Assessing translocation success of the endangered Persian fallow deer using a Bayesian Belief Network

F. Goudarzi,1,2 M. R. Hemami,2† H. Bashari,2 AND S. Johnson3

1Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Tehran, Iran
2Department of Natural Resources, Isfahan University of Technology, Isfahan, Iran
3Queensland University of Technology, GPO Box 2434, Brisbane, Queensland 4001 Australia

Citation: Goudarzi, F., M. R. Hemami, H. Bashari, and S. Johnson. 2015. Assessing translocation success of the endangered Persian fallow deer using a Bayesian Belief Network. Ecosphere 6(10):191. http://dx.doi.org/10.1890/ES14-00358.1

Abstract. For the past 50 years, the endangered Persian fallow deer (Dama mesopotamica) have been translocated to various sites throughout Iran. To better understand the varying degrees of success at the translocation sites, population growth rates were measured for all the sites, and factors believed to affect the growth rate, such as initial population structures of the translocated herds and habitat characteristics, were identified and modeled. The population growth rate was used as a proxy for translocation success. Quantitative ecological data for Persian fallow deer is scarce, but expert knowledge was readily available to inform and enhance fallow deer management options. We integrated the available quantitative data and qualitative information in a Bayesian Belief Network (BBN) model to predict Persian fallow deer translocation success. The BBN model was tested using scenarios based on previous translocations to 13 sites in Iran. It correctly predicted the success of translocated populations in 11 out of the 13 sites. This model may be used as a decision support tool for future translocations, and can assist in designing reintroduction programs of the Persian fallow deer. Moreover, it should be adapted to incorporate new knowledge as evidence of translocation successes and failures emerge. Although the BBN model was developed specifically for the translocation of Persian fallow deer, this approach can clearly be applied to design and assess the success of translocation programs of other endangered species, and may be extended to design and assess alternative conservation management strategies.

Key words: adaptive management; Bayesian Belief Networks; Dama mesopotamica; decision support tool; modeling.

Received 24 September 2014; revised 7 February 2015; accepted 18 March 2015; published 28 October 2015.

Copyright © 2015 Goudarzi et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. http://creativecommons.org/licenses/by/3.0/
† E-mail: mrhemami@cc.iut.ac.ir

INTRODUCTION

Reintroduction is an important but controversial tool in the management of threatened species (Kleiman et al. 1991, Steury and Murray 2004, Moorhous et al. 2009). Several reintroduction attempts have been performed during the last century (Kleiman 1989) with mixed results (Armstrong et al. 2007). The importance of evaluating conservation management strategies has gained increased attention and stimulated debate (Walsh et al. 2012).

Saving Persian fallow deer (Dama mesopotamica) from the edge of extinction has been one of the wildlife management successes in Iran. Reintroduction following captive breeding programs was the main management strategy which has rescued the species. Nonetheless, Persian fallow deer is still a threatened species (EN) due to its small population size (IUCN 2014).
populations of this rare species have the highest allelic richness, and therefore conserving these populations is particularly important (Fernández-García 2012). Since 1977, the species has been translocated to 12 sites from the first captive breeding semi-natural refuge (Dasht-e-Naz Wildlife Refuge) in northern Iran. All the translocation sites are either fenced areas or island sites where deer are provided with supplemental feeding. Despite the apparent environmental similarities, the population growth rates varied considerably across the sites with two populations already extinct (Zardalan and Kabudan). These differences may be related to management during the whole process of translocation, and therefore gaining a better understanding of the key factors and interactions that determine the success of fallow deer translocations, is very important for the effective conservation of this rare species, and motivated the development of the Bayesian Belief Network (BBN) model outlined in this paper.

