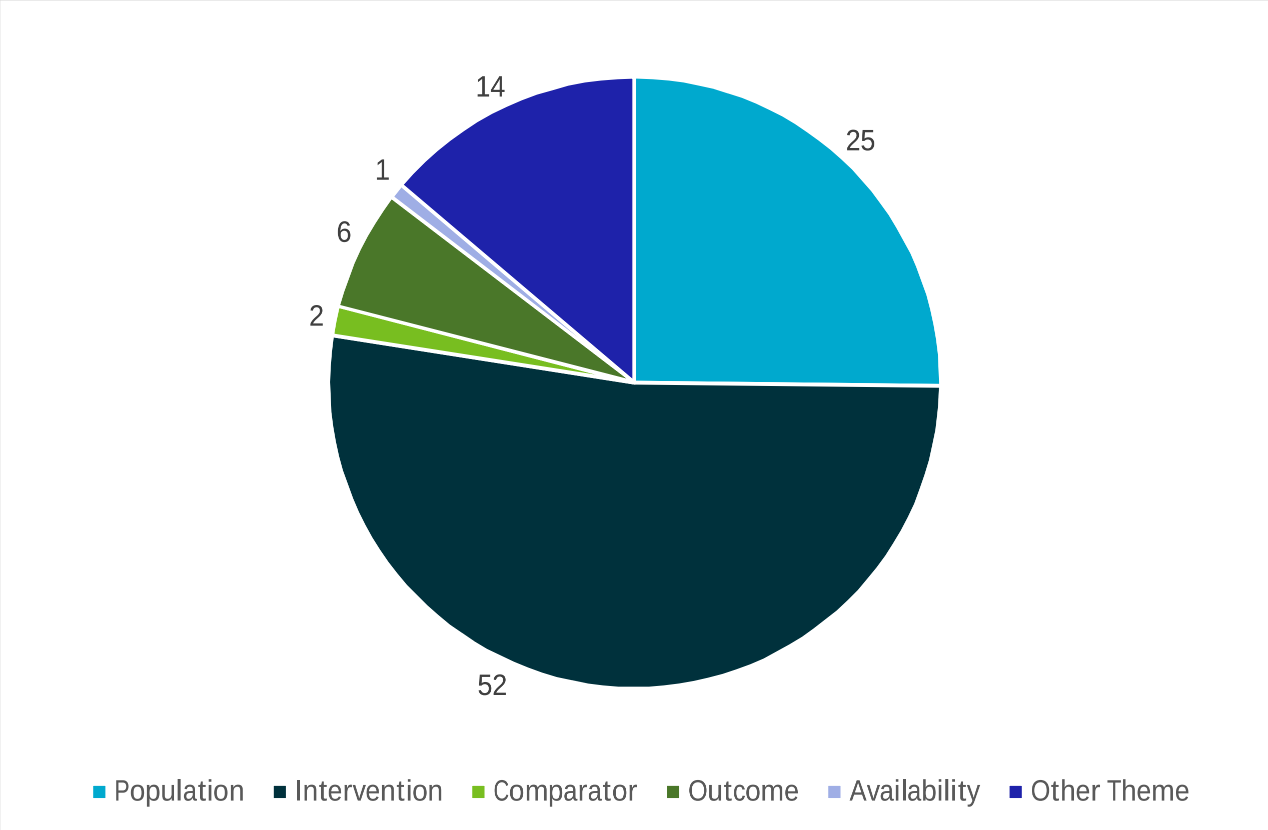

Figure 4. Percent of studies that were included after title filtering but subsequently excluded for different reasons. Population = not an empirical study in Australia, Intervention = no clear management interventions, Comparator = no control/treatment or before/after comparison, Outcome = no environmental benefit measured, Availability = full text could not be sourced, Other Theme = belonged in another Theme.

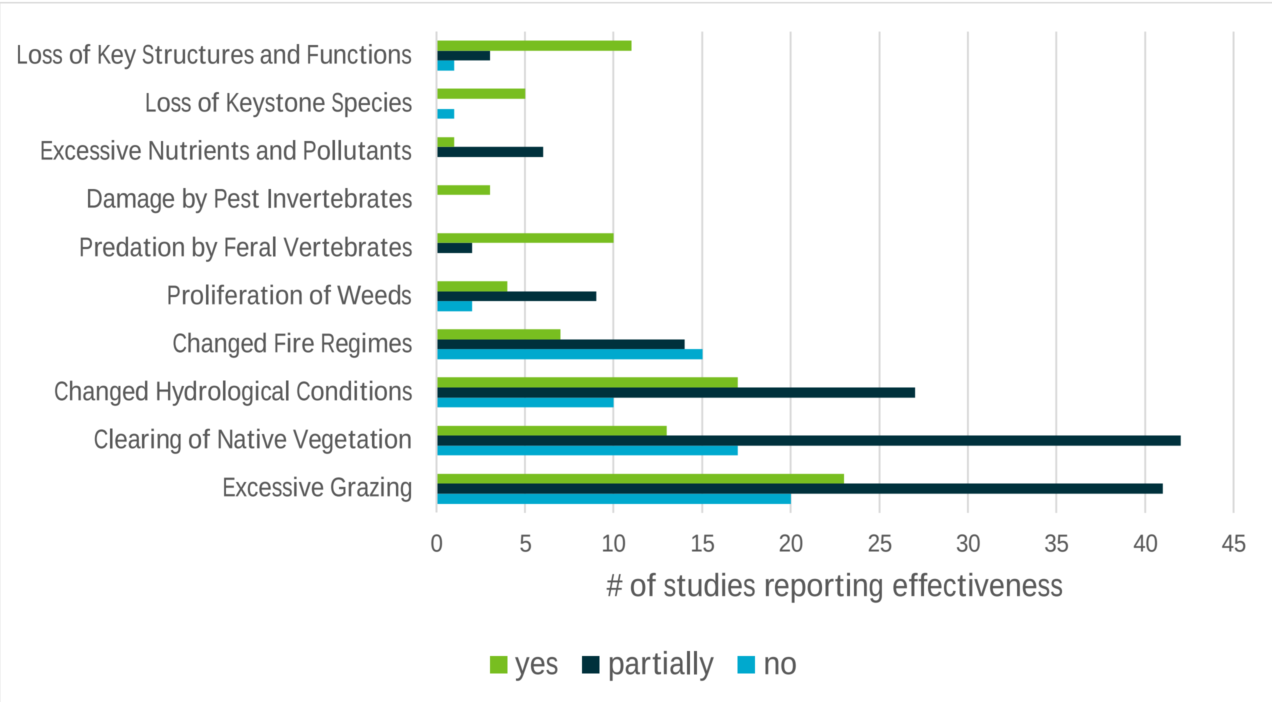

Figure 5. Number of studies reporting that interventions were definitely effective (yes), partially effective (partially) or not effective (no) across each of the 10 Themes.

