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Essay

Improving supplementary feeding in species conservation

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Abstract: *Supplementary feeding is often a knee-jerk reaction to population declines, and its application is not critically evaluated, leading to polarized views among managers on its usefulness. Here, we advocate a more strategic approach to supplementary feeding so that the choice to use it is clearly justified over, or in combination with, other management actions and the predicted consequences are then critically assessed following implementation. We propose combining methods from a set of specialist disciplines that will allow critical evaluation of the need, benefit, and risks of food supplementation. Through the use of nutritional ecology, population ecology, and structured decision making, conservation managers can make better choices about what and how to feed by estimating consequences on population recovery across a range of possible actions. This structured approach also informs targeted monitoring and more clearly allows supplementary feeding to be integrated in recovery plans and reduces the risk of inefficient decisions. In New Zealand, managers of the endangered Hihi (*Notiomystis cincta*) often rely on supplementary feeding to support reintroduced populations. On Kapiti island the reintroduced Hihi population has responded well to food supplementation, but the logistics of providing an increasing demand recently outstretched management capacity. To decide whether and how the feeding regime should be revised, managers used a structured decision making approach informed by population responses to alternative feeding regimes. The decision was made to reduce the spatial distribution of feeders and invest saved time in increasing volume of food delivered into a smaller core area. The approach used allowed a transparent and defendable management decision in regard to supplementary feeding, reflecting the multiple objectives of managers and their priorities.*

Keywords: decision making, nutritional ecology, population ecology, population recovery, supportive management

Mejoría de la Alimentación Suplementaria en la Conservación de Especies Ewen *et al.*

Resumen: *La alimentación suplementaria con frecuencia es una reacción instintiva a la declinación de poblaciones y su aplicación no se evalúa críticamente, lo que lleva a opiniones polarizadas sobre su uso entre los manejadores. Aquí abogamos por una estrategia más decisiva para la alimentación suplementaria para que la opción de usarla esté claramente justificada sobre, o en combinación con, otras acciones de manejo y las consecuencias pronosticadas sean entonces evaluadas críticamente después de su implementación. Proponemos combinar métodos de otro conjunto de disciplinas especialistas que permitirán la evaluación crítica de la necesidad, el beneficio y los riesgos de la alimentación suplementaria. Por medio del uso de la ecología nutricional, la ecología de poblaciones y la toma de decisiones estructuradas, quienes manejan la conservación pueden tomar mejores decisiones sobre qué y cómo alimentar al estimar las consecuencias de la*

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*recuperación poblacional a través de un rango de acciones posibles. Esta estrategia estructurada también informa al monitoreo enfocado y permite con mayor claridad la integración de la alimentación suplementaria a los planes de recuperación y reduce el riesgo de decisiones ineficientes. En Nueva Zelanda, los manejadores del hihi (*Notiomystis cincta*) que se encuentra en peligro de extinción, con frecuencia dependen de la alimentación suplementaria para apoyar a las poblaciones reintroducidas. En la isla de Kapiti, la población reintroducida de hihis ha respondido de buena manera a la alimentación suplementaria, pero la logística de proporcionar a una demanda en crecimiento recientemente sobrepasó la capacidad de manejo. Para decidir si el régimen alimentario debería revisarse y cómo hacerlo, los manejadores usaron una estrategia estructurada de toma de decisiones con información sobre las respuestas de la población a regímenes alternativos de alimentación. La decisión se hizo para reducir la distribución espacial de los comederos e invertir el tiempo ahorrado en incrementar el volumen de alimento que se lleva a una zona núcleo más pequeña. La estrategia usada permitió una decisión de manejo transparente y defendible con respecto a la alimentación suplementaria, lo que refleja los objetivos múltiples de los manejadores y sus prioridades.*

Palabras clave: ecología nutricional, ecología de poblaciones, manejo de apoyo, recuperación de poblaciones, toma de decisiones

