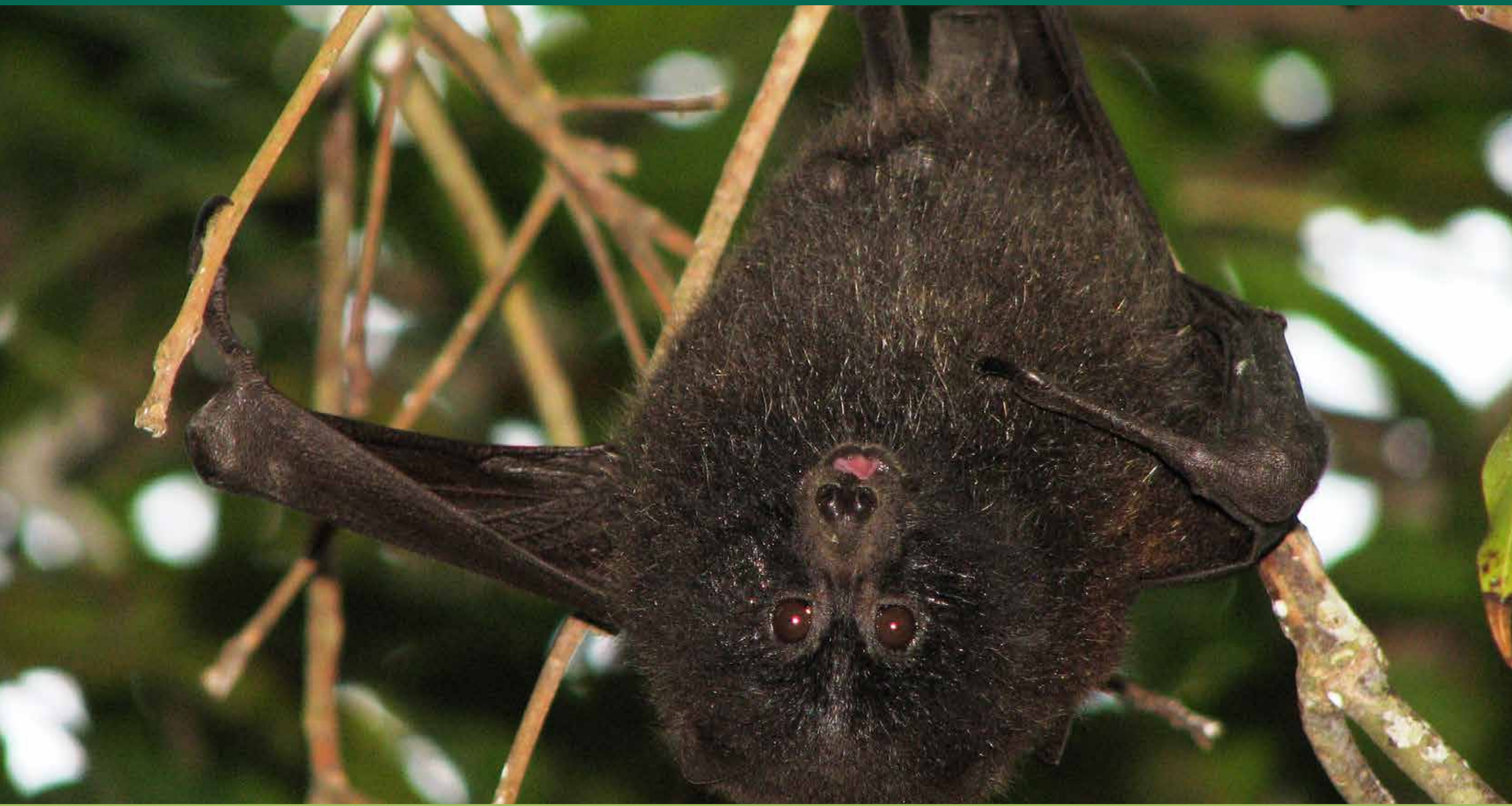
Threatened Species Recovery Hub

National Environmental Science Programme



Strategic decision-making for flying fox conservation on Christmas Island

Final Report

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Christmas Island location. Source: WAPC (2015).

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Cover image: Flying fox foraging. Image: Tanya Detto

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Executive summary

Recovery Teams provide a critical role in the provision of expertise and governance of threatened species management. But like all groups, their effectiveness may be limited by difficulties in reaching collective agreement on preferred actions under uncertainty. This project provides a template for problem formulation and group decision-making based on the cost-effectiveness of actions. Innovative elements include:

- use of argument maps to assist expert elicitation,
- non-linear value functions describing conservation payoffs, and
- estimation of cumulative benefit across multiple actions.

This report describes key elements of the approach and illustrates its application using a vignette, developed in collaboration with the Christmas Island Flying Fox Advisory Panel. The vignette is hypothetical, although based on real challenges, including land use change and attribution difficulties arising from multiple threats and associated speculation in the payoff of candidate management actions.

A spreadsheet based decision support tool developed for the flying fox can be adapted to assist recovery teams working on management priorities for species elsewhere.

Christmas Island flying fox foraging in a mango tree. Image: Tanya Detto

Introduction

The Christmas Island Flying Fox (CIFF) is endemic to Christmas Island, and is the sole remaining extant species of five endemic mammal species present on the island at the time of its settlement. Monitoring in 2012 suggested that it had declined by approximately 35% over the preceding 6 years, but more recent monitoring provides some evidence of subsequent recovery. A number of postulated threats are associated with historical decline in CIFF. While the island has witnessed significant land use and ecological change in recent decades, none of these factors have been clearly demonstrated to have a significant impact on flying foxes. Disturbance or predation by invasive species such as cats or yellow crazy ants might be contributing to population decline. Further potential threats include disease, or cadmium poisoning arising from mining activities. Alternatively, past land clearing, habitat loss or catastrophic events such as cyclones might be having delayed effects on population dynamics. One of these threats might be driving population decline or the cumulative and interactive effects of a subset (or all) of these threats may be responsible.

Current collaborative projects between the University of Sydney, University of Western Sydney, Taronga Zoo Conservation Society Australia, CSIRO and Parks Australia tackle different putative aspects of Christmas Island Flying Fox decline, including ecology and population dynamics, disease and physiological concerns. This ongoing work forms the basis for resolving the threats driving the decline of this species; while this work continues it remains timely to consider management actions that may improve the long-term persistence of the species and exploratory work that may best guide decision-making.

The project's aim was to build an analytic approach to investigate the impact of multiple threats on the CIFF and the benefits of strategic management. The approach sought to synthesise current understanding of the threats from disease, mining and habitat loss, invasive species, and other threats.

Context

The project built on past work in decision science applications in expert judgment and conservation management. Specifically:

- the project prioritisation protocol (Joseph et al. 2009),
- protocols for elicitation of expert judgment (Hemming et al. 2018), and
- more recent TSR Hub work dealing with evaluation of ex-situ management under project 4.1.5.

In the next section, we describe innovative extensions developed in this project, including:

- use of argument maps to assist expert elicitation,
- non-linear value functions describing conservation payoffs, and
- estimation of cumulative benefit across multiple actions.

Methodology

The project developed (a) a process for formulating the conservation problem over a series of four workshops or meetings, and (b) an excel-based decision support tool to capture and analyse key judgments informing management priorities. Both elements can be deployed in an online setting or in face to face meetings.

In this section we describe the main methodological aspects of the approach. In the Findings section we provide an illustrative application.

