Threatened Species Recovery Hub

National Environmental Science Programme

Cactus Dryandra (*Banksia anatona*). Image: Australian Network for Plant Conservation

Appendix 5
Threat Abatement Strategy detailed assumptions

This document is an appendix from: April E. Reside, Michelle Ward, C.J. Yong, James E.M. Watson, Andrew Rogers, Ruben Venegas Li and Josie Carwardine. (2021) A knowledge synthesis to inform a national approach to fighting extinction - Final Report. NESP Threatened Species Recovery Hub Project 7.7 report, Brisbane.

November 2021

The University of Queensland Australia

CSIRO

Appendix 5: Threat Abatement Strategy detailed assumptions

Appendix 5.1: Biosecurity

Summary

We estimated the cost of national biosecurity as a non-spatial cost of $906 million/year ($118/km2 for all of Australia). This was largely based on the reported spending from the Australian biosecurity enquiry (Craik et al. 2017), taking "IC1 – Prevention and preparedness" and "IC2 – Eradication and containment" with an adjustment for time value of money and an increase in the spending by **50%** to make it more "adequate" as recommended. We did not distinguish the action cost between taxa, threatened and non-threated species, as we felt that it was inappropriate to split the cost that way. This cost back-calculated for labour roughly equates to 60 management personnel, 630 experienced staff and 15,700 ground staff of a ratio 1:10:25, assuming only labour without any cost multipliers, and assuming no transport, consumables or equipment.

Biosecurity (pre-border, border, eradication and containment) is an overarching action conducted at the national level that covers aquatic and terrestrial: vertebrates, invertebrates, plants and pathogens (IGAB 2016). Biosecurity spending is a complex and multi-layered issue, with spending split amongst the federal government, states/territories, and the industry (Craik et al. 2017). Based on an independent review of Australia's biosecurity there were recommendations to keep the budget at least at the 2015/16 spending level (Craik et al. 2017). The return on investment on preventative spending can be up to 100-fold higher (Craik et al. 2017), and there needs to be an increase of funding of Steps 1 and 2 (prevention, preparedness, eradication and containment) that yield a higher return on investment compared to high spending in Step 3 (management of established pests and diseases) (Craik et al. 2017).

Assumptions

We estimated biosecurity to cost a non-spatial **$906 million/year**. This was based on the $565m of actual national spending in 2015 for Steps 1 and 2 brought forward at 1.5% for inflation, resulting in $704m/year in Dec-20 dollars. To address the underfunding of this area (Craik et al. 2017), we then applied a 50% increase in spending for this area. For our costing purposes, our biosecurity cost was all encompassing. We did not distinguish between taxon and threatened or non-threatened.

Assuming this only involves labour costs, this translates to roughly 60 FTE of management staff at $65/hr, 630 FTE of experienced staff at $45/hr, and 15,700 FTE of entry level staff at $30/hr.

Appendix 5.2: Critical Sites Access Management

Summary

Human related activities threatened 205 threatened species (88 plants, 57 birds, 29 reptiles, 9 frogs, 11 mammals, 6 inverts and 5 fish) (Ward et al. Unpublished results). We grouped threats that we assumed to have similar management effort, this included damage/disturbance at roosts, human intrusions & disturbance, hunting, hunting and collecting of native species, hunting and collecting plants, hunting and collecting terrestrial animals, illegal collecting, pig hunting, recreational activities, recreational activities (dog walking), and recreational activities (horse riding).

The effort estimated for the critical sites access management TAS focused on 3 management actions: gating off threatened species habitats to restrict human access, creating awareness of these off-limit locations with signage, and policy change and compliance (non-spatial).

Assumptions

Spatial maps

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

As there was no specific threat layer, we estimated the cost of implementing this TAS across the extent of Australia. We assumed that this layer would then be cropped to the relevant management extent i.e. a combined SNES species distribution layer of species that require this TAS (see Supp Material 2).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning (ground)

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species, planning out the fencing and signage locations. We estimated the effort for 100km2 to be 2 persons at entry level wage of $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management Action 1 – Policy and liaison (non-spatial)

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The first area this management action represented was policy change, compliance and education, involving tasks like cost for negotiation policy change, compliance, educating on the impact of threats on threatened species, and devising best management practice for long-term sustainability. The second area was the liaison and communication, involving the labour costs for liaison officers. We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

4. Management action 2 – Restrict access via gates and generate awareness with signage

This action represented on-site tasks to protect the critical sites, through the installation of physical barriers and signage for awareness around the perimeter. This non-spatial management action was assumed to be conducted annually at the national scale and only involved labour.

The installation of physical barriers, in our case gates, was assumed to occur around the perimeter at 5 gates per 100km2. We assume gates will be set up at critical access points to the sensitive areas. The gates are estimated to cost $2k each for materials and takes 2 people 2 days to construct it. The estimated cost was adapted from the low-end range ($1,500 to $3,000) of a driveway gate (https://www.oneflare.com.au/costs/gate). They will be replaced every 10 years and require the same effort.

The installation of generic signs was assumed to occur at 5 signs per 100km2. We assume signs will be designed under local managers direction and are placed strategically. The signs are estimated to cost $2k each for materials and takes 2 people 0.5 days to construct it.

They will be replaced every 10 years and require the same effort. The material cost was estimated for double sided signs standing at 1000mm high (https://www.qasigns.com.au/ground-sign-post-panel-sign)

We estimated the drive distance for structure erections to be 5kms per structure, the furthest point away from the operations centre (the centre of 100km2 area that is 10x10km. i.e. To construct 10 structures we will need to drive there and back of 5kms from the centre to the edge. (100km of driving = 10structuresX5kmsX2)

5. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels, involving tasks like walking through and checking for evidence of human intrusion, collection or hunting. We estimated the effort for 100km2 to be 2 persons walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

6. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis, and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Appendix 5.3: Disease Management (General)

Summary

The disease management threat abatement strategy (TAS) was assumed to address all disease threats combined, as the major biodiversity diseases (phytophthora, chytrid and myrtle rust) were found to have substantial spatial overlap in realised and potential distribution. With a total of 127 species-threat interactions, the diseases in focus are phytophthora (69), chytrid (24), myrtle rust (7), aerial canker (5), and 21 non-specified threat of disease (Ward et al. Unpublished results). The threatened species include plants (74), frogs (24), mammals (15), birds (9), inverts (3) and reptile (1) (Ward et al. Unpublished results). As eradication was unlikely for these diseases, the focus of the TAS was therefore education, awareness and containment of the disease. The generic disease management actions adopted for the TAS were disease monitoring, education & communication (including signs) to inform the public to prevent spread, and 2 levels of hygiene stations.

Important to note that the specific disease management (aerial and ground phosphite application) for phytophthora has been costed separately (see "Disease management Phytophthora" TAS for more detail). There has also been a national-level biosecurity action that has been costed separately across fauna, flora and diseases (see "Biosecurity" threat abatement for more detail).

Assumptions

Spatial maps

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

As there was no specific threat layer, we estimated the cost of implementing this TAS across the extent of Australia. We assumed that this layer would then be cropped to the relevant management extent i.e. a combined SNES species distribution layer of species that are susceptible to disease (see Supp Material 2).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We further included an estimate of effort of 3 weeks to account for extra work required for general disease management, like disease sample processing. This action was assumed to occur every 10 years in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species, collecting disease samples, and surveying site suitability for where signs and hygiene stations are to be erected. We estimated the effort for 100km2 to be 2 persons walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur every 10-years on-site.

We also estimated the effort to drive and survey the perimeter (40km of a 10x10km 100km2 management area) to find suitable spots for sign/hygiene station erection, and after installation the time was spent on annual checks. We assumed survey time was 10 minutes for every km driven. This action was assumed to occur every 10-years on-site.

3. Management action 1 – Signage and hygiene stations

The installation of generic signs was assumed to occur at 5 signs per 100km2. We assume signs will be designed under local managers direction and are placed strategically. The signs are estimated to cost $2k each for materials and takes 2 people 0.5 days to construct it. They will be replaced every 10 years and require the same effort. The material cost was estimated for double sided signs standing at 1000mm high (https://www.qasigns.com.au/ground-sign-post-panel-sign)

We estimated the cost for the installation of 2 levels of cleaning stations to prevent the spread of diseases, footwear hygiene stations and vehicle washdown stations. The

installation of footwear hygiene stations was assumed to occur at 5 per 100km2. The footwear hygiene stations are estimated to cost $5k each for materials and takes 2 people 2 days to construct it. The installation of vehicle washdown stations was assumed to occur at 1 per 100km2. The vehicle washdown stations are estimated to cost $45k each for materials and takes 2 people 2 days to construct it. We assumed that the installation locations for all cleaning stations will be allocated strategically under local managers direction. We estimated the drive distance for structure installations to be 5kms per structure, the furthest point away from the operations centre (the centre of 100km2 area that is 10x10km). i.e. To construct 11 structures we will need to drive there and back of 5kms from the centre to the edge. (110km of driving = 11structuresX5kmsX2).
They was estimated to occur every 10 years, assuming all structures are replaced every 10 years and required the same effort.

4. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis, and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We further included an estimate of effort of 3 weeks to account for extra work required for general disease management, like the implementation and communication of hygiene management plans. This action was assumed to occur every 10 years in the office (off-site).

Appendix 5.4: Disease Management (Phytophthora)

Summary

This TAS is a Phytophthora specific disease management and complements the general disease TAS (see Appendix 3) and the national-level biosecurity action across fauna, flora and diseases (see Appendix 1).

Phytophthora threatens 70 threatened species that include plants (58), birds (8), invertebrates (3) and reptile (1) (Ward et al. Unpublished results). The disease management of Phytophthora included actions to monitor the disease, the aerial application of Phosphite across the entire management area and manual injection of 1% of the management area.

Assumptions

Spatial maps

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

The management areas defined as the phytophthora treatment layer was the realised and potential distribution of phytophthora (see Supp. Material 2). We assumed that this layer would then be cropped to the relevant management extent in which an impacted species overlaps with the disease's distribution. (see Supp Material 2).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We further included an estimate of effort of 3 weeks to account for extra work required for general disease management, like disease sample processing. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species, collecting disease samples. We estimated the effort for 100km2 to be 2 persons walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management action 1 (a) – Phosphite application of infected areas

This action represented the aerial administration of phosphite to control Phytophthora. We based the core of our assumptions on the application recommendations from the Centre for Phytophthora Science and Management (CPSM No date).

We estimated the effort of aerial spraying the full 100% of management areas, performed as an aerial low volume mist spray done at a transect width of 20m. The aircraft hire was assumed to be $850/hr including a pilot with a working speed of 130km/h and transit speed of 250km/h. This was done twice annually 4-6 weeks apart.

The consumables of Phosphite was assumed to be a total of $55,680/km2 of a phosphite solution application of 40% v/v 6000L/km2, a summation of the cost of 40% phosphite $55,200/km2 and 1% adjuvant $480/km2. The recommended Phosphite concentration was 40% v/v 6000L/km2 (CPSM No date) that translated to 2400kg/km2 at $23/kg of phosphite (Monopotassium phosphate technical grade taken from eBay - *https://www.ebay.com.au/itm/Monopotassium-Phosphate-technincal-grade/174310281922?hash=item2895b3d2c2:g:idYAAOSwVzxe3edi)*. The recommended adjuvant was 1% adjuvant v/v 6000L/km2 (https://www.smbsc.com/pdf/SprayAdjuvants.pdf) that translated to 60L/km2 at $8/L ($160 for 20L container of protec plus spray adjuvant canola oil found from https://specialistsales.com.au - *https://specialistsales.com.au/shop/woody-weeds/wetting-agents-woody-weeds/protec-plus-spray-adjuvant-canola-oil/)*

4. Management action 1 (b) – Manual Phosphite application of infected areas

This action was to capture the manual injection of phosphite to plants that require more treatment, complementing the aerial application above. We estimated the effort required for manual injection to be 1% of the management area.

We assumed that this was done by foot, with the transect width walked being 10m and it takes 5 minutes for each tree injection. The consumable cost was $0.50 per tree (CPSM No date) that translated to $50,000/km2, assuming 1 tree every 10m2 or 100,000 trees/km2.

5. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels, involving tasks like walking through and collecting disease samples to evaluate outcome of action. We estimated the effort for 100km2 to be 2 persons walking through 30% of the management area by foot at transect widths of 250, with 20 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

6. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis, incorporating insights into the updated management planning, and disease sample processing. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We further included an estimate of effort of 3 weeks to account for extra work required for disease management, like the implementation and communication of hygiene management plans. This action was assumed to occur every 10 years in the office (off-site).

Appendix 5.5: Ecological Fire Regime Management

Summary

Fire regimes under management are governed by the extent, patch size, frequency and intensity ideal for each vegetation subgroup. In some cases this involved maintaining fine-scale mosaic patches of time-since burnt stages, and reducing the incidence and severity of large catastrophic fires. Species differ in tolerance to fire, and as such the frequency, intensity, extent, and timing is important. Many plants and communities require regular disturbance and burning, and some animals rely on post-fire growth and flowering of plants for habitat and resources. Other native fauna species depend on long unburnt vegetation for the provision of food, development of complex vegetation and ground-level structure for foraging and refuge from predation, and tree hollows for nesting and roosting. Changes in land use, management, and anthropogenic climate change have resulted in dramatic changes in fire regimes across Australia from pre-European fire regimes. Furthermore, many areas are experiencing larger, more frequent, and intense fires, often outside of the traditional fire season.

Here, we synthesised research to outline a broad set of ecological appropriate fire regimes with the goal to ensure threatened species persistence. This was used to estimate the effort of ecologically appropriate fire regimes across the entire distribution of threatened species in Australia according to the pre-1750 vegetation area. We have only included the regular fire management to reduce the size and intensity of large burns and have excluded all fire suppression costs and catastrophic fire costs, as they were inherently too context specific, haphazard and complex for this costing exercise.

We incorporated assumptions to address the extent, patch size, and frequency, but did not make any assumptions on the intensity of fire burning. The actions costed were 1) installation of fuel reduced buffers, and 2) prescribed burning (aerial burning in regional and remote areas, and ground burning in urban areas). The estimate of efforts was done in 2 steps. In the first step the action cost/km2 was allocated to the respective actions, and in the 2nd step we scaled the costs by vegetation type to account for frequency/extent of burn area and the proximity to urban settlements for level of ground support required.

We emphasise that these cost models are not spatially or method prescriptive, but instead an indication of the effort required that estimates generic costs across a broad-scale area.

These actions formulated are formulated to increase the persistence of threatened species while maintaining human safety, but not targeted at infrastructure and human protection.

Assumptions

Spatial maps

We used the pre-1750 vegetation map to determine the extent of area burnt (see Table 1 And Supp Material 2). We assumed that all of Australia will need fire management apart from Tropical rainforest and Temperate rainforest that were excluded from all costings (Table 1).

We used the Accessibility Remoteness Index of Australia (ARIA, see Supp. Material 2), where aerial prescribed burning was done in remote and regional areas, and ground burning was done in urban areas. We further used ARIA as a scaling factor for the fuel reduced buffer installation, using the urban areas as the base cost and scaling down the cost by a factor of 7.5 for regional and remote areas.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Table 1. The extent (Adapted from Enright and Thomas 2008) that used multiple lines of evidence, including paleo-environmental, ecological, historical, anthropological and archaeological, to estimate pre-European fire regimes in Australia, with particular focus on the extent to which the use of fire by Aboriginal peoples.