Introduction

Remnant populations of endangered species often require supportive management as a result of ongoing habitat degradation and, more recently, restoration. A common type of support is food supplementation. Food supplementation is broadly applied, typically because natural foods are hypothesized to limit a population of interest (Armstrong & Perrott 2000; López-Bao et al. 2010*a*) or because there is a hypothesized benefit to providing safe food sources free of veterinary drugs or poisons (Oro et al. 2008; Oro et al. 2013). Food supplementation is also thought to aid recovery of hunted populations (Delibes-Mateos et al. 2009). Alternatively, supplementation is applied as part of a suite of exploratory interventions set in place prior to understanding the exact factors limiting populations (Jones & Merton 2012).

However, previous studies have also demonstrated that supplementary feeding may negatively affect the population it is intended to help (Carrete et al. 2006; Blanco et al. 2011; Martínez-Abraín & Oro 2013) or have wider negative effects on the recipient ecosystem (Cortes-Avizanda et al. 2009*a*, 2009*b*; Deygout et al. 2009; Orros & Fellowes 2012). For example, Carrete et al. (2006) show that the presence of supplementary feeding stations depresses productivity in the Pyrenean population of bearded vultures (*Gypaetus barbatus*) during population recovery. This drop in productivity may be related to the increased presence of non-breeding floating individuals congregating at feeding stations, which may lead to a drop in breeding territory quality (Carrete et al. 2006). This, combined with uncertainty around reduction of pre-adult mortality (posited as a major benefit from food supplementation), led Carrete et al. (2006) to question the utility of food supplementation in this population. Even where there are no clear drawbacks, the choice to provide supplementary food is often not based on the theory of population limitation, and its expected benefits are often not carefully evaluated. These problems have led supplementary feeding to be included on a list of frequent dogmatic approaches to conservation (Martínez-Abraín & Oro 2013).

As a result of this potential for positive as well as negative outcomes, food supplementation appears to have polarized managers. In addition, there may be more fundamental concerns: it is realistic to imagine some conservationists may be averse to feeding wild populations because they view it as an unsustainable and unnatural intervention. The variety of potential motivations for the use of supplementary feeding (why to use it) and the uncertainty surrounding its potential outcomes (what to expect from it) inevitably affect management decisions. Our aim was to suggest that these general issues could be addressed by adopting a more strategic approach in which information from multiple disciplines is incorporated in a clear decision-making framework. In particular, we advocate the integration of nutritional ecology (Raubenheimer et al. 2009, 2012) and population ecology (Armstrong et al. 2002; Lande et al. 2003) to evaluate the optimal methods for supplementary feeding and their expected outcomes in terms of population recovery.

We believe structured decision making (SDM) (Gregory et al. 2012) provides an ideal framework for such a strategic approach. SDM is defined as the collaborative and facilitated application of multiple objective decision making and group deliberation methods to environmental management and public policy problems (Gregory et al. 2012). It is based on a conceptual iterative process (Fig. 1) in which objectives are explicitly stated, clearly defined alternative management strategies are evaluated in terms of their expected outcomes, and trade-offs are solved while explicitly accounting for uncertainty. The adoption of SDM can facilitate a more transparent approach to the choice of food supplementation and thus help clarify problems associated with the choice to use supplementation, what can be expected from it, and how it should be implemented. SDM can also improve the transparency of the decision process,