Problem formulation

Over a series of online workshops we formally described the conservation problem. Workshop content was guided by the steps of structured decision-making (Gregory et al. 2012). Specifically:

- **Workshop 1** – Introduction to argument maps as a graphical basis for problem formulation
- **Workshop 2** – Development of argument maps describing past, present and future population trends for CIFF. Specification of the base case against which candidate management actions are to be assessed. Description of future change in land use and climate. Identification of management alternatives.
- **Workshop 3** – Elicitation of expert judgments of the performance of each candidate action with respect to the future population size of CIFF.
- **Workshop 4** – Use of the decision support tool to inform priority management actions.

Decision support tool

The decision support tool is an extension to established approaches to the characterisation of cost-effectiveness in conservation, where the merit of an action in a finite budget setting is the difference in the probability of persistence with and without the action, divided by the cost of implementation (Joseph et al. 2009). Here we outline three innovative aspects of our work.

Use of argument maps to assist expert elicitation

Argument maps take a proposition and document claims (and counterclaims) supporting (and challenging) the proposition, along with accompanying evidence. For example, there may be a set of contested claims around the proposition that a species at some locale is in decline, including inferences from sparse monitoring data, putative threats, ecological theory, and observations elsewhere. We developed argument maps to support experts in their subsequent judgments about future population trajectories under various management scenarios (van Gelder et al 2016).

A pervasive shortcoming in human judgment is overconfidence (Burgman 2016). Assisted by explicit capture of supporting and refuting evidence via argument maps, the elicitation of judgments follows the formal structured 'IDEA' protocol described by Hemming et al. (2018). In general, formal structured techniques provide answers that are more accurate than do unstructured approaches. The IDEA protocol emphasizes anonymity in judgments, feedback, discussion and subsequent revision in a second round of elicitation (Hanea et al. 2018). In each round and for each question, experts provide

- a plausible lower bound,
- a plausible upper bound,
- a best estimate (lying between the bounds), and
- the level of confidence the truth lies between the specified lower and upper bounds.

The unweighted average of a group of experts comprising independent judgments almost always outperforms the best performing expert within the group over multiple questions.

An example of judgements for a single question are shown in Figure 1. Responses were provided by 12 anonymous experts. Plausible bounds for each estimate represent 90% credible intervals (adjusted from the confidence assigned by each expert). The pooled outcome aggregated over the 12 experts is used in subsequent analyses in the decision support tool.

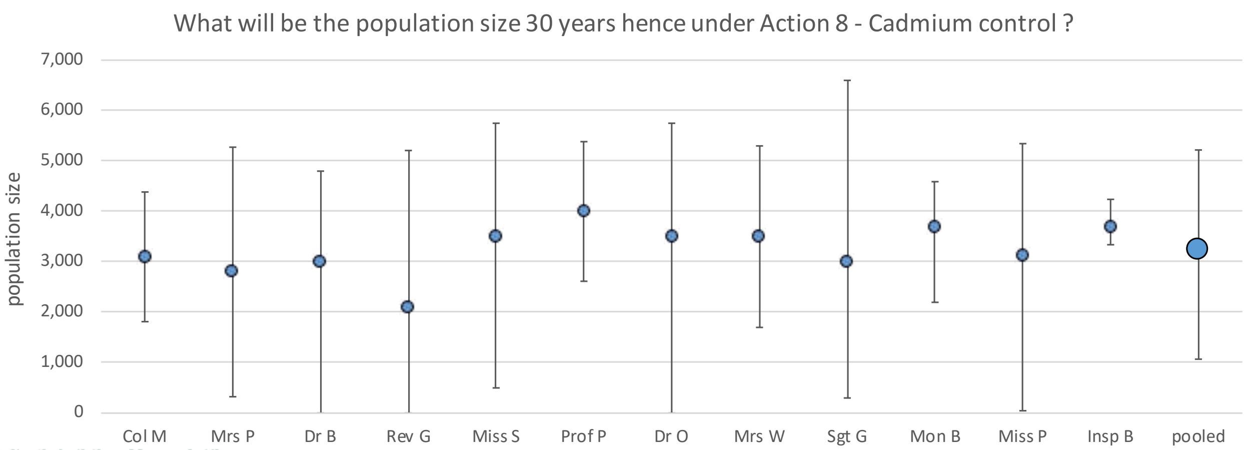


Figure 1. Example of outcomes of an expert elicitation involving 12 participants.

Non-linear value functions describing conservation payoffs

The extent to which managers and stakeholders care about gains and losses in conservation outcomes for an individual species may be distinctly non-linear. For many people and organisations, the sense of loss of the last 100 individuals of a species is a much greater loss than a decline from say 500 to 400 individuals.

The value $v_i(x_i)$ over x_i can be described by the equation,

$$v_i(x_i) = \begin{cases} \frac{1-\exp[-(x_i - x_i^L)/\rho_i]}{1-\exp[-(x_i^H - x_i^L)/\rho_i]}, \rho_i \neq \infty \\ \frac{x_i - x_i^L}{x_i^H - x_i^L}, \text{otherwise} \end{cases},$$

where x_i^L and x_i^H are the lowest and highest values in the range of x_i, respectively, and ρ is the exponential constant derived from a decision-makers value judgment (Kirkwood 1997). The value $v_i(x_i)$ ranges from 0 at x_i^L to 1.00 at x_i^H In the decision support tool we rescale value to the interval [0,100].

The variable x_i could be probability of persistence, consistent with the project prioritisation protocol of Joseph et al. (2009). But in our decision support tool we use population size as the key variable of interest. In our view, population size is a natural and more appropriate attribute for thinking about gains and losses and their value (Keeney and Gregory 2005). The lower bound (with a value of 0) is extinction, or $N= 0$. The upper bound (with value 100) is the carrying capacity of the island, N_K.

Where captive breeding is included in the set of candidate actions, our framework requires decision-makers to undertake two tasks involving value judgments:

1. Describe how value changes with change in the relative size of the population in the wild.
2. Describe the value of an ex-situ population relative to the wild population, and the extent to which that value depends on the size of the population in the wild.

The first task elicits the shape of the value function for the wild population. Figure 2 illustrates three possible outcomes. The dotted line shows a decision-maker with an emphasis on the existence value of the species. There is a dramatic increase in value in the range of 0 (extinction) to a population size of 200, but little additional value with greater population size. The straight dashed line might describe the value function of a decision-maker who values the lives of individuals of the species irrespective of total population size, consistent with a rights-based approach to welfare. The intermediate continuous line may stem from a range of value-based concerns, including considerable emphasis on existence value, but also an important functional role for the species in the ecosystem which is proportional to population size. It may also have a sole focus on existence value, but its muted trajectory (relative to the dotted line) may reflect the ecology of the species. All else being equal, the value associated with a doubling or tripling in population size of a species prone to boom and bust dynamics will be less than that for a species relatively insulated against stochastic perturbation, because even at large population sizes there may be a non-trivial risk of extinction.