Vegetation type	Natural Fire Interval	Assumed fire interval (years)	Assumed Extent for costings (% of 100km2)
Tropical rainforest	>300 years (very long)	300	0%
Temperate rainforest	>300 years (very long)	300	0%

Dry sclerophyll forest	30-100 years (Intermediate - Long)	65	1.90%
Wet sclerophyll forest	10-30 years and 50-100 years (intermediate - long) (average of 20 and 75)	47.5	2.11%
Desert	20-50 years (Long) rainfall-annual grass biomass event driven	35	2.86%
Semi-arid spinifex grasslands	10-30 years (intermediate - long) rainfall-spinifex biomass event driven	20	5.00%
Shrubland	10-30 years (Short - intermediate)	20	5.00%
Tropical savanna	2-4 years (very short)	3	33.33%

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We further included an estimate of effort of 3 weeks to account for extra work required for fire management, this included activities like using satellite imagery/aerial survey to evaluate distribution of seral stage/fuel age, determining extent to be burnt, determining desired burn patch size range, and to plan for seasonal burning that is rain/wind dependent. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning (Aerial)

This action represented the surveying needed of the management site. This involved flying and conducting surveys of 100% of the management area. This was done at 500m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually.

3. Pre-action field planning (ground)

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species. We estimated the effort for 100km2 to be 2 persons walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

4. Management action 1 - Fuel reduced buffer establishment

This action represented the effort to ensure that reduced fuel buffers are established before the prescribed burning. We acknowledge that this is done differently (if done at all) across Australia, and that this action is not spatially or method prescriptive, but instead an a placeholder for the effort and cost required to establish safe prescribed burning.

Our estimated effort was based on on-ground establishment to produce 50 m fuel reduced buffers, this will vary by context but we used it as an indication of cost across Australia. The estimated effort assumed was 0.57 hours/km (~ 1.5-2km per hour) to reduce fuel cover to ~10-15% (pers comms with Stephen van Leeuwen). We used a fixed perimeter length of fire breaks per 100km2 based on the patch size proportions required for burning in a particular context (pers comms with Stephen van Leeuwen).

We assumed 3 fixed patch sizes with the total perimeter for fuel reduced buffers assumed being 217km per 100km2. The first was 35% burnt by ≤ 2km2 patches, resulting in 35 of these patches with median 1km2 creating a perimeter of fire breaks of 140km (35x4km). The second was ~35% burnt by 2-10km2 patches, resulting in 5.83 of these patches with median 6km2 and a perimeter of fire breaks of 57 km (5.83x9.8km). The third was ~ 30% burnt by 10-60km2 patches, resulting in 0.86 of these patches with median 35km2 and a perimeter of firebreaks of 20km (0.86x 23.66km).

Along this 217km of perimeter, the fuel reduced buffer establishment was assumed to be done first with 2 people in the 4wd with a drag and flamethrower, followed by a crew of 4 walkers with drip-torches, and 1 driving the water truck to put out fires when necessary.

The 4wd effort was to create a cleared track with a drag and cold burn when necessary. We estimated the cost for a 5m harrow to scrape vegetation to be $1,690 (pasture harrows found from hayesproducts.com.au - https://hayesproducts.com.au/product/pasture-harrows-16-1-2ft-folding-1336/). For a mounted flame thrower we assumed that we required 1 litre per km of fire break at $1.25/L and the flame thrower was estimated at $400 (sheen flame gun weed killer back burning machine found from eBay - https://www.ebay.com.au/itm/Sheen-Flame-Gun-Weed-Killer-Back-Burning-Machine-Made-in-England/133457489654?hash=item1f12afaef6:g:dMsAAOSwAlJeVd24). All equipment was purchased every 10 years.

The crew of 4 with drip torches then did burns back to these 4wd cleared tracks, creating wider road buffers. We assumed 1L/km of drip torch burning at $1.25/L (25% unleaded at $1.40 and 75% diesel at $1.25) and the drip torches cost $330 each (based on driptorches found on specialistsales.com.au https://specialistsales.com.au/shop/farm-chemicals/farm-speciality-products/drip-torch-firelighter/pacific-fire-lighter-mkii-hand-held-drip-torch/, and pacfire.com.au https://www.pacfire.com.au/product/fixed-wand-fire-lighter-drip-torch/). All equipment was purchased every 10 years.

Ground support costs, this was a placeholder that can be replaced with any ground support like fuel dumps and other preparation needs. For effort estimation purposes, we assumed we needed a heavy duty appliance truck to be on site to provide water for suppression. Ground support cost was estimated at $200/hour and we assumed 2 water refills every 100km at a refill rate of $300 (based on "Water Cart (9,000 - 16,000L) wet hire rate: $125 - $178 + GST Per Hour" and "The average cost of refilling the water tank in a water cart is around $300 for 14,000 litres" taken from https://blog.iseekplant.com.au/blog/water-cart-hire-rates)

We scaled this cost based on our estimates for aerial vs ground burning, as a proxy to the proximity to urban settlement. We scaled the relative effort down for remote/regional areas using a factor of 7.5, this was to account for proximity of population that influences cost. We estimated a cost for ground support, in our case we have used a water truck as the estimation of effort, however we acknowledge that this can be replaced with fuel dump support, a stand-by water truck, or any other ground needs.

5. Management action 2 - Aerial burning

This action represented the aerial prescribed burning done in remote and regional areas. The estimated effort was to perform the aerial burn with aircraft dropping capsules at transect widths of 10km (personal comms with Sarah Legge and Sundance)

We assumed $1500/hr for aircraft hire and a working speed of 130km/h, based on an average cost of turbine helicopters and fixed wing aircrafts (pers comms with Sarah Legge). We assumed a drop rate of 1 capsule per second or 28 capsule drops/km (personal comms with Sundance), assuming a working speed of 130km/h or 28 seconds/km. Capsules/balls are at $0.35 that are injected with glycol that cause it to ignite 30/40 seconds later when it hits the round (pers comms with Sundance). We assumed an incendiary machine would cost $20k (no cost information available but an estimate found on a forum http://www.bladeslapper.com/viewtopic.php?t=8515). Potential brands considered were the raindance R3 dispenser and the red dragon taken from https://www.raindancesystems.com.au/capsules/ and https://www.sei-ind.com/products/red-dragon/)

We estimated a cost for ground support, in our case we have used a water truck as the estimation of effort, however we acknowledge that this can be replaced with fuel dump support, a stand-by water truck, or any other ground needs. Ground support cost was estimated at $200/hour and we assumed 2 water refills every 100km at a refill rate of $300/hr (based on "Water Cart (9,000 - 16,000L) wet hire rate: $125 - $178 + GST Per Hour" and "The average cost of refilling the water tank in a water cart is around $300 for 14,000 litres" taken from https://blog.iseekplant.com.au/blog/water-cart-hire-rates). The time estimated needed for the ground support was the time to drive the entire perimeter of the burn area as set out in the fuel reduced buffers, in this case 5.44 hours from a perimeter of 217km at travel speed of 40 km/h.

6. Management action 2 (b) - Ground burning (ARIA urban)

This action represented the ground prescribed burning done in urban areas (ARIA). The estimated effort was to perform the ground burn with a group of 4 walking with driptorches at transect widths of 500m.

We assumed a crew of 4 people, and they walked at the "high" resistance speed of 2.23km/h while performing the burn, regardless of resistance. We assumed they need an extra 10 minutes per km walked for burning activity. We assumed 1L/km of drip torch burning at $1.25/L (25% unleaded at $1.40 and 75% diesel at $1.25) and the drip torches cost $330 each (based on driptorches found on specialistsales.com.au https://specialistsales.com.au/shop/farm-chemicals/farm-speciality-products/drip-torch-firelighter/pacific-fire-lighter-mkii-hand-held-drip-torch/, and pacfire.com.au https://www.pacfire.com.au/product/fixed-wand-fire-lighter-drip-torch/). All equipment were purchased every 10 years.

Ground support costs, this was a placeholder that can be replaced with any ground support like fuel dumps and other preparation needs. For effort estimation purposes, we assumed we needed a heavy duty appliance truck to be on site to provide water for suppression.

Ground support cost was estimated at $200/hour and we assumed 2 water refills every 100km at a refill rate of $300/hr (based on "Water Cart (9,000 - 16,000L) wet hire rate: $125 - $178 + GST Per Hour" and "The average cost of refilling the water tank in a water cart is around $300 for 14,000 litres" taken from https://blog.iseekplant.com.au/blog/water-cart-hire-rates). The time required for the ground support was estimated to be as long as the crew took to walk and ground burn the area.

7. Post-action monitoring (Aerial)

This action represented the post-action surveying needed of the management site. This involved flying and conducting surveys of the action across 100% of the management area. This was done at 10km transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually.

8. Post-action monitoring (Ground)

This action represented the post-action monitoring needed on the ground, involving tasks like surveying the extent and severity of the fire management and the impacts on threatened species. We estimated the effort for 100km2 to be 2 persons walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

9. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Further assumptions

The generic fire management process (for a standard management of 100km2)

Installation of fuel reduced buffers are recommended to act as containment of prescribed burns and natural bushfires (pers comms with Stephen van Leeuwen). This acts as a preparation for the prescribed burning. In areas that do not require fuel reduced buffers, this can act as a placeholder for other pre-burn preparation costs. The buffers were estimated to be done with a crew of 4 walkers with drip-torches, 2 people in the 4wd with a drag and flamethrower, and 1 driving the water truck to put out fires if/when necessary. We used fixed patch sizes as a rough indication of the total perimeter needed for fuel reduced buffers, that amounted to 217kms per 100km2 (see spatial-based multiplier assumptions below).

We assumed fixed patch sizes for the costing of fuel buffer installations. We acknowledge that fuel buffer installations are context specific that vary vastly across the continent. To get an indication of fuel buffer installation, we have chosen one method and the underlying assumptions. However this is not prescriptive of method nor spatial effort, more a method of estimating effort required for the fuel buffer installation. We assumed a fixed proportion of patch size burns to calculate the perimeter needed for the buffers. We used a fuel buffer installation of 217km per 100km2 of managed area, that assumed a standardised patch size proportion of 35% of <2km2 patches, 35% of 2-10km2 patches, and 30% of 10-60km2 patches (pers comms with Stephen van Leeuwen).

The prescribed burning was the generic burning action that occurred, aerially burnt in remote/regional areas, and ground burning in urban areas. The aerial burning will be the average cost of a turbine helicopter and a fixed-wing craft flying with an incendiary capsule dispenser at a dispense rate of 1 capsule per second. We used 10km transects as an indication of approximate flying distance for the burning. This was also accompanied by ground support for fuel dumps and stand-by water trucks along the fire breaks. Ground burning was done with a crew of 4 walkers with drip torches, and an accompanying ground support for water trucks.

We simplified our fire regime cost models and adapted assumed fire intervals for vegetation type (Enright & Thomas 2008) that determined the extent of area burnt (see Table 2). To account for the “frequency” of burning, we further assumed that burns occurred on an annual rotational basis but limited by the extent of area burnt required, and when done in perpetuity this allows all areas within the management are to be of the same burnt age). This would be done at the local managers discretion to create the mosaic patterns of seral/fuel stages. i.e. an area that shouldn’t be burnt has 0% annual extent burnt (i.e. tropical/temperate rainforest, see Table. 2). An area that should be burnt 1 in 50 years has 2% extent annual area burnt, and if 2% is burnt annually for 50 years the rotation ensures the whole landscape has a 50-year burn “age” at the end of 50 years (similar to desert and wet sclerophyll forest, see Table. 2).

Looking at the proximity to human settlement and cost differences, Florec et al. (2019) showed that the changes in prescribed burning costs based on proximity to town scaled in costs by **5.05** (<5km), 1.29 (5-20 kms) and 0.67 (>20km). We assumed the maximum increase in cost was 7.5 times, calculated as the full range of the scale of cost differences (5.05/0.67).

For fuel reduced buffer installation, we scaled the relative effort down for any rural and regional area using a factor of 7.5, resulting in non-extent scaled fuel reduced buffer installation costs of $1,490/km2 for urban areas, and $198/km2 for regional and remote areas.

As we had split our prescribed burning actions by proximity to cities (ARIA scale – urban, regional and remote), our prescribed burning action had inherently captured this difference in costs with aerial (regional/remote) and ground (urban). We had a multiple of **15.9** for unscaled costs of aerial burning $73/km2 vs ground $1167/km2 (Table 2), not including transport to the management site. This was nearly double of the 7.5 multiplier assumed by

Florec et al (2019), however as we are considering generic actions in broad-scale areas we are comfortable with this.

Sense checking results

Our cost model for our fire regime management is split by vegetation type and action type: firebreak + prescribed burning done via aerial (remote/rural) vs ground (urban) (Table 2).

Any sense checking of numbers should be done with “unscaled costs” (assuming every km2 is managed), as our costs for the different vegetation types have been averaged across the 100km2 managed area to account for the extent of burning for the vegetation type (% of managed area). The costs that we compare our cost models to are costs to manage every km2.

Table 2. Table of our cost model output for fuel reduced bufferes and prescribed burning (aerial vs ground) for different vegetation types scaled by extent managed for a 100km2 managed area.

			Costs/km2			
Vegetation type	Assumed fire interval (years)	Assumed Extent for costings (% of 100km2)	Aerial action (regional/remote)		Ground action (urban)	
			Fuel reduced buffer	Aerial	Fuel reduced buffer	Ground
Unscaled cost	1	100%	$ 198	$ 73	$ 1,490	$ 1,167
Tropical rainforest	300	0%	$ -	$ -	$ -	$ -
Temperate rainforest	300	0%	$ -	$ -	$ -	$ -
Dry sclerophyll forest	65	2%	$ 4	$ 1	$ 28	$ 22
Wet sclerophyll forest	47.5	2%	$ 4	$ 2	$ 31	$ 25
Desert	35	3%	$ 6	$ 2	$ 43	$ 33
Semi-arid spinifex grasslands	20	5%	$ 10	$ 4	$ 75	$ 58
Shrubland	20	5%	$ 10	$ 4	$ 75	$ 58
Tropical savanna	3	33%	$ 66	$ 24	$ 497	$ 389

(1) Fuel reduced buffer installation

Fire management costs (pers. Comms with Stephen van Leeuwen)

- $980/km for Fire break establishment
- $800/km for fire break maintenance

Our unscaled fuel reduced buffer installation costs per unit area are $1,490/km2 that translates to per distance unit of $685/km (assuming fixed patch size and 217km of perimeter needed over 100km2). This is ~54% lower than what was quoted by Stephen, however we haven’t included transport costs (travel from closest city is done as a separate costing exercise). Our firebreak costs include labour, cost of travel “on-site” (4wd), accommodation/food, consumables like fuel, and driptorches.

(2) Prescribed burning cost checking

To get some general estimates of fire management costs to cross check our numbers, we used multiple sources (literature, personal communicaitons, government agencies) and the suggested costs were quite variable across different areas, ranging from $50 to $11.5k per km2.

Our costs compared here were only the prescribed burning action itself, unscaled for any vegetation type and does not including any travel to site and other planning and monitoring costs. Our costs for aerial prescribed burning appeared to be a conservative estimate, consistently under-estimating and ground prescribed burning lie within the range (see Table 3 below). Our costs for ground prescribed burning appeared to be overestimating for some and underestimating for others. As we will be applying a mix of both aerial (rural + remote) and ground (urban), and we are including fuel reduction buffers and other management actions, we expect the costs to be somewhere in between the wide-range of costs.

Table 3. Sense checking prescribed burning costs with cost suggestions from various sources.