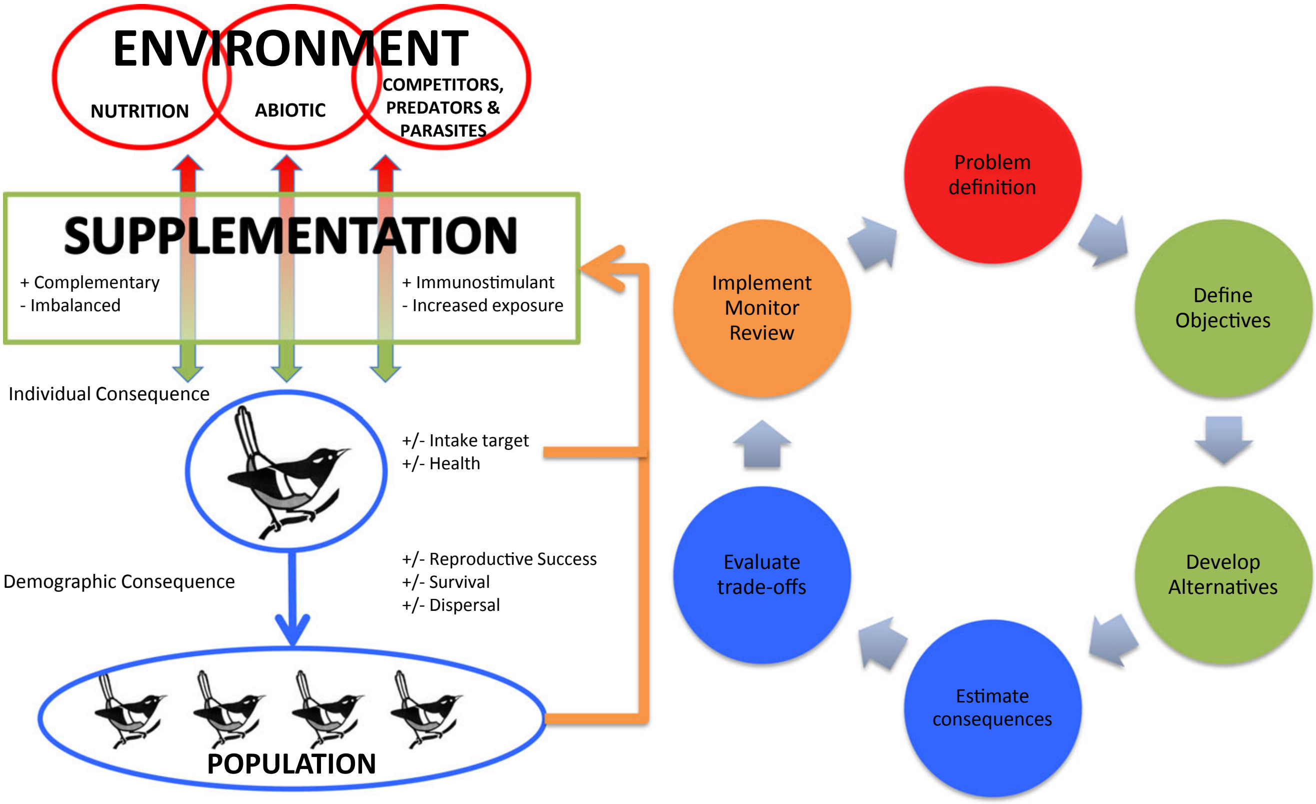

Figure 1. Conceptual representation of a strategic approach to supplementary feeding (supplementation rectangle, examples of influence [positive or negative] of environmental factors; orange arrows, learning phase in which effects are used to evaluate and perhaps modify the type of supplement or how it is provided; circles, 6-step structured decision making [SDM] process). Color coding shows how information from nutritional, individual, and population ecology can feed into the scientific components of an organized, inclusive, and transparent SDM approach.

ideally clarifying the role of food supplementation in the context of species recovery programs.

SDM does not guarantee positive outcomes; rather it ensures the most rational decision is made given the stated objectives and the available information. The process generates a transparent logbook of how the decision was made, thus enabling critical review. To illustrate how the application of SDM to supplementary feeding would work in practice, we provide an example involving supplementary feeding management of the New Zealand Hihi (*Notiomystis cincta*).

