Threatened Species Recovery Hub

National Environmental Science Programme

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

Appendix 4
Cost modelling methods for threat abatement strategies

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We estimated costs of threat abatement strategies following 3 broad steps (Fig. 1).

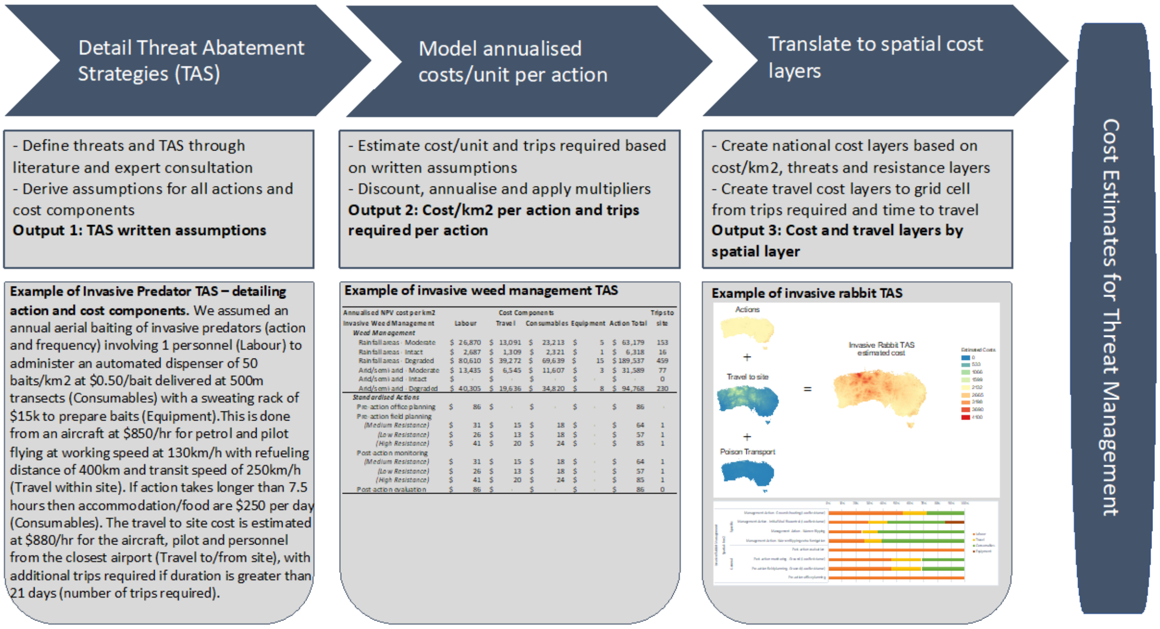

Figure 1. The three-step methodology overview to estimate costs for Threat Abatement Strategies (TASs). The middle grey row summarises the generic methodology that applies to each TAS, and in the bottom grey row we demonstrate the output of each respective step with a chosen TAS example

The first step detailed the threat abatement strategies, the actions and the cost components. To maintain consistency throughout we adopted three tiers of action descriptions for costing. Threat Abatement Strategies (TAS) (e.g. invasive predator management, hydrology management) were composed of a suite of actions to abate the threat (e.g. pre-action office planning, aerial baiting, post-action valuation), and nested within each action were four cost components: labour, travel within site, consumables and equipment (LTCE). Cost modelling was based at the LTCE level. In sum, we assigned a TAS to each biodiversity threat, derived a suite of actions for each TAS, defined a set of standardised actions, described in detail the cost components within these actions, and defined the cost multipliers required. In the second step we built the cost models based on detailed TAS assumptions from step 1.