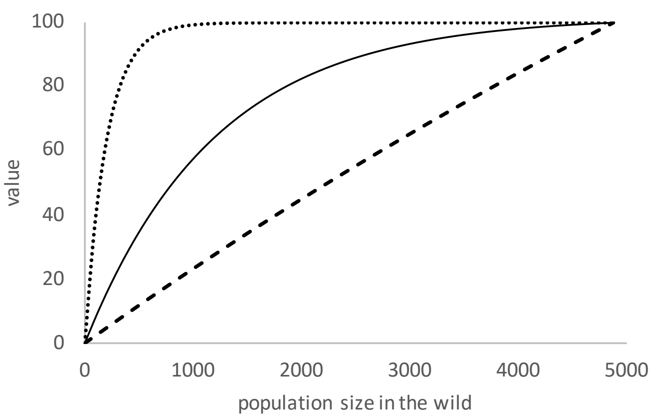


Figure 2. *Example of three different value functions.*

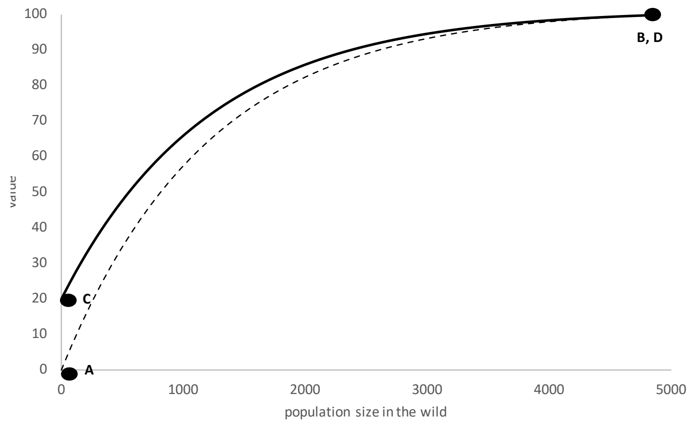
The second task acknowledges that for many decision-makers, the value of an ex-situ insurance population will depend on the status of the population in the wild. More specifically, managers that strictly view captive breeding only as a means of improving prospects for the wild population will assign little or no value to an ex-situ population where they perceive the in-situ population to be secure. They may however assign very substantial value to an ex-situ population if the species is at high risk of extinction in the wild. This dependency between the value placed on ex-situ and in-situ populations may be less pronounced or absent among decision-makers representing the interests of zoos or botanical gardens. They may articulate the extent to which they value an ex-situ population without regard to the status of the population in the wild.

In technical terms, the distinct possibility for conditional value judgments implies that the value assigned to the in-situ and ex-situ populations cannot simply be added together, because they are not preferentially independent (von Winterfeldt and Edwards 1986). The second task requires decision-makers to extend the thinking underpinning the value function they described in the first task to circumstances with and without an ex-situ population.

Figure 3 shows the value judgments of two hypothetical decision-makers, both of whom described a task 1 value function consistent with the intermediate continuous line in Figure 2. Point A represents extinction in the wild and no ex-situ population. It is the worst case, and by definition is assigned a value of zero. Point B is the best case, representing a wild population at carrying capacity and establishment of an ex-situ population. It is automatically assigned the maximum value of 100. While our two hypothetical decision-makers share the same value-based views on the status of the wild population in isolation, they have strongly contrasting views when considering an ex-situ and in-situ population collectively. Figure 3a places a high value on having an ex-situ population, irrespective of what's happening in the wild. Should the species go extinct in the wild, the presence of an ex-situ population represents very substantial value (point C), and without an ex-situ population, a wild population at carrying capacity is assigned relatively modest value. The difference between the two curves representing with and without an ex-situ population remains the same throughout the full range of change in the wild population. That is, in this instance, the value of the ex-situ population is independent of the status of the wild population.

Figure 3b is a decision-maker who is generally less enthusiastic about ex-situ management, and whose views of the value of an ex-situ population depends on status in the wild. Beginning from a modest but non-trivial value assigned to an ex-situ population at a wild population of zero (point C) they assign diminishing additional value as the status of the wild population improves. Where the wild population is at carrying capacity, there is no additional value of an ex-situ population (point D).

(a)



(b)

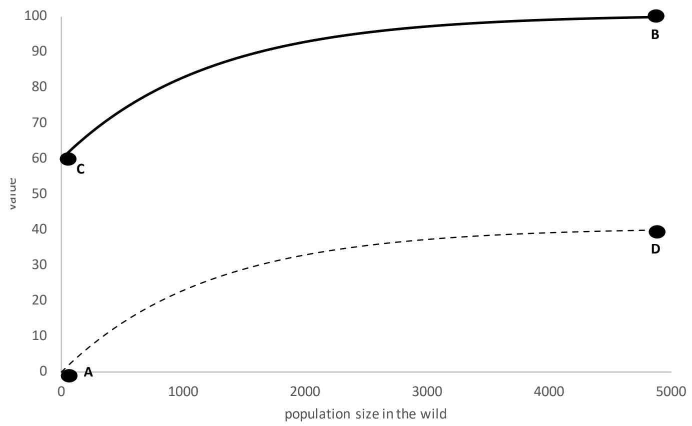


Figure 3. *The relative value of the wild population with (continuous line) and without (dashed line) an ex-situ insurance population for two hypothetical decision-makers, (a) and (b). Points A and B are the minimum and maximum, and by definition are assigned values of 0 and 100, respectively. Points C and D are elicited from the decision-maker. C is the relative value assigned to having an ex-situ insurance population, but extinction in the wild. D is the relative value of a wild population at carrying capacity, but no ex-situ insurance population.*

Together with technical judgments concerning the change in population size under various candidate management actions, these value judgments play a key role in estimating cost-effectiveness.

Estimation of cumulative benefit across multiple actions

The elicitation of expert judgment can be laborious and time-consuming. For three candidate actions, x, y and z, there are six possible combinations for implementation:

- x alone,
- y alone,
- z alone,
- x and y,
- x and z,
- y and z, and
- x, y and z

Where time and effort are unconstrained it would be desirable to elicit judgments of the benefit of all six scenarios, together with the 'do nothing' or base case scenario. But typically, recovery teams countenance more than three candidate actions, and the burden of formal elicitation can be overwhelming.

In our decision support tool we require judgments of the effect of *individual* actions and compute estimates of the aggregate payoff of multiple actions automatically in the spreadsheet. In doing so, we assume the effectiveness of any single action is independent of that of other actions. We also assume there is an upper limit on the aggregate benefit of multiple actions defined by the island's carrying capacity, N_K, which experts are asked to estimate.

The estimated population size under the base case is denoted N_B. The effect of an individual action i, described as a proportion of the difference between N_K and N_B, and denoted p_i, is

$$p_i = \frac{(N_i - N_B)}{(N_K - N_B)}.$$

Generalising over multiple actions, to estimate the aggregate proportional change P in population size (again relative to the difference between N_K and N_B), we use the formula,

$$P_m = 1 - \prod_{i=1}^{m}(1 - p_i).$$

The aggregate effect of m actions described in terms of population size is

$$N_m = N_B + P_m(N_K - N_B).$$

Beyond mangoes. Christmas Island flying fox enjoying the fruits of the island. Image: Paul Emery

Findings

The decision support tool was developed collaboratively with the Christmas Island Flying Fox Advisory Panel who at the time were considering impacts of a statutory strategic assessment for the island. The details of those deliberations are confidential. Here we provide an illustrative application of the decision-making process that is based only loosely on current circumstances.

Problem formulation

Despite considerable monitoring effort, the historical trends and current trajectory of the CIFF population are uncertain (Figures 4 and 5). We developed argument maps with the Advisory Panel to describe a range of plausible factors associated with tentatively identified past, present and future trends and their causes (Figures 6 – 8).

