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A structured decision-making approach for the recovery of kuaka / Whenua Hou diving petrel (*Pelecanoides whenuahouensis*)

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Cover: Kuaka being released from a burrow trap at the breeding colony on Whenua Hou. Photo: *Thomas Burns*.

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CONTENTS

Whakarāpopoto ā kaiwhakahaere

He taoka te kuaka Whenua Hou (*Pelecanoides whenuahouensis*) ki a Kāi Tahu, ā, ki te hapori whānui hoki. I te mea kei te takiwā o te 210 katoa ngā pakeke e ora tonu ana, ka kīia he manu puiaki, he mokorea ki Aotearoa, kua whakarārangtia hei koiora kei te pae o te rua mate - Kei Aotearoa ka kī, 'Threatened - Nationally Critical', ki te ao whānui ka kī 'Critically Endangered'. Ko tā te rangahau kātahi anō ka mutu, ahakoa kua patua ngā konihi whakaeke i tōna kau taiwhenua ki Whenua Hou, kāore anō te koiora nei kia hoki ora mai, ā, e pana tonu te koiora nei ki te pari o te rua e ngā take taimaha matatini. Ki te tautohu atu i ngā momo ara pai rawa atu ki te whāomoomo i te oranga tonutanga o te kuaka, i whakatūria e Te Papa Atawhai (DOC) i tētahi tukanga anga whakatau whakaaro (SDM).

I te haerenga o te tukanga SDM i whakatūria tētahi rōpū (he māngai nō ngā Papatipu Rūnaka, Te Rūnanga o Ngāi Tahu, DOC, Te Hao Ika me te Ahumoana, ētahi nō te ahumoana tonu, me Te Taiao Tonga). I whakahuahuatia atu e te rōpū nei kia whitu ngā uara, ngā whāinga hei tūāpapa mō te oranga tonutanga o te kuaka, ā, i tautohuhia kia 11 ngā rautaki whāomo torohū (hei whiringa). Ko ngā whāinga pūtake, te tikanga ia me whai wāhi atu, ko te whakamōrahi i kā taupori kuaka, ka noho te rangatiratanga me te kaitiakitanga ki a Kāi Tahu, ka whakamōkito i ngā pānga pūnaha hauropi, ka whakamōrahi i te aroha o tangata noa, ka whakamōkito i te utu o te mahi whāomoomo, me te pānga mai o te ahumoana. Ko ētahi ara anō ka hāngai ki te ū tonu ki tō nāianei tūāhua, ka whakapiki i te tikanga whakamāuru i te pokenga rama nā ngā kaipuke, ka whakatūria he rāhui ki te whakamahinga o ngā rama, ka whakapiki i te whakahaere o ngā tupu, ka whakatūria he whakahaerenga o tā rātou tukituki ki a rātou anō, ā, ko ngā nukuhanga kōhanga whāomo ki wāhi kē o taua motu tonu, ki motu kē atu rānei. Kātahi, nā te whakatū tauira, nā ngā tohutohu mātanga i matapae atu he aha ngā hua ka puta i ia momo whiringa, mō ia whāinga pūtake i a tātou e mārama pū ana he haurokuroku tonu. Heoi anō, i te matapaetanga o ngā hua, i taea e te rōpū te whakatere i ngā āhuatanga o te whakatau ara mataaho, o te whakatau ara kōataata nā ētahi taputapu whakatau whakaaro ine-kounga, ine-tātai kanorau ki te tautohu i te whiringa whāomo kuaka e tika ana.

I tautohuhia e te rōpū kuaka he pāhekotanga o te whakamāuru o te pokenga rama nā ngā kaipuke; te whakapiki o te whakahaere tarutaru, o te whakahaere tupu Māori hoki; te whakahaere i te tukituki i waenga i te taupori tonu; me te nukunuku kōhanga ki moutere kē ko te ara e whaihua ana te whakarauora i te kuaka, me te kapi i te nuinga o ngā whāinga. Me whai te whakatūtanga o ia wāhanga i tētahi poutama ki ngā momo māngai o te rōpū i te nanaotanga atu ki te pūtea e tika ana. Ko te tukanga SDM kuaka, he korowai mō te hunga i whai wāhi atu, nā te āhurutanga o tērā tukanga i whakaputa mai he tūtohutanga whai tikanga, he tūtohutanga kōataata hoki ki te whakarauora i tēnei taoka, ahakoa ngā taero, e kaha kitea e te mahi whakarauora i ngā koiora o te moana, e hāngai ana ki ngā whāinga tukituki, ki ngā uara rerekē, ki te haurokuroku hoki.

Executive summary

The kuaka / Whenua Hou diving petrel (*Pelecanoides whenuahouensis*) is a taoka (treasure) to Kāi Tahu, and the wider community. With only ~210 adults remaining it is one of the rarest birds of Aotearoa New Zealand and is listed as Threatened – Nationally Critical in Aotearoa and as Critically Endangered globally. Recent research suggested that, despite the removal of invasive predators from its sole remaining colony on Codfish Island / Whenua Hou, the species has not recovered, and ongoing complex pressures continue to put the species at risk of extinction. To identify the best conservation management options for kuaka recovery, the New Zealand Department of Conservation (DOC) initiated a structured decision-making (SDM) process.

During this SDM process, a rōpū (working group; consisting of representatives of the Papatipu Rūnaka, Te Rūnanga o Ngāi Tahu, DOC, Fisheries New Zealand, the fishing industry, and Environment Southland) was formed. This rōpū articulated seven values (objectives) fundamental to kuaka recovery and identified 11 potential conservation strategies (alternatives). Fundamental objectives included: maximising the number of kuaka and kuaka populations, Kāi Tahu to express rangatiratanga (sovereignty) and exercise kaitiakitanga (guardianship), minimising ecosystem impacts, maximising public appreciation, minimising costs to conservation management, and minimising impacts on fisheries. Potential alternatives included: status quo, increasing best practice mitigation of vessel-based light pollution, implementing light curfews, improving plant control, initiating competition management, and intra- or inter-island conservation translocations. The consequences for each alternative across each fundamental objective were then predicted using a variety of modelling techniques and expert elicitations, while explicitly accounting for uncertainty. Once consequences were predicted, the rōpū was able to navigate this decision-landscape explicitly and transparently using a variety of qualitative and quantitative decision-analytical tools to identify the preferred option for kuaka conservation.

The kuaka rōpū identified that a combination of improved mitigation of vessel-based light pollution, increased weed and native plant control, competition managment, and inter-island translocations provided the best outcome for kuaka recovery across the multiple objectives. These components should be subjected to a stepwise implementation with the different representatives of the rōpū once adequate funding has been secured. The kuaka SDM process provided an inclusive environment among participants and facilitated a rational and transparent recommendation for the recovery of this taoka in the face of challenges, common for marine species recovery, including competing objectives, differing value judgements, and uncertainty.

1. Background

The kuaka / Whenua Hou diving petrel (*Pelecanoides whenuahouensis*) was described as a new species to science in 2018 (Fischer et al. 2018a). This seabird is considered a taoka to Kāi Tahu and the wider community. Kuaka were once widespread in southern Aotearoa prior to the arrival of humans, but the species has been reduced to a single, small breeding colony (~210 adults; Fig. 1) within the dunes on Whenua Hou (Fischer et al. 2020a). Consequently, kuaka are listed as Threatened – Nationally Critical on the New Zealand Threat Classification System (Robertson et al. 2021) and as Critically Endangered on the International Union for Conservation of Nature Red List (Birdlife International 2022).

As the kuaka has only recently been recognised as a species, no formal recovery plan exists. However, the kuaka was subject to intensive monitoring and research between 2015 and 2020 (Fischer et al. 2017, 2018ab, 2020ab, 2021abc, 2022), which led to important insights. Despite removal of introduced predators from Whenua Hou in 2000, kuaka population growth remains negligible (Fig. 1), suggesting the species is under pressure from ongoing threats, as the population is not near carrying capacity (Fischer et al. 2020a). Kuaka are habitat specialists and the entire population nests in burrows in fragile dunes, < 20 m from the springtide line. Storms and storm surges erode these dunes, collapse burrows, and entomb birds within, and causing nest failure and adult mortality. Additionally, vessel-based light pollution within the direct vicinity of the colony can disorientate commuting birds, resulting in collisions and subsequent mortalities. Kuaka also compete for burrow sites with other seabirds, such as common diving petrels (*Pelecanoides urinatrix*) and korure / mottled petrels (*Pterodroma inexpectata*), causing nest failures. Finally, encroachment of invasive and native vegetation in the dunes on Whenua Hou renders these dunes more susceptible to storms. To utilise the gathered information and identify the preferred management options for kuaka recovery, the New Zealand Department of Conservation (DOC) applied a structured decision-making (SDM) process.

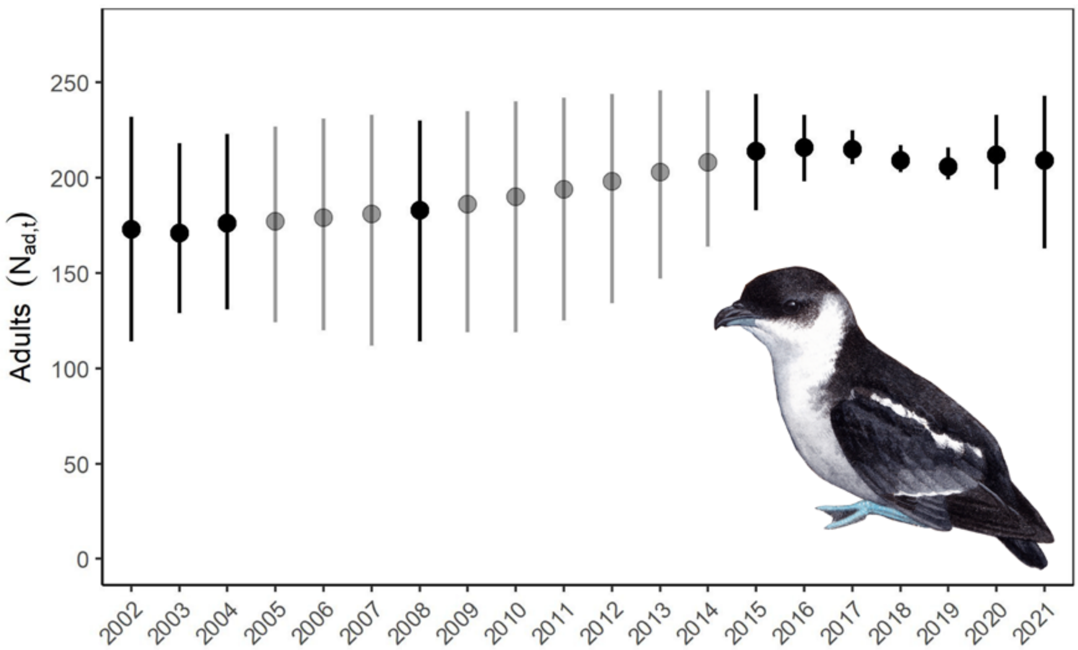

Figure 1. Kuaka / Whenua Hou diving petrel population size estimate. Symbols represent means with 95% credible intervals. Translucent symbols represent estimates inferred using data from previous and subsequent years, rather than direct estimates (solid symbols). Illustration by A. Jearwattanakanok.