We first modelled the cost per km2 and travel to site cost per km2 per km distance for each action (Eq. 2 and 3). We then structured the TAS costs to be a summation of the cost models across the management area of the actions and the distance travelled (Eq. 1), so that the total cost of a strategy was a function of action costs, travel to site costs and non-spatial costs for all actions included in the strategy.

$$TAS\ cost = \sum_{actions} (Action\ cost\ perkm^2\ \times\ Action\ area) + \sum_{actions} (Travel\ to\ site\ cost\ per\ km^2\ per\ km\ distance\ \times\ Action\ area \times 2\ \times\ Distance\ to\ site) + \sum_{actions} Non\ spatial\ costs \tag{1}$$

where

$$Action\ cost\ per\ km2 = \sum_{LTCE} Cost\ components\ \times annualisation\ NPV\ factor \times multipliers \times (management\ grid\ window\ size)^{-1} \tag{2}$$

and

$$Travel\ to\ site\ cost\ per\ km2\ per\ km\ distance = Travel\ cost\ per\ hour \times (transit\ speed)^{-1} \times Number\ of\ trips\ required \times annualisation\ NPV\ factor \times multipliers\ \times (management\ grid\ window\ size)^{-1} \tag{3}$$

The action cost per unit area was per km2 unless specified otherwise i.e. per km of river length or per in-stream structure (Eq. 1). The action areas were determined by the relevant threat extent (Eq. 1). Distance to site was measured from the closest city or airport to each grid-cell and multiplied by 2 to get a return trip (Eq. 1). Non-spatial costs (if any) are efforts that do not occur on-ground or vary with any spatial scale or variables, such as policy change (E1. 1). The cost components are the modelled costs for labour, travel within site, consumables and equipment (Eq. 2).

The annualization NPV factor was the standardisation coefficient of different payment frequency cashflows, NPV based on a 4% discount rate and an annuity-due of all payments (Eq. 2 and 3). The multipliers applied were 30% for on-costs, 10% for on-site contingencies, and 30% for uncertainty (Eq. 2 and 3).

The management grid window size represents the size over which the action is assumed to be implemented as part of a management effort and was assumed to be a standard management area of 100km2, unless otherwise specified (E1.2 and 3). The number of trips is based on the number of visits to a location required for onsite action to be completed in multiples of 21 days of field work (Eq. 3). The travel cost per hour includes vehicle cost and time compensation cost for personnel (Eq. 3). In all cases we assumed two people are required for carrying out field work together.
In the third step we extrapolated the action and travel costs to spatial layers by incorporating the relevant threat, landscape resistance and travel time layers. This process was done for each TAS separately for all management areas that are relevant in Australia.

2.1 Detailing Threat Abatement Strategies (TASs)

Detailing threat abatement strategies involved building and parameterising a mechanistic cost model. To do this we assigned a TAS to each biodiversity threat, derived a suite of actions for each TAS, defined a set of standardised actions, described the cost components within these actions, and defined the cost multipliers required.

Defining Threat Abatement Strategies

With the aim to estimate the cost required to address processes threatening Australia's biodiversity, we developed a list of TAS based on an up-to-date extensive set of threats (Chapter 1). This list had eight broad-level and 51 sub-category threats that threaten the complete Australian EPBC listed threatened species (1,796 species) (Chapter 1). We considered each threat and how it impacted the persistence of the threatened species and assigned each threat a TAS that was required to abate it. Threats of similar nature were grouped and assumed to be abated under the same TAS. As the purpose of this paper was to cost all threat abatements, although these threats were associated with a threat impact score of low, medium and high (Chapter 1) we weighted all threats to be of equal importance in our costing process. We excluded threat abatement for offshore islands (Appendix 3) as these require island specific approaches, opportunity costs associated with conservation actions (e.g. foregone mining profits, loss of logging revenue).

Deriving on-ground management actions

We assigned a suite of actions that collectively formed the TAS. These actions were derived to address the threat in entirety from the planning process, to the management, and to the evaluation process (adapted from (Carwardine et al. 2019; Iacona et al. 2018; Wenger et al. 2018). The complete eradication of threats with TAS actions was generally not feasible at broad scales, and for the majority the goal was threat abatement to a low level that will allow persistence of the threatened species.