Adaptive management is a structured, iterative process of decision making in the face of uncertainty (Holling 1978, Walters 1986) with the aim of reducing the uncertainty through assessing the outcomes of management actions (McCarthy et al. 2012). It requires a framework that can easily be updated as knowledge emerges and can assist managers to identify knowledge and data gaps. However, data on rarely studied species are usually not available, but may exist as expert knowledge. The first steps for developing such a framework therefore, are to collect all quantitative and qualitative data available for the target species and establish how a success will be measured (Johnson et al. 2010). This framework should also be able to accommodate different kinds of data and uncertainty concerning the ecology of the species. Many approaches have been developed to integrate data for building Decision Support Tools (DSTs) for wildlife conservationists as decision makers (Peterson and Evans 2003, Conroy et al. 2008), but most of DSTs only utilize quantitative data. Bayesian modeling provides an appropriate framework to develop adaptable DSTs integrating both experimental and experiential knowledge (McCann et al. 2006, Bashari and Smith 2010). Furthermore, BBNs facilitate the capture and evaluation of uncertainty in the model structure and parameters (Barton et al. 2012, Johnson and Mengersen 2012).

Translocation success is defined as establishing self-sustaining new populations in the target areas (Griffith et al. 1989, Fischer and Lindenmayer 2000) for a relatively long period depending on the lifespan of the species (Dodd and Seigel 1991). To evaluate the success of translocation programs, criteria such as Minimum Viable Population (MVP; Beck et al. 1994), the successful breeding of first wild-born animals (Kleiman et al. 1991), a positive recruitment rate over three years (Sarrazin and Barbault 1996), quantifying post-release survival and reproduction (King et al. 2012), and finite rate of increase ($\lambda$; Armstrong and Reynolds 2012) have been used.

The population growth rate ($r$) was considered as an appropriate criterion for evaluating translocation success because it encompasses several criteria (Armstrong and Reynolds 2012) in different post-release stages. We therefore used $r$ as the criterion to evaluate the success of the translocated populations of Persian fallow deer in Iran following the safe transfer of a herd to a new site. Factors such as sex and age composition, season of release, the number and interval of releases (Kleiman 1989), size of the translocated population (Steyr and Murray 2004), process of capturing and handling and habitat requirements (Ibánez et al. 2013) are known to influence translocation success of mammal species.

The optimum age-sex composition for reintroduction of Persian fallow deer has been suggested by Saltz (1996), but it has not previously been considered for reintroduction programs in Iran. Similarly, other acquired knowledge and existing management experiences have not yet been employed in a systems approach for adaptive management of this or other threatened species in Iran.

The aims of this study were threefold: (1) to assess the success of translocation programs of Persian fallow deer in Iran, (2) to develop a BBN decision support tool to assist in managing translocation of Persian fallow deer, and (3) to determine the most important factors influencing the success of Persian fallow deer translocations.
Methods

Study species

Persian fallow deer formerly ranged in North Africa from the Tunisian border to the Red Sea (Nowak and Paradiso 1983) through much of the Middle East, including Iran, Iraq, and possibly Jordan, Syria, Palestine and Southern Lebanon (Harrison 1968, Feldhamer et al. 1988, IUCN 2014). According to its historical distribution range, Persian fallow deer have existed in both cool-humid and warm-dry climates.

By the late 19th century, the population had been confined to south-western and western Iran, with still existing isolated groups in northern Iraq. Ellerman and Morrison-Scott (1951) reported on a last Mesopotamian fallow deer seen in Luristan, Iran near the upper Dez River in 1906, one captured (or killed as Talbot, 1960 mentioned) in Zacho, northern Iraq in 1917 and one in north of Kermanshah, Iran, about the same time. By the 1940s, it was considered globally extinct, until 1955 when a population was rediscovered in riparian thick forests of Khuzistan bordering the Dez and Karkheh rivers, south-west of Iran (Jantschke 1990). From 1964 to 1967 Iran Game Council captured three males and three females in their last stronghold in Karkheh and Dez forests and transferred 5 (2 males and 3 females) of them to Dasht-e-Naz Wildlife Refuge, a 55-ha Caspian lowland forest, in North of Iran, where the population successfully increased (the third male was offered to the von Opel zoo in Kronberg, Germany to substitute for a perished male that had sired a female earlier in 1960). Since 1977, captive-bred individuals from Dasht-e-Naz Wildlife Refuge were transferred to 12 new sites assessed as suitable habitats in different parts of Iran, where they experienced different fates. The sites’ locations and properties are respectively shown in Fig. 1 and Table 1. Most of these sites are located in the historical range of the species except Semeskandeh, Dasht-e-Naz and Bagh-e-Shadi.