2. Structured decision making and marine species recovery

Decisions in conservation management are among the most challenging that decision-makers can face. Decisions in conservation almost always involve multiple competing objectives subject to differing value judgements, scarce resources, high levels of uncertainty, and potentially catastrophic consequences if the wrong decisions were to be made (Moore & Runge 2012, Gregory et al. 2012, Hemming et al. 2022). These challenges are further exacerbated when the target species is a highly mobile, marine species, as decision-making on the conservation of these species is often subject to increased levels of uncertainty, complicated governance structures, and a higher number of competing objectives. SDM is a decision-analytical approach that has the potential to overcome these challenges. Yet, SDM has typically focused on terrestrial species, with few examples on marine species (e.g., Ewen et al. 2014, Canessa et al. 2020, Panfylova et al. 2019, Ferriere et al. 2021, McMurdo Hamilton et al. 2021ab).

SDM is a transparent, iterative, and values-based process to identify the best options for management while balancing multiple objectives. SDM processes consists of seven stages: 1) the formulation of a goal statement, 2) the articulation of fundamental objectives, 3) the identification of potential management alternatives, 4) the prediction of consequences, 5) the weighing of trade-offs, 6) the identification of the best option for management, and 7) the subsequent implementation (Fig. 2). A feedback loop that combines ongoing monitoring and updating of existing models allows for learning and adaptive management, following the initial identification of the best option (Converse et al. 2013). SDM is values-based (i.e., optimal choices depend on the underlying values) so participation of iwi, hapū, whānau, and key stakeholders is crucial to success. SDM processes enable inclusive and cooperative environments among participants and, ultimately, facilitate rational and transparent decision-making for the conservation of the target species, even in the face of challenges such as competing objectives that are not equally valued, and uncertainty.

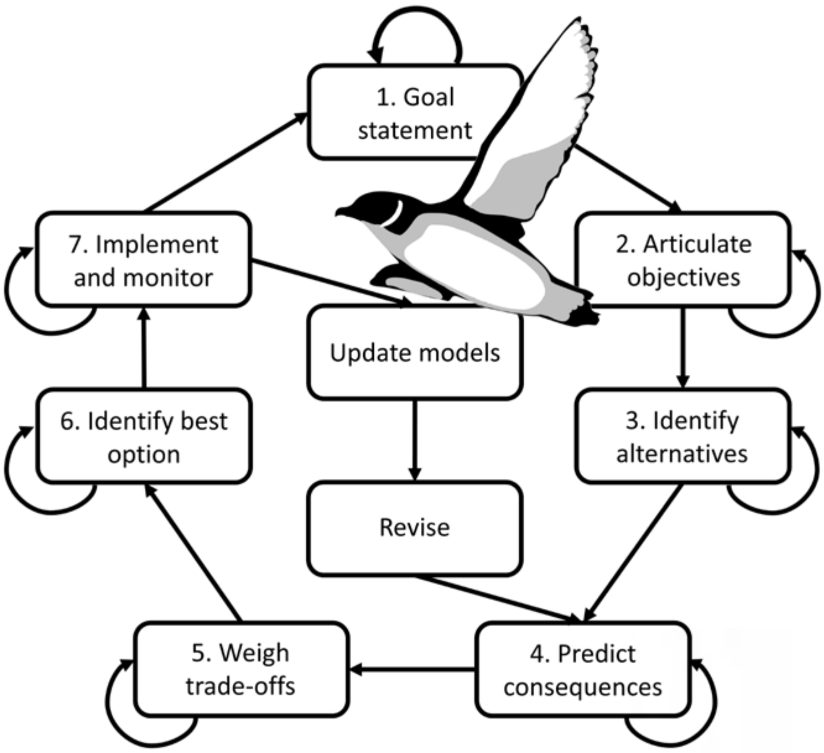

Figure 2. The seven steps in the structured decision-making cycle (adapted from Gregory et al. 2012 and McMurdo Hamilton et al. 2021ab). Illustration by J. de Hoop.

3. Methodology

Following the intensive research and monitoring in 2015–2020, DOC identified the relevant representatives of the Papatipu Rūnaka, Te Rūnanga o Ngāi Tahu, and stakeholder groups, including Fisheries New Zealand, Environment Southland, and the fishing industry (approx. 15 people; Appendix 1) to form a rōpū / working group for the kuaka SDM process. This rōpū worked through the full SDM process between November 2020 and December 2021, at the centre of which were two two-day hui in February 2021 and December 2021 (Fig. 3). The SDM process and the outcomes are detailed per SDM step as following:

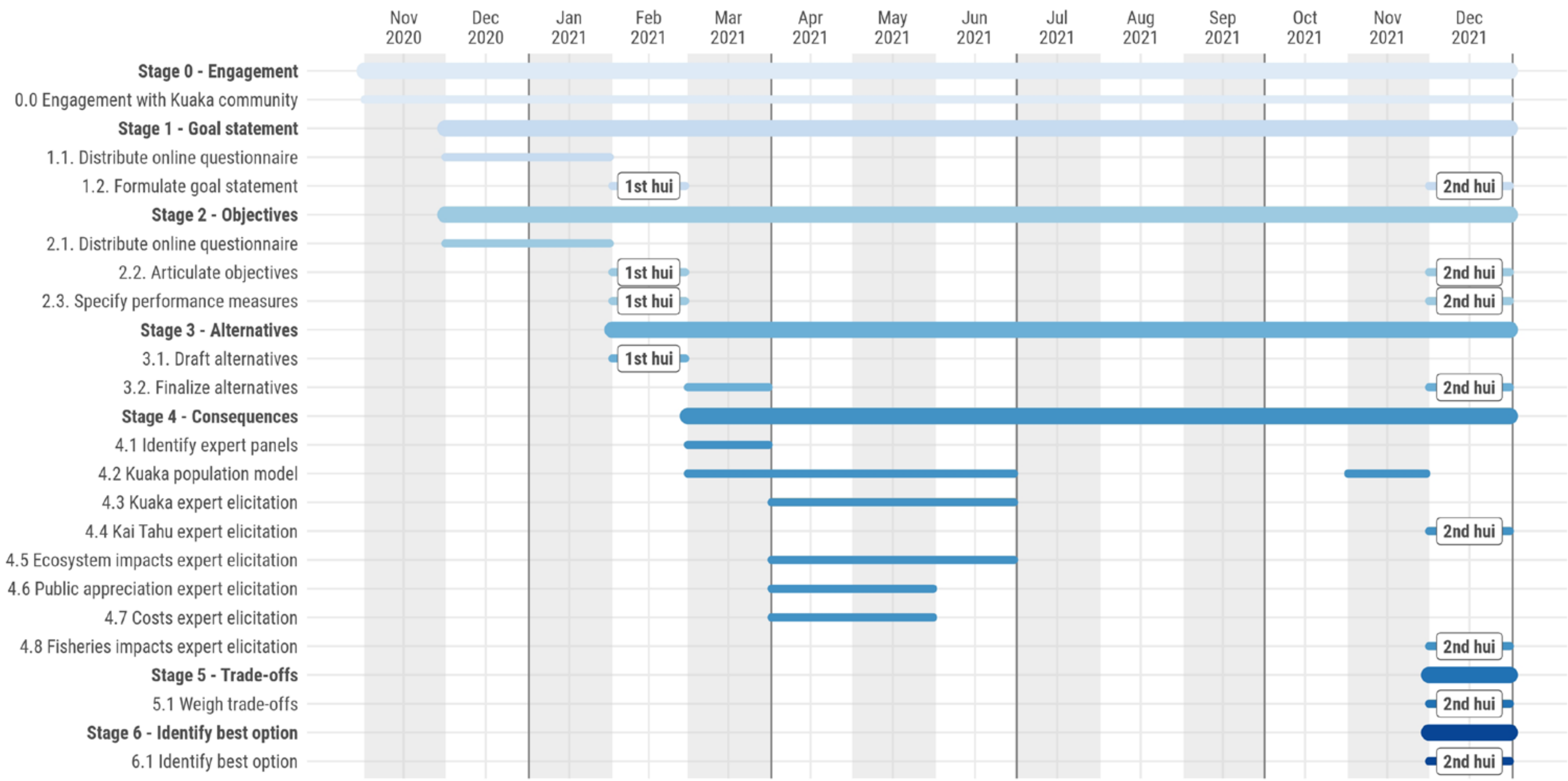

Figure 3. Gantt chart for the different structured decision-making stages the kuaka / Whenua Hou diving petrel rōpū / working group progressed through to identify the best options for conservation management.. The gap between June 2021 and December 2021 was caused by COVID-19 disruptions.

4. Conservation goal statement

Step 1 of the SDM process

The conservation goal statement highlights the focus and scope of the decision problem, describes why it has arisen, and identifies the decision-makers, as well as the time frame and legal framework within which a decision must be made (Gregory et al. 2012, Hemming et al. 2022). It may include up to seven core elements:

1. **Trigger**: Why does a decision need to be made? Why does it matter?
2. **Action**: What actions need to be taken?
3. **Constraints**: What are the constraints (legal, financial, political) on taking the stated action(s)? Are these perceived or real?
4. **Class or type of problem**: How many objectives are there? Do they conflict? What is the level of uncertainty?
5. **Decision-maker**: Who has the power to and will make a decision?
6. **Frequency and timing:** How often does a decision need to be made? Are other, related decisions needed?
7. **Scope**: How broad or complicated is the decision?

4.1 Process

This goal statement was initially drafted by the facilitators based on responses from participants gathered through online questionnaires sent to all participants prior to the first hui (https://forms.gle/BooDYiM6rhco5mrK9). Subsequently, the rōpū edited the goal statement over the course of the two hui to ensure it was fit for purpose.

4.2 Outcome

The kuaka, or Whenua Hou diving petrel, was once widespread in southern Aotearoa New Zealand prior to the arrival of humans, but the species has been reduced to a single, small population (~210 adults) on Whenua Hou. Despite removal of introduced predators from the island (2000), the population's growth remains negligible. This population is subject to several ongoing threats. Kuaka are a taoka to Kāi Tahu and the wider community. The species is critically endangered. Conservation management can potentially expand the range and abundance, and increase resilience of this critically endangered species. The decision that needs to be made is whether to apply focused conservation management for the kuaka. Management alternatives are not restricted to Whenua Hou, and may include the marine environments used by kuaka, and potential translocation sites within the takiwā (territory) of Kāi Tahu. The key decision-makers are Kāi Tahu, the Department of Conservation, and Fisheries New Zealand. When making decisions, they must recognise there are multiple fundamentally important values (objectives) that need to be balanced. In addition to biological and cultural objectives key economic and safety concerns from marine users, as well as resource constraints, must be considered. Representatives from these decision makers will work together to identify the best recovery strategy through a structured decision-making process. There is a desire to identify the best management options for the kuaka by 2022.