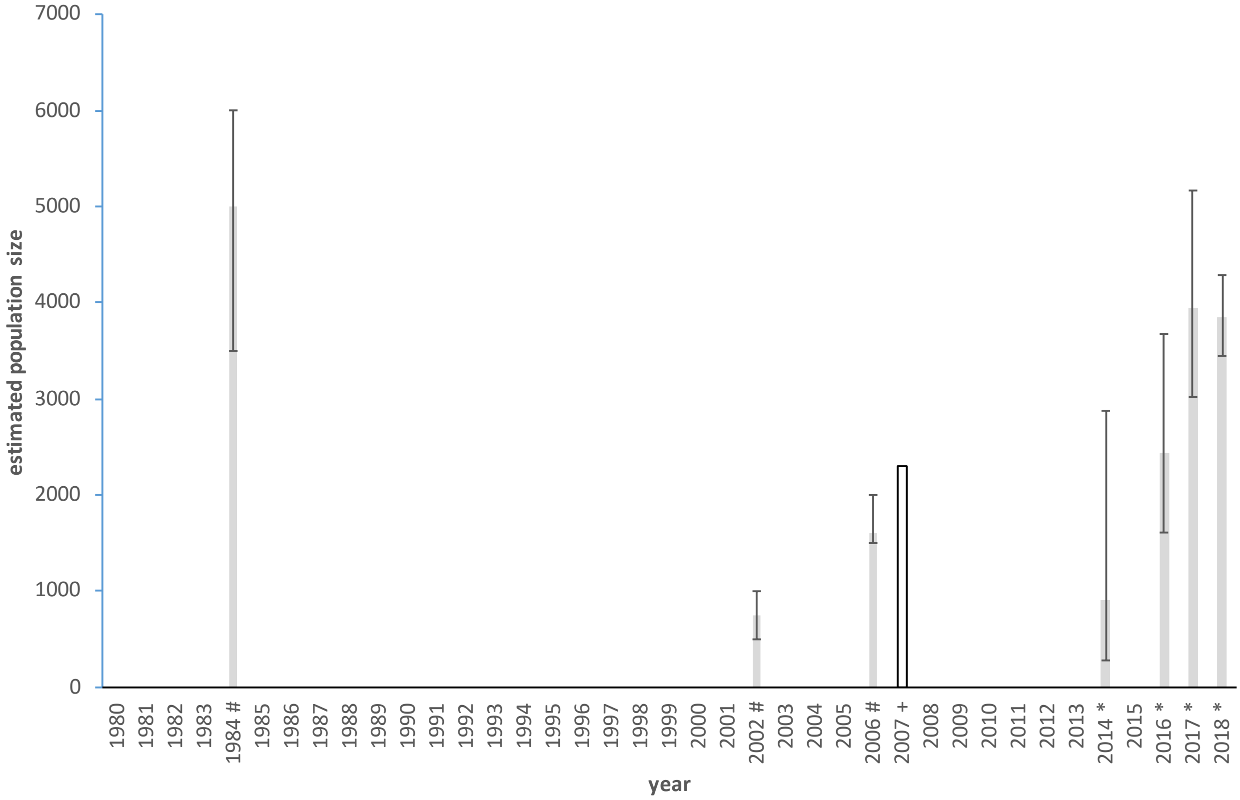


Figure 4. *Absolute population estimates from past surveys of CIFF using a variety of sampling methods. Interpretation of trends is made difficult by different methods used by different researchers.*

Notes

1984 - counts at camps plus incidental observations (Tidemann 1985).

2002 and 2006 - counts at camps (Corbett et al. 2003, James et al. 2007).

2014 - distance sampling (Director of National Parks 2014).

2016, 2017 and 2018 - mark-recapture (Todd 2019).

 # Error bars represent researchers' subjective judgment (of unspecified confidence or credibility level).

+ Uncertainty unreported, unpublished data from Parks Australia, cited in TSSC (2008) listing advice.

** Error bars represent 95% confidence intervals.*

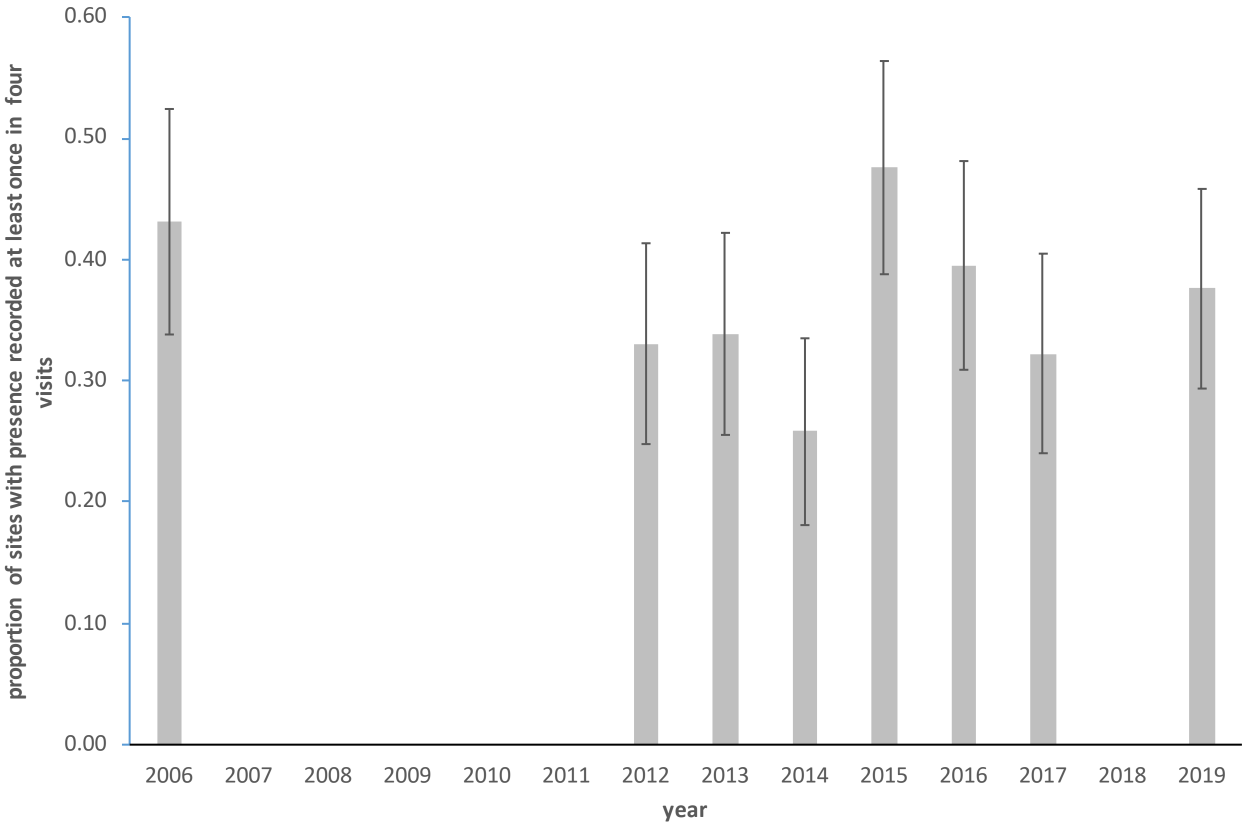


Figure 5. *Relative population estimates from past surveys of CIFF using a consistent sampling methodology comprising four nocturnal visits to each of >100 sites. Error bars indicate 95% confidence intervals.*