A Structured Decision Approach to Food Supplementation

Problem Definition

The first key step of any decision analysis is a clear definition of the problem. In this sense, the concerns and opposing views about supplementary feeding can reflect 2 slightly different, but linked, decisions. Managers may need to decide whether to implement supplementary feeding or not. This decision in turn may be linked to additional decisions about how to implement it (if at all). Questions associated with these decisions include what supplement should be provided; is the supplement sex and age dependent; how should food be provided to ensure that the required number of individuals of the target species gains access and obtains the right amount of nutrients; what method of application provides the least negative health effects; how does one ensure no wider negative ecosystem effects from supplementation; how long will supplementation be required; and what level of financial and logistic investment is sustainable for managers? The final 2 questions are important to consider at the outset, not least because experience tells us that management of critically endangered species can involve many years of ongoing commitment (Jones & Merton 2012). This perspective may rightly lead to a final question, what ecosystem restoration is required to reduce the target species' dependence on supplementary nutrients? These questions form the basis for the definition of the problem at hand. Of course, not all the questions may be relevant in all cases, and the difficulty of addressing them in the field may vary.

Objectives

In general, the decisions regarding whether and how to apply supplementary feeding must reflect the fact that supplementary feeding is normally only a tool to achieve some more general objective. One should ask whether there is a better way to achieve an objective. If not, one should determine the best feeding strategy to adopt. The definition of objectives then becomes the next key step in an SDM approach to food supplementation. In particular, SDM recommends a clear distinction between fundamental objectives (the core aims that reflect fundamental values and preferences) and means objectives, which are only important as stepping stones to the fundamental objective. We suggest that in most cases, population recovery will be the ultimate biological aim for conservation programs in which food supplementation is considered. It then becomes easier to assess supplementation as a support tool. For example, a possible means objective of maximizing the feeding rate of individuals at food stations may carry no value in itself; it may have value only for its expected effects on the survival of individuals and ultimately on the persistence of the population. Managers may also need to balance multiple fundamental objectives, such as population recovery, overall ecosystem functioning, and budget management. SDM provides a wide range of tools for dealing with multiple-objective decisions (Gregory et al. 2012; Converse et al. 2013).

Importantly, SDM is an inclusive process, encouraging participation from all relevant stakeholders, including governing bodies, and combining both scientific evidence and value-focused thinking (Nichols & Williams 2006). Decisions should be driven by objectives, and these are expressions of the concerns of all stakeholders. Values will be particularly important in decisions about supplementary feeding because they can express, for example, the preference managers have for multiple objectives, their level of risk tolerance to unintentional negative effects, and the societal limits to resourcing conservation management.

Management Alternatives

If the objectives are the key drivers of management decisions, alternative management strategies represent the available options managers can choose from. Therefore, the second step in the SDM process is the definition of such alternatives. These should represent a set of clear, feasible actions, ideally developed from collaborative review and creative discussion among managers, experts, and stakeholders (Gregory et al. 2012). The definition and evaluation of management alternatives in an SDM framework can provide the answer to 2 key questions: whether and how to implement supplementary feeding. To decide whether food supplementation is required, it is important to consider realistic alternatives that do not include it. Examples may include a status quo alternative, for recovery plans that currently do not include feeding, or a do-nothing alternative, or any other technical approach to the fundamental objectives (such as habitat restoration that does not include supplementary feeding). Again, this emphasizes the need to distinguish clearly between fundamental and means objectives: if population recovery is the sole objective, it should not matter how it is achieved.