		Our Aerial prescribed burning costs/km2 $ 73	**Our ground prescribed burning costs/km2** $ 1,167
Sense-checking costs	Cost indication per km2	Difference in $	
WA Cost per km2 for smaller areas (~300km2) Pers comms with stephen van leeuwen	$ 550	$ 477	($617)
WA Cost per km2 for bigger aresa (~1300km2) Pers comms with stephen van leeuwen	$ 300	$227	($867)
Florec et al. 2012 WA	$ 9,200	$ 9,127	$ 8,033
Tasmania	$ 11,500	$ 11,427	$10,333
Savannah burning	$ 75	$2	($1,092)
QLD governemnt suggest 2020 costs	$ 50	($23)	($1,117)
NSW SoS Urban	$ 90,000	$89,927	$88,833
NSW Rural	$ 26,700	$26,627	$25,533
NSW remote	$ 75,000	$74,927	$73,833

Sense checking sources:

- $5.5/ha for smaller areas (~300km2) $3/ha for larger burn areas (~ 1260km2) (pers comms with Stephen van Leeuwen). Pilbara region fire management costs that include travel, salary, allowances, vehicle costs and overheads
- Florec et al. (2012) estimated costs at around $92/ha based on a time series of data gathered from WA
- Forestry Tasmania indicated that fuel reduction burning costs in Tasmania can range from around $60-300 per ha but average around $115 per ha
- Savanna burning project suggested $0.50/ha to $1.00/ha (2020 costs)
- QLD Gov suggested $0.50/ha (2020 costs)
- NSW SoS suggested $900/ha for urban, $267/ha for rural, and $750/ha for remote

Ecologically sensible fire management regimes

Prescribed burn costing under ecologically sensible fire regimes are based on 4 main variables spatially. Fire frequency, the number of years between fire OR the number of fires in a given time. Fire extent, the area covered or "patchiness" of fire, to avoid targeting the same species with burning, but instead having "mosaic" burning alternating between various patches. Big fires generally don't leave any unburnt areas, but smaller wildfires do and these serve as important refuges for animals. Fire season, the time of the year suitable for fire management that is affected by vegetation type, burn objective, weather and associated environmental variables. Important to consider animal breeding cycles, i.e. spring fires remove food for mammals and birds. The fire intensity, temperature of the fire that varies according to windspeed, temperature, humidity, slope, fuel load, soil moisture and vegetation structure.

Appendix 5.6: Forestry management

Summary

Timber harvesting threatens 32 species (14 birds, 11 inverts, 10 plants, 1 reptile), and 8 mammals (Ward et al. Unpublished results). The threat abatement strategy included both non-spatial and spatial actions. For the non-spatial actions we included policy change, and mapping out forest extent/age distribution and increase accuracy of species occurrence models (non-spatial work accompanied by field information from below). This was then accompanied by spatial actions that included aerial/ground surveys for field information and forestry liaison officers. These were the liaison officer that are on-ground to communicate and monitor the threatened species habitats that overlap with forestry lands.

Assumptions

Spatial maps

The management layer used was the entire extent logging and production layer, which was the union of the current ABARES production and forestry layers combined with the full range of commercially viable forests (see Supp. Material 2). By including all potential timber harvesting areas, this was potentially a more complete view of impacted areas.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Management Action 1 - Aerial surveys

This action represented the surveying needed of the management site. This involved flying and conducting surveys of 100% of the management area to monitor forestry extent and configuration, age distribution of forests and monitoring of impacts of illegal timber harvesting. This was done at 500m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to be done every 5 years.

3. Management Action 2 - Ground surveys

This action represented the on-site surveying needed in forestry areas, to increase accuracy of species occurrence models by surveying for threatened species. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur every 5 years on-site.

4. Management Action 3 – Mapping forest extent/age distribution and increasing accuracy of threatened species occurrence

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. This action represented the non-spatial cost for personnel to incorporate field information, research, prior knowledge into a coherent mapping exercise. This was assumed to use information gathered from aerial and ground surveys. We estimated the total effort to be 12 weeks or 60 days of effort from 1 staff at management level at $65/hr and 10 experienced staff at $45/hr. This action was assumed to occur every 5 years in the office (off-site).

5. Management Action 4 – Policy change, compliance and education

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The tasks involved included negotiation policy change to stop logging in all threatened species distribution, compliance, communicating the impact of threats on threatened species, and devise best management practice for long-term sustainability. We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

6. Management Action 5 – Forestry liaison officers (spatial)

This action represented liaison officer that are on-ground to communicate and monitor the threatened species habitats that overlap with forestry lands. We estimated the total effort to be 3 weeks (15 days) of 2 ground staff at entry level pay of $30/hr, and they would stay on-site. This was done annually.

7. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis, incorporating insights into the updated management planning, and disease sample processing. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur every year in the office (off-site).

Appendix 5.7: Grazing Management

Summary

Grazing threatens 341 species (211 plants, 52 birds, 30 inverts, 18 mammals, 16 fish, 14 reptiles) (Ward et al. Unpublished results). The biggest impact from grazing was assumed to be the loss of native vegetation through land clearing, degradation from the loss of ground cover and soil erosion from trampling and grazing, and water quality degradation from livestock use of waterways (Stevens 2001). The management actions adopted in this TAS to abate these threats were communication/education, sustainable agricultural co-management, fencing key habitats and fencing and protecting waterways (Fisher et al. 2005; Natural Resources ; Staton & O'Sullivan 2006). The TAS here was not to be prescriptive but are in place to allow costs to be estimated. The details of the management needs to be worked out for the specific context of each threatened species and landholder.

Sustainable agricultural co-management was a placeholder action that included activities like keeping livestock out of areas where grazing was incompatible with impacted species, manage grazing at low levels where some grazing can co-occur with impacted species, grazing for shorter periods, excluding stock during parts of the year, and grazing management to maximise weed suppression.

Fencing was used to manage stocking rates and timing of grazing, both which will be adjustable by local conditions and impacted species requirements.

Grazing management in its entirety includes other grazing impacts by native animal grazers and feral grazer management. These were costed under separate TAS (see Large Invasive herbivores and Native Herbivore management). Further actions required on pastoral properties that are done in tandem, such as fire management, invasive predators and invasive weeds are not included here as they are also costed separately (see Ecological Fire Management, Invasive predators, and Invasive weed management).

Assumptions

Spatial Maps

There were 2 management layers used. The first was the grazing layer that was taken from ABARES that included the categories grazing native veg and grazing modified pastures (see Supp. Material 2). This was used for all actions. The second layer that was superimposed on top of the first layer was the Australian waterways layer (see Supp. Material 2). This was used for the waterway fencing cost estimate.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning (Aerial)

This action represented the surveying needed of the management site. This involved flying and conducting surveys of 100% of the management area, monitoring habitat extent and configuration and habitat quality. This also included monitoring of direct impacts like destruction of native vegetation through grazing and trampling, land clearing. This was done at 500m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually.

3. Pre-action field planning (Ground)

This action represented the on-site preparation needed, involving tasks like monitoring grazing pressure, land clearing, erosion, condition of land, impact on threatened species, monitoring water quality, and checking area suitability for fencing. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

4. Communication & education (non-spatial)

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. This was team of liaison officers to drive policy change, compliance and awareness. The tasks involved included communicating the use of better infrastructure for controlling grazing pressure, facilitating the increase of access of farmers to monitoring results, implementing best management practice for long-term sustainability, communicating the impacts of artificial water holes. We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

5. Sustainable co-management of land

This action represented liaison officer that are on-ground to communicate and work with land-users. This included the effort to co-manage the lands for farming impacts, and planning, implementing and managing the grazing management practices appropriate to each context (i.e. Monitoring stock entering fencing area). We estimated the total effort to be 3 weeks (15 days) of 2 ground staff at entry level pay of $30/hr, and they would stay on-site. This was done annually.

6. Threatened species key habitat fencing

This action represented the effort of fencing required to manage grazing for threatened species conservation. We assume fencing is done along the perimeter of 40km of the standard broad-scale of 100km2 in a square (10x10km), resulting in 400m of fencing per km2.

The costings involved initial costs of fence-line clearing and construction, that was assumed to be done every 20 years. The on-going maintenance was done annually. The equipment cost was $10k replaced every 10 years.

The initial fence line clearing labour was 62.5 hrs/km that was standard across all fencing types. For cattle fences that were 5 strand plain wire fences, the initial fence construction was estimated for labour at 25 hrs/km (team of 2 working at 12.5hrs each), materials at $7k/km (pers. Comms with Stephen van Leeuwen DBCA). The on-going maintenance and fence-line clearing was assumed to be around 20% of initial labour and 10% of initial material costs (Trust 2004), we assumed 5 hrs/km for labour and $700/km for materials.

7. Water way management Fencing to restrict access from livestock

This represented the cost of fencing for waterways. Although 100m was considered good practice, we assumed a 500m buffer either side of water that resulted in a total buffer of 1km (Hansen et al. 2015). We used the same assumptions as above for fencing costs, however instead of using the perimeter length we used the waterway map and estimated the effort to be the full length of fencing of both sides of the waterway. i.e. a 100km waterway length resulted in 200km length of fencing.

8. Post-action monitoring (Aerial)

This action represented the monitoring of the management action implementation and threat levels. This involved flying and conducting surveys of 100% of the management area. This was done at 500m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually.

9. Post-action monitoring (Ground)

This action represented the monitoring of the management action implementation and threat levels. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

10. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Further Assumptions

Fencing Costs

We assumed fencing was done for a perimeter of 40km, at the standard broad-scale of 100km2 in a square (10x10km), attributing 400m of fencing to each 1km2. Cost-wise, there is the initial costs of fence-line clearing and construction (done every 20 years), and then the on-going checking and maintenance costs (done annually). We also assumed $10k of equipment costs.

Fence line clearing labour was costed at 60 hours/km, as a team of 2 working 30 hours each per km. This was assumed to be standard across all fencing types. The fence-line clearing was estimated at $2.5k/km, based on the average of $1.95k/km for smooth and $3k/km for rocky terrain (pers. comm Stephen van Leeuwen DBCA) that translated to 62.5 person hours/km assuming $40/hour of wages.

Fence construction was assumed to differ in materials and labour depending on the animals that were excluded. Fencing for cattle assumed a 5 strand plain wire fence. This required labour at 25hours/km, a team of 2 working at 12.5 hours each, and the materials were costed at $7k/km.

This was based on $5.8k materials/km in 2012 Dollars that translated to ~$7k/km in 2020 dollars (Pers comms with Stephen Van Leeuwen DBCA). The estimate of labour was $1k Labour/km that translated to 25 person-hours/km at $40 per hour, or 12.5 hours/km as a team of 2.

Fencing for small feral animals (e.g. cats, foxes, rabbits) assumed floppy top design with hot wires removed from SA Arid recovery fence (Moseby & Read 2006). We estimated labour at 212.5 hours/km, a team of 2 working at 105 hours each. The materials were estimated at $9.6k materials/km 2012 dollars that inflated to $11k/km in 2020 dollars (Pers comms with Stephen Van Leeuwen DBCA). Labour was $8.5k labour/km that translated to 212.5 person-hours/km assuming 40/hour.

Fencing for Kangaroos was assumed to be with clipex posts and 15/180cm/15 tuffknot prefab with a stiff apron (15 horizontal wires, 180cm high section, and 15cm between pickets) (DELWP 2021; Giumelli & White 2016). Labour was estimated to be $3k/km that translated to 75 hours/km or a team of 2 working at 37.5 hours each. Materials were estimated at $5k/km.

For on-going fence checking, maintenance and fence-line clearing, we assumed it took 20% of initial construction labour, and that 10% of material is needed to reconstruct every year from damages. A report survey showed that approximately effort that was needed for maintenance for cat/fox fences (Long & Robley 2004). We then calculated the proportion to be ~20% based on the maintenance and checking time of 47hours/year/km for cat/fox fences (0.9hours/week/km) as a proportion of construction time of fencing at 212.5 hours/km. This resulted in ongoing fence maintenance for cattle to be 5 hours/km – team of 2 working at 2.5 hours/km each and materials at $700/km. For small feral animals, we assumed 42 hours/km, a team of 2 working at 21 hours/km each and materials at 1.1k/km . For Kangaroos fences we assumed labour at 15 hours/km, a team of 2 working at 7.5 hours each and materials at $500/km.

Appendix 5.8: Habitat restoration

Summary

The management goal was to ensure that all potential habitat for threatened species were restored. We have costed habitat restoration in all areas identified as cleared but restorable. Essentially, if it is cleared and restorable we do habitat restoration, if it is vegetated and there's a weed-threatened species there we do invasive weed management (see Invasive Weed Management), and finally if it is vegetated with no weed-threatened species there we don't do anything.

The habitat restoration action involved two actions, firstly weed control followed by bush regeneration. Weed control involves physical and chemical control, with the objective to control and contain established weeds when eradication isn't possible. As we assume weeds have patchy occurrences and are invasive of all potential habitats, we assumed an overall 30% of the management area needs weed treatment that is done annually, with 5% intensive weed management, 10% moderate weed management, and 15% light weed management. The bush regeneration of native vegetation involved using location-specific native seeds. Bush regeneration was assumed to occur for the entire management area and was done every 5 years. Where the land was cleared and needs new vegetation, we assumed bush regeneration efforts were split by 17% intensive, 33% moderate, and 50% light (maintaining the same proportion as invasive weed management of 5:10:15). We assumed that the effort of restoration would vary by vegetation type, and we scaled all final costs accordingly.

Assumptions

Spatial maps

We assumed habitat restoration would occur on cleared and restorable lands identified using an adapted land-use layer (see Supp. Material 2), and we scaled the costs using the summarised pre-1750 vegetation layer (see Supp. Material 2).

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent of restoration that is needed and the intensity of degradation. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management Action 1 – Policy change and compliance (non-spatial)

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The tasks involved the negotiation of policy change to address habitat retention issues, compliance, communicating the impact of threats on threatened species, and devise best management practice for long-term sustainability.
We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

4. Habitat Restoration (30% weed control + 100% bush regeneration)

We assumed that for the cleared and restorable management areas, 30% of the extent required weed control and 100% required bush regeneration. For costing purposes, we assumed 10m2 grids with 100,000 units per km2, and transect widths of 3.16x3.16. We assume that this 31,622 km of distance needs to be driven by a vehicle along these grids and staff are conducting weed management for each patch. There is no walking time penalty for terrain as we are driving along and not "walking" per se. The effort was estimated at the vegetation plot of 10m2. There was no distinction made between weed control and bush regeneration effort, and we assumed that the effort spent in each plot was split across 3 levels, intensive, moderate and light.

For Invasive weed control, this was done annually and we assumed for every management area, there was 5% intensive weed control with labour of 2.7mins/10m2 and herbicide costs of $0.55/10m2, there was 10% of moderate weed control with labour of 1.95mins/10m2 and herbicide cost of $0.34/10m2, and there was 15% light weed control with labour of 0.68mins/10m2 and herbicide cost of $0.14/10m2. (see Table 4 for summary, and further below for more detail)

For bush regeneration, we maintained the same proportion of 5:10:15 for the management effort but upscaled it to 100%. We assumed bush regeneration was done every 5 years and for every management area, there was 17% of intensive bush regen with labour of 2.7mins/10m2 and consumables cost of $18/10m2 (4xforestry tubes with seedlings, 4xtree guards, and 2xwatering), there was 33% of moderate bush regen with labour of 1.95mins/10m2 with consumables cost at $9/10m2 (2xforestry tubes with seedlings, 2xtree guards, and 1xwatering), and there was 50% light bush regen with labour of 0.68mins/10m2 with consumables cost at $4.50/10m2 (1xforestry tubes with seedlings, 1xtree guards, and 0.5xwatering). We assume equipment cost of $10k bought every 10 years. (see Table 4 for summary, see below for more detail)

We then scaled the costs by vegetation type and assumed our estimated costs were the middle point of forest and woodlands (Table 5.)