A flying fox camp. Image: Director of National Parks

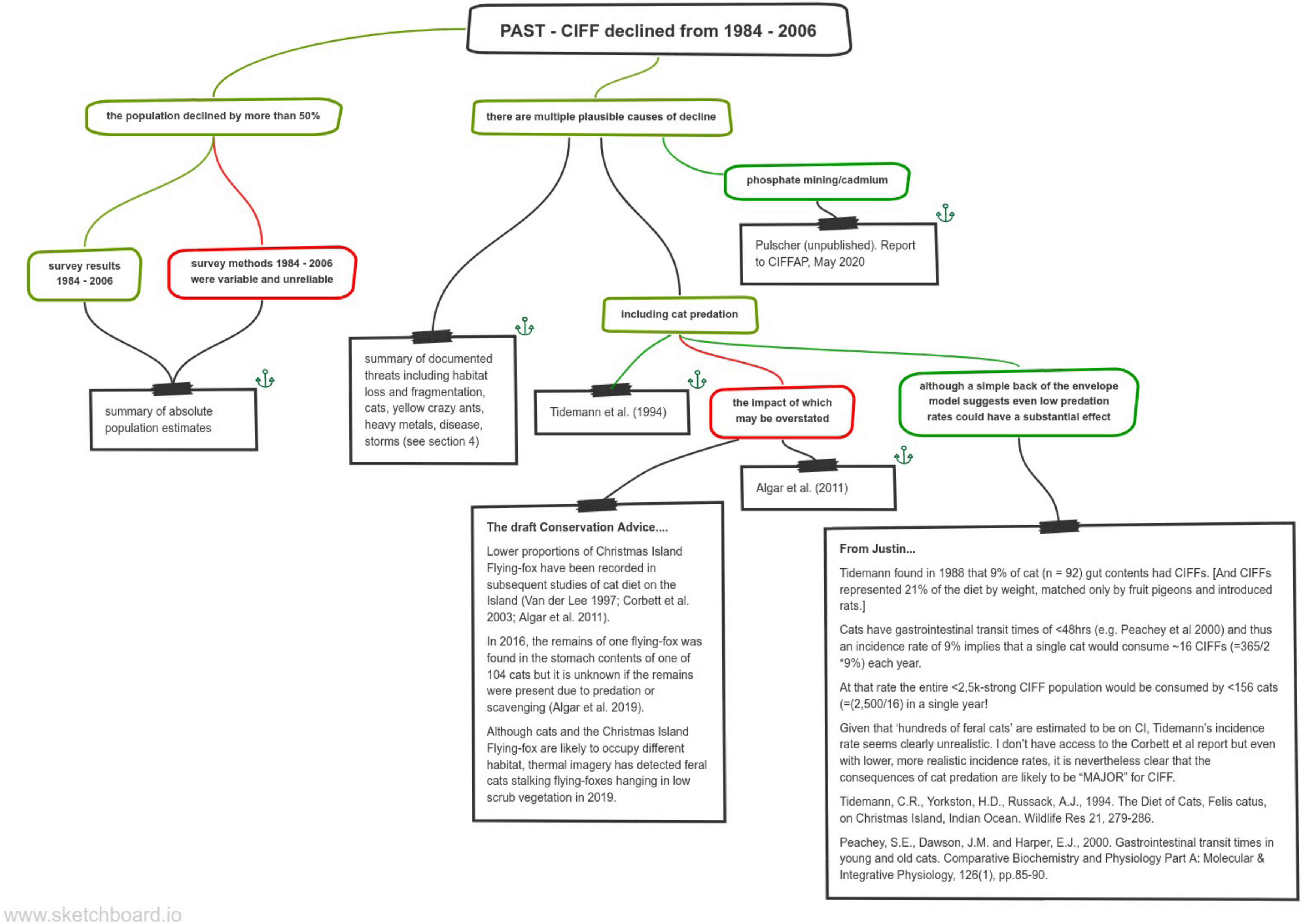


Figure 6. Argument map documenting views and evidence pertaining to past trends in the CIFF population. Green nodes support the proposition of decline and red nodes refute or weaken it. The map was prepared using the online platform sketchboard. Anchor icons are links to supporting documentation (not included here).

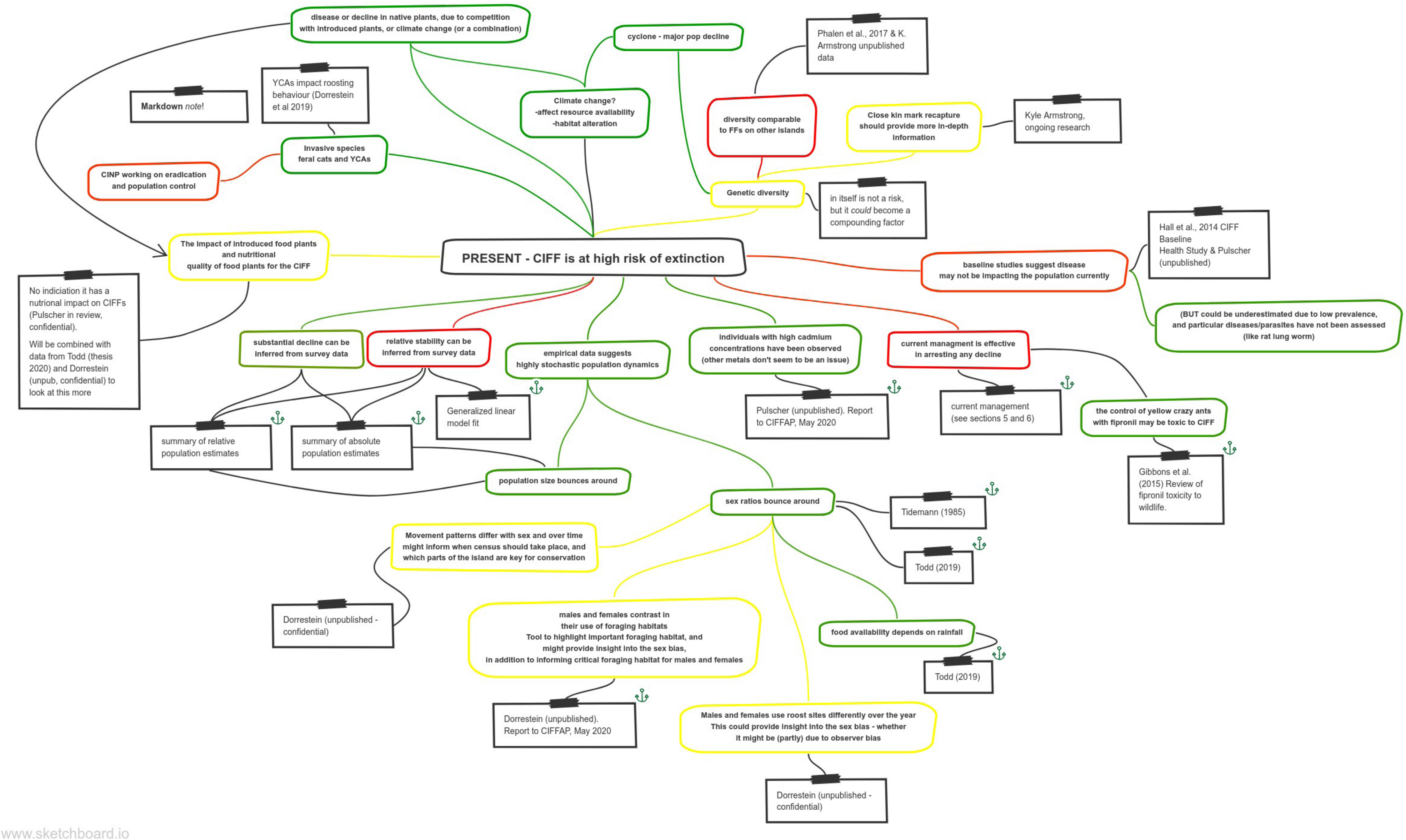


Figure 7. Argument map documenting views and evidence pertaining to the current status of the CIFF population. Green nodes support the proposition of decline, red nodes refute or weaken it, and yellow nodes neither support nor refute.