We assumed all actions are performed humanely, are undertaken by competent/skilled practitioners that follow best practices, and that landholders and stakeholders are willing to participate. We set actions assumptions to be generic yet realistic and applicable across a landscape, accounting for some spatial variation when deemed necessary (see **Error! Reference source not found.**). For all actions we made assumptions on the frequency of the occurrence of these actions (e.g. paid every "X" years over 80 years). The details of each management action are specified within each TAS (see Appendix 5, also see example in Box 2).

We used best practice biodiversity-focused management options and built upon cost information for threats when available. This was done by conducting scientific literature reviews, expert elicitation through costing workshops (see Acknowledgements), examining Australian threat abatement plans (TAP), Australian threat abatement advice, Australian action plans, and exploring publicly available costing data from various sources (see Appendix 5 for specific references). Only when no literature existed for cost information, have we addressed knowledge gaps and informed our cost models through transparent cost assumptions that can be adjusted by end-users in the cost models.

We excluded some elements of costs that are context specific and we advise that end-users add these where relevant: unforeseen changes in actions or pricings over time; costs associated with achieving social and political feasibility, such as comprehensive Traditional Custodian and Indigenous community engagement and time and process to get approval for projects/policies. We excluded costs related to land rent or purchase, which is an enabling action rather than threat abatement action, and we did not account for their opportunity costs.

Standardising actions

To standardise and include a comprehensive estimate of costs, on top of the management action itself we have included 4 other actions within each TAS. These are pre-action office planning, pre-action field planning, post-action monitoring and post-action evaluation. Pre-action office planning was an office-based (off-site) action that occurred before the management action. It required 3 weeks of person hours to perform per standardised management area and was done every year that the management action occurs. Pre-action field planning was an on-site scoping that occurred before the management action, with the costs involving the labour hours of personnel to plan the management action, the transport within site and the equipment needed. The Post-action monitoring was the on-site monitoring of the outcome of the action after the management action had occurred. The effort was costed like the pre-action field planning, with the costs involving the labour hours of personnel to monitor the area of management action, the transport within site and the equipment needed. The Post-action analysis was an off-site office-based action that involved the reporting requirements, the data analysis, and incorporating the insights into the updated management planning. It required 3 weeks of person hours to perform per standardised management area and was done every year that the management action occurs.

Costing Components of Actions

Within the actions required for each TAS, we focused and generated assumptions based on the individual cost components of Labour (L), Travel (T), Consumables (C), and Equipment (E). We used standardised cost component inputs across all actions when possible.

Labour

The Labour component was a summation of personnel hours required to complete the action. This included the time to conduct the action, and if on-site, the time to travel within the management area while conducting the action and the time to travel to/from the site. We assumed 250 working days a year with 7.5 hours of working time. For all actions that were on-site, we set the number of personnel to be a team of 2. To account for different levels of expertise required for the work we set the cost of labour at 3 levels, $30, $45, and $65 per hour corresponding to entry, experienced and management level. This resulted in 3 salary brackets that are in line with the Department of Environment and Energy (Department of Environment and Energy 2016a), with the entry level corresponding to the average of Australian Public Service (APS) levels 1-3 around $56k, experienced level corresponding to the average of APS levels 4-6 around $84k, and management level corresponding to the average of Executive level (EL) levels 1 & 2 around $122k (Department of Environment and Energy 2016a). The travel within site was modelled separately to the Travel to/from Site cost (see Travel). Labour costs for the travel within site was based on the corresponding level of expertise, however for the travel to/from site labour cost we compensated personnel for travel time at a fixed entry level rate of $30/hour and are incorporated into the Travel to/from site costs.

Consumables

The Consumables component referred to any cost that was consumed during the action. We standardised accommodation/food cost to $210 per day per person, any this would apply to any action that was estimated to require more than 7.5 hours of effort required. This included $150 allowance a night for accommodation, and food costs at $60 a day that included a $15 breakfast, a $20 lunch and a $25 dinner. Other action specific consumables (e.g. bait, petrol for prescribed burning, herbicide) were all specified in the respective TAS assumptions (see Appendix 5).