5. Objectives

Step 2 of the SDM process

SDM recognises that the 'best' decision is that which best achieves the objectives of the decision-makers and stakeholders. Therefore, the 'best' strategy cannot be defined unless the objectives are clear. SDM recognises at least three important types of objectives:

1. **Fundamental**: These objectives reflect the group's core values or end goals and are useful for comparing and choosing between a range of possible management strategies.
2. **Means**: These objectives are important for highlighting ways of achieving the fundamental objectives.
3. **Process**: These objectives state the desired approach to the decision-making process.

Articulating fundamental objectives is crucial to SDM (Gregory et al. 2012, Hemming et al. 2022). Each fundamental objective should be expressed as a statement capturing the underlying value and a verb indicating the desired direction of change (e.g., minimise/maximise). It is critical to separate means objectives from fundamental objectives, as focusing on a means objective risks judging alternatives incorrectly (e.g., double counting a value). A fundamental objective cannot be 'optimised', as optimisation (or efficiency) indicates that several fundamental objectives are being combined, which leads to hidden value judgments about what is 'optimal'. Fundamental objectives should be separate, allowing the decision to be approached rationally.

Each objective requires one or more performance measures to provide a metric by which to predict and compare the expected outcomes of alternatives. Performance measures can be direct, indirect proxies, or constructed scales.

5.1 Process

The kuaka rōpū articulated the fundamental objectives for kuaka recovery by going through a systematic approach:

- Before the first hui, online questionnaires were sent to all participants (https://forms.gle/BooDYiM6rhco5mrK9)
- During the first hui, all participants listed their aspirations and concerns (their values) for kuaka conservation.
- The participants then jointly separated means and process objectives from fundamental objectives and combined similar objectives until a final set of fundamental objectives was agreed upon.
- The facilitators compared the fundamental objectives identified by the rōpū with those indicated by responses to online questionnaires. As they did not differ, the online questionnaire responses were not further discussed.
- The rōpū jointly identified appropriate performance measures for each objective.
- At the second hui, the rōpū reviewed and fine-tuned the objectives and performance measures.

5.2 Outcome

The rōpū identified seven fundamental objectives and associated performance measures at the core of kuaka recovery (Table 1). Where appropriate, objectives were forecast until 2050 in line with Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy (New Zealand Government 2020). Furthermore, it was decided that the objective "Kāi Tahu express rangatiratanga and exercise kaitiakitanga" did not need a specific performance measure. Instead, Kāi Tahu representatives expressed the acceptability of alternatives against this fundamental objective directly (acceptable/maybe acceptable/not acceptable).

Table 1. Fundamental objectives and associated performance measures for kuaka / Whenua Hou diving petrel recovery.

FUNDAMENTAL OBJECTIVE	PERFORMANCE MEASURE
Maximise number of kuaka	Number of adults in 2050
Maximise number of kuaka populations[a]	Number of populations in 2050
Kāi Tahu express rangatiratanga and exercise kaitiakitanga	
Minimise ecosystem impacts	Number of affected species ($P_{extinction}$ > 0.01 on Whenua Hou in 2050)
Maximise public appreciation	Annual number screens reached
Minimise costs of conservation management	Cost in NZ $ over the first five years of implementation (i.e., 2022–2026)
Minimise impacts on fisheries	Level of impact (0 = no impact; 100 = catastrophic impact)

[a] At the second hui, the rōpū identified that "Number of kuaka" and "Number of kuaka populations" are two fundamentally different objectives, rather than different performance measures of the same objective.

6. Alternative management strategies

Step 3 of the SDM process

Once the fundamental objectives have been clearly established, it is possible to define and evaluate alternative management strategies that could achieve these. This step often includes the identification of threats to populations. Given the biological and non-biological complexity of most species recovery programmes, these alternative management strategies will typically involve combinations of actions. The same actions can appear as components of more than one strategy.

6.1 Process

The kuaka rōpū used the results of recent monitoring and research (e.g., Fischer et al. 2017, 2018ab, 2020ab, 2021abc, 2022) to identify potential management strategies for kuaka recovery by going through a systematic approach:

- At the first hui, participants were randomly allocated into two smaller working groups and were tasked with identifying all possible actions that could be implemented to recover kuaka.
- All participants then jointly compared identified actions, discussed these, and allocated actions into eight draft composite alternative strategies, aside from Status Quo.
- After the first hui, the facilitators fully specified the draft alternative management strategies, circulated them among participants, and edited them until no further feedback was received. This process brought the number of alternative management strategies to nine, alongside the Status Quo, as Reduce Lights B was added to fully explore the decision landscape.
- At the second hui, the rōpū reviewed the alternative management strategies and added another alternative (Dune A+B), resulting in a total of ten alternative strategies alongside Status Quo.

6.2 Outcome

The Status Quo and 10 alternative management strategies proposed for kuaka recovery are summarised in Table 2 and fully specified in Appendix 2. All alternative strategies were formulated under current knowledge and uncertainty. To address knowledge gaps, the rōpū also created an additional list of research priorities (Appendix 3).

Table 2. Summary of kuaka/Whenua Hou diving petrel alternative management strategies. A full description of each alternative is provided in Appendix 2. The number of ticks for each strategy indicates the intensity of the action.

ALTERNATIVE MANAGEMENT STRATEGY	ACTIONS										
	Biosecurity	**Monitoring**	**Comms & Advocacy**	**Plant management**	**Competition management**	**Intra-island translocations**	**Interisland translocartions**	**Best practice light mitigation**	**Light curfew**	**Best practice bycatch mitigation**	**At-sea monitoring**
Status Quo	✓	✓	✓	✓				✓		✓	✓
Reduce Lights A	✓	✓	✓	✓				✓✓✓		✓	✓
Reduce Lights B[a]	✓	✓	✓	✓				✓✓✓	✓	✓	✓
Dune A	✓	✓	✓	✓✓✓				✓✓✓		✓	✓
Dune B	✓	✓✓	✓	✓	✓			✓✓✓		✓	✓
Dune A+B[b]	✓	✓✓	✓	✓✓✓	✓			✓✓✓		✓	✓
Advocacy	✓	✓	✓✓✓	✓				✓✓✓		✓	✓
ChicksWH	✓	✓	✓	✓		✓		✓✓✓		✓	✓
ChicksOff	✓✓	✓✓✓	✓	✓			✓	✓✓✓		✓	✓
ChicksWH+	✓	✓✓	✓	✓✓✓	✓	✓		✓✓✓		✓	✓
ChicksOff+	✓✓	✓✓✓	✓	✓✓✓	✓		✓	✓✓✓		✓	✓

[a] Reduce Lights B was introduced between the first and second hui to fully explore the decision landscape.

[b] Dunes A+B was introduced at the second hui.

7. Consequences

Step 4 of the SDM process

Alternative management strategies can be compared according to their expected outcomes (or consequences) for the different objectives, which are in turn quantified using performance measures. These outcomes can be estimated from a model of the system, which is informed by available empirical data (e.g., from monitoring), data from similar systems as a surrogate, or expert judgement. When expert judgement is required, assessments should be obtained using best-practice protocols that include uncertainty (Martin et al. 2012, Hemming et al. 2018).

7.1 Process

The consequences of each alternative for each objective were estimated using six different and separate work streams: kuaka population dynamics, Kāi Tahu values, ecosystem impacts, public appreciation, costs of conservation management, and impacts on fisheries. Participants worked together with additional experts, where required, to generate consequences, while utilising a range of tools, including integrated population models (IPMs) and expert elicitations (either in person or online, supported by Shiny apps) to make use of both existing data and expert judgement. The steps taken to estimate consequences are detailed below.

7.1.1 Kuaka population dynamics

1. Monitoring data (2002–2021) were compiled and analysed using an IPM in the Bayesian modelling program OpenBUGS (Spiegelhalter et al. 2014) to estimate initial Status Quo vital rates (adult survival, juvenile survival, breeding probability, and breeding success) and population size, and simultaneously project the future population trajectory under Status Quo, while accounting for covariance between vital rates, environmental stochasticity, and individual stochasticity (Schaub & Abadi 2011, Kery & Schaub 2018, Fischer 2020, Fischer et al. 2022).

2. Through a combination of field research, literature reviews, and meta-analyses, the facilitators gathered any additional data needed and compiled this data with the initial IPM-based estimates of vital rates under Status Quo using a user-friendly Shiny app: https://docnewzealand.shinyapps.io/Kuaka_Population_App/.

3. The Shiny app was used to host an online expert elicitation (following best-practice protocols; Martin et al. 2012, Hemming et al. 2018), during which eight (diving) petrel experts (including representatives of DOC and Fisheries New Zealand; Appendix 4) were asked to estimate how the kuaka population would respond to each alternative strategy.

4. The experts estimated 31 different vital rates, population dynamics parameters, and carrying capacities through the Shiny app, which were directly integrated into either a single-population or a metapopulation IPM alongside the empirical data (Appendix 5). This enabled the facilitators to project future population trajectories under the different alternative management scenarios simultaneously, while accounting for covariance, environmental and individual stochasticity, and density dependence. This approach also estimated extinction probabilities. However, at the second hui, the rōpū decided that these were not ideal performance measures, as projections did not incorporate perceived future

changes in environmental variability (i.e., climate change). Instead, predicted population size and number of populations were used as performance measures.

It should be noted that the rōpū did not decide on a specific translocation destination site. For the kuaka dynamics predictions, Rarotoka Island (Centre Island, 38 km north of Whenua Hou) was used as the putative destination site. However, a separate decision-making process must be completed to confirm this site, or any other site, as a future destination site.

7.1.2 Integration with Kāi Tahu values

1. During the second hui, the facilitators held a kōrero/deliberation with six Kāi Tahu representatives (representing Ōraka-Aparima Rūnaka, Awarua Rūnaka, Hokonui Rūnaka, and Te Rūnanga o Ngāi Tahu; Appendix 4) to predict consequences under the objective "Kāi Tahu express rangatiratanga and exercise kaitiakitanga". During this korero the Kāi tahu representatives shared their whakaaro/thoughts and tautoko/support for each alternative and how it integrated with mātauranga Māori / Māori value systems. Specifically, Kāi Tahu representatives expressed whether each alternative was acceptable (acceptable, maybe acceptable, not acceptable) following the main principles of rangatiratanga/sovereignty and kaitiakitanga/guardianship, but also mahinga kai / customary harvests and mauri/life force.
2. Following the first kōrero, responses from Kāi Tahu representatives were included in a draft consequence table during the second hui, alongside the consequences for all other objectives, communicating the Kāi Tahu values to the whole rōpū. This stimulated further conversations with the entire rōpū allowing for any linguistic uncertainty to be resolved.
3. Following the review of the completed draft consequence table, including the consequences for other objectives, the Kāi Tahu representatives reviewed their initial responses and provided their final whakaaro and tautoko.