Table 4. Time spent for weed control and bush regeneration, shown with the consumables cost below for weed control (herbicide) and bush regeneration (regen costs). For more detail see “action” assumptions below.

	Effort level		
	Intensive	Moderate	Light
Minutes spent/10m2	2.70	1.95	0.68
Weed control extent	5%	10%	15%
Herbicide Costs/10m2	$ 0.55	$ 0.34	$ 0.14
Bush regen extent	17%	33%	50%
Regen Costs/10m2	$ 18.00	$ 9.00	$ 4.50

Table 5. Categories for scaling revegetation costs, adapted from Maggini et al 2013. Major Vegetation groups (Department of the Environment and Energy (Australia) 2016)

Scaling Factor	Proportions scaling it to "forest and woodlands"
0.4	Grasslands
0.6	Shrublands
0.6	Chenopods, samphire shrubs and forblands
1	Forest and woodlands
1	Mangroves
2	Rainforest
2	Wetlands

5. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels, checking for outcome of weed removal and bush regeneration. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

6. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Further assumptions

(a) Habitat restoration - Weed control detail

We assumed Intensive weed control at $1800/ha for areas that had high severity weed invasion (adapted from NSW SoS). We assumed this was chemical and physical control of invasive weeds with a focus on the higher effort woody weeds. As we assumed $40/hour for person hours, this equated to an effort **of 2.7 minutes per grid of 10m2** (3x3m)

We assumed moderate weed control was at $1300/ha for areas that had moderate severity weed invasion (adapted from NSW SoS). We assumed this involved chemical and physical control of invasive weeds with a combination of higher effort woody weeds and lower effort herbaceous weeds. Assuming $40/hour for person hours, this equated to an effort of **1.95 minutes per grid of 10m2** (3x3m).

We assumed Light weed control at $450/ha for areas that had low severity weed invasion (adapted from NSW SoS). We assumed this involved chemical and physical control of invasive weeds, with a focus on the lower effort herbaceous (i.e. spot spraying). Assuming $40/hour for person hours, this equated to an effort of **0.675 minutes per grid of 10m2** (3x3m)

We split herbicide need by woody weeds and herbaceous weeds. We assumed the volume of herbicide needed for woody weeds was 4000 litres/ha and 1000 litres/ha for herbaceous weeds (based on foliar spray for Grazon Extra Herbicide concentrate, found on https://specialistsales.com.au). We then calculated the herbicide costs and took the average across two herbicide types, one glyphosate product and one triclopyr product. The consumables for Intensive efforts was the average of the woody weeds, and for light weeding it was be the average of consumables needed for the herbaceous weeds. The moderate weeding effort was the average of the intensive and the light effort.

The selective herbicide, Grazon Extra herbicide concentrate (100g/L Triclopyr, 300g/LPicloram +8g/L Aminopyralid) was $699 per 20 Litres, with a mix rate is 500ml per 100L of water (as found on https://specialistsales.com.au , https://specialistsales.com.au/shop/woody-weeds/woody-weed-herbicides/liquid-chemicals/grazon-extra-herbicide-triclopyr-picloram-aminopyralid/?attribute_pa_size=1-litre&gclid=CjwKCAjwtNf6BRAwEiwAkt6UQpa6tlJ6_NiYFKuSCwNYyPF03UdA_WQrsrG3bHvZ

LR0SbcrNtO2HlhoCDbcQAvD_BwE). The non-selective Glyphosate Roundup biactive Herbicide concentrate (Glyphosate present as Isopropylamine Salt at 360g/L) was $199 for 20 Litres, and mix rate was 10ml per Litre of water (1L per 100L of water) (as found on http://specialistsales.com.au , https://specialistsales.com.au/shop/woody-weeds/woody-weed-herbicides/liquid-chemicals/roundup-biactive-herbicide-glyphosate/?attribute_pa_size=20-litre&gclid=EAIaIQobChMInuG-nofZ6wIVYZ_CCh2u5AaIEAkYASABEgJor_D_BwE)

This resulted in herbicide cost of $0.55/10m2 for intensive weed control (mainly woody). $0.34/10m2 Moderate weed control (50:50 mix of woody and herbaceous), and $0.14/10m2 Light weed control (mainly herbaceous)

(b) Habitat restoration - bush regeneration details

The consumables cost were based on a report produced in South Australia (NMVU 2016). The standard consumables cost for plant propagation (planting seedlings) were, forestry tubes with seedlings at $3/each, tree guard at $1/each, and watering cost at $1/unit. Our cost was $4 (forestry tube + tree guard), compared to a study that showed the average stem cost is $4.10 and average cost/ha was $2,614/ha (Collard et al. 2020).

There were 3 levels of bush regeneration required after the corresponding levels of weed control. We assumed **$18/unit (10m2)** for bush regeneration after intensive weed control of **17% of managed area** that included 4 forestry tubes with seedlings, 4 tree guards, and 2 watering sessions. We assume an effort of 2.7 minutes per grid of 10m2 (3x3m) (same rate of work as intensive weed control). We assumed **$9/unit (10m2)** for bush regeneration after moderate weed control of **33% of managed area**, that included 2 forestry tubes with seedlings, 2 tree guards, and 1 watering session. We assumed an effort of 1.95 minutes per grid of 10m2 (3x3m) (same rate of work as moderate weed control). We assumed **$4.50/unit (10m2)** for bush regeneration after light weed control of 50**% of managed area, that included** 1 forestry tube with seedlings, 1 tree guard, and half a watering session. We assumed an effort of 0.7 minutes per grid of 10m2 (3x3m) (same rate of work as light weed control).

Not used in this report, however for reference the Standard consumables cost If we were doing manual seeding can be assumed to be $0.6/unit (10m2) for native seeds. This includes 1.2grams/10m2 (OR 120kg/km2) needed of native seeds and a $500/kg of seed collection from local areas.

Sense Check

Isolating the bush regeneration action costs, our cost models estimated between $228,740 for grasslands to $1,143,700/km2 for wetlands. This was compared to a case study that looked at tubestock establishment that cost $176,300 to $639,600/km2 and direct seeding that cost $170,300 to $909,700/km2 (Summers et al. 2015).

Appendix 5.9: Reinstating Aquatic Connectivity

Summary

Lack of freshwater connectivity is a major threat to freshwater biodiversity, which require connected networks of suitable habitat to carry out various life history cycles and functions. In addition, connectivity will be important for climate change adaptation and access to thermal refuges. There are multiple “instream structures” (i.e. bridges, ford crossings, weirs, culverts etc) that can impede freshwater connectivity. This can interrupt spawning, seasonal migrations, restrict access to preferred habitat or resources, hamper genetic flow, increase predation susceptibility as congregating below barriers, and impede larval drift through creation of still water. In NSW, the problematic structures were mainly weirs, followed by causeways and culverts, even though the most common structures were bridges they had minimal disturbance to flow and passage. If they don’t impede fish migration, they are not considered a threat, but physical structures that cross waterways can become a potential barrier to fish.

The main goal of this threat abatement strategy is to ensure connectivity of waterways, and this was done via investigation to determine whether a structure acts as a barrier and whether action is necessary. As each instream structure is context specific, we assumed a generic response and applied an assumed proportion of remediation action and the corresponding costs.

The proposed management actions for identified instream structures was to assign assumed proportions to determine what actions needed to be done on the number of structures. The cost estimation adopted for hydrology threat mitigation strategy was based on the number of instream water structures found in the threatened species range, identified through government spatial information provided by state/territories.

In summary, the proportion of structures that need an action implemented is 1/3, and of which the instream structures that are obsolete and can be removed is 1/15 (1/3 *20%) and structures that need a new fishway installed is 4/15 (1/3 * 80%). We do nothing for the remaining 2/3 of structures as it was not a barrier to fish passage

Assumptions

Spatial maps

We used the number of instream structures found throughout Australia (see Supp. Material 2). We also used the pre-1750 vegetation layer for the restoration management layer.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 1 instream structure to be 3 days of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur every 20 years in the office (off-site)

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like visiting the instream structure and conducting surveys. We estimated the effort for 1 instream structure to be 1 full day of 2 persons of entry level at $30/hr. This action was assumed to occur every 20 years on-site.

3. Management action 1 - Liaison with instream structure users (1/3 of structures)

This action represented liaison officer to engage commercial and recreational fisheries, recreational users, agricultural stakeholders before any remediation occurs. This was only estimated for instream structures that are assumed to need remediation. We estimated the total effort to be 3 weeks (15 days) of 2 ground staff at entry level pay of $30/hr, and they would stay on-site. This was done every 20 years. We applied 33.33% on the cost, as we assume only a third need remediation. The other 2/3 have no impact on fish movement.

4. Management Action 2 – Removal of obsolete structures (1/15 of all structures - 20% of 1/3)

After liaison with stakeholders, obsolete structures can be removed. The cost estimate used was \$530k in Dec-21 dollars (SMEC 2010) (\$650k in 2010 \$ value at 1.5% inflation, stripping out implicit 30% contingency multiplier) to remove structure, inclusive of all labour, materials and equipment). We added in cost of accommodation and travel for 2 personnel, assuming it takes 30 days for 2 personnel to complete job. This was done every 20 years. We applied a 6.67% multiplier (1/15) to costs as it only applies to 1/15th of the number of structures.

5. Management Action 3 – Installation of fishways (4/15 of all structures - 80% of 1/3)

After liaison with stakeholders, we estimated the cost to modify structures and install a fishway. We adopted the cost estimate of \$1.14m in Dec-21 dollars (SMEC 2010) (\$1.4 in 2010 \$ value at 1.5% inflation, stripping out implicit 30% contingency multiplier) to modify structure and install a fishway, inclusive of all labour, materials and equipment. We added in cost of accommodation and travel for 2 personnel, assuming it took 60 days for 2 personnel to complete job. This was done every 20 years. We applied a 4/15th multiplier to costs as it only applies to 4/15th of the number of structures.

6. Management action 4 – riparian restoration (4/15 of all structures - 80% of 1/3)

This was done for the area around each fishway installation in threatened species habitat. We assumed the same cost assumptions of habitat restoration costs (see Appendix 8 Habitat Restoration) but adapted to restoration needed per instream structure.

The riparian area for restoration was assumed to be 100m up and down stream of barrier, with a buffer of 100 m on either side (recommended riparian vegetation widths from: Hansen et al. 2015; Wenger et al. 2018). This resulted in the total management area to be 0.04km2 per instream structure for both river banks (0.2km river length*0.1km buffer*2sidesofriverbank).

We assumed that for every instream structure, 0.4km needs to be driven by a vehicle along these grids. There was no walking time penalty for terrain as we are driving along and not “walking” per se, and any required walking to move through the 10m2 units is already included in the activity time for weed management/bush regen.

The riparian restoration cost per structure was calculated from above and we then applied a 4/15th multiplier as we assume only 4/15th of structures need riparian restoration.

7. Management action 5 – Manual removal of Debris (4/15 of all structures - 80% of 1/3)
This was assumed to be done for the area around each fishway installation in threatened species habitat. Debris removal takes 2 personnel 3 days to do per structure and this was done annually.

8. Management Action 6 – Policy change and compliance (non-spatial)
This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The tasks involved included effort for negotiation of policy change to address hydrology issues, compliance, communicating the impact of threats on threatened species, and to devise best management practice for long-term sustainability. We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

9. Post-action monitoring (4/15 of all structures - 80% of 1/3)
This action represented checking efficacy of installation of fishways, riparian restoration and debris removal. We estimated the effort per instream structure was 1 day of 2 persons of entry level at $30/hr. This action was assumed to occur once every 5 years on-site.

10. Post-action evaluation (4/15 of all structures - 80% of 1/3)
This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort per instream structure to be 0.5 day at the experienced level rate at $45/hr. This action was assumed to occur every 5 years in the office (off-site).

Further Assumptions

Assumptions for 1/3 of structures that need remediation was adapted from a study conducted in the Namoi Catchment (Industries 2006). It showed that one-third (33%) of instream structures in the study area need remediation (162/496 sites), of which the 3 highest contributors were weirs (69), causeways (34) and culverts (25). For cost estimation purposes, we do not distinguish between the structure type (i.e. weirs, bridges, causeways, etc.).

For 1/3 of instream structures we needed to implement actions. The first action is to determine whether the instream structure can be removed, done through engagement of commercial and recreational fisheries, recreational users, agricultural stakeholders etc. After the engagement, for 1/15 (20% of 1/3), we removed the obsolete instream structures. The 20% of structures that need removal vs 80% of structures that needed a new fishway installed is roughly set to reflect the local communities and stakeholders preference to modify rather than remove structures.

Cost estimate of $530k to remove structure, inclusive of all labour, materials and equipment ($650k in 2010 $ value at 1.5% inflation, after removing the implicit 30% contingency multiplier from data source as we apply these at the end, see below for more detail)

For 4/15 (80% of 1/3) we estimated the cost to install fishways, implement riparian habitat restoration, and implement annual debris removal. We costed the modification effort of instream structures by installing a fishway when removal is not feasible. The cost estimate was $1.14m in Dec-20 $ to install fishway ($1.4m in 2010 $ value at 1.5% inflation, after removing the implicit 30% contingency multiplier from data source as we apply these at the end). Further follow-up actions associated with fishway installation were the annual removal of debris that obstruct fishways and the riparian habitat restoration around fishways as fish are more subject to predation with the congregation of fish at these bottlenecks.

The cost estimates of $650k and $1.4m (in 2010 $ value with 30% implicit contingency multiplier) were from a report that looked at 5 weir structure solutions (SMEC 2010). For each situation, they considered all construction options and went for the most viable and suitable option, with the average cost being $1.4m to construct a fishway and $650k for removal of weir.

To account for monitoring and change in instream structural usage over time, we assume a 5-yearly monitoring on the new fishway structures, and every 20 years the full action is repeated (i.e. all instream structure need to be reassessed for efficacy, fish migration, removal and/or fish way installation).

Appendix 5.10: Invasive Fish Management

Summary

The main actions for invasive fish management were policy, signage for education and awareness, manual removal of invasive species, invasive fish barriers for Trout, invasive fish barriers for Tilapia, and riparian restoration. All actions were done per river distance in km instead of per unit area.

Assumptions

Spatial maps

The general management layer was based on river networks to split rivers by major and minor types (see Supp. Material 2). The management layer for galaxias were the distribution of galaxias and its intersection with the trout distribution overlaid on the river networks see Supp. Material 2). The management layer for tilapia threatened species was the intersection of tilapia distribution and irrigated lands, overlaid on the river networks layer. We also used the pre-1750 vegetation layer for the restoration management layer.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Action

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species. We estimated the effort for 100km to be 2 persons of entry level at $30/hr walking along 30% of the river length (only one side) to observe the condition of the river and observe for invasive species. This action was assumed to occur at the walking rate that was consistent with "moderate resistance" of the Terrain Ruggedness Index (TRI) along the river bank. This action was assumed to occur annually on-site.

3. Management Action 1 - Policy, compliance and awareness

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The tasks involved effort to drive policy change, compliance and awareness on invasive fish. We estimated the total effort to be 1 FTE at management level at $65/hr and 10 FTE experienced staff at $45/hr. This action was conducted annually.