Equipment

Equipment costs were any necessary equipment to conduct the field actions, these were TAS action specific.

Travel

Travel costs were calculated separately as Travel within site and Travel to site We assumed a standard milage travel cost at $0.95/km with a 4x4 Landcruiser Trayback set up for field work that includes on-roads (licensing and insurance), fuel, servicing, and running repairs, and turned over every 80,000 km (van Leeuwen Personal communication). We also assumed a standard transit speed of 80 km/h and a working driving speed of 40km/h.

We assumed an air travel rate of $850/hour that included air vehicle hire, petrol and the pilot adapted from (Hardy & Fuller 2017). We assumed a transit speed of 250km/h and a working speed of 130km/h. We also assumed a maximum flying distance of 400km before refuelling was required, with a 2*50km distance required to be flown to refuel at transit speed, as that is the assumed furthest distance from any point to the centre of a rectangular 100km2 management grid (Adapted from (Wenger et al. 2018)).

Travel within site was calculated as a cost/km2 based on vehicle costs incurred for the duration of the management action on site, and this was calculated within the TAS cost models as they were activity specific. We costed Travel within site by land travel at $285/day, derived from an assumed 300km/day of driving regardless of effort (300km*$0.95/km, see 2.1.4.4). We then multiplied this by the number of days vehicles are needed on site for the TAS specific action. The cost for Air Travel within site were TAS specific of the time it took to conduct any aerial activities.

Cost component multipliers

We applied 3 explicit cost multipliers to our cost components as an explicit step, with all individual costs quoted in this paper are before applying the multipliers. Multipliers were combined multiplicatively to each relevant cost component.

A 30% multiplier was applied to Labour costs to account for overheads. This accounted for employment on-costs like insurance, superannuation and leave. This was in line with on-cost percentages used for professional staff at the University of New South Wales in NSW and ACT (HR 2018a, b) , and overhead costs applied to action costs in South Africa (van Wilgen et al. 2016).

A 10% multiplier was for on-site contingencies and applied to Labour, Travel and Consumable cost components for any on-site based work. This accounted for unforeseen circumstances like bad weather and logistical problems when the action occurs outdoors. The 10% was chosen as an average of a suggested 5% (van Leeuwen Personal communication) and 15% (NESP Personal communication).

A 30% multiplier was for uncertainty in the cost estimates and applied to all actions for Labour, Travel, Consumables and Equipment. This accounted for any under budgeting that was likely to occur. The 30% was recommended in the NESP 7.7 cost workshop (NESP Personal communication).

2.2 Modelling costs for each action

In this section, we set standardised assumptions, described the landscape variations considered, described the general modelling process to estimate the action costs, and described the general process to estimate the travel to site cost.

We set up individual TAS cost models in Microsoft Excel to address context specific cost estimates, and end-users are encouraged to modify the assumptions that are in highlighted fields (Appendix 6). The cost model template was adapted from Carwardine et al. (2019). For further details of each cost model see assumptions in Appendix 5.

Action modelling assumptions

Here we summarise the set of assumptions made for each action.

Standardised Management Area

We assumed economies-of-scale and all actions were estimated at standardised areas of management, and costs were then later scaled back down to per grid cell (1kmx1km) and then applied to the management area. We assumed for all land-based management a management grid size of 100km2 and for water ways a management length of 100kms. There were two action exceptions, Instream Structure Management and Fish barriers Construction that were costed based on the number of generic sites instead of an area.

Discounting

The time horizon for the cost modelling is 80 years from 31st of December 2020 to 31st of December 2100. We present all cost estimates as an annualized Net Present Value (NPV) as at 31st of December 2020 accounting for the frequency of actions and using a discount rate of 4%. As costs for different actions are incurred at different frequencies, we standardised the cost timings to an NPV annuity-due payment, with all annualised NPV costs incurred at the start of each calendar year.