Translocation success

Initial population size, successful breeding of the translocated animals and recruitment rate affect population growth rate, which is our criterion for translocation success when combined with transfer success. We used two methods for estimating population growth rate \(r\) of Persian fallow deer populations in Iran. The first method is a regression of the natural logarithm of population size (\(\log N\)) against census years (Sinclair et al. 2006) and was used for the population growth rate in Dasht-e-Naz, Ashk Island and Miankotal, where the population censuses were available for many years. For the second method, the growth rate was estimated using the exponential growth rate formula on the basis of population sizes at the time of the release and the last census

\[ N_t = N_0 e^{rt} \]

where, \(N_t\) is the number of individuals at year \(t\), \(N_0\) is the number of individuals at the year of release, and \(r\) is the population growth rate. This method was used for the other translocation sites including Semeskandeh, Bagh-e-Sahdi, Tunnel-e Reno, Bijar, Helveh (Karkheh), Lavandevil, Dena, Mianrood (Dez) where deer were recently translocated.

Modeling

The BBN model.—When developing the BBN, we adhered to the guidelines proposed by Marcot et al. (2006) and Johnson et al. (2010). The first step in constructing the BBN is to carefully define the outcome of interest (translocation success) and then identify the variables affecting it. We listed key factors affecting translocation success of the species as reported in the literature, and depicted the ecological casual web as an influence diagram. The key factors affecting translocation success can be organized into three groups: management scenario variables, habitat suitability variables and transfer success. Next, the influence diagram was converted into a BBN, by defining variable nodes and their states and populating the model with conditional probabilities. Table 2 contains details of the node descriptions, and states (conditional probability tables are available by request).

Available literature about Persian fallow deer, expert opinion, population and habitat condition documents and applied management in each translocation program were used to build and quantify the BBN model. We used the BBN software modeling application, Netica (Norsys Software 2010), to depict nodes and dependencies between nodes, and to convert the influence...
diagram into an initial BBN (Fig. 2).

Expert elicitation.—The states for each node were determined and probabilities calculated to populate the conditional probability tables (CPTs) using expert judgment. Where appropriate, available knowledge were used to define the states of the nodes (transfer success, hand feeding, translocation season, repeated release, predator effect, accessibility, elevation, climate, terrain, translocation program, age composition, sex composition, and initial female number). Available data for the defined variables were collected after developing the model structure; and hence did not directly influence expert opinions when populating the CPTs. Parentless nodes (input variables) were assigned a uniform probability distribution across the states when there was complete uncertainty about their prior conditions (Marcot et al. 2006). Conditional probability tables of child nodes represent a combination of all states of its parent nodes, and were populated according to judgements of four experts who previously worked on the ecology of the species, including one of the authors of this article (M.-R. Hemami), on the basis of functional relationships between factors. To facilitate population of these tables and maintain logical consistency in the probabilities, we used a Delphi approach (O’Hagan et al. 2006) and selected specific scenarios; (1) the best-case scenario where all parent nodes are in their best states, (2) the worst-case scenario where all parent nodes are in their worst states and, (3) scenarios where all nodes, except parent nodes are at their best states (Cain 2001). These scenarios were sent to the experts to provide probabilities for them. For instance, the experts answered the query of: P(site security | predator = no, accessibility =

Fig. 1. Current distribution of translocated populations of Persian fallow deer in Iran. The numbers refer to sites in which Persian fallow deer were introduced. Introduced population to Kabudan Island and Zardalan (circles with crosses) have been extirpated.
Table 1. Properties of sites where Persian fallow deer populations have been translocated.