7.1.3 Ecosystem impacts

1. The facilitators conducted a literature review and compiled a list of all threatened mammal, bird, reptile, invertebrate, and plant species that regularly occur within the dune system in Waikoropupū / Sealers Bay, Whenua Hou, resulting in a list of 36 species (Cadenhead & Deans 1982, Partick 1997, Middleton 2007, Wickes & Rance 2010, Hoare et al. 2015, Trewick et al. 2016, de Lange et al. 2017, O'Donnell et al. 2017, Baker et al. 2019, Fischer et al. 2018b, 2019, Hitchmough et al. 2021, Robertson et al. 2021).
2. The facilitators built a second user-friendly Shiny app (https://docnewzealand.shinyapps.io/KuakaApp/), which contained information on the 36 species, their occurrence within the dune system on Whenua Hou, and information on the different management alternatives.
3. The facilitators hosted an online expert elicitation through this Shiny app with 14 different experts consisting of ecologists, ornithologists, herpetologists, entomologists, and botanists (including representatives of DOC; Appendix 4). These experts provided us with estimates of the extinction probability on Whenua Hou by 2050 for any species affected by proposed alternatives following best practice guidelines (Martin et al. 2012, Hemming et al. 2018).
4. Following further online conversations with the experts, the facilitators rescaled expert responses to separate background extinction rates from impacts caused by the implementation of alternatives.
5. At the second hui, the rōpū decided that species whose extinction probability exceeded 0.01 are to be considered as species impacted by alternatives, the total of which became the final performance measure.

It should be noted that, while impacts were estimated specifically, several alternatives benefited local flora and fauna. However, the rōpū considered negative impacts a reason to reconsider a decision, while benefits were considered a "nice-to-have".

7.1.4 Public appreciation

1. Following the first hui, the facilitators consulted with the DOC National Communications team (Appendix 4) on how to best estimate consequences for the public appreciation objective and received the advice to use past data from DOC social media channels (Facebook, Twitter, Instagram, and LinkedIn) to estimate future reach.
2. To predict the social media reach as a proxy for public appreciation, the facilitators compiled past DOC social media data (2020–2021) and categorised the data by relevant topic (i.e., marine spatial management, weed management, translocations, seabirds, and advertised content). The facilitators then modelled the reach of an individual story depending on the content of the story, the annual number of stories for a given seabird species, and the annual reach via amateur channels. The predicted reach per story was then multiplied by the predicted number of seabird stories per year and the annual background reach was added to predict total reach per alternative.
3. The facilitators discussed model results with the DOC National Communications team, who advised that any alternative management strategy including competition management should be considered as Status Quo, as competition management would not be advertised through social media.
4. The rōpū discussed the model results online and at the second hui and considered these adequate proxies, despite the model results being based on DOC social media data only.

7.1.5 Costs to conservation management

1. The facilitators, who have experience budgeting for this and other species, constructed initial budgets (to 2050) for each alternative management strategy.
2. Costs were discussed with members of the rōpū, representing the DOC Marine Species Team and the Murihiku Operations Team (Appendix 4), who were also familiar with budgeting for this species. Consequently, a 10% contingency was added to all alternatives to account for unanticipated factors.
3. At the second hui, costs were presented as 1) annualised costs over the 29-year timeframe (2022–2050) and 2) the costs over the initial first five years of implementation (e.g., 2022–2026). The rōpū decided that the latter was a more fit-for-purpose metric to compare costs among alternative strategies.

7.1.6 Impacts on fisheries

1. At the second hui, the facilitators conducted an expert elicitation with four experts consisting of Fisheries New Zealand representatives, industry representatives, quota holders, and fishers (Appendix 4), following best practice guidelines (Martin et al. 2012, Hemming et al. 2018).
2. Fisheries experts constructed a scale of impact in which 0 equals no impact of kuaka management on fisheries and 100 equals catastrophic impact of kuaka management on fisheries. Catastrophic impact was defined as restrictions and regulations.
3. Once this scale was constructed, experts were asked to express their perception on the impacts of the proposed management strategies. The expert elicitation included both in-person and online participants, who participated through online forms (https://forms.gle/5NviPbb82LtzRFsE9).

7.2 Outcome

Alternatives were predicted to perform differently when viewed through different objectives. Dunes A+B was predicted to be the best performing alternative when considering the number of kuaka in 2050 (Fig. 4). Only ChicksOFF and ChicksOFF+ resulted in more than one kuaka population. Status Quo was unacceptable to Kāi Tahu. Advocacy was predicted to reach the most screens (Fig. 6). Status Quo, Reduce Lights A, Reduce Lights B, Advocacy, ChicksWH, and ChicksOFF+ was predicted to have the lowest ecosystem impacts (Fig. 5). Status Quo was predicted to be the cheapest (Fig. 7) and had the lowest impact on fisheries. A full comparison of the consequences for each of the alternative can be found in the consequence table (Table 4).

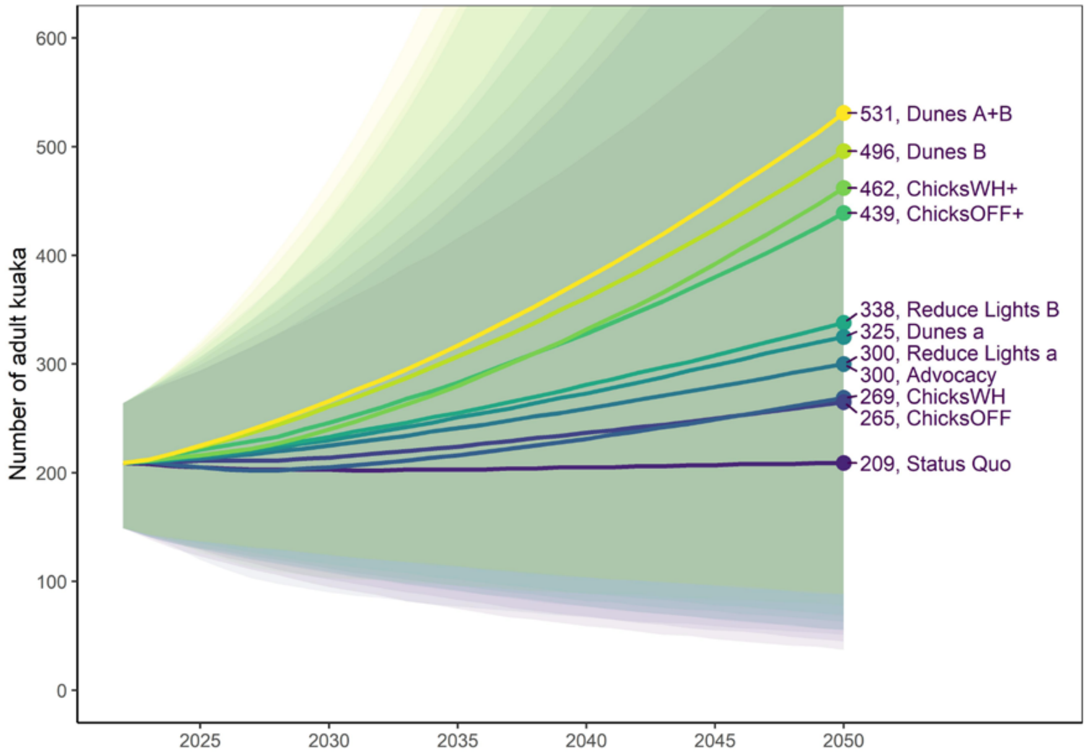

Figure 4. Predicted kuaka/Whenua Hou diving petrel population projections under alternative management strategies. Lines represent medians, the shading 95% credible intervals.

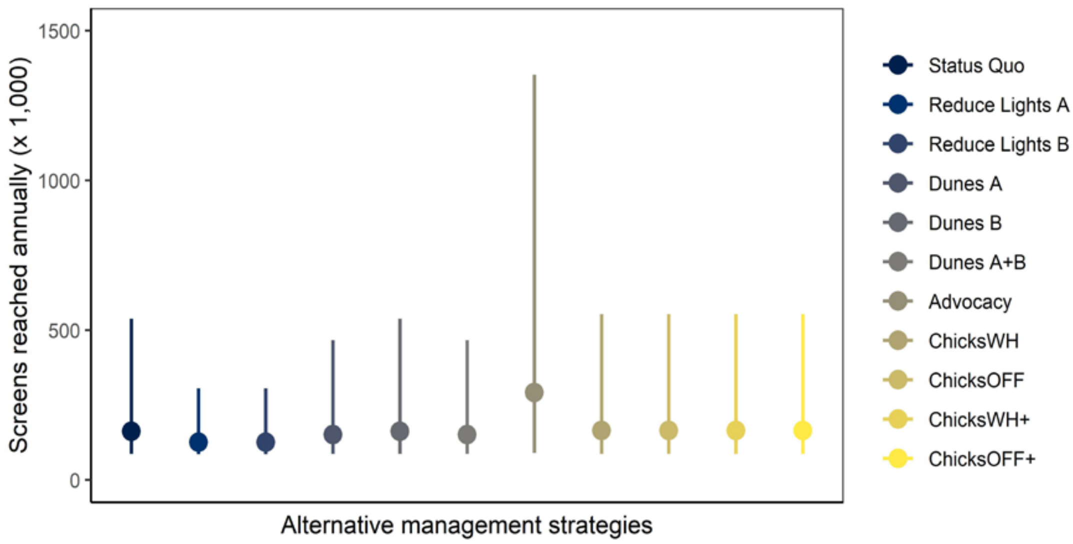

Figure 5. Estimated annual reach (in number of screens reached) per alternative kuaka/Whenua Hou diving petrel management strategy. Symbols represent means with 95% credible intervals.