4. Management action 2 – Signage for awareness

The installation of generic signs was assumed to occur at 5 signs per 100km. We assume signs will be designed under local managers direction and are placed strategically. The signs are estimated to cost $2k each for materials and takes 2 people 0.5 days to construct it. They will be replaced every 10 years and require the same effort. The material cost was estimated for double sided signs standing at 1000mm high (https://www.qasigns.com.au/ground-sign-post-panel-sign)

5. Management Action 3 – Manual removal of invasive fish

This was estimated as a team of two full time staff per 100km river length at $30/hr to manually remove invasive fish from rivers. We required 2 personnel required per 100km river length.

6. Management action 4 – Fish barriers (trout and tilapia)

This is setting up fish barriers for invasive species and was split across trout and tilapia.

We estimated costs to manage trout only where the distribution of galaxias are threatened by trout. This was further varied by major barriers required in major rivers and minor barriers required in minor rivers. For major rivers, we assumed that we needed 20 concrete barriers needed per 100kms. They cost $1m to build (labour + equipment) (pers comms in NESP workshop), and we assumed they took 60 days to build with 2 personnel. We also assumed they need to be rebuilt every 20 years, and the maintenance cost is $100k done every 5 years, that has separate travel and accommodation/food costs. For minor rivers, 20 mesh barriers are needed per 100kms.

We assumed they cost $30k to build (labour + equipment) and they take 1 day to build with 2 personnel. They need to be rebuilt every year so there was no maintenance cost as rebuilt every year.

We estimated costs for tilapia management where the river network intersects with irrigated land. We assumed we needed 1 screen barrier on irrigation channels per 100kms of river length. We estimated the cost of $1.4m to build (labour + equipment) (Hutchison M. 2011) and we assumed it took 60 days to build, and they need to be rebuilt every 20 years with the maintenance cost being $100k done every 5 years.

7. Management action 5 – Riparian restoration (30% weed control + 30% riparian regen)
This was for any riparian area that intersected with a threatened species distribution.
We assumed the same costs in “Appendix 8 - Habitat Restoration” with some adaptations to the riparian habitat.

We buffered riverbanks by 100 m either side (recommended riparian vegetation widths from: Hansen et al. 2015; Wenger et al. 2018), reslting in the total management area to be 20km2 per 100km length of river for both river banks (100km river length*0.1km buffer*2sidesofriverbank). We assumed riparian regeneration was done 5-yearly with 2 personnel. We assumed that for every 100km length of river, 200km of distance needs to be driven by a vehicle along these grids and staff are conducting weed management and riparian management for each patch.

8. Post-action monitoring
This action represented the monitoring of the management action implementation and threat levels. We estimated the effort for 100km to be 2 persons of entry level at $30/hr walking along 30% of the river length (both sides would equate to 60km) to observe the condition of the river and observe for invasive species, and that sampling time was 10 minutes spent every km walked. This action was assumed to occur at the walking rate that was consistent with “moderate resistance” of the Terrain Ruggedness Index (TRI) along the river bank. This action was assumed to occur annually on-site.

9. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Appendix 5.11: Invasive Large Herbivore Management

Summary

We estimated costs for a combined large invasive ungulate management plan, where the invasive ungulate threat (68 pigs, 54 goats, 11 deer, 12 generic grazers, 8 horses and more) threaten 164 species (119 plants, 26 birds, 10 invert, 4 reptiles and 4 mammals) (Ward et al. Unpublished results). The impact of invasive ungulates was predominantly grazing and habitat degradation. Control methods for each of the large invasive grazer ungulate species were generally similar; therefore, we have costed out management across a combined map of occurrence of invasive ungulates. The management goal was to keep populations at low enough levels to abate the impact of large invasive ungulate grazing, and to limit the spread into unaffected areas.

The three proposed methods of management were 1) judas monitoring, 2) aerial culling in open-canopy vegetation types and areas of low human population density (remote and very remote Australia) accompanied by ground management of a proportion of the area (mustering), and 3) ground culling in areas that weren't suitable for aerial culling, i.e. anywhere with dense vegetation or areas of high human population density (Urban + inner/outer regional).

We have assumed that aerial culling can be implemented across multiple species simultaneously. We also treated mustering as a generic action across species, even though mustering, trapping and baiting have to be tailored to the species when finer management scales are taken into account.

Assumptions

Spatial maps

The general management layer was a combination of the available large invasive ungulates distribution (Pigs, goats, deer, horses, and camels, see Supp. Material 2). To determine suitability of actions for aerial or ground culling, we used a combination of ARIA and a vegetation map to determine general canopy cover (see Table 6). The management area for aerial culling was in open canopy vegetation or in all remote Australia. The management area for ground activity was everywhere else, i.e. dense canopy vegetation in remote/very remote Australia, and all urban and regional areas.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Table 6. Major Vegetation groups (Department of the Environment and Energy (Australia) 2016) and whether management for invasive species such as baiting and shooting can be done via ground control, or from helicopter. This is subject to conditions, for example, post severe bushfire many habitats become open enough for aerial shooting. In contrast, in wetter conditions vegetation may become thicker and therefore aerial management is not possible.

Ref #	Major Vegetation Group	Ground or Aerial
1	Rainforests and Vine Thickets	Ground
2	Eucalypt Tall Open Forests	Ground
3	Eucalypt Open Forests	Ground
4	Eucalypt Low Open Forests	Ground
5	Eucalypt Woodlands	Aerial
6	Acacia Forests and Woodlands	Aerial
7	Callitris Forests and Woodlands	Ground
8	Casuarina Forests and Woodlands	Aerial
9	Melaleuca Forests and Woodlands	Ground
10	Other Forests and Woodlands	Ground
12	Tropical Eucalypt Woodlands/Grasslands	Aerial
14	Mallee Woodlands and Shrublands	Aerial
30	Unclassified Forest	Ground
11	Eucalypt Open Woodlands	Aerial
13	Acacia Open Woodlands	Aerial
32	Mallee Open Woodlands and Sparse Mallee Shrublands	Aerial
31	Other Open Woodlands	Aerial
15	Low Closed Forests and Tall Closed Shrublands	Ground

16	Acacia Shrublands	Aerial
17	Other Shrublands	Aerial
18	Heathlands	Aerial
19	Tussock Grasslands	Aerial
20	Hummock Grasslands	Aerial
21	Other Grasslands, Herblands, Sedgelands and Rushlands	Aerial
22	Chenopod Shrublands, Samphire Shrublands and Forblands	Aerial
23	Mangroves	Aerial
24	Inland Aquatic - freshwater, salt lakes, lagoons	Aerial
25	Cleared, Non-Native Vegetation, Buildings	Ground
26	Unclassified native vegetation	Ground
27	Naturally Bare - sand, rock, claypan, mudflat	Aerial
28	Sea and Estuaries	Aerial
29	Regrowth, Modified Native Vegetation	Ground
99	Unknown/No Data	Ground

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning (Aerial)

This action represented the surveying needed of the management site. This involved flying and conducting surveys of 100% of the management area for the presence of large invasive ungulates. This was done at 500m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually. This is only done for areas that need aerial culling

3. Pre-action field planning (Ground)

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site. This was only done for areas that need ground shooting

4. Management action 1 – Judas monitoring:

This action was to place a “Judas” individual in herds and monitor the movement of herds. This type of monitoring has been done for donkeys, pigs, and camels (Energy 2017). We assumed a general Judas monitoring process that was done aerially and performed in 4 steps. The general process followed: fly into area and capture target(s) with tranquiliser ,sterilisation of the animal in the field, put on a tracking collar, and finally release it strategically where there are other herds. This was done every 3 years

We assumed 30% of the area needs to be surveyed at 500m transect width before the right “judas” is found. We need 1 “Judas” individuals per 10km2 and all judas(s) are captured in one go. A study showed initial setup costs of USD 7.6k in 2005 dollars, males cost USD5 and takes 14:57+/- 1.08 mins in field to perform, females cost USD17 and takes 7:20+/- 2.37 & 8:22+/-0.37 minutes to perform in field (both pregnant and non-pregnant) (Campbell et al. 2005). We converted USD to AUD and from 2005 to 2020 dollars. For timing we took the average of maximum time for both sexes assuming 50:50 sex ratio. This is resulted in the sterilisation set up equipment to be estimated at $22k and the in-field sterilisation process takes 13 minutes and costs $31.79. We assumed It took 10 minutes to then put one collar on the Judas animal, and it costs $3k per collar(Department of Environment 2015), and it needed to be replaced every 3 years (Wilurara 2014).We assumed 30% of area needed to be flown before appropriate herd found to strategically release Judas individuals.

5. Management action 2(a) – Aerial culling:

This action represented the aerial culling of the management area. This was estimated to be done at 100m transect widths with a $850/hr cost of aircraft hire, pilot and ammunition. We have also costed for one “entry” level staff at $30/hr to be on the helicopter for observation of animals culled, ethics etc. The maximum flight distance was 400km before refuelling needed to occur. This action was assumed to occur annually

6. Management action 2(b) – accompanying ground management for aerial culling:

This action represented the need for ground management of area that has been aerially culled (mustering), to complete the culling process. We assumed that 10% of the area of aerial culling needs to be mustered. We assumed 4 personnel in 4 separate vehicles required for mustering, and It takes half a day to muster an area of 10km2. This is done annually.

7. Management action 3 - ground shooting:

This action represented the ground shooting costs. When vegetation was too dense, we estimated the cost of engaging a ground shooting professional shooter. We assumed they had to walk in 200m transects for 100m shooting range to hit target accurately, and it took 20 minutes to track and shoot an animal. Bullets are costed at $1.80/bullet and shots are 100% accurate i.e. 1 shot per cull (costs taken from a pack of 200 .308 bullets at $359 from www.thebarn.net.au). We assumed that 3 animals are culled/km2. This was adapted from the density of invasive pigs at 2.2-3.5 pigs/km2 (Caley 1993). We assumed we need 2 experienced shooters at the experienced level at $45/hr and this is done annually.

8. Post-action monitoring (aerial)

This action represented the monitoring of the aerial culling. This involved flying and conducting surveys of 30% of the management area. This was done at 100m transect widths with a $850/hr cost of aircraft hire and pilot. This action was assumed to occur annually and only in areas of aerial culling.

9. Post-action monitoring (ground)

This action represented the monitoring of the ground culling activity and remaining threat levels. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site and only done for areas that need ground shooting

10. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Sense check for aerial culling

The sense check from an aerial culling report from the Whitsundays (Council 2018; Hardy & Fuller 2017) was fitted for a regression model (n=27 for labour+flight time) had formula *Aerial culling cost = $3,883 + 84*AreaServiced.* Using an area serviced of 100km2, we get $123/km2 ($12,283 for 100km2).

Our cost models estimated $111/km2 (5% labour, 92% flight costs, and 3% accommodation). This is a very similar cost for our models vs actual data.

Sense Check for ground culling

The average of a trained shooter costs $750 a day, taken from costs suggested by NSW SoS ($500/day $350/night only) and costs listed on AFACMS (afacms.com.au) of 500-1000 a day.

For a low resistance walking environment, our cost model estimates per km2 were 0.57 days of effort at $646/km2. For high resistance walking environment, our cost model estimates per km2 were 0.86 days of effort at $985/km2. These both translated to a day rate of roughly $1,140 for 2 personnel with accommodation, consumables and travel within site These numbers are similar to what is available.

Appendix 5.12: Invasive Predator Management

Summary

Invasive predators (cats-152, foxes-94 and dingoes-19) threatened 265 species (139 mammals, 91 birds, 27 reptiles and 8 frogs) (Ward et al. Unpublished results). We collated a coordinated invasive predator control that combined control of cats, foxes and dingoes, with the management goal to control the population of each of the invasive predators to densities low enough to permit persistence of impacted threatened species. The management actions taken were aerial baiting and ground baiting.

Assumptions

Spatial maps

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

The general threat abatement layer was a combination of the species distribution of cats, foxes and dingoes. The management layer for ground baiting was estimated to occur in areas where Dasyurus maculatus subspecies occured, there was dense vegetation (see Table 7) or higher human population density (urban Australia - ARIA) (see Table 7. And Supp. Material 2). The management layer for aerial baiting occurred in all other areas, i.e. areas where Dasyurus maculatus subspecies doesn't occur, open canopy and lower human population density (inner/outer regional and remote/very remote Australia – ARIA) (see Table 7 and Supp. Material 2). We acknowledged that dingoes are protected in certain areas in Victoria but we still cost for the laying of baits for cats and foxes in those areas.

Table 7. Major Vegetation groups (Department of the Environment and Energy (Australia) 2016) and whether management for invasive species such as baiting and shooting can be done via ground control, or from helicopter. This is subject to conditions, for example, post severe bushfire many habitats become open enough for aerial shooting. In contrast, in wetter conditions vegetation may become thicker and therefore aerial management is not possible.

Ref #	Major Vegetation Group	Ground or Aerial
1	Rainforests and Vine Thickets	Ground
2	Eucalypt Tall Open Forests	Ground
3	Eucalypt Open Forests	Ground
4	Eucalypt Low Open Forests	Ground
5	Eucalypt Woodlands	Aerial
6	Acacia Forests and Woodlands	Aerial
7	Callitris Forests and Woodlands	Ground
8	Casuarina Forests and Woodlands	Aerial
9	Melaleuca Forests and Woodlands	Ground
10	Other Forests and Woodlands	Ground
12	Tropical Eucalypt Woodlands/Grasslands	Aerial
14	Mallee Woodlands and Shrublands	Aerial
30	Unclassified Forest	Ground
11	Eucalypt Open Woodlands	Aerial
13	Acacia Open Woodlands	Aerial
32	Mallee Open Woodlands and Sparse Mallee Shrublands	Aerial
31	Other Open Woodlands	Aerial
15	Low Closed Forests and Tall Closed Shrublands	Ground
16	Acacia Shrublands	Aerial
17	Other Shrublands	Aerial
18	Heathlands	Aerial
19	Tussock Grasslands	Aerial
20	Hummock Grasslands	Aerial
21	Other Grasslands, Herblands, Sedgelands and Rushlands	Aerial
22	Chenopod Shrublands, Samphire Shrublands and Forblands	Aerial
23	Mangroves	Aerial
24	Inland Aquatic - freshwater, salt lakes, lagoons	Aerial
25	Cleared, Non-Native Vegetation, Buildings	Ground
26	Unclassified native vegetation	Ground
27	Naturally Bare - sand, rock, claypan, mudflat	Aerial
28	Sea and Estuaries	Aerial

29	Regrowth, Modified Native Vegetation	Ground
99	Unknown/No Data	Ground

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, performing observations and checking for invasive predator tracks, done annually. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

Other tasks involved the same staff set up the cameras and maintained them.We estimated the numbers required to be 1 camera every 10km2 and they cost $750 each, it takes 30 minutes to set one up, replaced every 5 years. They take 30 minutes to be maintained (memory card and battery), this occurs twice a year during pre-action field planning and post-action monitoring. They also set up the sand pad and placed 1 every 10km2 and they there is no set up cost but takes 30 minutes to set up. Checking and resetting it takes 30 minutes for each activity, this occurs twice during the pre-action field planning.

The set up of GPS collars is not costed here, but if the estimate would be 1 GPS collar every 25km2 and they cost $3000 per collar, it takes 3 hours to track, catch and collar an invasive predator, this is replaced every 5 years. This needs to be maintained (potted) for $750 every year for a similar 3 hours of time, this occurs once a year during pre-action monitoring.