| Site name         | Year(s) of translocation | Total no. translocated | Area (ha) | Latitude and longitude (E, N) | Climate† | Elevation‡ (m) |
|-------------------|--------------------------|------------------------|-----------|-------------------------------|----------|---------------|
| Dasht-e-Naz       | 1964–1967                | 7                      | 55        | 53°11‘30“–53°12‘30”, 26°42‘30“–36°41‘30” | sub-humid | –5            |
| Tunnel-e-Reno     | 2007                     | 6                      | 10        | 46°23‘50”, 33°40‘32”          | sub-humid | 1100–2600     |
| Miankotal         | 1993                     | 20                     | 170       | 51°52‘–51°60”, 29°32‘–29°37” | warm semi-arid and temperate humid | 2000         |
| Mianrood (Dez)    | 2009                     | 19                     | 74        | 48°26‘18.6”, 32°06‘41.8”     | warm arid | 50–80         |
| Dena              | 2009                     | 15                     | 100       | 51°21′, 30°58′               | cold sub-humid and humid | 1360–4413    |
| Bagh-e-Shadi      | 2006                     | 6                      | 50        | 54°08′37”, 29°48′10”         | arid      | 2300          |
| Lavandevel        | 2006–2007                | 11                     | 14        | 48°52′, 38°18′               | temperate humid | –10         |
| Helveh (Karkheh)  | 2007–2008                | 39                     | 75        | 48°14′18′, 32°04′14′         | warm arid | 50            |
| Ashk Island       | 1977–1989                | 52                     | 2115      | 45°28′42″–45°34′19″, 37°20′11″–37°26′46″ | semi-arid | 1274–1350     |
| Bijar             | 2007                     | 6                      | 40        | 36°00′–36°73′, 47°25′–47°53′ | semi-arid | 1533–2187     |
| Semeskanede       | 1977                     | 27                     | 180       | 53′7", 36′33"               | temperate humid and sub-humid | 50–190       |
| Kabudan Island    | 1989                     | 6                      | 3175      | 45°33′48″–45°40′26″, 37°27′01″–37°31′08″ | semi-arid | 1525          |
| Zardalan          | 1989                     | 22                     |           | 45°27′, 34′19″               | semi-arid | 1370          |

† Determined by De Martonne method.
‡ Above sea level.
§ Not protected.

island) as highly secure (high: 90%; medium: 8%, low: 2%). To combine the expert judgement of the four experts, we used an unweighted average. These values were then used in the CPTs of the nodes. Probabilities for the remaining scenarios were interpolated using the CPT calculator (Cain et al. 2001, Bashari et al. 2009), which is a linear interpolation.

Sensitivity analysis.—After completing all the CPTs, and testing the model to confirm that it behaved in accordance with known situations and expert knowledge, sensitivity analysis of the model was performed (Johnson et al. 2010). The relative influence of parent nodes on the target node (translocation success) was evaluated by identifying those model parameters for which variations in CPT values cause the greatest change in the model outcome (Johnson et al. 2010). By selecting a certain state of the node of interest, its probability is assigned a value of 100% to represent the fact that a certain event has occurred. In BBN modeling this is referred to as entering hard “evidence” into the model, and it is also possible to enter uncertain evidence in a BBN model, which is known as entering virtual or soft evidence. Probabilities for other nodes were calculated as mutual information in the network (Howes et al. 2010). To assess the importance level of the proximate parent nodes of a given child node without diluting the influence of outer nodes (Bashari and Hemami 2013), we also assessed the sensitivity of each child node to variations in its parent nodes. Moreover, to assess the effect of more important and influential factors on success or failure of translocation programs at each site, sensitivity analysis was performed for each site separately. The characteristics of each site were entered into the model as a scenario and then sensitivity analysis was done for that scenario.