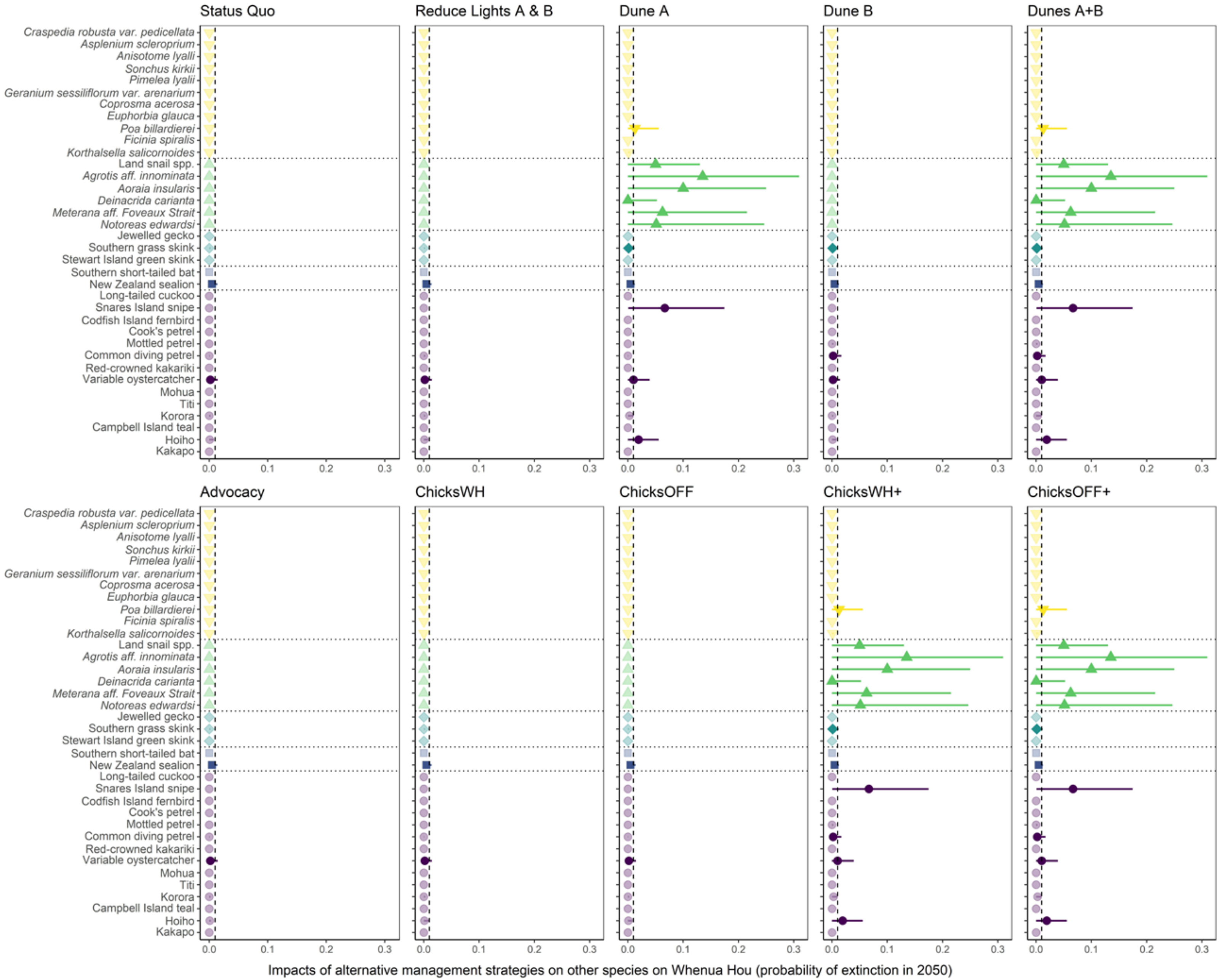

Figure 6. Estimated impacts of alternative management strategies on 36 threatened taxa occurring in the dunes of Whenua Hou. Symbols represent means with 95% credible intervals. Extinction probability was measured as negative impacts due to an alternative management strategy, on top of background extinction rates. Translucent symbols indicate that the probability of extinction is < 0.01 (dashed line). Colours and dotted lines indicate different species groups.

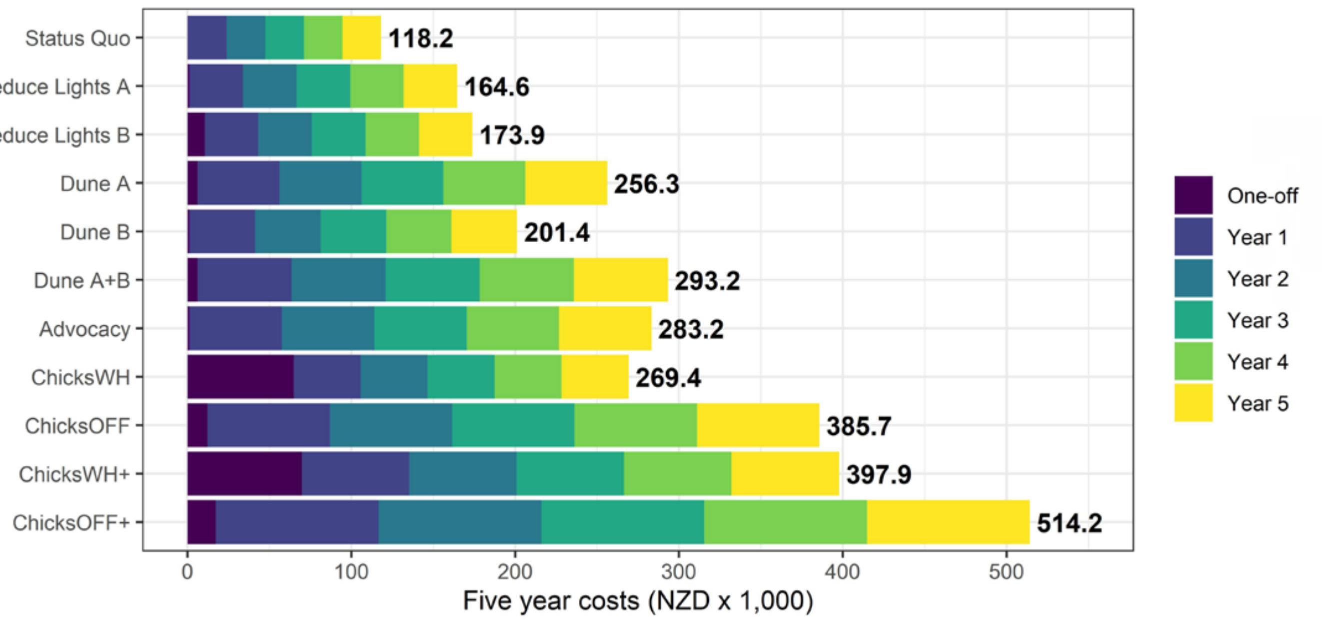

Figure. 7 Estimated five-year costs of alternative kuaka/Whenua Hou diving petrel management strategies, in NZD.

Table 4. Kuaka/Whenua Hou diving petrel structured decision-making consequence table. Uncertainty is represented by 95% CIs (in brackets).

ALTERNATIVE MANAGEMENT STRATEGY	OBJECTIVES						
	MAXIMISE NUMBER OF KUAKA	MAXIMISE NUMBER OF POPULATIONS	KĀI TAHU EXPRESS RANGATIRATANGA & EXERCISE KAITIAKITANGA	MINIMISE ECOSYSTEM IMPACTS	MAXIMISE PUBLIC APPRECIATION	MINIMISE COSTS TO CONSERVATION MANAGEMENT	MINIMISE IMPACTS ON FISHERIES
	$N_{adults,\ 2050}$	$N_{populations,\ 2050}$		$N_{species\ impacted}$ **($P_{extinction}$ > 0.01)**	$N_{screens\ reached}$ **x 1000 (annually)**	**$ x 1000 (2022–26 total)**	**Constructed scale (0 = no impact; 100 = catastrophic impact)**
Status Quo	209 (37–688)	1 (1–1)	Unacceptable	0 (0–2)	163 (87–538)	118.2	16.9 (11.3–27.5)
Reduce Lights A	300 (56–989)	1 (1–1)	Acceptable	0 (0–2)	126 (85–305)	164.6	21.3 (15.6–36.3)
Reduce Lights B	338 (63–1130)	1 (1–1)	Maybe acceptable	0 (0–2)	126 (85–305)	173.9	97.5 (95–100)
Dune A	325 (55–1228)	1 (1–1)	Acceptable	9 (0–12)	151 (87–467)	256.3	21.3 (15.6–36.3)
Dune B	496 (89–1892)	1 (1–1)	Acceptable	0 (0–4)	163 (87–538)	201.4	21.3 (15.6–36.3)
Dune A + B	531 (88–2228)	1 (1–1)	Acceptable	9 (0–13)	151 (87–467)	293.2	21.3 (15.6–36.3)
Advocacy	300 (56–989)	1 (1–1)	Maybe acceptable	0 (0–2)	292 (90–1353)	283.2	21.3 (15.6–36.3)
ChicksWH	269 (51–884)	1 (1–1)	Acceptable	0 (0–2)	165 (87–553)	269.4	21.3 (15.6–36.3)
ChicksOFF	265 (45–920)	2 (1–2)	Acceptable	0 (0–2)	165 (87–553)	385.7	21.3 (15.6–36.3)
ChicksWH+	462 (78–1902)	1 (1–1)	Acceptable	9 (0–13)	165 (87–553)	397.9	21.3 (15.6–36.3)
ChicksOFF+	439 (69–1750)	2 (2–2)	Acceptable	9 (0–13)	165 (87–553)	514.2	21.3 (15.6–36.3)

8. Trade-offs and identifying the best option

Steps 5 & 6 of the SDM process

The best strategy is the one that is believed to be the most likely to achieve the objectives. For single-objective decisions, it is easy to choose the strategy that provides the best outcome. However, when faced with multiple objectives, it is important that all of the alternatives are carefully considered, particularly when there are conflicting objectives and trade-offs are required. The final selection of a management strategy may be affected by the uncertainty that surrounds the estimated outcomes of the candidate strategies. SDM provides several tools to account for uncertainty and trade-offs, which can improve transparency and provide decision-makers with a more complete assessment of the problem..

8.1 Process

Using the consequence table (Table 4), the rōpū examined trade-offs between the number of kuaka, the number of kuaka populations, the Kāi Tahu objective, ecosystem impacts, public appreciation, costs to conservation management, and impacts on fisheries. Specifically, the rōpū applied a series of qualitative and quantitative decision-analytical tools to simplify the consequence table rationally, account for uncertainty, facilitate deliberation, and allow for a transparent identification of the best option for kuaka management:

1. Upon completion of the consequence table, the rōpū members voted anonymously on acceptable (multiple) and preferred (one single) alternative management strategies in person and online (https://forms.gle/jtQDYZ3rEjiCMR2t9).
2. The rōpū identified hard constraints and removed options that did not meet these constraints.
3. The rōpū identified the alternative management strategies that were dominated (i.e., outperformed across all objectives) by alternative strategies and removed these.
4. Once the consequence table was simplified, the rōpū members anonymously ranked the remaining alternative management strategies from most preferred to least preferred.
5. To further investigate individual values placed on different objectives, the rōpū applied both Single Multi-Attribute Rating Technique Exploiting Ranks (SMARTER) and Single Multi-Attribute Rating Technique using Swings (SMARTS; Edwards & Barron 1994) in person and online (https://forms.gle/jt8yy4iZJDroYTYm6). We used both techniques, as some participants preferred to rank objectives while others preferred to weigh them. SMARTER / SMARTS weights were used with standardised consequences through value-modelling to provide performance values.
6. Following the deliberations spurred by the voting and ranking rounds, the simplification of the consequence table, and SMARTER / SMARTS results, the rōpū conducted a final ranking exercise.

8.2 Outcome

The first ranking round suggested a dichotomy within the rōpū, as some participants preferred alternative strategies that maximised the number of kuaka (e.g., Dunes B), while others preferred strategies that maximised the number of populations (e.g., ChicksOFF (Fig. 8A). In addition, some participants favoured intra-island translocations (ChicksWH or ChicksWH+).

Identifying hard constraints and dominating alternatives did not resolve the dichotomy in the rōpū. Specifically, alternatives had to be acceptable to Kāi Tahu and as such, Status Quo was not considered viable. Reduce Lights B was also further investigated, as the implementation of the light curfew may be constrained by international maritime laws and extensive socialisation processes with Kāi Tahu. Reduce Lights B was therefore not considered viable. Dune B dominated Dune A and, consequently, Dune A was removed from the consequence table. However, the dichotomy in the rōpū remained evident in the ranking exercise even following the simplification of the consequence table (Fig. 8B).