3. Management action – Aerial baiting:

This occurs was estimated to occur in areas with open canopy. The aerial baiting was assumed to occur at 500m transects with 50 baits/km2 at $0.50 per bait, and the pilot and aircraft cost was estimated at $850/hr.

As the bait is classified as a schedule 7 poison, there was an extra delivery cost of $1.6/km to abide by the health department regulations of transport (pers comms with Stephen Van Leeuwen DBCA). The $1.60/km accounted for a small refrigerated truck including salary and accommodation for 2 people. The bait is assumed to be only delivered once to management site, regardless of the number of trips required to perform the field work. A sweating rack is required to be purchased every 10 years.

4. Management action – Ground baiting

Ground baiting occurs in Dasyurus maculatus subspecies distribution areas, dense vegetation areas or higher human population density (urban - ARIA). This action represented the effort needed to lay the ground baits. To avoid poisoning non-target threatened native predators (i.e. Quolls) baits were dug into the ground by 10cm during ground-baiting. We assumed it took 5 minutes/bait to place, and we accounted for 50 baits/km2 at $0.50 per bait delivered at 500m transects. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 100% of the management area by foot at transect widths of 500m. TThis action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

As the bait is classified as a schedule 7 poison, there was an extra delivery cost of $1.6/km to abide by the health department regulations of transport (pers comms with Stephen Van Leeuwen DBCA). The $1.60/km accounted for a small refrigerated truck including salary and accommodation for 2 people. The bait is assumed to be only delivered once to management site, regardless of the number of trips required to perform the field work. A sweating rack is required to be purchased every 10 years.

5. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels, this included surveying the predator count based on tracks, maintain cameras, and monitor and reset sand pads

We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. Cameras take 30 minutes to be maintained (memory card and battery), this occurs twice a year during pre-action field planning and post-action monitoring. Sand pad checking and resetting takes 30 minutes, this occurs twice during post-action monitoring.(one reset and one check). All equipment costs have been covered in pre-action field planning. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

6. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

<u>Sense Checks</u>

TAP 2015 cat data estimates at ~$175/km2 for aerial baiting.

Our costs come to $81/km2 and is lower than the TAP costs/km2, before including travel to the site for the aircraft. The inclusion of this distance will bring us closer to the estimates as for flying the travel makes up the biggest proportion.

Appendix 5.13: Invasive Rabbit Management

Summary

The European rabbit (Oryctolagus cuniculus) has been a long-term pest in Australia, and threatens 127 species: 103 plants, 19 birds, 2 mammals and 3 reptiles. The rabbit management goal is to manage the population to low levels (<0.5 rabbit per hectare). More than 50 rabbits/km2 (0.5 rabbits/ha) can inhibit the regeneration of plants (TAP 2016). Rabbits have been estimated to cost agriculture production losses $241m/year (2014 dollars).

We applied the 3 stages as outlined by DPI NSW (https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/rabbits/rabbit-control) and used the TAP 2016 costs to validate our numbers. Costings with stages adapted from DPI NSW:

1) Initial biocontrol reduction - 10 yearly administration of RHVD1-K5
2) Follow up control - 5 yearly fumigation and warren destruction
3) Advanced control - Annual ground shooting

There needs to be a combination of methods to achieve our management goal of keeping rabbit populations at low levels. We adapted the 3 stages as outlined by DPI NSW (Cox Unknown date). The initial biocontrol reduction of a 10 yearly administration of RHVD1-K5. The rabbit biocontrol (Myxoma and RHDV) removes large numbers of rabbits, reducing the feral predator populations that depend on rabbits for food source; and subsequently allows native animals to recover (Pedler et al., 2016). Resistance can be developed to the biocontrol viral strains (Strive and Cox, 2019) and updated biocontrols will be necessary. The second stage was the follow up control, a 5 yearly fumigation and warren destruction. The third stage was the ongoing population control can then be achieved by annual ground shooting, accompanied by on-going monitoring of rabbit populations.

Assumptions

Spatial maps

The management layer used was the distribution map of rabbits (see Supp. Material 2). We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. We inlucded an extra week (5 days) to prepare the viral biocontrol bait. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like spotlighting transects to estimate rabbit abundance and counting warrens along transect lines. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management Action 1 – Initial biocontrol reduction

We assume that a new viral biocontrol needs to occur every 10 years. We assumed the use of viral biocontrol (RHDV1) as it is efficient at the spatial scale. We adapted the administration of viral biocontrol process from *PestSmart* (Sharp 2016).

We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 100% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked to lay baits. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

The administration of the biocontrol is to first perform “free-feeding” of non-baited feed to lure the rabbits, then feed the rabbits the baited feed that has the virus. All estimated costs were averaged across carrots and oats, as different rabbits prefer different baits.

The Non-baited feed estimated cost was an average of 2 feeds with carrots at 20kg/km at $2/kg (Broadcast/trailing) and 3 feeds with oats at 5kg/km at $1.80/kg (trailing only). We assumed that baited feed was 10% of the initial non-baited feed applied and translated to treated Carrots at 2kg/km and treated Oats at 0.5kg/km

The supplier of RHDV1 K5 viral biocontrol was from the NSW Department of Primary Industries’ (NSW DPI). Each 10ml of reconstituted RHVD1-K5 was to 90ml of water, and each vial (10ml) cost $120 with $50 for shipping with couriers (both prices ex GST) (Pers comms with Tiffany O’connor virology.enquiriesatdpi.nsw.gov.au). One vial of K5 was assumed be used to coat ~10kg of freshly diced carrots or ~5kg of oats, they were stored in safe plastic bags and used within 24 hours of prep.

As the viral biocontrol is classified as a schedule 7 poison, there was an extra delivery cost of $1.6/km to abide by the health department regulations of transport (pers comms with Stephen Van Leeuwen DBCA). The $1.60/km accounted for a small refrigerated truck including salary and accommodation for 2 people. The viral biocontrol was assumed to be only delivered once to management site, regardless of the number of trips required to perform the field work. The cost estimate for equipment was assumed to be $10k and replaced every 10 years. This included a Bait mixer, 5% sodium hypochlorite, and PPE.

4. Management action 2(a)– Follow up control: habitat destruction – warren ripping

We adapted the warren ripping as outlined by DPI NSW and DPIRD (Cox Unknown date; DPIRD 2018). Warren ripping was assumed to occur throughout the whole management extent, and we assumed habitat destruction occurred every 5 years, and that there was on average 1 warren per km2. We assumed the tractor has to drive in 1km transect widths throughout the whole range at 25km/h, and a tractor took 30 minutes to rip one warren. The estimated cost was $150/hr of the tractor dry hire with 2 personnel working on it. (adapted from “4x4 Tractor (180-229 hp) dry hire rate: $136 - $148 + GST Per Hour” - *https://blog.iseekplant.com.au/blog/tractor-hire-rates*). Equipment was the Triple tine ripper part at $1800 replaced every 10 years (taken from kanga m range 3 tine ripper - www.tradefarmmachinery.com.au). When the warren is not suitable to be ripped, it is fumigated (next step) that occurs in areas not suitable for ripping.

5. Management action 2(b) – Follow up control: Fumigation (10%)

This fumigation occurs in 10% of the management areas that weren't suitable for warren ripping. We adapted the procedure laid out by DPIRD (DPIRD 2016). We assumed on average 1 warren every 1km2, and each warren has 4 openings on average and it took 60 minutes for 2 personnel to fumigate one warren. We assumed the tractor has to drive in 1km transect widths throughout the whole range at 25km/h at $150/hr of the tractor dry hire with 2 personnel working on it. We assumed this occurred every 5 years.

We assumed 2 Aluminium phosphide tablets are needed per opening at$0.027/tablet (8 tablets per warren with 4 openings). We assumed the use of aluminium phosphide 56% tablets, with each fumigation tablets contain 560g/kg of aluminium phosphide which produces 330 g/kg phosphine gas. Each 3 gram tablet releases 1 gram of phosphine gas when exposed to moisture in the air or soil (Sharp 2012). This was estimated at ~$9/kg, that contained 333.33 tablets that are 3g each equating to $0.027/tablet (Aluminium Phosphide tablets on Alibaba -https://www.alibaba.com/showroom/aluminum-phosphide-tablets.html)

Special s7 poison delivery required. We assume that poison is only delivered once to the management site, regardless of the number of trips it takes to perform one action. There was an extra delivery cost of $1.6/km to abide by the health department regulations of transport (pers comms with Stephen Van Leeuwen DBCA). The $1.60/km accounted for a small refrigerated truck including salary and accommodation for 2 people. The phosphide was assumed to be only delivered once to management site, regardless of the number of trips required to perform the field work.

6. Management action 3 - ground shooting:

This action represented the ground shooting costs. We assumed they had to walk in 200m transects for 100m shooting range to hit target accurately, and it took 20 minutes to track and shoot an animal. Bullets are costed at $1.80/bullet and shots are 100% accurate i.e. 1 shot per cull (costs taken from a pack of 200 .308 bullets at $359 from www.thebarn.net.au). We assumed after biocontrol and warren ripping + fumigation, we will have 10 rabbits culled per km2. We assumed we need 2 staff at the experienced level at $45/hr and this is done annually.

7. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels to check for the outcome of rabbit management.. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

8. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

<u>Sense checking (all our costs are *sans* travel to site)</u>

To compare like for like costs, we compared the per treatment action costs, as these were what was displayed in the Rabbit TAP 2016 (Energy 2016). All our compared modelled costs were lower than the Rabbit TAP 2016 costs, likely due to the intensity of our actions across the broad-scale landscape (number of warrens, fumigation time, etc.).

Stage 1 – initial biocontrol reduction

Costs from the Rabbit TAP 2016 was $5,200/km2 ($52/ha) using oat/carrot baits (Energy 2016).

In our costs models, the per treatment cost including multipliers was $904/km2, this was lower than the estimated $5,200/km2 above.

Stage 2 – follow up control – fumigation and warren destruction

The warren destruction costs from the TAP 2016 were $5,500/km2 average cost for warren destruction ($55/ha from $40/ha for moderate infestation and $69/ha for using bobcat) (Energy 2016). The fumigation costs from the Rabbit TAP 2016 were $16,100/km2 over 1 visit ($161/ha from $56/ha using aluminium phosphide and $105 per hectare for labour from a $70/hour contractor that needs approximately 1.5 hours for 1 hectare) (Energy 2016).

In our cost models, we assumed that there was 1 warren per km2 on average, and tractors took 30 minutes to rip one warren and 60 minutes to fumigate one warren. For warren-ripping, we costed it at 247/km2. This was lower than the $5,500/km2 from the TAP, probably due to our assumption of number of warrens per km2 or the amount of time it takes for the tractor to rip one warren.

For fumigation the per treatment cost was at $590/km2 for the area. This was lower than the $16,100km2 from the TAP, probably due to our assumption of number of warrens per km2, the amount of time it takes to fumigate one warren, and to a lesser extent the cost of the aluminium phosphide tablets.

Stage 3 – advanced control - on-going maintenance with shooting

The Rabbit 2016 TAP costs were $19,950/km2 based on a 8 weeks a year at a 300 hectare site (This is from $133 - $266/hectare per year based on ground shooting costs of $5-10k per week for ground shooting for a 300 hectare site, as they need about 8 weeks a year $40k-80k) (Energy 2016).

Our cost models for ground shooting of rabbits assumed 12 rabbits culled/km2 at 10 minutes per cull. At the low resistance level for walking through landscape, we costed the shooting to cost $1,367/km2. This was lower than the TAP.

Appendix 5.14: Invasive Weed Management

Summary

We had a total of 577 species by threat interactions, of which there were general weeds (531), lantana (26), buffel grass (16), gamba grass (3) and bitou bush (1), threatening plants (497), birds (39), inverts (19), reptiles (14), mammals (7) and fish (1) (Ward et al. Unpublished results).

We assumed a generic invasive weed management, as the majority of our weed threats are non-descript general weed species. The main action assumed was weed control that involved physical and chemical control, with the objective to control and contain established weeds as eradication wasn’t possible.

As an indication of the efforts across a broad scale, we assumed weeds had patchy occurrences and were invasive of all potential habitats. We did not assume a threat layer and instead used the intersection of vegetated areas and weed-threatened threatened species distribution as the management area.

We assumed the effort required for the base case scenario was 30% of the overall extent of management area that needed weed treatment, with 3 levels of intensity as an indication of varying efforts that were potentially required within a management area (5% intensive effort, 10% moderate, and 15% light).

We then adapted the estimated extent to reflect how the efforts of weed control might vary across a spatial landscape, depending on the level of intactness and the vegetation type. Using “degraded rainfall areas” as our base, we then scaled down the extent by the Integrity Index (Beyer et al. 2020) and an adapted arid/semi-arid and rainfall Australian eco-region map (see Supp. Material 2). We applied the following extents:

Matrix of extent assumed for weed management effort		Vegetation type	
		Rainfall areas	Arid/semi-arid
Intactness	Degraded	30%	15%
	Moderate	10%	5%
	Intact	1%	0%

Assumptions

Spatial maps

Invasive weed management and Habitat Restoration were similar actions, so we distinguished where each of them were applied. Essentially, if it was “cleared and restorable” we performed Habitat Restoration, if it was “vegetated” and there was a weed-threatened species we performed Invasive Weed Management, if it was vegetated with no weed-threatened species there we didn’t estimate any costs.

Our management layer for invasive weed management was the vegetated areas in the adapted land-use map (see Supp. Material 2) overlaid with the Integrity Index layer (Beyer et al. 2020) and IBRA Australian ecoregions (see Supp. Material 2).

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail). NB Biosecurity is costed as a standalone management action across the different threat abatement strategies (see Appendix 5.1 – Biosecurity).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the invasive weeds and the impact on threatened species. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Invasive weed management

We assumed that for areas that had vegetation as the land-use (see Supp. Material 2) there was a maximum of 30% of the extent that required weed control. For costing purposes, we assumed 10m2 grids with 100,000 units per km2, and transect widths of 3.16x3.16. We assume that this 31,622 km of distance needs to be driven by a vehicle along these grids and staff are conducting weed management for each patch. There is no walking time penalty for terrain as we are driving along and not “walking” per se. The effort was estimated at the vegetation plot of 10m2. We assumed that the effort spent in each plot was split across 3 levels, intensive, moderate and light.

For Invasive weed control, this was done annually with 2 personnel and we assumed for every management area. For the base case scenario, we assumed that there was 5% intensive weed control with labour of 2.7mins/10m2 and herbicide costs of $0.55/10m2, there was 10% of moderate weed control with labour of 1.95mins/10m2 and herbicide cost of $0.34/10m2, and there was 15% light weed control with labour of 0.68mins/10m2 and herbicide cost of $0.14/10m2 (see Table 8 and further below for more detail). We then scaled the base case scenario by intactness level (adapted from the integrity index (Beyer et al. 2020) and Australia’s Ecoregions (see Table 8).

Table 8. The Using “degraded rainfall areas” as our base, these tables show the extent and corresponding scaling factor by the Integrity Index (Beyer et al. 2020) and an adapted arid/semi-arid and rainfall Australian eco-region map (see Supp. Material 2).