5 Results for each Theme

The following sections provide results in terms of the total number of studies available that assessed the effectiveness of each management intervention and the percentage of those studies that found evidence of effectiveness, presented by Theme. Conclusions of any prior reviews are also presented, along with brief notes on limitations of the approach and key recommendations for future on-ground investment as well as monitoring and research priorities. Note that references to all the sources included in the Bank for each Theme are not presented in the text of these sections. Instead, the full list of references for sources included in the Bank can be found at the end of this report. In-text citations in the sections that follow focus on studies not necessarily included in the Bank but that specially informed the interpretation of conclusions, limitations, and key recommendations.

5.1 Theme: Excessive Grazing

Volume of studies & their conclusions about effectiveness

We found 72 studies of the effectiveness of managing grazing in Australia to achieve environmental benefits (Table 4). Twelve of those studies examined both the effects of managing the timing of grazing (including rest periods) as well as reducing the total grazing pressure (through management of livestock, native grazers, and/or non-native herbivores) so are listed twice in Table 4. Overall, partial effectiveness was most commonly reported. This may be because many studies assessed multiple specific ‘treatments’ (e.g. rest at different times of year with different amounts of total grazing) and generally found only some of them to be particularly effective. Reducing total grazing pressure was definitely effective in more than 30% of studies, while no study concluded that managing the timing of grazing was definitely effective. About a quarter of studies found grazing management ineffective.

Conclusions about effectiveness were also mixed for every type of outcome assessed, including increases in diversity, nativeness, soil condition, vegetation health, structural diversity, and ground cover. The details of the interventions were also varied, including examination of rotational and high density short duration (‘crash’) grazing as well as different timing of rest periods and total stocking rates. We discovered enough studies of this type of intervention that this could be a topic amendable to more formal, quantitative assessment to explore the conditions under which management is most likely to be effective. However, it is also possible that there would be too much variation in interventions and outcomes measured to draw strong conclusions. Qualitative assessment of comments on each of the studies suggests that effectiveness may depend mostly on starting conditions and the application of sufficient rest or spelling periods. In addition, full benefits may only be apparent after both wet and dry years (i.e. after recovery and then subsequent stress) and may only apply to some species and not others.

Table 4. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of excessive grazing.

Grazing Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Manage timing of grazing	16	25%	75%	0%
Reduce total grazing pressure	71	23%	44%	33%

Prior review conclusions

We found two prior reviews of grazing management for environmental benefit, both of which reviewed quite a small number of studies (11 and approximately 4). The larger one focused on reductions in total grazing pressure to achieve soil recovery and found the intervention not very effective on hill country, but otherwise effective particularly over several years. The smaller review qualitatively assessed studies that managed the timing of grazing in conservation areas through tactical rest and concluded that rest periods generally increase nativeness of the system.

Limitations & notes

The specific interventions assessed were quite varied but in small details, and were often combined with other interventions including fire and weed management. These details may make a significant different to effectiveness, particularly in different local circumstances. However, such variation also means that many studies are unique and thus it is inherently difficult to draw conclusions about overall effectiveness across them.

Managing the timing of grazing was much less studied than reducing total grazing pressure. But in reality, this might result simply because timing of grazing was rarely used as an intervention by itself – it was usually secondary to also reducing the total amount of grazing. Thus, a more nuanced analysis might seek to define common *combinations* of interventions to explore their effectiveness.

Key recommendations

Interventions to reverse or at least halt the negative effects of excessive grazing are generally at least partially effective as assessed over a substantial number of studies. It is likely that the degree of recoverability depends on both starting conditions and fine details of the intervention involved. Thus, implications are as follows:

<u>Investment</u>

- Supporting grazing management for environmental benefit will almost always be a sound investment, but particularly if managers are able to experiment, monitor, and adjust at local scales to suit local conditions rather than have a specific action dictated to them.

<u>Monitoring</u>

- Quick, simple methods that help managers do their own monitoring will help support local experimentation and thus more cost-effective investment.

- General monitoring of the effects of grazing management may no longer be needed, unless it is specifically tied to research on the effects of starting conditions or fine variation of interventions, in timing of grazing in particular.

Research

- Given the volume of studies already conducted, research effort could usefully be devoted to exploring in more detail whether further insights can be gained across the suite of studies (through systematic review and meta-analysis or similar techniques).

5.2 Theme: Clearing of Native Vegetation

Volume of studies & their conclusions about effectiveness

We found 65 studies that reported on the effectiveness of actions to restore native ecosystems following some degree of clearing (Table 5), some of which reported on the use of multiple revegetation/regeneration interventions and are thus considered multiple times in Table 5. There were more studies reporting on traditional revegetation, matching plantings to local composition, than any other intervention including encouraging natural regeneration. There were a handful of studies of the effectiveness of specifically engineering the composition or structure of plantings to be different that current local composition but to still stimulate natural system recovery (e.g. using specific plantings to improve soil condition to eventually lead to system recovery).

By far, the most common outcome assessed was increases in the diversity of native species, though the target taxa were often quite different (mostly plants, birds, reptiles, ants and beetles). The most common interventions of encouraging natural regeneration and revegetating to match local composition were usually only partially effective at increasing diversity. Partial effectiveness was both due to differential effectiveness on different taxonomic groups and due to the fact that regenerated or revegetated sites rarely reached 'reference' or 'benchmark' condition even though most studies were longer term and/or selected sites with a long chronosequence, even up to 100+ years since regeneration/revegetation. In fact, some longer term studies reveal a pattern in which outcomes continue to improve over some years but then plateau well before reference condition is reached, often for unknown reasons (Cristescu et al. 2012), though in agricultural landscapes, the loss of nearby intact systems to supply colonists may be an important cause of only partial recovery (Munro et al. 2007). While a coarse comparison, the percent of studies reporting effectiveness suggested that encouraging natural regeneration (where possible) is more likely to be effective than revegetating, though it is still most likely to only partially achieve desired outcomes.