While employing SMARTER/SMARTS and value modelling further highlighted the dichotomy in the rōpū, it also provided more insights. Specifically, both SMARTER and SMARTS showed that values placed on number of kuaka and number of populations were almost equal (Fig. 8CE). Value modelling showed that preferred alternative strategies were either Dunes B or ChicksOFF, underscoring the continuing dichotomy. However, while ChicksOFF+ was the best alternative strategy when only placing values on number of kuaka and number of populations, SMARTER/SMARTS and value modelling illustrated that this alternative strategy was penalised due to the costs to conservation management and ecosystem impacts that came with this option (Fig. 8DF).

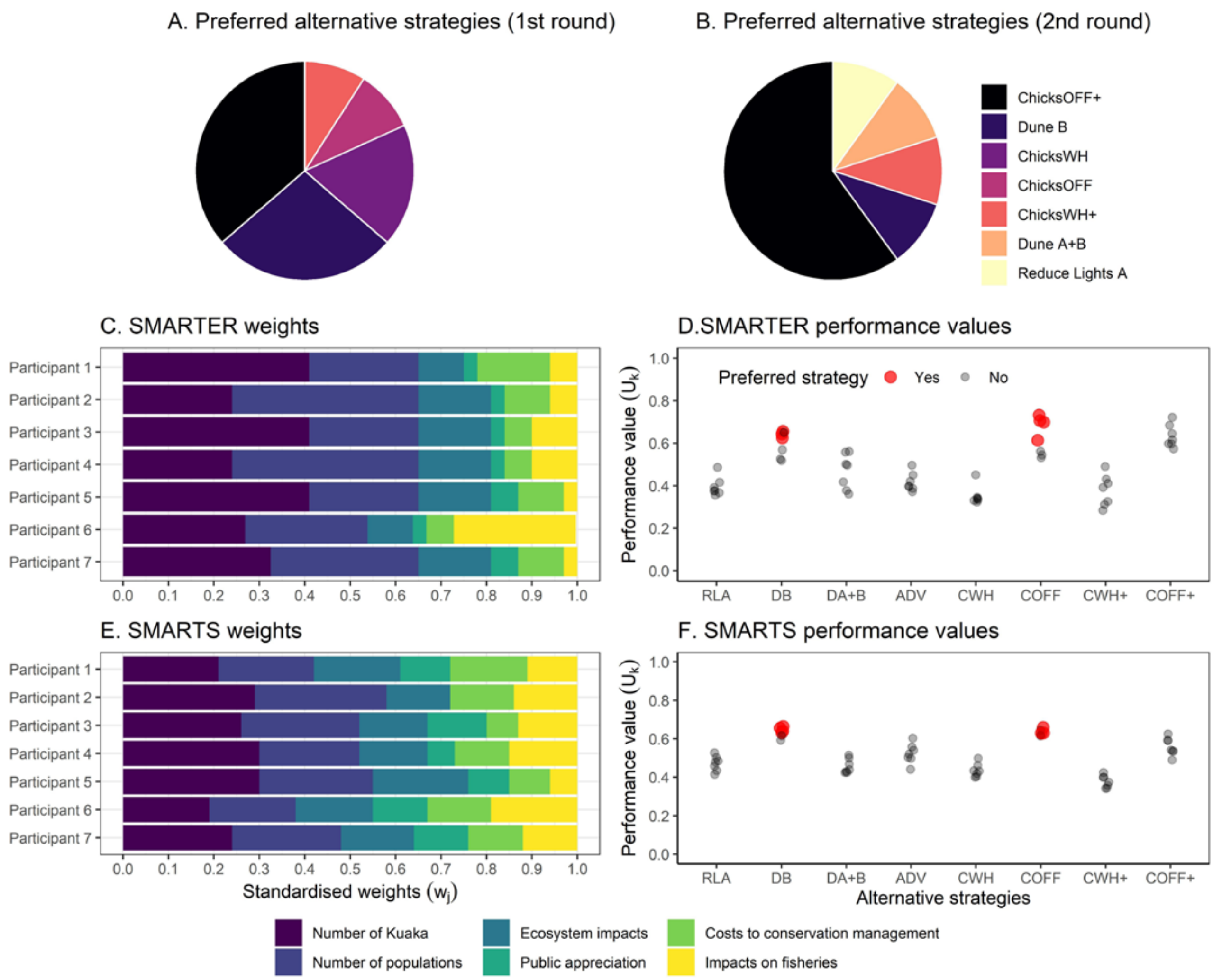

Figure 8. Outcomes of the different steps used to explore the trade-offs between the different kuaka/Whenua Hou diving petrel alternative management strategies. AB show the preferred strategies following two rounds of anonymous ranking. CE show the standardised weights placed on different objectives by different participants following SMARTER and SMARTS, respectively. DF show the standardised performance values per strategy, after reduction of the consequence table, using the standardised weights obtained through SMARTER and SMARTS, respectively. Note that acceptability by Kāi Tahu was a hard constraint, placed above these objectives and as such was not included in SMARTER / SMARTS. RLA = Reduce Lights A, DB = Dunes B, DA+B = Dunes A+B, ADV = Advocacy, CWH = ChicksWH, COFF = ChicksOFF, CWH+ = ChicksWH+, COFF+ = ChicksOFF+.

Deliberation spurred by these decision-analytical tools revealed several important insights. Firstly, ChicksWH and ChicksWH+ were alternative strategies that mostly arose out of concerns about the implementation of inter-island translocations. In other words, intra-island translocations were not favoured over inter-island translocations, but concerns were present about harvesting and hand-rearing protocols. Second, following SMARTER / SMARTS, values placed on costs to conservation management and ecosystem impacts were further questioned. The metric of ecosystem impacts did not successfully capture ecosystem benefits, particularly in the long-term. The costs to conservation management were not very large in comparison to other projects. After further consideration, the rōpū decided that both costs and ecosystem impacts across all alternative strategies are reasonably low.

Consequently, the rōpū conducted a final anonymous ranking exercise in which all participants ordered the different remaining alternative strategies by preference. The results showed all participants unanimously ranked one strategy, ChicksOFF+, as their preferred option.

9. Implementation

> **Step 7 of the SDM process**
>
> The last step in SDM is to identify mechanisms for the implementation of the recommended management strategy, ongoing monitoring to ensure accountability with respect to on-the-ground results, and review so that new information can be incorporated into future decisions.

The rōpū discussed a stepwise kuaka management programme, based on the recommendation of ChicksOFF+ (see Appendix 2 for full specification of this option), and identified several streams of work that should be included. Expression of rangatiratanga and exercising of kaitiakitanga by Kāi Tahu is an overarching and fundamental principle to all of these streams of work.

- **Permissions and funding.** Firstly, support from the Whenua Hou Komiti and Kaitiaki Rōpū ki Murihiku for the recommended strategy should be sought. Secondly, kuaka should be recognised as a national priority within prioritisation frameworks of DOC. Thirdly, adequate funding (either within DOC, or through research partnerships, or sponsorships) must be found. Finally, formal translocation proposals must be submitted. This stream of work is to be led by DOC.
- **Communications and advocacy.** All organisations represented on the kuaka rōpū will aim to heighten outreach to the public through their own communications channels.
- **Biosecurity.** Ongoing biosecurity to protect the colony on Whenua Hou remains a priority. Once a translocation site has been identified, biosecurity requirements for this site must be reviewed. This stream of work is to be led by DOC.
- **Monitoring.** Starting from the 2022 season, the Status Quo monitoring (two weeks in early October and two weeks in mid-January) will be extended to incorporate an additional week in late September. This additional week will allow time to identify burrows of other seabirds for competition management (pending approval). If needed, additional time could be spent completing the competitor management. This stream of work will be led by DOC and Kāi Tahu.
- **Best practice mitigation of light pollution.** Improved and clear guidelines for best practice mitigation of light pollution will need to be communicated to marine users as soon as possible (e.g., through a one-pager). Industry, Fisheries New Zealand, Environment Southland, Kāi Tahu, and DOC will work together on this stream of work.
- **Plant management.** In January/February 2023, a four-person team will set out to spot spray invasive grasses and native rushes in the dunes on Whenua Hou for a week (pending approval and funding). This will require the installation of an IBC (intermediate bulk container) in the back dune. Grass control should take place during this time due to the seeding times of grasses. However, cutting and pasting of shrubs encroaching dunes could be done at a different time of the year due to concerns about hoiho / yellow-eyed penguin (*Megadyptes antipodes*) disturbance. Plant management will have to continue in subsequent years, but potentially at a lower intensity. This stream of work will be led by DOC and Kāi Tahu.
- **Competition management.** During the last week in September 2022, all common diving petrels breeding in the dunes (either in pure common diving petrel or in hybrid pairs) will be euthanised (pending approval). During mid-January 2023, the mottled petrels breeding in the dunes will also be euthanised (pending approval). Advice from vets on the best euthanasia methods will be sought. Competition management will have to continue in

subsequent years, albeit at a lower intensity. This stream of work will be led by DOC and Kāi Tahu.

- **Inter-island translocations.** Prior to translocations off Whenua Hou, the ideal translocation protocols must be developed. This will include a test translocation within the dunes of Whenua Hou, potentially in 2023 (pending approval and funding). A test translocation will allow for the development of 1) optimal extraction techniques, 2) further testing of nest boxes, and 3) optimising hand-rearing protocols. Simultaneously, the preferred translocation site must be identified. Current candidates include Rarotoka Island, Te Kākahu-o-Tamatea / Chalky Island, and a yet-to-be-determined predator-free site on Rakiura / Stewart Island. DOC and Kāi Tahu will lead on this stream of work.

While the rōpū did not consider the formation of a formal recovery group necessary, the continuation of communication with the kuaka rōpū, following this SDM process, to ensure continuity and engagement, was considered crucial. The streams of work outlined above will be progressed with ongoing engagement with the entire kuaka rōpū. As such, the SDM process has successfully provided the foundation for the future implementation of kuaka management.

10. Acknowledgements

The authors are deeply grateful to all participants of the kuaka SDM process, who kindly and patiently provided their time, energy, knowledge, and insights, both during and outside of hui (listed in Appendix 1). The authors are also indebted to the many additional experts who generously provided their insights and wisdom.

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Appendix 1

Kuaka / Whenua Hou diving petrel structured decision-making hui, team, and participants

First hui

Taku tai o Te Tītī Marae, Ōraka / Colac Bay.

10–11 February 2021

Second hui

Southland Fish and Game, Waihōpai / Invercargill.

15–16 December 2021

Structured decision-making team:

Facilitators: Kevin Parker (Parker Conservation Ltd.) and Johannes Fischer (Department of Conservation, Marine Species Team)
Decision support: John Ewen (Zoological Society of London)
Analysis support: Caio Kenup and Doug Armstrong (Massey University)
Note taker: Shannon Weaver (Department of Conservation, Marine Species Team; first hui only)

Table A1: Kaiuru/participants on kuaka / Whenua Hou diving petrel structured decision-making hui.