For decisions about implementation, nutritional ecology offers a useful framework in which to cast hypotheses of nutrient limitation and choice of nutrient supplementation (potentially providing useful aspects of decision objectives and alternatives) (Fig. 1). Currently, choice of supplements is mostly based on expert judgment and commercially available products (e.g., Wombaroo lorikeet and honeyeater food [Passwell & Wombaroo Food Products, South Australia] or sugar water solution for New Zealand Hihi, or Aves Nectar [Beaphar Raalte, Holand] for Mauritian Olive White-Eye [*Zosterops chloronothos*]). However, this delivery of food supplements may carry a major fault. Food is an umbrella term for a diverse range of changing nutritional requirements that an individual requires throughout its life history (Raubenheimer et al. 2009; Walker et al. 2013). Food supplements might not provide what is missing in a balanced natural diet and may exacerbate nutrient imbalance such that intake targets (an individual's nutritional requirements over a given time frame [Raubenheimer et al. 2009]) are not met. Negative consequences of imbalanced nutritional diets have been observed in at least 2 bird species (male biased offspring sex ratios resulting from a protein and lipid imbalance in food supplements in the Kakapo Parrot [*Strigops habroptilus*] [Raubenheimer & Simpson 2006] and sex biased mortality in nestlings from a protein and lipid rich supplement in the Hihi [Walker et al. 2013]). Crucially for the conservation sector, what is needed is a method for refining what foods are provided. Nutritional ecology is a framework that can help meet this challenge, for example, by linking how the different nutrients present in the natural diet of a species relate to its nutrient requirements.

Consequence Estimation

We have highlighted how a clear definition of the fundamental objectives is the key to the evaluation of possible management strategies. How, then, can managers move from a range of choices to a final decision? Logically (and in the SDM framework), the decision is made by comparing management alternatives in terms of their expected outcomes for all fundamental objectives. For comparisons to be possible, appropriate measures should be defined for every objective. For example, assessments of supplementary feeding for birds have reported earlier breeding, increased clutch size, and improved fledging success (Komdeur 1996; Robb et al. 2008; Schoech et al. 2008; Oro et al. 2013). Similarly, for taxa other than birds there are reports of ready use of feeding stations (López-Bao et al. 2008; Poole & Lawton 2009) and benefits linked to improved condition or reproduction (López-Bao et al. 2010*b*; Newey et al. 2010). These measures of success include directly measuring vital rates (reproductive success and survival) that directly influence population growth, as well as other proximate measures (e.g., feeder use, condition, health) that may affect population growth. Both directly measured vital rates and proxies of management success can be good indicators, but they are only truly so if they contribute, or represent, desired population responses to supplementation. Confusion between proxies and fundamental objectives can have substantial implications for recovery programs (see Armstrong et al. 2007, where a clear increase in the vital rate of reproductive success in one Hihi population had a highly uncertain effect on the management objective of population recovery).

Therefore, decision makers should be involved in completing, or be presented with, a consequence table (Gregory et al. 2012). In its simplest form, this reports the expected outcomes of every management alternative under all objectives, each expressed in terms of the chosen measures (Table 1). For supplementary feeding, this means evaluating measured benefits and costs (vital rates, dispersal, or proxies for these) in terms of true metrics of conservation success (e.g., population recovery). If population recovery is the key biological aim of management plans considering supplementary feeding, then population ecology is the ideal framework within which to estimate demographic consequences to alternative management choices (e.g., food types and feeder design) so as to allow future projection of conservation outcome. Monitoring the demographic responses to implemented management alternatives may also provide decision makers with stronger evidence in the consequences stage of SDM (Fig. 1). For example, quantifying demographic responses to management alternatives with and without food supplementation and for management alternatives with different food types has been used in Hihi conservation across a series of reintroduced populations (Armstrong & Perrott 2000; Armstrong & Ewen 2001; Armstrong et al. 2007; Chauvenet et al.2012).

Potential negative consequences should also be considered. Perhaps the least serious of these is a failure to detect a positive response from individuals or populations to supplementation. In terms of objective-specific success, the negative consequence here can become the net cost (monetary and logistic) of commitment to unhelpful management. This may be the case, for example, in current efforts at diversionary feeding of Hen Harrier (*Circus cyaneus*) to reduce their consumption of Red Grouse (*Lagopus lagopus scoticus*) on U.K. grouse estates (New et al. 2012). More worrying is the possibility that supplementary feeding may distract managers from alternative conservation approaches that may better achieve population recovery, a situation that represents an investment trap or sunk cost (where managers tend to justify and protect earlier choices [Gregory et al. 2012]).