A discount rate of 4% assumes a nominal interest rate of 5.6% and an inflation rate of 1.5%. All cost data input gathered from literature are inflated to Dec-20 Australian dollar values at a 1.5% interest rate. We adopted a real discount rate in line with the recommended 4% for government projects where the benefits can be articulated but not translated easily to monetary terms (DTF 2013). This achieved a balance between the criticised high discount rate of 7% used in government projects (Terrill & Batrouney 2018) and the low risk free rate risk free rate of 0.1% in December 2020 (RBA 2021).

Spatial variations in actions

We accounted for landscape variation in our cost models from publicly available GIS layers, and modelled different levels of cost estimates for the corresponding heterogeneity. There were two main ways that landscape heterogeneity influenced actions, the first spatial variation changed the type of action that was conducted, and the second spatial variation changed the level of effort required to conduct the action.

Spatial variation in action type

At the broad-scale level, we deemed certain actions more suitable in particular spatial areas influenced by human population density, major vegetation type and occurrence of other threatened species.

We used the 5 levels of remoteness from Accessibility/Remoteness Index of Australia (ARIA) (ABS 2018) as a proxy of population density to perform threat abatement actions safety. The 5 levels in Australia were urban, inner regional, outer regional, remote, and very remote (ABS 2018), and these levels influenced certain actions that had an option between ground or aerial action. An example would be the Ecological Fire Regime TAS, with aerial burning occurring in all regional and remote areas, and ground burning occurred in urban areas (See Appendix 5: Ecological Fire Regime Management for more details).

We also used major vegetation groups (Department of Environment and Energy 2016b) as an indication of canopy cover as to whether certain actions were suitable in an area. For Large Invasive Herbivore TAS, the action of aerial culling occurred in open-canopy vegetation types and areas of low human population density in remote and very remote Australia, and the ground culling action occurred everywhere else (see Appendix 5.11 Invasive Large Herbivore Management for more details).

Certain threatened species were assumed to be affected by threat abatement action and their distribution was used as a spatial variable. We wanted to avoid poisoning non-target threatened species like the Spotted-tail quoll *(Dasyurus maculatus subspecies*). For baiting options in Invasive Predator Management, we costed for ground-baiting in areas where *D. maculatus subspecies* occurred (Department of Agriculture 2017), major vegetation groups associated with thick canopy cover (Department of Environment and Energy 2016b), and areas with high human population density in urban Australia (ABS 2018). We costed for aerial baiting in all other areas (see Appendix 5.12: Invasive Predator Management for more details)

We wanted to avoid overlapping of efforts of TAS with similar actions. We defined mutually exclusive areas for Habitat Restoration TAS and Invasive Weed Management TAS, as they had had similar actions with the former being a more intensive scaled-up version of the latter. We created a "restorable habitat" land layer by overlaying the Australian land-use map (ABARES 2021) with the major vegetation group (Department of Environment and Energy 2016b), excluding land uses unlikely to be converted to threatened species habitat due to their intensive use, such as intensive agriculture. We conducted the Habitat Restoration TAS in all areas that were cleared and restorable, and we conducted the Invasive Weed Management TAS in areas that were vegetated and had threatened species impacted by invasive weed (See Appendix 5.8: Habitat Restoration and Appendix 5.14: Invasive Weed Management for more details).

Spatial variation in action effort

At the broad-scale level, we assumed vegetation type and terrain ruggedness to influence the effort required to conduct actions.