Interestingly, while the number of studies was low, overall effectiveness was much higher for the 'engineering' interventions. These were often designed to use plantings to stimulate a particular ecological process that may be critical for recovery rather than simply replace the dominant species that might be expected to be there in the absence of clearing/modification. Engineering composition to stimulate certain soil processes and/or recruitment of other plant species may be particularly effective. These results suggest that refocusing restoration on the restoration of key processes rather than specific ecosystems *per se* could be worthy of much deeper exploration and experimentation, even if it does represent a departure from currently-held principles about the importance of local composition and local provenance.

Table 5. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to reverse past vegetation clearing.

Intervention to address clearing	# studies	Effectiveness reported		
		% no	% partial	% yes
Encourage natural regeneration	16	19%	56%	25%
Revegetate, matching local composition	46	26%	65%	9%
Revegetate, engineering new composition	4		25%	75%
Revegetate, engineering new structure	4	25%	25%	50%
Manage fire regimes to restore native system	2	50%	50%	--

Prior review conclusions

We also found three prior reviews of the effectiveness of regeneration and revegetation interventions, all focused on the effectiveness of revegetating matching local composition. Two of these reviews were in the context of revegetating agricultural landscapes and one (a review of 71 studies) was in the context of mine-site rehabilitation. All concluded that revegetation is only partially effective at increasing the diversity or abundance of native species, even when combined with other interventions such as restoring key structures like coarse woody debris.

Limitations & notes

Clearly, the more novel interventions show some promise but have been poorly studied (likely because they are only being applied on ground in very limited ways). It is possible that considerably more information exists, as Munro et al. (2007) specifically noted that much of the information on outcomes of revegetation is in reports or unpublished theses that are simply not available. Even where sources are available, Munro et al. (2007) also found that information on the detail and context of the work done (e.g. a fully explanation of the intervention) was often lacking, particularly according to a standard classification, limiting the possible use of rigorous synthesis methods.

Many more studies were available that assessed the revegetation itself as the outcome. In other words, the only outcomes measured were about the survival or growth rates of planted tubestock. Different interventions were often assessed in that context (e.g. whether biochar improves the establishment of planted vegetation). These were excluded from the Knowledge Bank as broader environmental outcomes of revegetation were not assessed, but represent a missed opportunity to investigate broader outcomes. Interestingly, many of these studies were conducted as trials at experimental stations (i.e., sites where the current experiment would eventually be plowed under to allow a new experiment) and thus were also missed opportunities to actually revegetate landscapes.

Key recommendations

Interventions to regenerate or revegetate after partial or complete clearing of native vegetation are generally at least partially effective as assessed over a substantial number of studies. However, full recoverability may be unlikely, even over long periods of time. This result appears to be robust across multiple taxonomic groups and conditions. There are suggestions that 'engineering' approaches that focus on using revegetation to restore processes rather than a full complement of dominant species may be more successful, but evidence is quite limited. Thus, implications are as follows:

<u>Investment</u>

- Continue to invest in regeneration and revegetation, particularly the former where it is deemed possible. However, do not expect full recovery of ecosystems. Consider this implication carefully when proposing to do regeneration/revegetation as part of an offset as 'like-for-like' may be impossible to create through management and restoration.

<u>Monitoring</u>

- Monitoring of plant and bird responses to revegetation may no longer be a cost-effective way to spend limited monitoring funds. Sufficient information may currently be available to predict partial recovery toward reference conditions for both these taxonomic groups.
- Instead, monitoring funds should be particularly directed toward application of interventions to engineer specific composition or structure and thereby stimulate key ecosystem recovery processes. These need to be both applied more and monitored more to understand whether they have much greater potential to be effective.

<u>Research</u>

- As interventions to engineer specific composition or structure should move away from the realm of scientific experiments and more into mainstream on-ground application, research should find new ways to explore the deeper processes involved in ecosystem recovery to develop and trial additional 'engineering'-style interventions.

5.3 Theme: Changed Hydrological Conditions

Volume of studies & their conclusions about effectiveness

We discovered 54 studies of the effectiveness of actions intended to benefit the environment through improvement in hydrological conditions (Table 6). All but one were focused on the management of environmental water – either through release into rivers and streams from dams and weirs (most commonly) or management specifically for floodplains and wetlands.

Conclusions about effectiveness from these studies were mixed, with the majority suggesting these interventions were partially effective, but a significant proportion also concluded that interventions were not effective. In part, this may be because the detailed actions were often quite variable (including construction of fishways, management of flow velocities, as well as release of environmental water both in-stream and sufficient for overbank flows) as were the intended outcomes assessed.

Even across studies that assessed the same type of outcome, conclusions about effectiveness were mixed. For example, 11 studies looked at the effects of managing release of water from dams and weirs on the maintenance or restoration of natural processes like fish and invertebrate movement and migration. Yet two of those found the interventions ineffective, four found them partially effective, and five found them definitely effective. The differences in study conclusions could be due to different species examined, amount of time management had been in place, the presence of fishways, the pattern of riffles and pools resulting, etc. There were simply too many differences among studies to permit a more nuanced examination of the conditions under which the interventions were deemed to be effective because essentially, every study was unique.

Table 6. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of changed hydrological conditions.

Hydrological system Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Create structures that reduce erosion	1	0%	100%	0%
Manage release of water from dams & weirs	40	15%	50%	35%
Manage water for floodplains & wetlands via regulators	13	31%	46%	23%
Reduce extraction of surface and ground waters	0	--	--	--
Reduce populations of predatory, parasitic & competing pests (fish)	0	--	--	--

Prior review conclusions

We found two prior reviews of the effectiveness of managing the release of environmental water from dams and weirs – one focused on the release of water itself for waterbird breeding and one on fishway construction or modification. However, these weren't necessarily reviews of other published literature but rather large analyses of existing data sourced from a variety of published and unpublished datasets. Their purpose was not to evaluate overall effectiveness but to identify important conditions or thresholds, or even just to showcase success. We also found one additional review that simply highlighted the volume of studies on environmental flows in Australia that were focused on methods development, empirical systems understanding, etc. (Davies et al. 2014). They found that only 12% of studies (a total of 19) actually examined the success of an implemented environmental flow event and overall, there were mixed conclusions about effectiveness across these studies (just like in the Knowledge Bank review).

Limitations & notes

There are a variety of ways in which interventions to address changed hydrological conditions do not necessarily lend themselves to this kind of review methodology, or to assessment of effectiveness in the first place. These are frequently large, landscape-scale interventions which makes replication very challenging. Effects are often not expected for many years to come and so are rarely assessed. And most importantly, the critical intervention is usually a change in flood or flow *regime*, not an individual watering event. Yet empirical research and monitoring often focus on the consequences of individual events as they can be assessed in more tractable time frames.