A range of other negative outcomes have been extensively reviewed elsewhere and include emergence of health problems from parasites and nutritional imbalances (e.g., Robertson et al. 2006; Blanco et al. 2011; López et al. 2011), alteration of the relationship between the target species and its ecosystem (Carrete et al. 2006), biased access to feeding stations by dominant individuals or individuals of other species (Newey et al. 2010; Moreno-Opo et al. 2012), altered dispersal (Oro et al. 2013), and cascading effects on non-supplementary feeder-using species (Orros & Fellowes 2012; Oro et al. 2013). Alternatively, where there is strong positive population response to supplementary feeding, commitment costs can also arise. Without careful planning, resources to continue feeding a growing population can quickly go beyond the capacity of managers to do so (e.g., Chauvenet et al. 2012).

Uncertainty and Trade-Offs

The presence of expected positive and negative outcomes will generate trade-offs between consequences relative to single or multiple objectives. For example, a supplementary feeding strategy could be expected to provide greater population growth than doing nothing, but at the same time it may have a greater budget requirement or involve a risk of negative cascade effects. SDM can incorporate a range of decision-analytic methods to deal with such trade-offs (Keeney & Raiffa 1976). In our case study, we provide an example of a simple weighted linear additive method.

The decision will generally be further complicated by uncertainty surrounding the expected consequences of management alternatives. Again, SDM can use a variety of methods to account for such uncertainty. Managers could compare consequences under different scenarios (worst to best case) or use confidence intervals or distributions for predictions obtained by quantitative models or expert elicitation. Finally, adaptive management can be used to directly address key uncertainties. For example, Armstrong et al. (2007) used a passive adaptive management approach to quantify population growth rates under a series of management alternatives focused on supplementary feeding in a Hihi population on Mokoia Island.

Using SDM to Decide Appropriate Supplementary Feeding in Hihi

In the following example, SDM was used to assist the managers of a threatened bird species in New Zealand to

Table 1. Estimated consequences of supplementary feeding regimes on each conservation objective relative to Hihi on Kapiti island, New Zealand.[a]

	All considered feeding alternatives and raw consequence values					
Objective	*Redistribute feeders, same amount of food*	*Redistribute feeders, increase food*	*Increase food to existing feeders*	*Maintain current feeding regime*	*Redistribute feeders, dynamic feeding[b]*	*Remove Hihi*
Maximize number of Hihi	80	160	180	80	180	0
Minimize cost of management[c]	60	65	100	75	70	0
Minimize extinction risk[d]	0	0	0	0	0	1
Dominated alternatives discarded and consequences normalized						
Maximize number of Hihi	0.44	0.89	–	–	1.00	0.00
Minimize cost of management	0.14	0.07	–	–	0.00	1.00
Minimize extinction risk	1.00	1.00	–	–	1.00	0.00
Weighted normalized scores for each alternative reflecting relative preferences for different objectives						
Maximize number of Hihi	0.20	0.40	–	–	0.45	0.00
Minimize cost of management	0.05	0.02	–	–	0.00	0.32
Minimize extinction risk	0.24	0.24	–	–	0.24	0.00
TOTALS	0.49	0.66	–	–	0.69	0.32

[a] *Numbers reported are the estimated consequence that each alternative has on each objective.*
[b] *Providing as much food as required by the birds by responding to demand.*
[c] *Cost of management is a constructed scale of hours of effort required by managers (0 if no feeding and 100 if ad libitum).*
[d] *Probability of population extinction in 20 years.*

decide what supplementary feeding regime to implement. In this example, the focus was on whether to and how to best provide the standard sugar water food supplement typically used in Hihi management. Our example does not include a nutritional component. Nutritional considerations have been previously evaluated in Hihi management (Armstrong et al. 2007; Walker et al. 2013) but have yet to be included in any SDM approach with Hihi, or any other species globally. We describe the actual decision process of the group under the constraints of making the decision within a single 3-h workshop in November 2013. Prior to the workshop, a remote elicitation of objectives and alternatives was undertaken via email. The workshop was attended by 7 Hihi Recovery Group members, 3 from the New Zealand Department of Conservation (DOC), 2 from community conservation groups, and 2 university researchers.