Vegetation groups have different characteristics that will influence weed management and habitat restoration actions within these areas. We created an "effort" multiplier for major vegetation groups, adapted from rough habitat restoration cost estimates by broad vegetation type (Maggini et al. 2013). For Invasive Weed Management and Habitat

Restoration we applied this multiplier as a scaling factor to our base costs (See Appendix 5.8: Habitat Restoration and Appendix 5.14: Invasive Weed Management for more details)
Ecological fire regimes under management are governed by the extent, patch size, frequency, and intensity ideal for each vegetation subgroup subgroup (Queensland Parks and Wildlife Service 2013). Our fire regime cost models assume that the only variable was the extent of management area burnt (%), while keeping patch burn size fixed (see Appendix 5.5: Ecological Fire Regime Management for more details). From the assumed pre-European fire intervals by vegetation type (years) (Enright & Thomas 2008) we inferred the proportion of area burnt by taking the inverse. Just by using the extent of area burnt is convenient, as by doing annual burns of the extent of area burnt (%), the rotation ensures the whole landscape has the same burn "age". For example, an area that has an assumed fire interval of 50 years has an inferred 2% extent management area burnt (1/50), and if 2% management area is burnt annually on rotation for perpetuity all areas will be of the same burn "age" of 50 (see Appendix 5.5 Ecological Fire Management for more details).
Landscape ruggedness influenced actions that involved walking. If an action was performed on foot, apart from the effort to conduct the action itself, the labour costs were influenced by walking speed and the transect widths through the management area. We set the 3 terrain levels based on the topographic ruggedness index (TRI) (Riley et al. 1999), we reclassified it to low resistance terrain from 0 to 31, moderate resistance from 31 to 110, and high resistance from 110 to 698. We chose the TRI to be an all-encompassing index account for the changes to the base walking speed by rough terrain, steepness, and surface area.
For actions that required walking, we assumed a simplified assumption of a base walking speed of 4.46 km/h adjusted for three levels of terrain ruggedness, 100% speed on normal terrain, 3.35km/h at 75% on moderate terrain and 2.23 km/h at 50% speed on rough terrain. We assumed that this would be the average walking speeds for all personnel regardless of gender, weight and height.
For base walking speed, an Australian pedestrian crossing assumed a walking speed of 4.32km/h (1.2m/s) for crossing a road, although this varied when it was the red man flashing or the green crossing man (Truong et al. 2018). In a study considering ruggedness, the preferred walking speed was 4.46km/h on smooth terrain (1.24+/-0.17m/s), and 3.85km/h (1.07+/-0.05 m/s) on rough terrain (Gast et al. 2019). Walking on a rough terrain, humans

use 115% more energy cost due to mechanical work in the centre of mass and substrate, more decelerations and accelerations, shorter step lengths and wider step widths and other stabilisation efforts (Gast et al. 2019). Steepness was considered using a digital elevation model (DEM) in a South African study, with assumed standard walking speed of 3km/h and a 2X multiplier for the "steep" areas with a 40 degrees cut off (van Wilgen et al. 2016). Total surface area was considered based on a digital elevation model (DEM), and when compared to a planar area there was up to 1.5 times the surface area and would increase walking (Wenger et al. 2018).

Create cost models

This section describes the general process of the action cost modelling, with all costs modelled and summed across the cost components, adjusted for the time value of money, creating an annualised cashflow, and standardising for a per unit area cost (Eq. 2).

$$\begin{aligned} &\mathit{Action\ cost\ per\ unit\ area} \\ &\quad = \sum_{LTCE} \mathit{Cost\ components} \times \mathit{annualisation\ NPV\ factor} \\ &\quad \times \mathit{multipliers} \times (\mathit{management\ grid\ window\ size})^{-1} \end{aligned} \tag{2}$$

We set up all the generic assumptions in the "Overall Assumptions" tab that applied across all TAS cost models, and these acted as building blocks for the models. This included all the transect widths, wages, discount rates, multipliers and any other standardised assumptions. We then setup the TAS cost models in separate Excel tabs with the naming convention following the TAS name.

The cost modelling process started with translating action from qualitative assumptions to quantitative numbers over a standardised management area. For each action within the TAS, we estimated the costs for each cost component based on the specified TAS action assumptions. These calculations were TAS-specific and done in the sub-sections within the Excel tabs (see Appendices 5 and 6).