Research is also highlighting that flood and flow regimes are major systems drivers, and changed hydrological conditions often lead the system to shift toward a terrestrial one rather than simply result in degradation. Thus, 'effectiveness' depends on whether there is an explicit desire to maintain a specific water-dependent ecosystem as opposed to a terrestrial system. In that context, more general outcomes about ecosystem health or species diversity are not as clearly relevant.

As a result, many authors have suggested that the critical emphasis needs to be on developing a systems understanding and using empirical studies to test that systems view, rather than directly assess 'effectiveness' of individual watering events (Poff and Zimmerman 2010, Davies et al. 2014). Synthesising such flow-ecology research and associated systems models may be a much better way to consider effectiveness of environmental water interventions, even though they may involve very few studies of actual interventions.

Finally, it was surprising that so few studies were found on the effectiveness of reducing water extraction and reducing populations of pest fish like carp. In both cases, it was likely due to lack of measuring broader environmental benefits from these actions, and because many may be reported in the grey literature where they are difficult to discover.

Key recommendations

As the best way forward may involve better creation and testing of systems models, the implications are a bit different than for other Themes:

Investment

- It is clear that environmental water interventions do impact on the system, just not always in the ways anticipated. Thus, the more investment in these interventions in different situations and circumstances, the better, as long as monitoring and research are built in to be able to learn more about system functioning and key drivers.

Monitoring

- To enable better systems understanding, consistent monitoring methods and outcome variables may be critical. Progress is being made, but this is an area in which methods development has been substantial and many options still exist, fragmenting the available evidence so it cannot be directly compared.

Research

- Given the large variation across studies and circumstances, research effort may be better placed in deliberate testing of broader systems models rather than studying every small variation and local circumstance that may impact on effectiveness. Longer-term studies (10 years or more) are critical.

5.4 Theme: Changed Fire Regimes

Volume of studies & their conclusions about effectiveness

We found a total of 36 studies that attempted to intervene in the overall fire regime to improve an ecosystem or, occasionally, a specific species or population. In some cases, this simply involved introducing fire where there had been none previously (at least in recent management history). We did restrict the sources included to those that actually imposed a change in *regime* back toward one thought to be more aligned with historical patterns over ecological or evolutionary time scales, not just those that intended to use fire once or as a specific management tool regardless of historical regime. These were frequently studies about applying fire to ecosystems thought to have some degree of fire dependence, though some focused on protecting fire-sensitive ecosystems from regimes too frequent or intense.

In general, effectiveness was highly mixed, with most studies reporting either no or partial effectiveness. A wide variety of outcomes was assessed, though there were no obvious patterns suggesting that certain outcomes are more likely to be achieved than others. Changing fire extent and/or intensity appeared less effective than adjusting intervals or seasonality; however, many of the studies of intensity involved limited time frames (few were >10 years) and thus limited opportunity for new regimes to become established. Thus, comparison between the two interventions for which there is evidence may not be valid.

Table 7. Number of studies and percent reporting no, partial, or definite effectiveness for interventions intended to address the problem of changed fire regimes.

Fire Regime Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Change fire extent and/or intensity	7	72%	14%	14%
Change fire intervals and/or seasonality	29	34%	45%	21%
Protect sensitive habitats from fire	0	--	--	--

Prior review conclusions

We found one prior review of the effectiveness of changing fire regimes which focused on a shift from wildfire to prescribed burning on the Arnhem Plateau, deliberately intended to benefit biodiversity and align with historical indigenous fire management practices. The review concluded that such a shift was effective at providing benefit to biodiversity.

Limitations & notes

There were many more studies available on controlled or prescribed burns that were intended for fuel reduction rather than to achieve ecological benefits. A few of these measure potential biodiversity benefits (in which case they were included in the Bank), but the bulk of these may represent a missed opportunity to learn about fire as an ecological systems driver.

This is an especially important goal to consider – learning about fire as a systems driver – because one overarching pattern was that increasing fire frequency favours some species of ants and arthropods, plant species etc. but disadvantages others. In other words, fire drives ecosystems into different states (not necessarily better or worse ‘health’ or ‘condition’) and thus ‘effective’ depends explicitly on which states are desired. Often it was hard to say whether the intervention was effective or not because a desired state was not articulated. Instead, most studies compared the effects of different fire frequency or intensity rather than necessarily evaluating the effectiveness of a specific intervention.

Key recommendations

Similar to Changed Hydrological Conditions, the best way forward may involve better creation and testing of systems models that incorporate fire as a key driver, as well as better articulation of desired outcomes in this context. Implications are thus:

Investment

- It is clear that fire regimes have significant consequences for ecosystems and that frequently, some species or aspects of the system benefit while others do not. It is thus critical to be clear about investment goals when investing in actions related to fire. Investment in these interventions in different situations and circumstances better coupled with monitoring and research should facilitate more rapid learning about fire as a key driver and thus better surety about investing in fire management to achieve NRM goals.

Monitoring

- Monitoring of the broader environmental consequences of any change in fire regime, including fuel reduction burns, should help build a better systems understanding needed to underpin confident investment.

Research

- Given the large variation in effectiveness information, research effort may be best used to create and deliberately test systems models with fire as a key driver rather than studying ‘effectiveness’ *per se*. As for other Themes in which regime changes are really the aim of the intervention, longer-term studies (10 years or more) are critical.

5.5 Theme: Proliferation of Weeds

Volume of studies & their conclusions about effectiveness

Somewhat surprisingly, we only found 15 studies that assessed the effectiveness of weed interventions at producing broader biodiversity outcomes (Table 6). The vast majority of the studies found during the review process assessed effectiveness in terms of weed mortality, suppression of establishment, or sometimes reduction of weed density, but did not assess any further environmental consequences of those efforts. Most of the evidence about weed mortality also comes from controlled field trials rather than actual on-ground NRM activities. Arguably, this is a better way to learn about what might work to kill weeds, but it is unclear whether these methods are just as effective when implemented outside a controlled trial situation. In other words, there is a great deal of evidence about how to destroy weeds in controlled situations, but much less evidence about the NRM benefits achieved at scale, in real-world application.

Only three of the five interventions were assessed for broader environmental benefits. Interventions most directly related to limiting the spread of weed populations (controlling outlying populations and cleaning vehicles and footwear between sites) were not assessed at all in the studies we identified.