Problem Statement

The reintroduced Hihi population on Kapiti island depends on supplementary feeding of a sugar water solution (Chauvenet et al. 2012). A revised program of supplementary feeding was needed to reverse the dramatic population declines recorded from 2009 to 2013. In 2009, DOC found that the ad libitum feeding regime, in place since 2000, was unsustainable for managers due to cost and time requirements. Since 2009 a 25% reduction in food regime has been in place, but monitoring shows the reduction has drastically reduced Hihi abundance (approximately 180 adults before the feeding reduction to approximately 80 adults in 2013 [D. Correia et al., unpublished data]). Under both feeding regimes, 9 supplementary feeding stations were maintained during the breeding season (October-March); 4 outlying stations were closed during the nonbreeding season (April–September). The 25% reduction was calculated per feeding station per month from maximal volumes consumed in 2009. The new program needed to comply with the capacity of the DOC staff to service feeders, ensure a sustained population of Hihi on Kapiti island, and be supported by the Hihi Recovery Group. The DOC Wellington District regional director was the decision maker, following advice from the Hihi Recovery Group. Any modifications to the program needed to be in place by the start of the November 2013–February 2014 breeding season.

Objectives

Email elicitation of the wider recovery group (28 members) (see Ewen et al. 2013 for group composition and function) identified 3 fundamental objectives: maximize number of Hihi (the measureable attribute is the number of Hihi); minimize cost of management (the measureable attribute is the number of staff hours required to feed birds and is expressed as a constructed scale bounded by 0 if no feeding and 100 if feeding is ad libitum and spread across the current distribution of supplementary feeding stations); and minimize extinction risk (the measureable attribute is the probability of extinction of the population in 20 years). Each expert was asked to score their relative preference of objectives. The most preferred objective was scored 100, and preferences for the other objectives were assigned scores relative to this. For example, a score of 50 shows an expert considered that objective half as important as their most preferred objective. These value scores were then averaged across experts, and the scores were normalized to sum to 1 (Table 2).

Table 2. Weighting[a] of Hihi conservation objectives by experts.

	Individual score							Total[b]		
Objective	*Expert 1*	*Expert 2*	*Expert 3*	*Expert 4*	*Expert 5*	*Expert 6*	*Expert 7*	*Score*	*Rank*	*Weight*
Maximize number of Hihi	100	100	100	100	100	100	80	97.14	1	0.45
Minimize cost of management	80	60	75	50	60	90	60	67.86	2	0.31
Minimize extinction risk	20	50	60	65	20	40	100	50.71	3	0.24

[a] *The higher the score the more preferred the objective.*
[b] *Individual scores averaged across experts and then normalized.*

Alternatives

Similarly, e-mail elicitation was used to identify 6 potential management alternatives: redistribute outlying feeding stations into the core area and provide the same amount of food (thus making it easier to service feeders); redistribute outlying feeder stations into the core area and provide more food; revert to ad libitum feeding without redistributing feeding stations; maintain the current feeding regime; implement a dynamic feeding regime to match variation in demand in the core area and remove outliers; or remove Hihi from Kapiti island. These 6 alternatives included an exhaustive representation of what the Hihi Recovery Group members considered once they had agreed on their management objectives. The last alternative effectively represents the decision of whether to use supplementary feeding or not because the recovery group considered not feeding the population as not valid given that previous population monitoring showed very low population abundance and poor viability on the island (Chauvenet et al. 2012). This makes removal of Hihi from the island a worst-case scenario relative to 2 of the 3 objectives and allows exploration of how the working group values the Hihi population on the island.