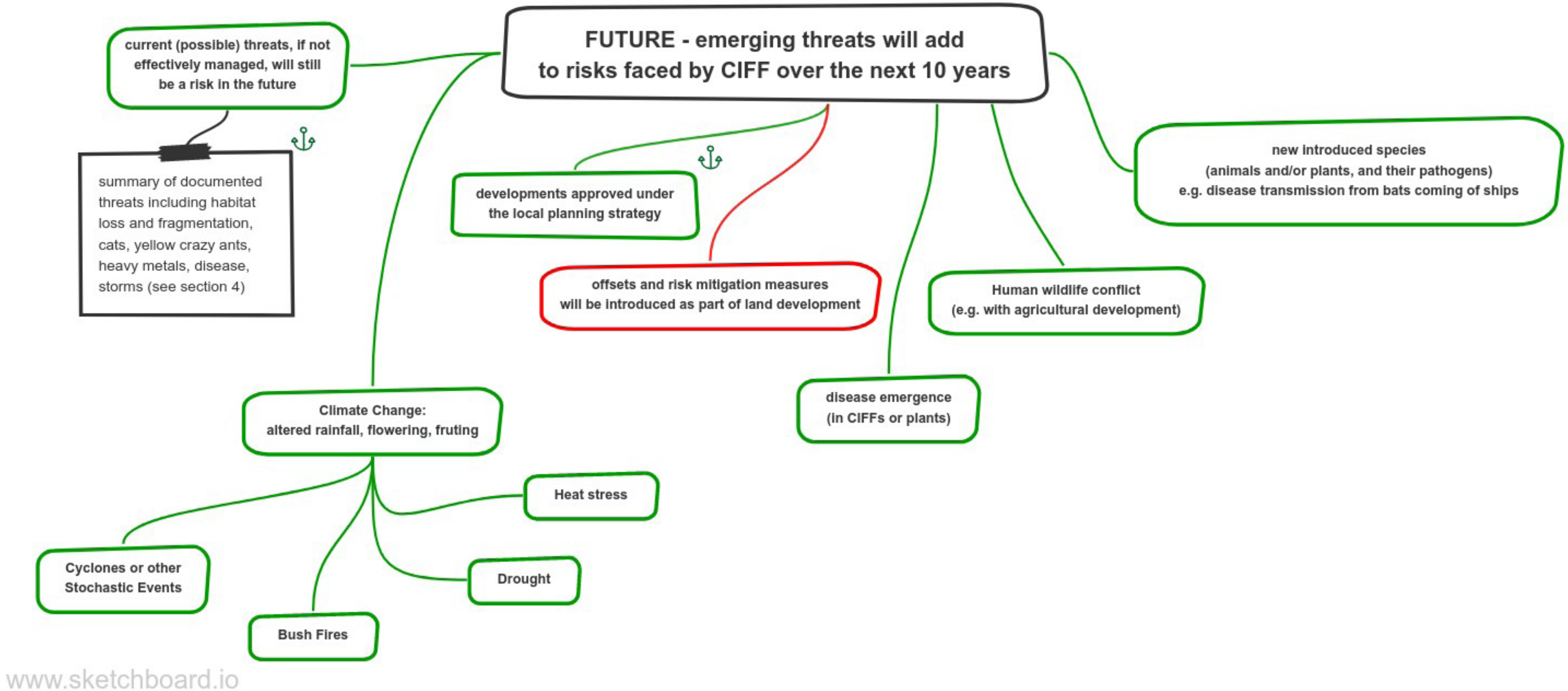


Figure 8. Argument map documenting views and evidence pertaining to the future trajectory of the CIFF population.

In online workshops we specified,

- management under the base case (Table 1),
- future land use (Figure 9), and
- candidate management actions (Table 2).

The time horizon over which the payoff of candidate management actions was to be assessed was 30 years. Again, we emphasise that these details are illustrative, and only coarsely based on actual deliberations of the Advisory Panel.

Table 1. *Base case scenario against which candidate management actions are to be assessed.*

The base case for CIFF management
• cats - status quo (i.e. attempt eradication within 4 years) • yellow crazy ants - status quo control effort • forest regeneration - status quo rehabilitation plan • status quo constraints on clearing of primary rainforest • regulatory control of hunting with status quo enforcement effort • minesite rehabilitation - one third of sites restored (by area)