While limited in number, the results available suggest that interventions to address the problem of proliferation of weeds are usually at least partially effective at increasing the abundance, cover, or number of native species (the outcomes most commonly measured in these studies). A broad range of methods were used, including application of herbicides and controlled burns. There was some evidence that effectiveness was only short-term and on-going intervention was required. Effectiveness of controlling transformer weed species was potentially less effective, though evidence only comes from two studies.

Table 8. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of proliferation of weeds.

Weeds Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Control weeds in revegetation & remnants	4	0%	50%	50%
Control outlying populations of weeds	0	-	-	-
Reduce weed presence and density next to native vegetation and waterways	9	11%	67%	22%
Control transformer weed species (including flammable grasses)	2	50%		50%
Clean vehicles & footwear between sites	0	-	-	-

Prior review conclusions

We found no prior reviews of the effectiveness of weeds interventions in producing broader biodiversity outcomes.

Limitations & notes

A great deal of the weed management literature lies in 'grey' sources – reports, fact sheets, and 'success' case studies. Most of these are not readily discoverable and don't meet the strict criteria for inclusion in a systematic map. In many cases this is for the same reasons that published, peer-reviewed studies were excluded (outcomes measured were only in terms of weed mortality not broader environmental benefits). However, in many cases the limitations are that interventions are not clearly described or outcomes are reported at a high qualitative level even though more rigorous data may have been collected. Taking this broad grey literature into account, it is clear that much more could be concluded about weed management effectiveness as an NRM action but it is rarely reported in a way that allows for this type of assessment.

It is also possible (likely?) that the broader environmental benefits of weed management are not clearly assessed in the literature because weed management is often undertaken as a secondary activity and the literature reports mostly on the primary intervention (revegetation, grazing management, etc.). Such combined interventions also make it difficult to disentangle the effects of individual interventions used.

Key recommendations

Evidence of the broader environmental benefits of weed management in on-ground real-world applications is still quite limited. Particularly given the increasing costs and extent of weed management in Australia, the implications for investment, monitoring and research are as follows:

<u>Investment</u>

- Where evidence exists, actions are usually at least partially effective so weed management is still a reasonable investment as long as the following suggestions for monitoring and research are also considered.

<u>Monitoring</u>

- There is a need for a deliberate shift away from monitoring the weeds themselves toward monitoring broader environmental outcomes.
- There is a need to focus on synthesising more monitoring results from the grey literature to see if we can explain the conditions under which weed management does not need to be ongoing to maintain outcomes (where management might be most cost-effective).

<u>Research</u>

- New research on the effectiveness of controlling transformer weed species may be vital.
- New research is required on how to prevent weed spread/dispersal to new sites as such studies were not found but may be most important to cost-effectiveness (since once a weed becomes established, intervention may need to be ongoing and only partially effective).

5.6 Theme: Predation/Damage by Feral Vertebrates

Volume of studies & their conclusions about effectiveness

Only 12 sources were discovered that actually assessed the biodiversity benefits of controlling feral or domestic vertebrate predators in some way (Table 9). Ten of these assessed the effectiveness of killing predators, while only two assessed more indirect actions like controlling access to native prey. Interestingly, all studies about the benefits of killing predators suggested the intervention was definitely effective, while controlling access to native prey was only partially effective. However, about half the studies of effectiveness examined it in relation to a single prey species or narrow taxonomic group (e.g. effects of baiting on lizard communities, or spotted-tailed quoll populations) rather than addressing whether broader ecosystem benefits resulted. Where ecosystem benefits were assessed, they were generally measures of native species abundance or diversity.

While alternative interventions have been suggested including altering habitat so it no longer favours exotic/introduced/feral predators as well as supporting larger/healthier populations of native species that might compete with predators, we found no studies that measured the effectiveness of these alternative interventions.

Table 9. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of predation/damage by feral vertebrates.

Feral predator Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Kill introduced predators & pigs	10	0%	0%	100%
Remove habitat for introduced predators & pigs	0	--	--	--
Control access by domestic/introduced predators & pigs	2	0%	100%	0%
Support natives that compete with introduced predators	0	--	--	--

Prior review conclusions

Only one review presented sufficient information on management actions and their effectiveness. It was a review of 25 years of fox control using 1080 poison for the management of rock-wallaby colonies in Western Australia. They concluded that this control method was effective at increasing numbers of rock wallabies and was most successful when it included baiting in a buffer zone around the treatment area, thereby limiting reinvasion of foxes.

Limitations & notes

There were clearly many more studies that involved lethal control of introduced predators and pigs. However, most were excluded because they did not measure broader NRM outcomes beyond the immediate efficacy of the method at producing mortality of predators/pigs. These were frequently studies by government departments who noted limited resources to conduct post-intervention monitoring. Other studies were excluded because, while they did monitor both predator and prey populations often using motion-sensing cameras ('camera-traps'), they did not perform this monitoring in a context in which interventions were being used to limit predator populations. In other words, they were studying 'natural' population dynamics rather than management interventions.

Many papers assessed feral vertebrate interventions in production landscapes where the intent was to reduce livestock predation. These papers were excluded on the basis they presented no direct evidence of environmental outcomes, though such a result may be possible or even likely from these agricultural interventions.

Finally, we found very little evidence that alternative interventions are being trialled. Altering habitat so it no longer favours exotic/introduced/feral predators as well as supporting larger/healthier populations of native species that might compete with predators were not well represented even in the initial search results.

Key recommendations

Evidence of the environmental benefits of controlling feral vertebrate predators is surprisingly limited given the frequency with which the action is undertaken and the wealth of knowledge about the most effective mechanisms to kill these animals. Our results suggest that:

<u>Investment</u>

- The most common method for controlling feral vertebrate predators is lethal control and this method consistently provides positive biodiversity outcomes, so is likely to be a reliable investment despite the relatively low total volume of evidence. This is particularly true where conservation of particular prey species is desired.
- Studies also suggested that baiting with 1080 poison was the most cost-effective method particularly at larger scales, though that could be a subject for more detailed review.

<u>Monitoring</u>

- Some monitoring resources could be effectively re-directed toward assessing broader environmental outcomes rather than simply reductions in the feral predators themselves.

<u>Research</u>

- There is significant scope for research opportunities (particularly postgraduate student projects) that assess the ecosystem-level outcomes of feral predator control actions.
- Useful progress could be made by ensuring that the more in-depth research on predator and prey population dynamics that is already occurring is paired with interventions to address the problem of predation by feral vertebrates. At the moment, these are mostly decoupled.