Consequences and Recommendation

Workshop attendees were asked to work together to provide a consensus estimate of the consequences of each management alternative for the stated objectives (Table 1). In many cases there was available information on consequences from previous monitoring, and this was used. Where estimates needed to be generated based on expert opinions, the group worked collaboratively to discuss reasoning for any values suggested. In all cases, this small working group, with highly shared interests and experience with Hihi management, quickly converged on consensus estimates. For example, the expected number of Hihi under some management alternatives was supported by direct evidence from previous demographic modeling (Chauvenet et al. [2012] for ad libitum and D. Correia et al. [unpublished data] for 25% food cap). In contrast, the estimation of costs was based on the experience of the island rangers charged with providing the food supplement and their manager who has overseen the project for many years. Cost was based on the premise that the time taken to reach all feeding stations was more important than the amount of food that could be carried. The remainder of the working group were happy to accept the values these particular experts provided. Extinction probability was based on the predictions of previous demographic models both in the presence and absence of supplementary feeding. Although the nutritional components of our case study were not considered here, we did ground our predicted consequences in population ecology with prior demographic modeling of this population under various supplementary feeding regimes.

An initial screening of the consequence table (Table 1) showed that the alternative to maintain the current feeding regime was dominated by the alternative to redistribute outlying feeding stations into the core area and provide the same amount of food (that is, the latter alternative performed the same or better on all objectives). Similarly, the alternative to revert to ad libitum feeding without redistributing feeding stations was dominated by the alternative to implement a dynamic feeding regime to match variation in demand in the core area and remove outliers. We therefore simplified our consequence table to include only 3 objectives and 4 alternatives. We then rescaled the estimated consequences to a scale of 0 (worst) to 1 (best). Following this we multiplied the normalized weight of fundamental objectives by their respective normalized consequence scores to produce a weighted normalized score for each action. This was calculated using a simple weighted additive method:

$$S_i = \sum_{k=1}^{O} c_{ik} w_k, \qquad (1)$$

where S_i is the aggregate score for management alternative i, c_{ik} is the normalized expected outcome for alternative i in regard to objective k, and w_k is the weight of objective k (Keeney & Raiffa 1976). The best decision then corresponds to the alternative with the highest aggregated value.

In our case, 2 alternatives provided similarly high scores (redistributing outlying feeder stations into the core area and provide more food and implement a dynamic feeding regime): either may be a valid approach. The Hihi recovery group agreed that the redistribution of feeders, compensated by an increase in the food provided, was easiest to implement and should be supported on the island.

Discussion

Supplementary feeding is one of a suite of potential management interventions. Unfortunately, too often, supplementation has been used as a knee-jerk reaction to population decline, which has led to recent criticisms that characterize supplementation as conservation dogma (Martínez-Abraín & Oro 2013). We agree with this criticism but emphasize that supplementary feeding should not be shied from a priori any more so than other forms of intervention (e.g., exotic predator control, reserve fencing, restoration). We view the core issue of poor, or negative, results from supplementation to be often related to poor decision making. Good decisions should also be based on the best available evidence, such as careful consideration of the nutritional needs of supplementary-fed target species and a clear quantitative estimate of how supplementary feeding is expected to contribute to population recovery.

We suggest the main decision of whether and how to implement supplementary feeding can be considered within SDM, which should help managers avoid many of the faults of current approaches to supplementary feeding. We emphasize that setting objectives should always be viewed as context specific and remain part of the formal SDM approach. Of primary importance is making an explicit link between population theory (factors limiting the population) and management (how supplementary feeding helps overcome this limitation). Within the SDM process this is the first essential step of problem definition. Furthermore, we recommend recasting the currency of relevant measured alternatives and consequences within SDM so that they are nutritionally explicit and targeted at the fundamental objectives of the recovery effort. We hope our conceptual approach combined with our case study has highlighted the potential utility of supplementary feeding and will provide an important set of considerations for managers. In doing so, we are encouraging a more acceptable and successful form of supportive management for in situ conservation.

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