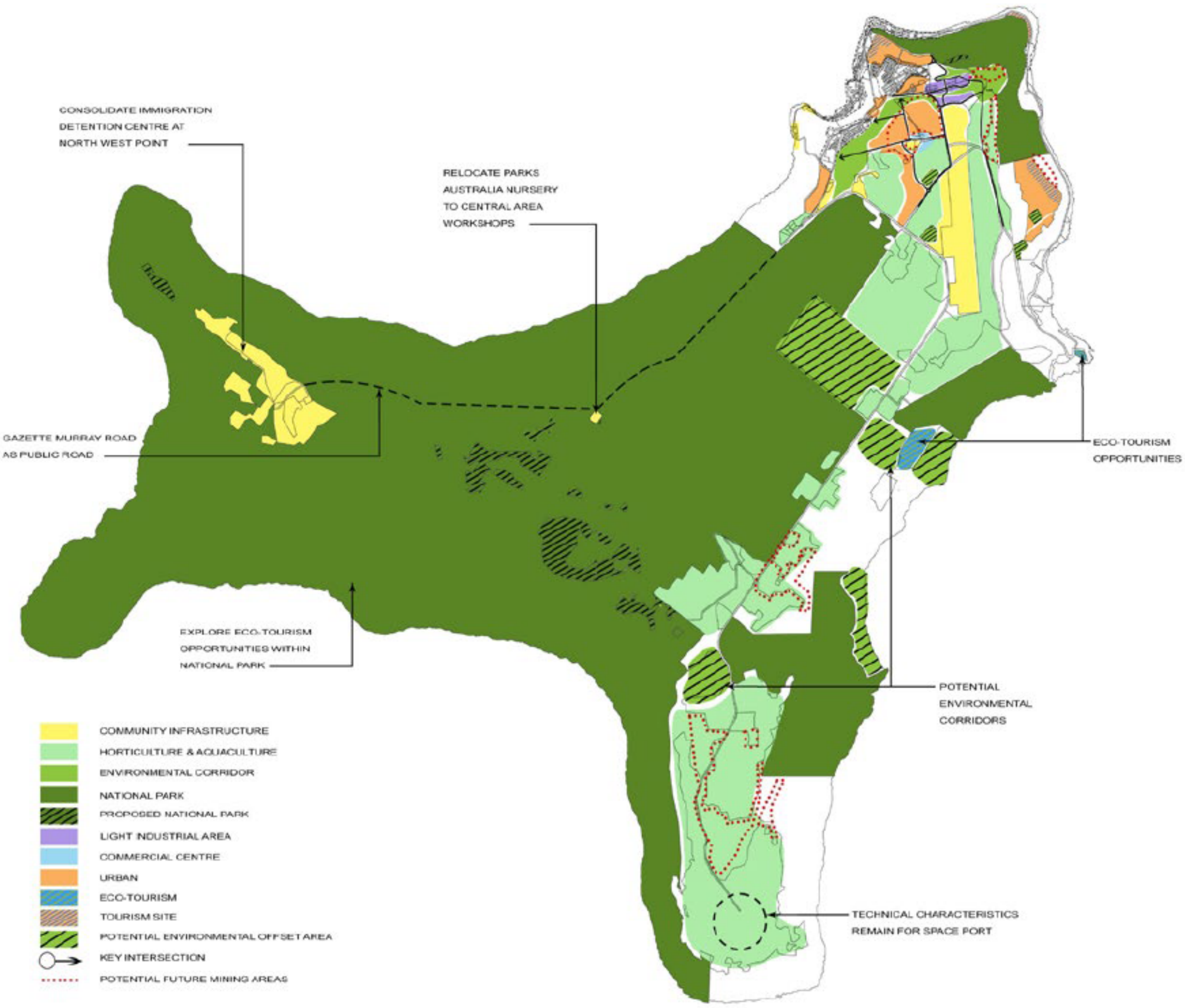


Figure 9. *Scenario for future land use at Christmas Island. Source: WAPC (2015).*

Table 2. Candidate management actions.

Action	Description
Ex-situ	Established on Christmas Island using 20 founder individuals. The aim would be to increase the insurance population to 35 - 60 individuals within 5 years.
Cat control plus	Status quo (base case) plus 20 % additional effort targeted to CIFF
Yellow crazy ant control plus	Status quo (base case) plus additional resourcing to target baiting at CIFF roost sites
Forest regeneration plus A	An additional 1.5 ha per year, restoration with indigenous species, incl. an emphasis on indigenous food plants for CIFF
Forest regeneration plus B	An additional 7.5 ha per year, restoration with indigenous species, incl. an emphasis on indigenous food plants for CIFF
Expand conservation estate A	All high conservation areas
Expand conservation estate B	As above plus Ethel Beach, Smith's Point, and 25% of area identified as 'rural'
Cadmium control	Improved dust control prior to mined material being brought to the crusher and dryer

Decision support tool

The illustrative example and its outcomes are included in the accompanying spreadsheet, *ciff_FR_with_ex-situ_demo.xslm*. The figures and tables shown in this section are taken directly from the spreadsheet.

The outcomes of expert judgment of the payoffs of individual candidate actions, together with their costs are shown in Figure 10. In general the pay-off of actions is modest, relative to the base case. We note that in this illustrative application, the best estimate of a population size of approximately 3,100 individuals at the end of a 30 year time horizon for base case management represents more than 60% of the best estimate for the carrying capacity of the island. This judgment implies a belief that the suggestion of a recovering population in the recent past (Figure 4) may be sustained over the next 30 years, but not with any great conviction. The lower bound on the base case (and several actions) is less than 1,000 individuals.

Figure 10. *Pooled judgments of the payoffs of eight candidate actions alongside estimated population sizes for the island's carrying capacity (Q1) and the base case (Q2). The cost of each actions is shown above its corresponding judgment. Note that the spreadsheet accommodates up to 12 candidate actions (i.e. up to 14 questions).*

Key

Q1 Under ideal conditions (e.g. prior to human occupation) what do you think is the carrying capacity of the whole island?

Q2 What will be the population size 30 years hence under the base case?

Q3 What will be the population size 30 years hence under Action 1 - Ex-situ ?

Q4 What will be the population size 30 years hence under Action 2 - Cat control plus ?

Q5 What will be the population size 30 years hence under Action 3 - Yellow crazy ant control plus ?

Q6 What will be the population size 30 years hence under Action 4 - Forest regeneration plus A ?

Q7 What will be the population size 30 years hence under Action 5 - Forest regeneration plus B ?

Q8 What will be the population size 30 years hence under Action 6 - Expand conservation estate A ?

Q9 What will be the population size 30 years hence under Action 7 - Expand conservation estate B ?

Q10 What will be the population size 30 years hence under Action 8 - Cadmium control ?

The cost-effectiveness of candidate actions is shown in Table 2. The reported conservation benefit is the difference in *value* between best estimates for population size under the base case and each action. For the value judgments made in our illustrative example (see accompanying spreadsheet), the action with the greatest merit (i.e. highest cost effectiveness) was establishment of an ex-situ population.

Figure 11 plots the cumulative payoff of implementing multiple actions, together with cumulative cost. The graph can be used to gauge the strength of the argument for additional funding. Note that the graph does not include the value of an insurance population (but this is included in the conservation benefit and cost effectiveness calculations of ex-situ action in Table 2). The cumulative payoff of the top three actions (ex-situ, cadmium control and cat control plus) is estimated to be an increase in population size from 3 159 under the base case, to 3 412, at a cost of $7.1 million over 30 years. No other action (or combination of actions) will beat this magnitude of anticipated improvement for this level of funding.

Table 2. *The cost-effectiveness of candidate actions ranked in order of merit.*

Action	estimated population size in 30 years	conservation benefit	cost ($m)	cost-effectiveness
Ex-situ	3274	1.64	4.10	0.40
Cadmium control	3249	0.71	2.25	0.32
Cat control plus	3162	0.20	0.78	0.26
Expand conservation estate B	3667	2.71	26.78	0.10
Expand conservation estate A	3439	1.71	21.96	0.08
Forest regeneration plus B	3461	1.81	36.63	0.05
Forest regeneration plus A	3128	-0.01	7.33	0.00
Yellow crazy ant control plus	2965	-1.10	0.84	-1.31

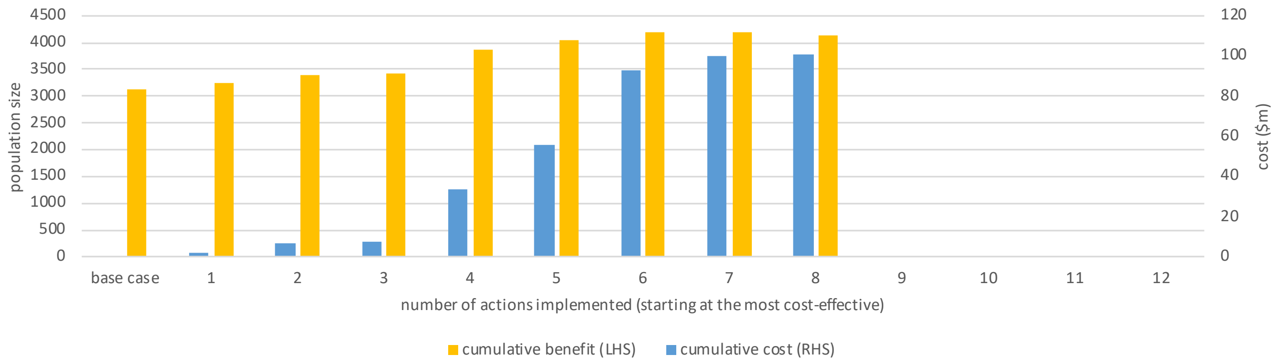


Figure 11. *The cumulative conservation benefit of implementing multiple candidate actions described in terms of population size in the wild, along with cumulative costs. Actions are implemented in order of merit according to their cost-effectiveness. Note that the spreadsheet accommodates up to 12 candidate actions.*

For our illustrative example, modest payoffs come with modest costs for the top three actions, suggesting they may be worth implementing, depending on resource availability. There is a material increase in estimated population size for the fourth most cost-effective action (expand conservation estate B), but it also carries a high price tag. Where resources are constrained, the limited benefits may not justify investment in actions beyond those included in the base case. But the high uncertainty in future population size under the base case (Figure 10) suggests a need for ongoing monitoring.