5.7 Theme: Damage by Pest Invertebrates

Volume of studies & their conclusions about effectiveness

Only three studies were discovered that assessed the environmental benefits of controlling pest (non-native, exotic, introduced) invertebrates (Table 10). All of them focused on controlling species that act as predators, parasites and/or competitors of native species and the outcome measured was always increase in the abundance of native species following control. While sample size is small, all studies concluded that control measures were definitely effective at increasing the abundance of native invertebrates, though repeated intervention (e.g. multiple applications of insecticide) was often required and outcomes were not achieved immediately but rather after multiple seasons. There were no studies that examined the environmental benefits of controlling herbivorous pest invertebrates.

Table 10. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of damage by pest invertebrates.

Pest invertebrate Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Reduce populations of plant-feeding pests	0	--	--	--
Reduce populations of predatory, parasitic & competing pest invertebrates	3	0%	0%	100%

Prior review conclusions

We found no prior reviews of the effectiveness of pest invertebrate interventions in producing broader biodiversity outcomes.

Limitations & notes

Although there were many examples of actions being undertaken to control exotic invertebrate species, the outcomes measured were almost always simply changes to the populations of pests themselves, not resulting environmental benefit. Thus, these studies were excluded from the Bank. Notably for pest invertebrates, ants were the only taxon of pests controlled for which subsequent environmental outcomes were assessed.

Many populations of pest invertebrates were reduced to achieve agricultural benefits and those studies were excluded because environmental benefits were not measured. In many cases, it would be reasonable to assume that wherever agricultural benefits were achieved, environmental benefits were as well (e.g. for widespread control of plague locusts). However, the direct empirical evidence for this (the scope of this review) is lacking.

Key recommendations

Evidence of the environmental benefits of controlling pest invertebrates is almost completely lacking. The only evidence available focuses on the control of pest ant species, though all studies available suggested that control efforts are definitely effective at increasing the abundance of native species. Implications are as follows:

Investment & Monitoring

- As so little direct evidence of environmental benefit is available, investment in reducing damage by pest invertebrates should always be coupled with investment in monitoring the environmental benefits (not just reductions in the pest populations themselves).

Research

- Cross-sector research that assesses both the agricultural and environmental benefits of interventions to reduce the damage done by pest invertebrates would dramatically increase the knowledge base as interventions are performed much more frequently for agricultural benefit.
- Research on the benefits of controlling any taxon of pest invertebrates other than ants would be a unique and thus valuable contribution.

5.8 Theme: Excessive Nutrients & Pollutants

Volume of studies & their conclusions about effectiveness

We discovered only seven studies assessing the effectiveness of efforts to reduce the transfer of nutrients and pollutants into native ecosystems, all focused on vegetation buffers. Of these, there was only one examining buffering of terrestrial ecosystems – all others were riparian buffer strips intended to reduce sediment, nitrogen and phosphorous transfer. The vast majority of these studies suggested that vegetated buffers were only partially effective.

One key reason for partial effectiveness was that most studies compared a few different types of buffers and generally found that grassy buffers were more effective than woody buffers (planted or retained), particularly at reducing sediment transfer. The one study that reported definite effectiveness assessed buffers consisting of mixed woody species (planted) but did not compare those to any other type of buffer. Thus, its conclusions are consistent with those of the studies that reported partial effectiveness.

Buffers were also only partially effective because they were better at reducing sediment transfer than reducing nutrient transfer. Effectiveness also varied with width, as wider buffers were generally more effective than narrower ones. Importantly, effectiveness also varied with slope and speed of surface water flow, suggesting that buffers may fail to limit sediment transfer and control erosion during high-volume or extreme storm events.

Table 11. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of excessive nutrients and pollutants.

Nutrient/Pollutant Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Avoid chemicals in and next to native vegetation	0	-	-	-

Plant or maintain densely rooted vegetation next to native vegetation and waterways	7	0%	86%	14%
Plant or maintain scattered trees next to wooded native vegetation	0	-	-	-
Reduce movement of livestock into native vegetation	0	-	-	-

Prior review conclusions

We found no prior reviews of the effectiveness of efforts to reduce the amount and transfer of nutrients and pollutants in/into native ecosystems in Australia. We did find one global review of riparian buffers that included some Australian data, though it was dominated by data from North America (Hansen et al. 2015). This review suggested that riparian buffers of ~20-38m are generally effective for controlling erosion and reducing nutrient inputs to some degree, but other types of outcomes may require greater widths. Interestingly, we also found one attempt to review to effectiveness of river restoration in Victoria (Brooks and Lake 2007), but despite examining records for 2,247 restoration projects, concluded that there were insufficient data to review effectiveness. They found that only 14% of project records indicated that any form of monitoring was carried out and from that monitoring, there was insufficient data to determine the requirements for successful riparian restoration.

Limitations & notes

The limited evidence found appears likely to result from insufficient monitoring of riparian restoration rather than limited application of the intervention. Multiple studies specifically mentioned limited data availability on buffer performance under natural field conditions, despite the fact that buffers are an accepted water quality mitigation tool (e.g., McKergow et al. 2006). Riparian restoration has been a commonly employed intervention in Australia yet environmental outcomes seem rarely reported, including in the grey literature, meaning the lack of evidence may be real and not just resulting from a lack of discoverability in the grey literature. The grey literature did seem to be dominated by broad scale assessments of overall sediment transport dynamics, or methods to monitor erosion at large scales.

However, the one grey literature source included in the Bank (Hairsine 1997) was a short report of multiple research projects by the Cooperative Research Centre for Catchment Hydrology, none of which was discovered in searches of the published literature. Thus, it is possible that additional high quality studies exist in the grey literature but are difficult to discover.

It seems likely that the lack of evidence for other interventions like terrestrial buffers, including the use of scattered trees to limit wind transfer, results from limited application of these other approaches.

Key recommendations

Grassy riparian buffers in particular seem to generally be effective at reducing sediment transfer into waterways, though are less successful at reducing nutrient transfer and are overall less successful during high-volume water flow (e.g. after extreme storm events). However, the amount of evidence available is extremely small compared to the frequency with which these interventions are generally undertaken. Woody riparian buffers may be less effective and there is almost no evidence available about terrestrial buffers, partly because this is a more novel intervention not undertaken very frequently. Implications for investment, monitoring and research are thus:

Investment

- Grassy riparian buffers, particularly wider ones, are probably a worthwhile investment without the need for detailed monitoring. Grassy plantings should be preferred over purely woody plantings.
- Terrestrial buffers (i.e. those adjacent to remnant terrestrial native vegetation) are worthwhile investing in as long as actions are coupled with excellent monitoring or new research as these are interventions we need to learn more about.