NAME	AFFILIATION	FIRST HUI		SECOND HUI	
		11 Feb	12 Feb	15 Dec	16 Dec
Tāne Davis	Ōraka-Aparima Rūnaka	✓	✓	✓	✓
Stewart Bull	Ōraka-Aparima Rūnaka	✓	✓	✓	
Hom Ryan	Hokonui Rūnaka	✓	✓	✓	✓
Estelle Leask	Awarua Rūnaka	✓			
Holly Brown	Te Rūnanga o Ngāi Tahu		✓		
Mark Witehira	Te Rūnanga o Ngāi Tahu			✓	
Ros Cole	DOC, Murihiku Operations	✓	✓	✓	✓
Igor Debski	DOC, Marine Species	✓	✓	✓	✓
Graeme Taylor	DOC, Marine Species	✓	✓	✓	✓
Johannes Fischer	DOC, Marine Species	✓	✓	✓	✓
Allen Frazer	Fisheries New Zealand	✓			
Jean Davis	Fisheries New Zealand	✓	✓	✓	✓
Rodney Tribe	Ngāi Tahu Fisheries			✓	✓
Carol Scott	Southern Inshore Fisheries			✓*	✓*
Olaf Nilsen	Southern Inshore Fisheries		✓	✓	
Kathryn McLachlan	Environment Southland				✓
Total		11	9	12	11

*Online attendance

Online observers:

Katie Clemens-Seely (Department of Conservation, Marine Species Manager)
John McCarroll (Department of Conservation, Murikihu Operations Manager)

Appendix 2

Alternative conservation management strategies for kuaka / Whenua Hou diving petrel recovery

Table A2. Full description of Status Quo and ten alternative management strategies for kuaka / Whenua Hou diving petrel recovery

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Status Quo	Access by permit only and following standard quarantine procedures. Access to dune system subject to additional restrictions. Annual voluntary conservation rodent dog checks of vessels operating around Whenua Hou.	NA	Burrow counts, CMR, and burrowscoping of WHDPs following standard protocols with two pax for two weeks during courtship/ egg-laying (Oct) and two weeks during fledging (Jan). Annual total: 4 weeks.	NA	~19% of foredune vegetation cover is non-native. Annual selective spot spraying of introduced grasses (e.g., *D. glomerata*, *H. lanatus*, *L. perenne*) in eastern third of foredunes with haloxyfop in knapsacks. 1–2 pax ~1 day in summer.	NA	NA	NA	~0.8 vessels/night in Waikoropupū (Sealers Bay), ~31% of which use floodlights. All inshore trawl and BLL, and some setnet vessels around Whenua Hou have PSRMPs stating to minimise unnecessary light use. Deepwater VMPs may state minimize light use. No PSRMPs, VMPs, or specific light MGMT for other fishing vessels, including cray potting vessels. Advice sheet for cruise ships. No guidelines for other marine users (e.g., recreational fishing vessels).	Observer coverage for large trawl at 56–74%, 0.2–0.4% for small trawl, 16–32% for small BLL, and 14–27% for small setnet vessels within Stewart Snares Shelf (2015/16–2017/18). Data collection focused on bycatch. No monitoring for other marine users.	Voluntary 4 nm setnet ban around Whenua Hou and additional marine sanctuaries and setnet bans (commercial wand recreational) in Southern South Island (including Te Waewae, Catlins, and Port Pegasus). 12 nm marine reserve around Auckland Islands. Vessel specific mitigation guidelines on PSRMPs and VMPs for all trawl, BLL, SLL, and setnet vessels following standards set in NPOA seabirds 2020.	Press releases related to scientific publications (~1 press release per year). Small FB (~800 followers) and Twitter accounts (~500 followers).

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Reduce Lights A[d]	Status Quo	NA	Status Quo	NA	Status Quo	NA	NA	NA	Status Quo, but all fishing vessels, including cray potting vessels, and other marine users operating around Whenua Hou informed to reduce unnecessary deck and non-navigational lights to a minimum. Light management as a heightened priority on all inshore and deepwater OPs, VMPs, and PSRMPs within breeding distribution.	Status Quo, but improved recording of deck strikes through existing observer programme. Time-lapse camera monitoring of light use in Waikoropupū.	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Reduce Lights B[e]	Status Quo	NA	Status Quo	NA	Status Quo	NA	NA	NA	Status Quo, but all marine users refrain from using any flood- or spotlights within Waikoropupū between September and January. In addition, within the kuaka breeding distribution, outside Waikoropupū, all fishing vessels, including cray potting vessels, as well as other marine users informed to reduce unnecessary deck and non-navigational lights to a minimum. Light management as a heightened priority on all inshore and deepwater OPs, VMPs, and PSRMPs within breeding distribution.	Reduce Lights A[d]	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Dune A	Status Quo	NA	Status Quo	NA	Status Quo, but intensive annual spot spraying of introduced grasses (e.g., *D. glomerata*, *H. lanatus*, *L. perenne*) with haloxyfop in foredune as well as cutting and pasting shrubs (e.g., *C. proprinqua*, *M. australis*, *H. salicifolia*, *G. littoralis*, *L. scoparium*, *P. colensoi*, *M. umbellata*) in backdune with glyphosate. In addition, thinning out of *F. nodosus* and *A. novaezealandia* with glyphosate. One week operation in summer with 4 pax.	NA	Status Quo	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Dune B	Status Quo	NA	Status Quo, but with two additional weeks during courtship (late Sep) to detect arriving CDPs. Annual total: 6 weeks	NA	Status Quo	Culling of all CDPs and mottled petrels detected on the ground within the foredune (<20 m from tide line), including CDPs in mixed pairs. CDPs flying overhead to be ignored.	Status Quo	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo
Dune A + B[f]	Status Quo	NA	Dune B	NA	Dune A	Dune B	Status Quo	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
Advocacy[g]	Status Quo	NA	Status Quo	NA	Status Quo	Status Quo	Status Quo	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo, but increased output and reach through dedicated DOC communications plan that aligns with overarching biodiversity comms (0.1 FTE), including video/ photographer visits to Whenua Hou. Dedicated policy advisor at 0.1 FTE to develop targeted international policy and management papers, advocate at targeted national and international conferences, and interact on targeted international forums.

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
ChicksWH	Status Quo	NA	Status Quo, but with two additional weeks prior to fledging (late Dec) to select harvest candidates and prepare nest boxes. Annual total: 6 weeks	NA	Status Quo	NA	Translocation of 30% of all WHDP chicks (~15 individuals) ~14 days-before-fledging from fragile and accessible burrows in foredunes to central backdune. Chicks housed and hand-reared inside wooden purpose-built nest-boxes following standard protocols. Purpose-built shed on Whenua Hou for food prep. No acoustic attraction. Extraction of chicks by hand. Transport in small crates on foot. Installation of dummy burrows to increase settlement. Annually, for 5 years.	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
ChicksOFF	Status Quo	Access by permit and following standard quarantine procedures.	Status Quo, but with two additional weeks prior to fledging (late Dec) to select harvest candidates and prepare nest boxes. Annual total: 6 weeks	CMR and burrowscoping of WHDPs following standard protocols for one week during courtship/ egg-laying (Oct) and four weeks during hand-rearing/ fledging (Dec–Jan). Annual total: 5 weeks.	Status Quo	NA	NA	Translocation of 30% of all WHDP chicks (~15 individuals) ~14 days-before-fledging to a sand dune free of invasive predators. Chicks hand-reared inside wooden purpose-built nest-boxes following standard protocols. Food prep on separate facility on translocation site. Extraction of chicks by hand. Transport in small crates by helicopter. No acoustic attraction. Annually, for 5 years	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo

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Table A2 continued

	BIOSECURITY		MONITORING		MANAGEMENT ON WHENUA HOU		TRANSLOCATION		AT-SEA MANAGEMENT			ADVOCACY
	Whenua Hou	**New site[a]**	**Whenua Hou**	**New site[a]**	**Plant management[b]**	**Competition management**	**Within Whenua Hou colony**	**New site[a]**	**Light management**	**At-sea monitoring**	**Bycatch management[c]**	**Communications**
ChicksWH+	Status Quo	NA	Status Quo, but with two additional weeks during courtship (late Sep) to detect arriving CDPs and two additional weeks prior to fledging (late Dec) to select harvest candidates and prepare nest boxes. Annual total: 8 weeks	NA	Dune A	Dune B	ChicksWH	NA	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo
ChicksOFF+	Status Quo	ChicksOFF	Status Quo, but with two additional weeks during courtship (late Sep) to detect arriving CDPs and two additional weeks prior to fledging (late Dec) to select harvest candidates. Annual total: 8 weeks	ChicksOFF	Dune A	Dune B	NA	ChicksOFF	Reduce Lights A[d]	Reduce Lights A[d]	Status Quo	Status Quo

[a] The translocation site (island) must consist of a coastal sand-dune, free of invasive predators, within the rohe of Kāi Tahu.

[b] Weed and plant management were separated at the first kuaka SDM hui but fused here with differences explained per alternative.

[c] Bycatch management was not discussed during the first kuaka SDM hui but included here in the Status Quo for clarity and transparency.

[d] Status Quo and Reduce Lights A were fused at the first kuaka SDM hui but separated here for clarity and transparency.

[e] Reduce Lights B was introduced to fully explore the decision frame and allow for transparency in the trade-offs that will have to be made.

[f] Dunes A+B was added during the second kuaka SDM hui.

[g] While initially named Comms+, Advocacy better captures the full span of this alternative.

Appendix 3

Future kuaka / Whenua Hou diving petrel research priorities

Priority kuaka / Whenua Hou diving petrel research questions:

- How do adverse interactions between kuaka and vessels (i.e., through deck strikes) impact population dynamics?
- Does juvenile distribution differ spatiotemporally from adults and consequently affect population dynamics?
- Does common diving petrel distribution differ spatiotemporally from kuaka and is there potential for interspecific competition offshore?
- What is the most suitable translocation site for kuaka?
- Which sound attraction regime maximises recruitment into a translocated population?
- How many females can relay following egg harvest (for artificial incubation, hand-rearing, and translocation)?
- How would double-clutching affect female survival?
- How successful is artificial incubation and complete hand-rearing of chicks?
- What is the optimal food for hand-rearing translocated chicks?
- How do adverse interactions between kuaka and native predators (e.g., ruru / morepork; *Ninox novaeseelandiae*) impact population dynamics?
- How do marine mammals (i.e., rāpoka/ New Zealand sealions; *Phocarctos hookeri*) affect kuaka population dynamics by moving through the dunes?
- How do the movements of dunes affect kuaka population dynamics?
- Does (direct or indirect) ingestion of plastics affect kuaka population dynamics?
- Do any diseases impact kuaka population dynamics?
- Are common diving petrel genes propagated into the kuaka gene pool through successful hybridisation?
- Are kuaka suffering from inbreeding depression?