Matrix of extent assumed for weed management effort		Vegetation type	
		Rainfall areas	Arid/semi-arid
Intactness	Degraded	30%	15%
	Moderate	10%	5%
	Intact	1%	0%
Scaling factors with 30% being the baseline (degraded rainfall areas)		Vegetation type	
		Rainfall areas	Arid/semi-arid
Intactness	Degraded	1.00	0.50
	Moderate	0.33	0.17

	Intact	0.03	-

4. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

5. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Further assumptions

We assumed Intensive weed control at $1800/ha for areas that had high severity weed invasion (adapted from NSW SoS). We assumed this was chemical and physical control of invasive weeds with a focus on the higher effort woody weeds. As we assumed $40/hour for person hours, this equated to an effort **of 2.7 minutes per grid of 10m2** (3x3m)

We assumed moderate weed control was at $1300/ha for areas that had moderate severity weed invasion (adapted from NSW SoS). We assumed this involved chemical and physical control of invasive weeds with a combination of higher effort woody weeds and lower effort herbaceous weeds. Assuming $40/hour for person hours, this equated to an effort of **1.95 minutes per grid of 10m2** (3x3m).

We assumed Light weed control at $450/ha for areas that had low severity weed invasion (adapted from NSW SoS). We assumed this involved chemical and physical control of invasive weeds, with a focus on the lower effort herbaceous (i.e. spot spraying).

Assuming $40/hour for person hours, this equated to an effort of **0.675 minutes per grid of 10m2** (3x3m)

We split herbicide need by woody weeds and herbaceous weeds. We assumed the volume of herbicide needed for woody weeds was 4000 litres/ha and 1000 litres/ha for herbaceous weeds (based on foliar spray for Grazon Extra Herbicide concentrate, found on https://specialistsales.com.au). We then calculated the herbicide costs and took the average across two herbicide types, one glyphosate product and one triclopyr product. The consumables for Intensive efforts was the average of the woody weeds, and for light weeding it was be the average of consumables needed for the herbaceous weeds. The moderate weeding effort was the average of the intensive and the light effort.

The selective herbicide, Grazon Extra herbicide concentrate (100g/L Triclopyr, 300g/LPicloram +8g/L Aminopyralid) was $699 per 20 Litres, with a mix rate is 500ml per 100L of water (as found on https://specialistsales.com.au , https://specialistsales.com.au/shop/woody-weeds/woody-weed-herbicides/liquid-chemicals/grazon-extra-herbicide-triclopyr-picloram-aminopyralid/?attribute_pa_size=1-litre&gclid=CjwKCAjwtNf6BRAwEiwAkt6UQpa6tIJ6_NiYFKuSCwNYyPF03UdA_WQrsrG3bHvZLR0SbcrNtO2HlhoCDbcQAvD_BwE). The non-selective Glyphosate Roundup biactive Herbicide concentrate (Glyphosate present as Isopropylamine Salt at 360g/L) was $199 for 20 Litres, and mix rate was 10ml per Litre of water (1L per 100L of water) (as found on http://specialistsales.com.au , https://specialistsales.com.au/shop/woody-weeds/woody-weed-herbicides/liquid-chemicals/roundup-biactive-herbicide-glyphosate/?attribute_pa_size=20-litre&gclid=EAIaIQobChMInuG-nofZ6wIVYZ_CCh2u5AaIEAkYASABEgJor_D_BwE)

This resulted in herbicide cost of $0.55/10m2 for intensive weed control (mainly woody). $0.34/10m2 Moderate weed control (50:50 mix of woody and herbaceous), and $0.14/10m2 Light weed control (mainly herbaceous)

Sense Check

We spoke to Vanessa Adams who has done some weed models, and they used a similar approach in one of their weed models, for each grid cell they modelled whether weed density was low, moderate or high (roughly 5%, 20%, and 50%) that indicated the percentage cover that needed managing for each grid cell. Their weed treatment was based on specific weeds and time to work on them ranging from 8-41 hours per hectare (0.48-2.46 minutes/10m2). Our assumption of 30% landed right in the middle of hers, and also included varying intensity to account for different time spend as we don’t have any specific weeds we are assigning the task to.

Appendix 5.15: Invasive and Problematic Bird Management

Summary

There were 33 threat interactions with invasive/problematic bird species threatening 15 threatened bird species. The 2 management actions were ground shooting (to control bell miners, noisy miners, yellow-throated miners, starlings, mynas and martins) and installing nest boxes with protection (nest-boxes, chick shelters, cockatubes, protect hollow-bearing trees and iron tree collars). As we did not use threat distributions for the invasive birds, we estimated the effort for ground shooting to occur across 30% of the managed area. The first year required a higher cull rate at 80 birds/km2 and subsequent years being at 12 birds/km2 (15% of year 1). Nest protection involved setting up nest boxes with protection once every 20 years, with annual maintenance of the boxes to clean out the debris.

Assumptions

Spatial maps

We costed both actions across a national scale, however these should be cropped to the desired extent of the action. To create a proxy for the ground shooting layer needed, the end-user should combine the distribution of threatened species that were threatened by bell miners, noisy miners, yellow-throated miners, starlings, mynas and martins. To create a proxy for the nest box protection layer, the end-user should combine species distributions that need nest protection.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management action 1 - ground shooting:

This action represented the ground shooting costs. As we used the distribution of the threatened species and not the threat (i.e. the problematic bird), we assume that only 30% of the habitat needs to be ground shooting managed.

We assumed that the initial culling effort required was different to subsequent years, where in year 1 the shooting is more intense at 80 birds culled/km2, and in subsequent years where the shooting was at 15% (12 birds culled/km2). This cull rate and percentage of birds in subsequent years was adapted from Crates et al. (2020) where they took 7 days to cull ~350 miners across 4.3km2 in the 1st year, and in subsequent years ~54 miners are culled across 4.3km2. We assumed they had to walk in 200m transects for 100m shooting range to hit target accurately, and it took 10 minutes to track and shoot a bird. Bullets were costed at $1.80/bullet and shots are 100% accurate i.e. 1 shot per cull (costs taken from a pack of 200 .308 bullets at $359 from www.thebarn.net.au). We assumed we need 2 shooters at the experienced level at $45/hr and this was done annually.

4. Nest-box and protection installation

The cost estimated involved walking through and installing the nest boxes and the corresponding protection. We assumed we needed *1 nestbox/km2 and* we needed 2 staff at the experienced level at $45/hr to walk through the area at 500m transects. The initial cost *was estimated at $500/nestbox ($460 nestbox + $40 for protection), takes 60 minutes for installation and protection and assumed to occur every 20 years. The maintenance of nestboxes occurred annually and took 20 minutes*

For nest box cost estimates, we took the maximum amount at$460/nestbox across Cockatubes sold at $460 a tube (found from landcaresj.com.au - https://landcaresj.com.au/cockatubes-saving-black-cockatoos/), costs of other generic nestboxes that ranged from $39 – 129 and $30 - 57 for nest boxes (found from https://www.nestingboxes.com.au and https://birdboxesaustralia.com.au/shop/). The nestbox protection can be a metal sheet that doesn't allow predators to climb up, estimated to be $40 (dealing with predators - https://nestwatch.org/learn/all-about-birdhouses/dealing-with-predators/ and metal sheet from bunnings - https://www.bunnings.com.au/australian-handyman-supplies-1200-x-600mm-0-75-galvabond-mini-sheet_p0910181)

For nestbox installation time, we estimated it took 60 minutes to assemble (see Assembly Mounting care from www.nestingboxes.com.au - https://www.nestingboxes.com.au/epages/shsh6893.sf/en_AU/?ObjectPath=/Shops/shsh6893/Categories/Assembly_Mounting__Care). The maintenance of nestboxes of 20 minutes per nestbox was estimated for the time to climb up, clean and remove any debris.

5. Post-action monitoring

This action represented the monitoring of the outcome of invasive problematic bird management. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked, *observing invasive and problematic birds.*. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

6. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Appendix 5.16: Map and Protect Refugia

Summary

To address the threats climate change and chytridiomycosis (chytrid), experts have indicated that locating the places that serve as refugia is a crucial action, which then can inform the important areas in need of protection. In addition, mapping is required to locate the areas that are suitable, and areas that are unsuitable, for wind turbines, to avoid habitat and flight paths of species at risk of turbine collision. There are 2 components to the cost that are done every 5 years, the non-spatial (mapping) and spatial costs (surveying). This includes but is not limited to disease for frogs, turbine threat to birds, etc.

We include a generalised non-spatial labour cost for mapping, this cost is multiplied by the total number of threatened species that need map and protect. We then cost the spatial component for a combined layer of all threatened species for all threat groups (ignoring any differentiation and doing it as one large threat group). Spatial cost is an annual general survey of the threats (30% ground). This survey does not refer not to the threatened species but the threat (i.e. habitat loss), and it is important to have on-site surveys of the habitat through on-ground verification of habitat quality etc.

Assumptions

Spatial maps

As we didn't have a threat map, we used the national scale as the base map, with end-users cropping this to the desired extent of refugia mapping.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur every 5 years in the office (off-site), and only costed once per 100km2 for the combined threat group layer.

2. Ground surveys

This action represented the effort of conducting surveys of the habitat quality. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur once every 5 years on-site, and is only costed once per 100km2 for the combined threat group layer.

3. Management Action 1 – Mapping and protecting (non-spatial)

This non-spatial management action was assumed to be conducted at the national scale and only involved labour. The tasks involved the amount of time for personnel to incorporate field information, research, prior knowledge into a coherent mapping exercise. We estimated the total effort to be 12 weeks (60 days) of 1 personnel of management level at $65/hr and 1 experienced staff at $45/hr. This effort was then multiplied by the number of species that need mapping and protecting. This action was conducted every 5 years.

Appendix 5.17: Native Herbivore Management

Summary

Native herbivores (mainly macropods like kangaroos, wallabies and quokkas) threaten 83 threatened species (69 plants, 9 birds, 4 mammals and 1 reptile) primarily through grazing and to a lesser degree competition.

Fencing has shown to be a moderately effective method on reducing grazing pressure (Kangaroo Management Taskforce 2020). In the long term, exclusion fencing without population control can shift the “problem” or grazing pressure elsewhere, and there is the possibility of loss of genetic diversity through lack of population connectivity for species that are restricted in range (Kangaroo Management Taskforce 2020).

Decommissioning or fencing waterholes has shown to have no impact on red kangaroo distribution (Fukuda et al. 2009), and a recent review coupled with an experiment in the rangelands confirmed that water restriction had no effect on macropod density, the distribution of macropods instead dictated by food (Lavery et al. 2018). Lavery et al. 2018 however urged for larger scaled experiments, generating >10km distances between waterholes, and longer monitoring periods in dry hot months. There is however anecdotal evidence that water hole decommissioning works for grey kangaroos that are more sensitive to water shortage than red kangaroos (Kangaroo Management Taskforce 2020). This option has lower social acceptability when compared to fencing and commercial shooting due to death from thirst, and it is recommended to accompany this action with shooting to manage kangaroos that “hang” around fenced off water holes (Kangaroo Management Taskforce 2020). These effects are expected to diminish after these closures have been established.

Threatened species impacted by native herbivores are predominantly narrow ranged, occurring across less than 1,000 km^2. For example, the Shapely Zieria (*Zieria formosa*)’s entire distribution is only 0.7 km2. There are 15 species (14 plants, and the Houtman Abrolhos Painted Button-quail (*Turnix varius scintillans*) with distributions <50km2, so keeping the problematic native herbivores out of their distributions are important. Furthermore, in some cases the problematic native herbivore was themselves threatened, such as for the Broad-leaf Daviesia (*Daviesia ovata*) which is threatened by browsing from

Quokkas (*Setonix brachyurus*; listed as Vulnerable). Therefore, fencing off critical populations to exclude problematic native herbivores was the recommended action.

For the small proportion of threatened species with broader ranges, where fencing off important sites is infeasible, decommissioning waterholes has been recommended for impacted species (Healy et al. 2020; James et al. 1999). Water remoteness is gaining evidence for being important for biodiversity, and is recommended for reducing the spread of invasive species e.g. feral herbivores and cane toads (Tingley et al. 2013). We recommend fencing and water hole decommissioning across the landscape, excluding ground culling as culling was not found to be the optimal action for the impacted threatened species. We varied the management level of fencing and water hole decommissioning by the natural range of the species (narrow, medium and broad). We estimated the effort of 100% of range fencing for the 42 narrow-ranged species or range 0.7 – 946 km^2 (which could potentially place species in the category for critically endangered depending on other factors). We estimated the effort for 10% of range fencing for the 21 medium-ranged species with range 1000 km^2 – 10,000 km^2. We estimated the effort for no decommissioning waterholes for the 38 broad-ranged species with range >10,000 km^2. Decommissioning water holes can involve a simple turning off a tap, closing off artesian bores, ground tanks or fencing (Kangaroo Management Taskforce 2020). As we couldn't determine the type of artificial waterhole, we assumed that exclusion fencing will be applied around the waterhole as a generic response. We assumed decommissioning of 2 waterholes per 100km2 through waterhole fencing to reduce water availability.

The literature points to **general threat abatement** of macropods that involved culling. The cost estimates for culling were modelled but did not form a part of the total TAS. Our estimates assumed coordinated professional non-commercial ground shooting for 15% of the area (a proxy of populations harvested at 15% for grey and 17% for red kangaroos for macropod species conservation (Hacker et al. 2019)).

Assumptions

Spatial maps

We used a national scale layer to cost out the 3 management layers for fencing, and these can then be cropped by the end-user to the desired ranges to suit narrow ranged threatened species, medium ranged threatened species and broad-ranged threatened species.

We included 3 walking speeds to account for walking resistance based on Topographic Ruggedness Index (TRI) to account for landscape ruggedness that would influence activity time of certain actions (see Supp Material 2). The corresponding walking speeds for low, medium and high resistance were 4.46km/h, 3.35 km/h, and 2.23 km/h (see general methods for more detail).

Actions

1. Pre-action office planning

This action represented planning that was required for the TAS, involving tasks like getting permits and/or organising the field work. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

2. Pre-action field planning (ground)

This action represented the on-site preparation needed, involving tasks like surveying the extent and severity of the threats and the threatened species. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500m, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

3. Management action 1 - ground shooting (modelled but not included in overall TAS)

This action represented the ground shooting costs (same assumptions as Large Invasive Herbivore management). We assumed they had to walk in 200m transects for 100m shooting range to hit target accurately, and it took 20 minutes to track and shoot an animal. Bullets are costed at $1.80/bullet and shots are 100% accurate i.e. 1 shot per cull (costs taken from a pack of 200 .308 bullets at $359 from www.thebarn.net.au). We assumed that 3 animals are culled/km2. This was adapted from the density of invasive pigs at 2.2-3.5

pigs/km2 (Caley 1993). We assumed we need 2 experienced shooters at the experienced level at $45/hr and this is done annually.

4. Management action 2 - Threatened species key habitat fencing (Narrow and medium ranged species)

This action represented cost of the appropriate length of fencing required to restrict access from macropods for threatened species conservation. The costings involved initial costs of fence-line clearing and construction, that was assumed to be done every 20 years. The on-going maintenance was done annually.

We varied the amount of fencing based on the natural range of the species, and assumed that fencing was based at the broad level management area (i.e. unioned across all species within that group) and assumed to be done in a square. The 42 narrow-ranged species was assumed to have 100% of range fenced with their distribution range from 0.7 – 946 km^2,resulting in the fencing perimeter/100km2 for the narrow ranged species group was 40km (100% of 100km2 produces a 100km2 square of 10x10km). The 21 medium-ranged species was assumed to have 10% of their range fenced, with their distribution ranges from 1000 km^2 – 10,000 km^2, resulting in the fencing perimeter for the medium ranged species group to be 12.65km (10% of 100km2 produces a 10km2 square of 3.16x3.16km)

The initial fence line clearing labour was estimated at 62.5 hrs/km that was standard across all fencing types. The initial fencing for Kangaroos was assumed to be with clipex posts and 15/180cm/15 tuffknot prefab with a stiff apron (15 horizontal wires, 180cm high section, and 15cm between pickets) (DELWP 2021; Giumelli & White 2016). Labour was estimated to be $3k/km that translated to 75 hours/km or a team of 2 working at 37.5 hours each. Materials were estimated at $5k/km. The initial fence line clearing and construction was done every 20 years. For on-going fence checking, maintenance and fence-line clearing, we assumed it took 20% of initial construction labour, and that 10% of material is needed to reconstruct every year from damages. This resulted in ongoing fence maintenance for Kangaroos fences to have assumed labour at 15 hours/km, a team of 2 working at 7.5 hours each and materials at $500/km. The equipment cost was $10k replaced every 10 years. For more fencing details see “further assumptions” below.