Monitoring

- Monitoring, even basic monitoring of relatively immediate outcomes, should happen more frequently (or be better reported?) if these interventions continue to be common ones in Australia. Otherwise, we are missing a significant opportunity to learn from widespread interventions.

Research

- Research on terrestrial buffers, coupled with actual on-ground intervention, is a key gap that limits innovative expansion of interventions (which may be needed to achieve national and international goals and agreements).
- Major insights could be gained very cost-effectively from post-hoc assessment of benefits achieved for riparian restoration projects conducted in the past. This would require space-for-time substitution instead of direct assessment of change over time and thus would require significant on-ground empirical assessment as well as deeper grey literature investigation. Such an approach would be able to provide much deeper more substantial insights than are possible at the moment.

5.9 Theme: Loss of Keystone Species

Volume of studies & their conclusions about effectiveness

We discovered only six studies that examined whether reintroduction of keystone species (or 'ecosystem engineers') produced broader environmental outcomes as predicted by the theoretical concepts of keystone species and ecosystem engineers (Table 12). Two of these studies were of plant restoration (*Themeda* grass) and the remaining four were native mammal reintroductions. The two *Themeda* studies were conducted in the same experimental study system but over different time periods and with different types of outcomes measured. They suggest that restoration of *Themeda* does stimulate an overall increase in nativeness and provide ecosystem services in terms of nutrient regulation. Reintroduction of keystone mammals was usually deemed effective at supporting natural processes and functions, including ecosystem services, though often those services were only measured in minor ways (e.g. increased movement of soil). The one study that reported no effectiveness found no difference in native vertebrate use of bettong burrows versus rabbit burrows, suggesting no special 'engineering' effect of bettongs.

Table 12. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of loss of keystone species.

Keystone Species Intervention (keystone reintroductions)	# studies	Effectiveness reported		
		% no	% partial	% yes
Reintroduce keystone species (animals, micro-organisms) (captive breed if necessary)	4	25%	0%	75%
Revegetate, engineering composition	2	0%	0%	100%
Revegetate, engineering structure	0	--	--	--

Prior review conclusions

We found no prior reviews of the broader environmental effectiveness of reintroduction of keystone species in Australia.

Limitations & notes

While it is clear that more species reintroductions/translocations have been performed in Australia, they are usually intended to benefit the individual species being reintroduced and thus are not about providing a keystone or 'engineering' broader environmental benefits. Studies purely about reintroduction to benefit a single species were excluded from the Bank. Even where studies focused on the reintroduction of a species that was expected to provide broader benefits, those broader outcomes were rarely assessed. Instead, the outcomes assessed were purely about the survival and establishment of the species reintroduced. This was also the Theme with the fewest potential sources to filter, suggesting that even though reintroduction/translocation is not an uncommon intervention in Australia, particularly for plants, the outcomes are rarely reported in a discoverable way through either the published or grey literature.

Key recommendations

Though the broader environmental benefits of keystone species reintroductions have rarely been assessed, the studies that do exist suggest these actions are generally effective. Implications for investment, monitoring and research are thus:

Investment

- Reintroductions of keystone species or 'ecosystem engineers' are worthwhile investing in as long as actions are coupled with new research as these are interventions we need to learn more about and they are difficult to monitor.

Monitoring

- It is particularly challenging to monitor the outcomes of these reintroductions, particularly given the need to assess broader outcomes in addition to the immediate establishment of the species being reintroduced. Thus, monitoring should be done primarily in the context of new research, with robust experimental design and assessment methods that are likely to be beyond the budget and skills of managers.

Research

- Research needs to be tightly paired with on-ground interventions as most monitoring will need to be done in the context of fairly complex research projects. It would be useful to focus more on keystone plant species as they are easier to reintroduce and the available data suggests they may be particularly successful but also particularly under-studied.

5.10 Theme: Loss of Key Structures & Functions

Volume of studies & their conclusions about effectiveness

This theme captured a range of more directly interventionist approaches that involve physically altering the structure of habitats or landscapes, or intervening in the population dynamics of native species that may be deemed 'overabundant'. Many of these interventions are relatively new and novel, and thus it was surprising that we discovered 16 studies that assessed the environmental outcomes of these types of interventions (more than most of the other Themes).

The vast majority of these studies (15) were focused on site-scale addition of key habitat structures like nest boxes, coarse woody debris, or snags in waterways. These interventions were usually deemed effective, though some were only partially effective. Interestingly, the outcome almost always assessed was improved habitat quality specifically for target fauna. The one study that assessed the effectiveness of adding coarse woody debris for improving native ground cover in general found it was only partially effective as results were at least partially confounded by high rainfall and partial kangaroo exclusion. The two other studies that concluded partial effectiveness involved several different actions (one was the combination of nest boxes and coarse woody debris addition and the other was the additional of glider poles and canopy bridges over roads) so little can be concluded about the circumstances under which this theme of interventions may be only partially effective.

One additional study was found of the effectiveness of specifically creating or deliberately managing movement corridors. It found that the intervention was ineffective at increasing gene flow and genetic diversity, though the managed connection was used as additional habitat by a range of species.

No studies were discovered of the effectiveness of managing and protecting refugia or of controlling overabundant native species.

Table 13. Number of studies and percent reporting no, partial or definite effectiveness for interventions intended to address the problem of loss of key habitat/landscape structures and functions.

Key Structure/Function Intervention	# studies	Effectiveness reported		
		% no	% partial	% yes
Create and/or manage movement 'corridors'	1	100%	0%	0%
Protect and manage refugia	0	--	--	--

Protect, manage & restore keystone habitat structures (mature trees, logs, snags in water, etc.)	15	0%	21%	79%
Control overabundant native species	0	--	--	--

Prior review conclusions

We found no prior reviews of the direct assessment of effectiveness of restoring key habitat structures and functions in producing broader biodiversity outcomes.

Limitations & notes

We found many additional studies that described actions designed to improve site or habitat condition but they were excluded from the Bank because they did not adequately demonstrate a biodiversity benefit. Examples of this included projects that provided nest boxes for wildlife but only used nest box occupancy as a measure of success. Animals could simply be switching to nest boxes from natural hollows. So biodiversity benefit needs to be demonstrated by comparing, for example, breeding success in nest boxes compared to natural hollows, or animal survival in areas with and without nest boxes.

Similarly, the presence of a species in a corridor, on a rope-bridge over a freeway, or in a freeway underpass does not provide evidence of true functional connectivity or genetic dispersal. Without this demonstrated biodiversity benefit these studies were excluded. This is not to say these structures will not work – merely that most studies did not actually measure a true biodiversity benefit, e.g. overcoming barriers to dispersal, or improved breeding success.