Appendix 4

Experts consulted to inform consequences of kuaka / Whenua Hou diving petrel alternative management strategies

Table A3: Members of kuaka rōpū and additional experts consulted to inform the consequences of the various alternatives along different objectives.

NAME	KUAKA RŌPŪ	KUAKA ELICITATION	KĀI TAHU ELICITATION	ECOSYSTEM IMPACTS ELICITATION	PUBLIC APPRECIATION ELICITATION	COSTS ELICITATION	FISHERIES IMPACTS ELICITATION
Tāne Davis	✓		✓				
Stewart Bull	✓		✓				
Hom Ryan	✓		✓				
Estelle Leask	✓						
Holly Brown	✓						
Mark Witehira	✓		✓				
Ros Cole	✓	✓		✓		✓	
Igor Debski	✓	✓		✓	✓	✓	
Graeme Taylor	✓	✓		✓		✓	
Johannes Fischer	✓	✓		✓	✓	✓	
Allen Frazer	✓						
Jean Davis	✓						✓
Rodney Tribe	✓		✓				✓
Carol Scott	✓						✓
Olaf Nilsen	✓		✓				✓
Kathryn McLachlan	✓						
Matt Rayner		✓					
Brendon Dunphy		✓					
John Stewart		✓					
William Gibson		✓					
Bruce McKinlay				✓			
Brian Rance				✓			

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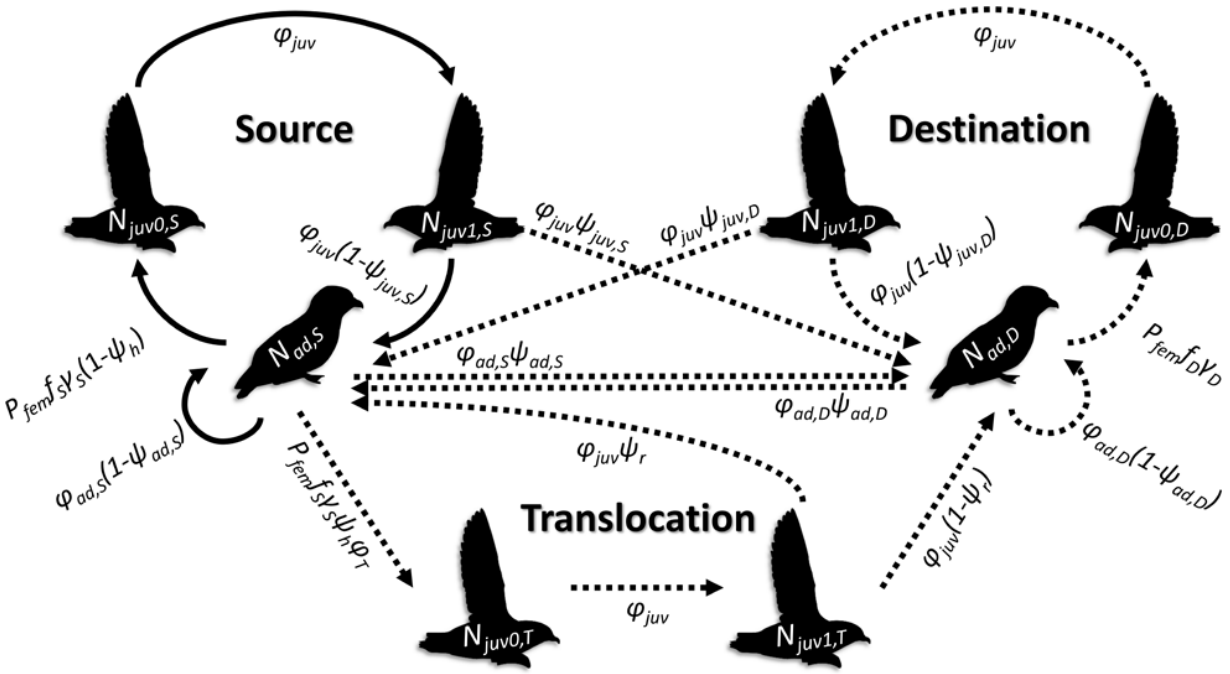
Table A3 continued

NAME	KUAKA RŌPŪ	KUAKA ELICITATION	KĀI TAHU ELICITATION	ECOSYSTEM IMPACTS ELICITATION	PUBLIC APPRECIATION ELICITATION	COSTS ELICITATION	FISHERIES IMPACTS ELICITATION
Dave Houston				✓			
Eric Edwards				✓			
Graeme Elliott				✓			
Graeme La Cock				✓			
Lynn Adams				✓			
Rod Hitchmough				✓			
Ursula Ellenberg				✓			
Will Brockelsby				✓			
Cassandra Spearin					✓		
Ligs Hoffman					✓		
Total	16	8	6	14	4	4	4

Appendix 5

Integrated population model and resulting estimates

To predict future kuaka population trajectories under different alternative management strategies, various iterations of an integrated population model (IPM) were used (Fig. A1). Per strategy, we used our IPM to estimate vital rates and population size, integrate expert elicited values, and predict future trajectories, while accounting for various sources of uncertainty. Estimated vital rates and metapopulation dynamics based on a fusion of empirical estimates and expert elicitations are shown in Fig. A2.



$N_{ad,S}$	Adults at the source
$N_{juv0,S}$	Juveniles arising from fledglings at the source
$N_{juv1,S}$	One-year-old juveniles at the source
$N_{juv0,T}$	Juveniles arising from translocated fledglings
$N_{juv1,T}$	One-year-old juveniles from a translocation
$N_{ad,D}$	Adults at the destination
$N_{juv0,D}$	Juveniles arising from fledglings at the destination
$N_{juv1,D}$	One-year-old juveniles at the destination
$\varphi_{ad,S}$	Adult survival at source
φ_{juv}	Juvenile survival
f_S	Breeding probability at source
γ_S	Breeding success at source
P_{fem}	Probability of being female
ψ_h	Harvest rate
φ_T	Survival of translocated fledglings until fledging
ψ_r	Return-to-source probability
$\varphi_{ad,D}$	Adult survival at destination
f_D	Breeding probability at destination
γ_D	Breeding success at destination
$\psi_{ad,S}$	Transition p. of adults from source to destination
$\psi_{ad,D}$	Transition p. of adults from destination to source
$\psi_{juv,S}$	Transition p. of juveniles from source to destination
$\psi_{juv,D}$	Transition p. of juveniles from destination to source

Figure A1. Diagram of the integrated population model (IPM) used to predict kuaka / Whenua Hou diving petrel population trajectories under various alternatives. Solid arrows indicate a single-population IPM, dotted lines indicate a metapopulation IPM (used for ChicksWH, ChicksOFF, ChicksWH+, and ChicksOFF+). Illustrations by J. de Hoop.

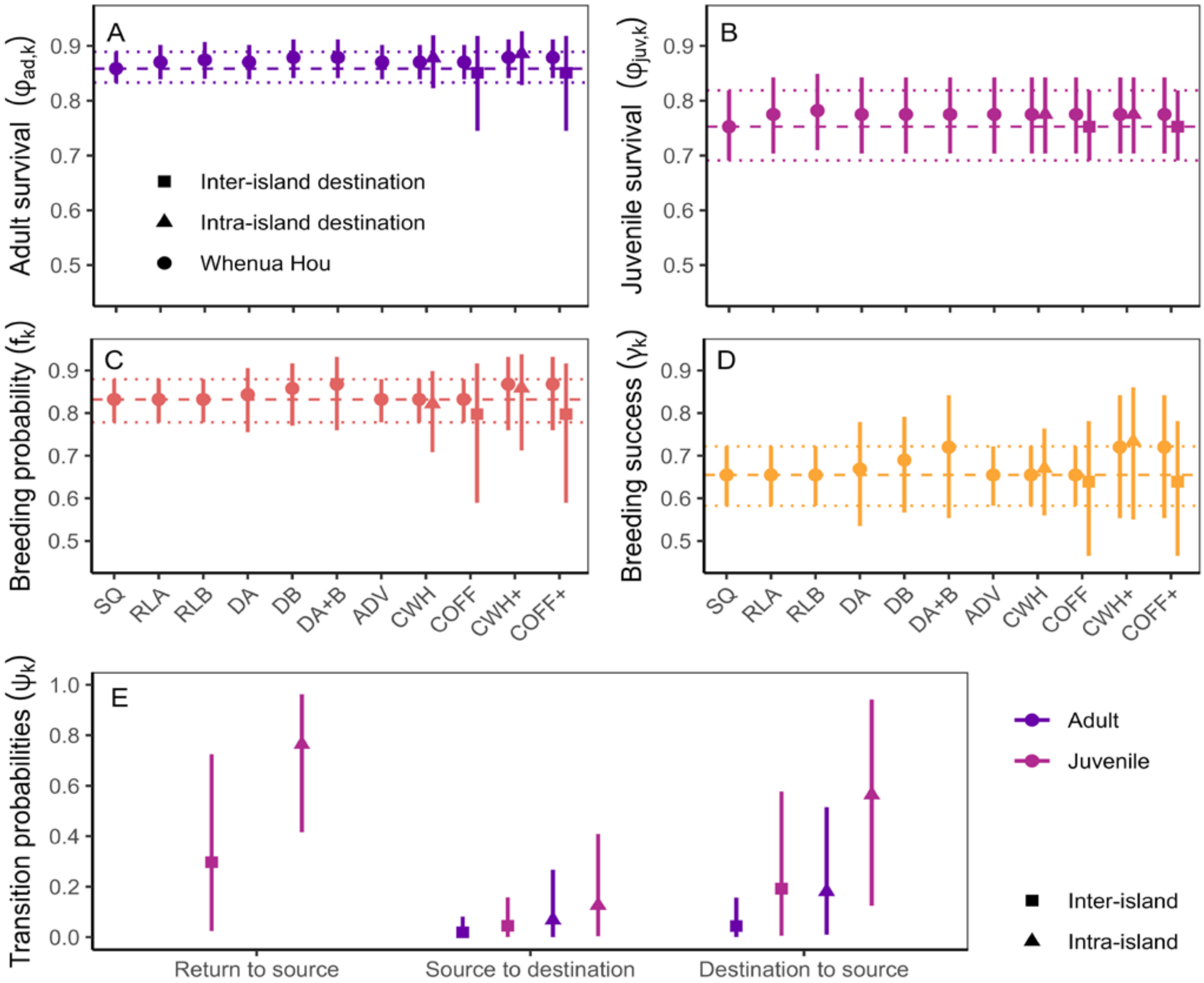


Figure A2. Estimates of kuaka vital rates and population dynamics parameters under alternative management strategies for the different metapopulations based on a combination of empirical estimates and expert elicitations. Symbols represent means with 95% credible intervals. Dashed and dotted lines represent Status Quo estimates. SQ = Status Quo, RLA = Reduce Lights A, RLB = Reduce Lights B, DA = Dunes A, DB = Dunes B, DA+B = Dunes A+B, ADV = Advocacy, CWH = ChicksWH, COFF = ChicksOFF, CWH+ = ChicksWH+, COFF+ = ChicksOFF+.