After estimating all the actions costs, we then presented a summary table of the cost estimates. In the header section of each TAS excel tab, columns C to K described the action details per standardised management area of 100km2. The details included the number of trips required for any on-site work, the total effort estimated for the cost components (if relevant), the action cost estimate per annum accounting for the number of times the action was incurred within the year, and the execution frequency required over the time horizon of 80 years.

We wanted to create consistent and additive annualised cash flows, as costs were incurred at different frequencies (i.e. once every 5 years or once every 20 years). We discounted all cash flows to get an 80-year Net Present Value (NPV) accounting for the frequency of cost (see 2.2.1.2). We then transformed this NPV to an annuity payment that is paid at the start of each year for 80 years, a standardisation across all payments so that costs for all actions can be compared and added. This process of calculating the NPV and annualisation of cash flows are shown in Columns L to P in the summary table of each Excel TAS cost model.

We then divided all the costs by the standardised area to calculate a per unit area cost (per km2 unless otherwise specified), applied the corresponding cost multipliers for the relevant cost components (see 2.1.5), and resulted in the final annualised NPV cost per unit area including multipliers.

Travel to site cost

This cost estimate was driven by the travel to site cost incurred for travelling to/from the management area, multiplied by the distance to site and size of area managed (Eq. 1). For land travel we assumed the travel time was to the closest big city (Weiss et al. 2018) and for air travel we assumed the distance from the management grid cell to the closest airport as the crow flies (see Appendix 2). The distance to travel was multiplied it by 2 to get the total travel distance of a return trip. The management area affects the travel cost, as we assume a standardised management area, and a larger area requires more trips to that area.

We then derive the travel to site cost per unit area per km distance (Eq. 3)

$$\begin{aligned}
&Travel\ to\ site\ cost\ per\ unit\ area\ per\ km\ distance \\
&\qquad = Travel\ cost\ per\ hour\ \times (transit\ speed)^{-1} \\
&\qquad \times Number\ of\ trips\ required \\
&\qquad \times annualisation\ NPV\ factor \times multipliers \\
&\qquad \times (management\ grid\ window\ size)^{-1}
\end{aligned} \tag{3}$$

We costed the Travel to/from the site by land travel at an hourly rate of \$136/hour, inferred from \$76/hour assumed transit rate of 80km/h at (80km/h*\$0.95/km, see 2.1.4.4) and

$60/hour for 2 personnel travel time compensation (2*$30/hour, see 2.1.4.1). This was then multiplied by the time needed to drive a vehicle to the closest city

The delivery of poisonous goods legally required secure transport and was costed as a separate item. We costed secure poison delivery at $1.60/km of land travel, accounting for a refrigerated truck with two staff, running fees, petrol, salary, allowances, and accommodation (van Leeuwen Personal communication). This amounted to $128/hour from the assumed 80km/h transit speed (80km/h* $1.60/km). This was applied to 1080 invasive predator bait that is classed as an S7 poison and RHDV1-K5 vials for rabbit biocontrol.

We costed Air Travel to/from site at $880/hour that included the cost of the base air travel rate of $850/hour with 1 management personnel compensated for travel time at $30/hour (see 2.1.4.4). The cost was then multiplied by the

The multiplication by $(transit\ speed)^{-1}$ provides an hours per km distance travelled. This when multiplied by distance (in Eq. 1) we get the total time needed for travel to site.

Given our assumption that a standard management action was carried out over an area of 100km2 (100 grid cells), we created a cost-sharing window of 100 neighbouring 1km2 grid cells such that each grid cell incurred 1% of the travel cost required for the management area to distribute the travel cost of the distance travelled. For example there would be 2.6 "travel trips" to a management area if the total spatial area managed is 260km2 with each grid cell incurring 1% of cost (260km2*1%). The exceptions to this cost-sharing window were any TAS with riparian management where the cost was divided across the length of the river, and for Hydrology management TAS with no cost-sharing window as travel to the locations was site specific.