This particular case (evidence for the effectiveness of creating and/or managing movement corridors) provides particularly clear insight into both the limitations and the benefits of the Knowledge Bank approach. Close to 100 empirical studies have been conducted in Australia on movement corridors for native animals and results have been synthesised in a systematic review (Doerr et al. 2010, Doerr et al. 2014), which concluded this type of intervention is partially effective and provided further detail about how to design connections so they will definitely be effective for a broad range of taxa. Yet this review and the vast majority of the studies it considered are not included in the Knowledge Bank because they were based on studying remnant connections (not planted ones) that aren't directly managed for movement. Thus, these are not studies of a deliberate management intervention and their conclusions depend on the assumption that managers can create these same remnant conditions through replanting and active management. While this may be a valid assumption, it is critical to test it with at least some direct studies of the effectiveness of created connections. Given the frequency with which this action has been employed in recent years in Australia, it seems to be a key gap that the intervention itself and its actual outcomes are rarely being studied.

Studies assessing the effectiveness of controlling overabundant native species, particularly kangaroos and noisy miners, were expected but not found. We suspect this is because studies involving kangaroo control are generally in the grey literature and thus not easily discoverable. In the case of noisy miners, this is likely because most studies to date have been indirect (comparing areas with more or fewer noisy miners) or in experimental plots rather than at-scale. Noisy miner control as an actual NRM intervention has only recently become possible, so empirical evidence of effectiveness should be available in future years.

Especially protecting and managing refugia is a relatively new intervention and the lack of evidence likely reflects limited application of this intervention thus far. The outcomes are also likely to be challenging to research given the spatial and temporal scales involved.

Key recommendations

There appear to be clear biodiversity benefits associated with the restoration of important habitat structures. However too many studies define the success of these interventions only by whether or not they are used by animals, rather than whether or not they are used to overcome the original impediment to restore proper ecological function.

Investment

- The available evidence suggests the restoration of important habitat structures within sites is a worthwhile investment for the benefit of wildlife species, several of which are likely to be threatened.
- Newer interventions like protecting refugia and controlling overabundant species are worthwhile investing in as long as actions are coupled with excellent monitoring or new research as these are interventions we need to learn more about.

Monitoring

- Monitoring of effectiveness should move away from simple immediate measures of success such as ‘use’ or ‘occupancy’ and focus instead on whether or not proper ecological function (e.g. dispersal) is restored.

Research

- Useful progress could be made by ensuring that the more in-depth research on things like connectivity that is already occurring is paired with actual landscape interventions. At the moment these are mostly decoupled, yet there has been significant activity for both resulting in much on-ground action yet little direct evidence of its effectiveness and this could relatively easily be redressed.

6 Final remarks

The overwhelming pattern across all these results is that relatively little is being learned about the effectiveness of on-ground interventions to improve the Australian environment. In only a few cases can overall conclusions be drawn, and those conclusions usually suggest that interventions are only partially effective. It is unclear whether full effectiveness is achievable in some situations, under some conditions, or with additional (perhaps more novel) interventions. As a result, there may be only a few things that it is worth ceasing to monitor (like overall bird and plant species richness responses to revegetation). But it is clear that priorities should shift toward experimenting with more novel interventions and conducting monitoring in a way that is more linked to research – that can focus on truly assessing outcomes rather than simply reporting on immediate activities.

More complete exploration of barriers to learning and options to embed adaptive learning systems into on-ground intervention and research programs are presented in the main report (Doerr et al. 2017). These options for accelerating learning are the most critical outcomes to come from the initial development of the Bank.

Nonetheless, because an original aim of the project was to derive recommendations separately about the confidence of investing in on-ground actions, prioritising investments in monitoring, and prioritising research, the following high-level suggestions on these specific issues are provided below.

6.1 Investment in on-ground interventions

The vast majority of current interventions are still worth investing in but we can only be confident of partial success in most cases. Even where substantial numbers of studies were found, there was a great deal of variation in the details of interventions, outcomes measured, antecedent conditions, timing, etc. This means that confident investment depends on local details in ways we don't fully understand yet (and may never understand). Thus, investing in on-ground actions is probably a 'safe' thing to do specifically when it is coupled with local experimentation and learning (see below) and/or major science/practice partnerships (also see below).

6.2 Investment in monitoring

Much existing monitoring focuses simply on quantifying what was done (like killing weeds or feral predators, planting tubestock, etc.). While this is partly about ensuring and reporting compliance when public investment is made in the intervention, we should be looking for even cheaper, simpler ways to do this really basic activity monitoring. The effort saved could then be redirected toward monitoring broader environmental outcomes.

6.3 Investment in local knowledge, experimentation and learning

Our results suggest that the freedom to make local decisions about the details of an intervention is probably an important part of being able to more rapidly learn what works best. The support to experiment and try new things locally, and then the capacity to learn from those experiments and adjust – all at a local scale – is probably particularly critical to long-term success. A national view of effectiveness could then be formed through better information sharing and learning across these local/regional contexts. This may sound similar to what currently happens in some regions. However, part of the key is to make learning itself a goal, and the changes to business-as-usual could be significant, including a reduction in completely bespoke local tailoring of interventions (to allow a few options to be compared with replication) and a change in compliance reporting such that learning goals themselves are included (rather than making environmental improvement and/or social engagement the only goals).

6.4 Investment in science-practice partnerships at scale

It was clear during the process of constructing the Knowledge Bank that science is commonly done in places where practitioners aren't implementing on-ground actions, and vice versa. There is tremendous potential in linking these different communities (and their existing sources of funding), and doing so *before* interventions are planned and implemented. Much progress has been made in Australia with building these sorts of partnerships but they often form after interventions are designed and applied, rather than before. Yet early partnerships have much more potential to create the right hybrid conditions for both effective learning and maximising positive outcomes. This also requires embracing the concepts in the section above, as it means being comfortable investing in multiple different actions at once, knowing they won't all be equally effective but that the aim is to learn. As the capacity of on-ground managers to participate in these learning processes may be limited in some cases, these partnerships could be implemented experimentally at first in just a few key regions, to see how much learning about effectiveness can actually improve environmental investment and outcomes.

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

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FOR FURTHER INFORMATION

Land and Water
Veronica Doerr
t +61 2 6246 4099
e veronica.doerr@csiro.au
w www.csiro.au

Land and Water
Micah Davies
t +61 2 6246 4096
e micah.davies@csiro.au
w www.csiro.au