Discussion

Payoffs in our illustrative example are modest relative to the base case population size of 3 159 individuals. If judgments under the base case were halved and all else remained unchanged[1], the case for further funding is more compelling (Table 3, Figure 12). Here the top three actions yield an improvement from 1 564 individuals to 4 389 at a cost of $3.9 million. Note that the rank order and magnitude of the cost-effectiveness of actions changes dramatically with a halving of the base case population estimate (Table 3).

Table 3. *The cost-effectiveness of candidate actions ranked in order of merit where the estimated population size under base case management is halved to 1,564 individuals.*

Action	estimated population size in 30 years	conservation benefit	cost ($m)	cost-effectiveness
Cat control plus	3162	20.33	0.78	26.08
Yellow crazy ant control plus	2965	19.03	0.84	22.68
Cadmium control	3249	20.84	2.25	9.27
Ex-situ	3274	21.22	4.10	5.17
Forest regeneration plus A	3128	20.12	7.33	2.75
Expand conservation estate A	3439	21.84	21.96	0.99
Expand conservation estate B	3667	22.84	26.78	0.85
Forest regeneration plus B	3461	21.94	36.63	0.60

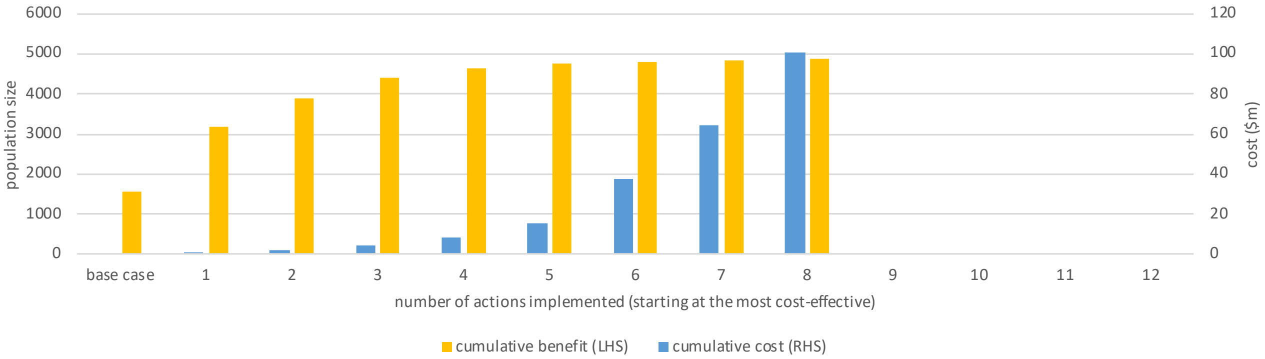


Figure 12. *The cumulative conservation benefit and cost of implementing multiple candidate actions in a hypothetical scenario where the estimated population size under base case management is halved to 1,564 individuals.*

We emphasise that analyses and decisions need to be revisited whenever there is an appreciable change in

- understanding of the population trajectory under status quo or base case management (typically inferred from monitoring),
- the payoff of candidate actions,
- the availability of candidate actions, and
- the costs of actions (e.g. change in technology).

[1] Note that this is a highly implausible scenario. If base case judgments were to be revised downwards then in all likelihood, estimates of population sizes would likewise require downward revision. We include it here just to demonstrate the importance of periodic review of decisions with updated information.

Application of research

Impact of the research (to-date and potential in future)

This research progresses the Threatened Species Strategy's commitment to effective planning for conservation (Commonwealth of Australia 2021).

The project directly contributed to CIFFAP's ongoing advice to Parks Australia, including assisting in the synthesis of recent research findings and an updated assessment of the merit of candidate management actions. The project also provided an opportunity to inform potential avenues for mitigating impacts on CIFF associated with ongoing development of land use change scenarios under the Christmas Island strategic assessment.

Broader implications – for other places or species

The process and decision support tool can be readily adapted to other threatened species and Recovery Teams.

Future research priorities

The main avenue for future research is extension of the decision support tool to evaluation of candidate management actions over multiple species. This is especially important in the context of Christmas Island where several candidate actions (e.g. cat eradication, yellow crazy ant control) are expected to benefit several threatened species beyond CIFF.

Data sets

The main product of this research is an excel-based decision support tool. There are two accompanying files, the selection of which will depend on whether or not the user wants to explore the merit of captive breeding CIFF alongside other candidate actions. The two files are

- ciff_with_ex-situ.xlsm
- ciff_without_ex-situ.xlsm

There is also a pre-populated demonstration file that includes the details of the illustrative application described in this report:

- ciff_with_ex-situ_demo.xlsm

The files have been submitted to the Hub and are available from Terry Walshe on request, email twalshe@unimelb.edu.au

You can also download all three of the files at this link on the Hub website: https://www.nespthreatenedspecies.edu.au/11730

On opening either file, the user will see a security warning notifying you that *macros have been disabled*. You'll need to click the *enable content* button to use the spreadsheet.

You'll also need to make sure the add-in *Solver* is activated. Go to File>Options and click on *Add-ins* on the menu on the left side of the pop-up for *Excel Options*. Find *Solver Add-in* in the list and highlight it by clicking on it. Now click on Go… towards the bottom of the pop-up (don't click on OK). This brings up another pop-up, *Add-ins*, from which you need to check the box for *Solver Add-in*, then click OK. If you run into trouble further details are available at https://support.microsoft.com/en-us/office/add-or-remove-add-ins-in-excel-0af570c4-5cf3-4fa9-9b88-403625a0b460

Further guidance on use of the spreadsheets is provided at each tab.

Recommendations

To insulate against shortcomings in group dynamics, we recommend Recovery Teams utilise a structured approach to decision-making that includes:

- the use of argument maps and formal protocols for the elicitation of expert judgment to insulate against overconfidence,
- explicit value judgements describing losses and gains in conservation outcomes with change in population size, and
- appraisal of the cumulative pay-off and cumulative costs of implementing multiple actions.

Analyses and decisions need to be revisited whenever there is an appreciable change in

- understanding of the population trajectory under status quo or base case management (typically inferred from monitoring),
- the payoff of candidate actions,
- the availability of candidate actions, and
- the costs of actions (e.g. change in technology).

Conclusion

Recovery teams provide sound governance and accountability in threatened species management, but like all groups, their effectiveness may be compromised by the challenges of scientific uncertainty, myopia and overconfidence. The outcomes of this project provide a basis for navigating difficult conservation decisions in group settings, including those requiring remote online meetings. The problem formulation process and spreadsheet-based decision support tool described in this report offers an effective pathway for overcoming the pitfalls of decision paralysis and poorly conceived recommendations.

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Ethics statement:

Not applicable

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Further information:

http://www.nespthreatenedspecies.edu.au

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