5. Management action 3 - Water-hole decommissioning (Broad ranged species)

This action is to decommission the water-holes to reduce macropod density in the area, and was only applied to the 38 threatened broad-ranged species with range >10,000 km^2. We assumed 2 waterholes are decommissioned every 100km2. We then assumed each waterhole required 4km of fencing (1000x1000m square of fencing), to create a reasonable distance to reduce macropod pressure on fencing from water source (Kangaroo Management Taskforce 2020). We decommissioned water-hole based on the natural range of the

The initial fence line clearing labour was estimated at 62.5 hrs/km that was standard across all fencing types. The initial fencing for Kangaroos was assumed to be with clipex posts and 15/180cm/15 tuffknot prefab with a stiff apron (15 horizontal wires, 180cm high section, and 15cm between pickets) (DELWP 2021; Giumelli & White 2016). Labour was estimated to be $3k/km that translated to 75 hours/km or a team of 2 working at 37.5 hours each. Materials were estimated at $5k/km. The initial fence line clearing and construction was done every 20 years. For on-going fence checking, maintenance and fence-line clearing, we assumed it took 20% of initial construction labour, and that 10% of material is needed to reconstruct every year from damages. This resulted in ongoing fence maintenance for Kangaroos fences to have assumed labour at 15 hours/km, a team of 2 working at 7.5 hours each and materials at $500/km. The equipment cost was $10k replaced every 10 years. For more fencing details see “further assumptions” below.

6. Post-action monitoring

This action represented the monitoring of the management action implementation and threat levels, walking through and checking for outcome of native herbivore management. We estimated the effort for 100km2 to be 2 persons of entry level at $30/hr walking through 30% of the management area by foot at transect widths of 500, with 10 minutes of activity time spent every km walked. This action is costed at 3 levels of landscape resistance of walking speed, low, medium and high levels of the Terrain Ruggedness Index (TRI). This action was assumed to occur annually on-site.

7. Post-action evaluation

This action represented the office work required to evaluate the TAS, involving activities like data reporting requirements, the data analysis and incorporating insights into the updated management planning. We estimated the effort for 100km2 to be 3 weeks of planning person hours at the experienced level rate at $45/hr. This action was assumed to occur annually in the office (off-site).

Sense Check

The average of a trained shooter costs $750 a day, taken from costs suggested by NSW SoS ($500/day $350/night only) and costs listed on AFACMS (afacms.com.au) of 500-1000 a day.

For a low resistance walking environment, our cost model estimates per km2 were 0.57 days of effort at $646/km2. For high resistance walking environment, our cost model estimates per km2 were 0.86 days of effort at $985/km2. These both translated to a day rate of roughly $1,140 for 2 personnel with accommodation, consumables and travel within site (Travel to site was calculated separately). These numbers are comparable to public literature.

Further Assumptions

Fencing Costs

We assumed fencing was done for a perimeter of 40km, at the standard broad-scale of 100km2 in a square (10x10km), attributing 400m of fencing to each 1km2. Cost-wise, there is the initial costs of fence-line clearing and construction (done every 20 years), and then the on-going checking and maintenance costs (done annually). We also assumed $10k of equipment costs.

Fence line clearing labour was costed at 60 hours/km, as a team of 2 working 30 hours each per km. This was assumed to be standard across all fencing types. The fence-line clearing was estimated at $2.5k/km, based on the average of $1.95k/km for smooth and $3k/km for rocky terrain (pers. comm Stephen van Leeuwen DBCA) that translated to 62.5 person hours/km assuming $40/hour of wages.

Fence construction was assumed to differ in materials and labour depending on the animals that were excluded. Fencing for cattle assumed a 5 strand plain wire fence. This required labour at 25hours/km, a team of 2 working at 12.5 hours each, and the materials were costed at $7k/km.

This was based on $5.8k materials/km in 2012 Dollars that translated to ~$7k/km in 2020 dollars (Pers comms with Stephen Van Leeuwen DBCA). The estimate of labour was $1k Labour/km that translated to 25 person-hours/km at $40 per hour, or 12.5 hours/km as a team of 2.

Fencing for small feral animals (e.g. cats, foxes, rabbits) assumed floppy top design with hot wires removed from SA Arid recovery fence (Moseby & Read 2006). We estimated labour at 212.5 hours/km, a team of 2 working at 105 hours each. The materials were estimated at $9.6k materials/km 2012 dollars that inflated to $11k/km in 2020 dollars (Pers comms with Stephen Van Leeuwen DBCA). Labour was $8.5k labour/km that translated to 212.5 person-hours/km assuming 40/hour.

Fencing for Kangaroos was assumed to be with clipex posts and 15/180cm/15 tuffknot prefab with a stiff apron (15 horizontal wires, 180cm high section, and 15cm between pickets) (DELWP 2021; Giumelli & White 2016). Labour was estimated to be $3k/km that translated to 75 hours/km or a team of 2 working at 37.5 hours each. Materials were estimated at $5k/km.

For on-going fence checking, maintenance and fence-line clearing, we assumed it took 20% of initial construction labour, and that 10% of material is needed to reconstruct every year from damages. A report survey showed that approximately effort that was needed for maintenance for cat/fox fences (Long & Robley 2004). We then calculated the proportion to be ~20% based on the maintenance and checking time of 47hours/year/km for cat/fox fences (0.9hours/week/km) as a proportion of construction time of fencing at 212.5 hours/km. This resulted in ongoing fence maintenance for cattle to be 5 hours/km – team of 2 working at 2.5 hours/km each and materials at $700/km. For small feral animals, we assumed 42 hours/km, a team of 2 working at 21 hours/km each and materials at 1.1k/km . For Kangaroos fences we assumed labour at 15 hours/km, a team of 2 working at 7.5 hours each and materials at $500/km.

Appendix 5.18: Policy, education and regulation (Non-spatial)

Summary

There are a certain number of threats that do not have specific direct management actions, and rather require policy change to abate the threat. We treat this as a strictly non-spatial costing. We have grouped similar threats together, and devised a list of 5 policy changes: Fisheries management (policy & education), Manage nutrient loads (policy & education), Regulation of herbicide & pesticide use (policy, regulation & education), Wind turbine planning (policy & planning), and Management of pollution (policy, planning & regulation).

We include a generalised non-spatial labour cost for policy change, and this cost was multiplied by the total number of threat groups regardless of the number of threatened species affected.

Assumptions

Actions

1. Management Action 1 – Policy and liaison (non-spatial)

This was a national level, non-spatial cost (person hours). The first area represented tasks like cost for negotiation policy change, compliance, educating on the impact of threats on threatened species, and devising best management practice for long-term sustainability. We further included an area for liaison and communication, involving the labour costs for liaison officers however we assumed that this was non-spatial and only labour is accounted for. We estimated the effort to be 1 FTE at management level at $65/hr, 10 FTE experienced staff at $45/hr and 25 FTE entry level staff at $30/hr. This non-spatial management action was assumed to be conducted annually. The total was then multiplied by the number of threat groups listed above.

References

Beyer, H. L., O. Venter, H. S. Grantham, and J. E. M. Watson. 2020. Substantial losses in ecoregion intactness highlight urgency of globally coordinated action. Conservation Letters **13**:e12692.

Caley, P. 1993. Population Dynamics of Feral Pigs (Sus Scrofa) in a Tropical Riverine Habitat Complex. Wildlife Research **20**:625-636.

Campbell, K. J., G. S. Baxter, P. J. Murray, B. E. Coblentz, C. J. Donlan, and V. C. G. 2005. Increasing the efficacy of Judas goats by sterilisation and pregnancy termination. Wildlife Research **32**:737-743.

Collard, S. J., P. J. O'Connor, T. A. A. Prowse, D. Gregg, and A. J. Bond. 2020. Objectives versus realities: Spatial, temporal, financial and social deficiencies in Australia's public revegetation investment model. Ecological Management & Restoration **21**:35-41.

Council, W. R. 2018. Feral animal aerial shoot project update - 2018.

Cox, T. Unknown date. Integrated rabbit management - rabbit control in N. Department of Primary Industries, editor. Invasive Animals CRC.

CPSM. No date. Background to Phytophthora cinnamomi as a plant pathogen that impacts on ecosystem function and health in Australia in C. f. P. S. a. Management, editor.

Craik, W., D. Palmer, and R. Sheldrake. 2017. Priorities for Australia's Biosecurity System– An Independent Review of the Capacity of the National Biosecurity System and its Underpinning Intergovernmental Agreement.'. Commonwealth of Australia: Canberra, ACT.

Crates, R., L. Rayner, M. Webb, D. Stojanovic, C. Wilkie, and R. Heinsohn. 2020. Sustained and delayed noisy miner suppression at an avian hotspot: Sustainable and successful noisy miner management. Austral ecology **45**:636-643.

DELWP. 2021. Kangaroos and Wallabies. Wildlife Management Methods.

Department of Environment. 2015. Threat abatement plan for predation by feral cats.

Department of the Environment and Energy (Australia). 2016. National Vegetation Information System (NVIS) version 4.2 Major Vegetation Groups. Available from http://www.environment.gov.au/land/native-vegetation/national-vegetation-information-system/data-products (accessed March 2017).

DPIRD. 2016. Rabbit Control: Fumigation. Department of Primary Industries and Regional Development, WA.

DPIRD. 2018. Rabbit warren and harbourage destruction. Department of Primary Industries and Regional Development, WA.

Energy, D. o. t. E. a. 2016. Threat abatement plan for competition and land degradation by rabbits in D. o. t. E. a. Energy, editor.

Energy, D. o. t. E. a. 2017. Threat abatement plan for predation, habitat degradation, competition and disease transmission by feral pigs (Sus scrofa). Background Document. .

Enright, N. J., and I. Thomas. 2008. Pre-European Fire Regimes in Australian Ecosystems. Geography Compass **2**:979-1011.

Fisher, A., L. Hunt, C. James, J. Landsberg, D. Phelps, A. Smyth, and I. Watson. 2005. Managing for biodiversity in the rangelands. Desert Knowledge CRC and Tropical Savannas CRC.

Fukuda, Y., H. I. McCallum, G. C. Grigg, and A. R. Pople. 2009. Fencing artificial waterpoints failed to influence density and distribution of red kangaroos (Macropus rufus). Wildlife Research **36**:457-465.

Giumelli, J., and B. White. 2016. Exclusion fencing: fighting ferals. Research Report. Kondinin Group.

Hacker, R. B., K. Sinclair, and L. Pahl. 2019. Prospects for ecologically and socially sustainable management of total grazing pressure in the southern rangelands of Australia. The Rangeland Journal **41**:581-586.

Hansen, B. D., P. Reich, T. R. Cavagnaro, and P. S. Lake. 2015. Challenges in applying scientific evidence to width recommendations for riparian management in agricultural Australia. Ecological Management & Restoration **16**:50-57.

Hardy, S., and B. Fuller. 2017. Project Report: A Review of the Feral Animal Control Program in the Whitsunday Regional Council Area from 2012-13 to 2016-17. Whitsunday Regional Council.

Healy, A., A. I. T. Tulloch, and R. J. Fensham. 2020. Dryland communities find little refuge from grazing due to long-term changes in water availability. Journal of Arid Environments **176**:104098.

Hutchison M., S. Z. a. N. A. 2011. Mozambique Tilapia, the Potential for Mozambique Tilapia (Oreochromis Mossambicus) to Invade the Murray-Darling Basin and the Likely Impacts: a Review of Existing Information. in C. o. A. Murray-Darling Basin Authority, editor.

IGAB, I. A. o. B. 2016. National Environment and Community Biosecurity Research, Development and Extension Strategy 2016–19. National Biosecurity Research, Development and Extension Framework.

Industries, N. D. o. P. 2006. The Assessment & Modification of Barriers to Fish Passage in the Namoi Catchment.

James, C. D., J. Landsberg, and S. R. Morton. 1999. Provision of watering points in the Australian arid zone: a review of effects on biota. Journal of Arid Environments **41**:87-121.

Kangaroo Management Taskforce, L. L. S. 2020. Options for integrated kangaroo management in the Western region - A practical uide for active management.

Lavery, T. H., A. R. Pople, and H. I. McCallum. 2018. Going the distance on kangaroos and water: A review and test of artificial water point closures in Australia. Journal of Arid Environments **151**:31-40.

Long, K., and A. Robley. 2004. Cost effective feral animal exclusion fencing for areas of high conservation value in Australia in V. Department of Sustainability and Environment, editor. Natural Heritage Trust.

Moseby, K. E., and J. L. Read. 2006. The efficacy of feral cat, fox and rabbit exclusion fence designs for threatened species protection. Biological Conservation **127**:429-437.

Natural Resources, N. Y. Stock management on watercourses. Government of South Australia.

NMVU. 2016. NRM Review and Price Guide for Significant Environmental Benefits. Native Vegetation Management Unit.

Sharp, T. 2012. Diffusion fumigation of rabbit warrens. Standard Operating Procedure. PestSmart website.

Sharp, T. 2016. Bait delivery of Rabbit Haemorrhagic Disease Virus (RHDV1) K5 strain. Standard Operating Procedure. PestSmart website.

SMEC. 2010. Options analysis and concept design or fish passage for Weirs of the Northern Murray-Darling basin

Staton, J., and J. O'Sullivan. 2006. Stock and waterways: A manager's guide, Land & Water Australia, Canberra.

Stevens, W. 2001. Declining Biodiversity and Unsustainable Agricultural Production-Common Cause, Common Solution. Science, Technology, Environment and Resources Group.

Summers, D. M., B. A. Bryan, M. Nolan, and T. J. Hobbs. 2015. The costs of reforestation: A spatial model of the costs of establishing environmental and carbon plantings. Land Use Policy **44**:110-121.

Tingley, R., B. L. Phillips, M. Letnic, G. P. Brown, R. Shine, and S. J. E. Baird. 2013. Identifying optimal barriers to halt the invasion of cane toads *Rhinella marina* in arid Australia. Journal of Applied Ecology **50**:129-137.

Trust, N. H. 2004. Cost Effective Feral Animal Exclusion Fencing for Areas of High Conservation Value in Australia. State Government Victoria.

Ward, M., J. Carwardine, C. J. Yong, J. E. M. Watson, J. Silcock, G. S. Taylor, M. Lintermans, G. R. Gillespie, S. T. Garnett, J. C. Z. Woinarski, R. Tinglet, R. Fensham, H. J. Conrad, H. B. Hines, J. D. Roberts, M. J. Kennard, M. S. Harvey, D. G. Chapple, and A. E. Reside. Unpublished results. A national-scale dataset for threats affecting Australia's imperilled flora and fauna.

Wilurara, N. R. A. 2014. New judas camel collars up and running.

Further information:

http://www.nespthreatenedspecies.edu.au

This project is supported through funding from the
Australian Government's National Environmental Science Program.

Threatened Species Recovery Hub

National Environmental Science Programme