To achieve fair and ethical working conditions, we set the maximum time for personnel to be on-site conducting an action as 21 continuous days. Any action that needed more effort than the maximum allowed time on-site required subsequent additional trips. The assumed number of trips makes no distinction between the same team going out and back multiple times to complete the task in 21-day blocks, and multiple teams going once to complete the task within 21 days. i.e. if we have a job that takes 100 days, the trips needed is 5 (100/21 rounded up). Required personnel time is constant at 100 days, number of trips = 5, accommodation = 100 nights. We have either 1 team doing it in 5 consecutive trips (4*21 days and 1*16 days), or we have 5 teams doing it within 21 days (5*20).

We applied a similar discounting and annualising for the trips required as like the cash flows (see 2.2.1). After getting the number of trips, we then considered the frequency of travel over the projection period. As different actions have different frequencies (i.e. action occurs every “X” years), we calculated the NPV of the number of trips over 80 years, and then re-annualised the number of trips required per year. For example, an action that occurs every year for a period of 80 years equates to 80 total trips, and the NPV @4% of trips required = 24.87, and the re-annualised NPV trips required = 1. This is expected as it is 1 trip a year. Whereas if an action occurred every 10 years for a period of 80 years, this equates to 8 total trips, the NPV @4% of trips required = 2.95, with the re-annualised NPV trips required = 0.12. In this scenario, we only expect to travel 0.12 times a year, as we are only travelling once every 10 years. We then applied the multipliers to each of the relevant costs.

2.3 Translating cost models to spatial cost layers

We translated the costs per unit area to a total, summed TAS spatial layer, the spatial action cost layers and the spatial travel cost layers. Each TAS had different numbers of spatial actions and cost layers depending on the required action map layers and the modes of transport used (see Appendix 2). The TAS GIS cost layers were applied on a spatial scale and captured a degree of spatial variation for varying action efforts conducted over a large area. The TAS GIS cost layers reflect the average effort that is needed across a spatial area rather than prescribing detailed local scale actions.

We created an excel tab for each TAS cost model (hereon “GIS summary”) that provided all critical information to translate cost models to spatial layers (see Appendix 5). The analysis in this section was done in ArcGIS version 10.4 (Redlands 2016) (Appendix 2 for summary of all baseline datasets)

Using the GIS summary we created the spatial action cost layers by reclassifying the per unit area values of each spatial layer (for example, listed as Map A in the GIS tab) to the corresponding total TAS cost per unit, accounting for any spatial variation in costs. We created a spatial travel cost layer by reclassifying each grid cell by the corresponding number of annualized trips required. We calculated the travel cost for air travel and ground travel using a time to city map (see Eq. 4 and Appendix 2). Where available, all spatial cost and travel layers were then extracted to where the threat exists spatially, however if no threat layer existed we presented the layers at the national scale. We then summed the spatial cost layer and the spatial travel cost layer to form the total cost layer.

$$
\begin{aligned}
&Total\ spatial\ cost \\
&\quad = (Total\ cost\ per\ km2\ for\ Map\ A\ across\ all\ actions) \\
&\quad \times (Area\ covered\ by\ Map\ A\ for\ correposnding\ resistance\ level\ ) \\
&\quad + 0.01 \times 2 \times (total\ annualised\ trips\ for\ Map\ A\ with\ Airport\ Map) \\
&\quad \times (Distance\ to\ closest\ airport) \times (250km/h)^{-1} \times (\$1241\ per\ hour) \\
&\quad + 0.01 \times 2 \times (total\ annualised\ trips\ for\ Map\ A\ with\ Map\ Road) \\
&\quad \times (time\ to\ closest\ city) \times (\$208.40\ per\ hour)
\end{aligned}
\tag{4}
$$

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Further information:

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