Model validation.—We considered population growth rate combined with transfer success as a quantitative criteria for translocation success. The growth rates of 13 translocated populations were used to validate the model. Each translocation program was represented as a scenario in the BBN model, and we compared the BBN predictions for growth rate and translocation success of the scenario to its actual population growth rate. We set 80% accuracy as the BBN validation threshold as this is well above 50%, which is the expected accuracy level under complete uncertainty of the model outcome (Howes et al. 2010), but less than a 95% level of confidence so that we account for the small sample size (MacGillivray et al. 2014).
| Node                          | Description                                                                 | States                                                                                           |
|-------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Translocation success         | Success of translocation program for Persian fallow deer assessed by both growth rate and transfer success of the translocated population. | Excellent: Both the growth rate and transfer success are high. Good: The growth rate is high, but the transfer success is moderate. Moderate: The growth rate is moderate. Poor: The growth rate is low. |
| Growth rate                   | Exponential increase in the number of Persian fallow deer populations over a determined period of times.          | Good: growth rate $\geq 0.2$; moderate: growth rate: $0.01$–$0.2$; poor: $<0.01$.                  |
| Transfer success              | Success of transfer program assessed by the mortality rate during the course of transfer.                          | High: The mortality rate is zero. Moderate: A limited mortality rate ($\leq 0.2$) occurs during the course of transfer. Low: A considerable mortality rate ($>0.2$) occurs during the course of transfer. |
| Habitat suitability           | Suitability of the site for Persian fallow deer with regard to site security, forage condition, physical resources and historical occupancy of the site by the species.  | High: The ecological condition of the site is optimal for the species. Moderate: The ecological condition of the site is sub-optimal for the species. Low: The ecological condition of the site is unfavourable for the species. |
| Management scenario           | Combination of management activities with regard to reintroduced group structure, translocation season, repeated release and hand feeding. | Good: The management scenario leads to a high growth rate of the translocated species. Moderate: The management scenario leads to a moderate growth rate of the translocated species. Poor: The management scenario leads to a poor growth rate of the translocated species. |
| Site security                 | Security status of the site with regard to predator risk and human access.                                              | High: The risk of predation and man-induced threats is low. Medium: The risk of predation and man-induced threats is moderate. Low: The risk of predation and man-induced threats is high. |
| Physical resources            | Climate and topographic appropriateness of the site for the species.                                                     | Good: Climate and topography are optimal for survival and reproduction of the species. Moderate: Climate and topography are sub-optimal for survival and reproduction of the species. Poor: Climate and topography are not favourable for survival and reproduction of the species. |
| Hand feeding                  | Whether or not the translocated population receives supplementary food.                                                     | Yes, no.                                                                                          |
| Translocation program         | Whether or not the site is located in the historical distribution of the species.                                          | Reintroduction: The species has previously been occurred in the site. Introduction: The species has not historically been presented in the site. |
| Reintroduced group structure  | Sex-age composition of the translocated herd.                                                                           | Good: The composition of the translocated herd is optimum for reproduction. Moderate: The composition of the translocated herd is moderate for reproduction. Poor: The composition of the translocated herd is poor for reproduction. |
| Repeated release              | Number of translocations to a site.                                                                                     | High: more than 4 times; medium: 2–4 times; low: no repeat.                                       |
| Initial female number         | Number of females in the translocated herd.                                                                             | High: female number $\geq 13$; medium: 6–13 individuals; low: female number $< 6$.                |
| Age composition               | Reproductive age of females.                                                                                                | Good: more than 99% of females are prime-aged; moderate: 70%–90% of females are prime-aged; poor: less than 70% of females are prime-aged. |
| Sex composition               | Male/female ratio.                                                                                                        | Good: females number is more than 2 times of males; moderate: female $\geq$ males, but less than 2 fold; poor: females $<$ males. |
| Predator effect               | Whether or not a predator present in the area.                                                                          | No, yes.                                                                                          |
| Accessibility                 | Accessibility level of the site.                                                                                           | Island: The site accessibility is limited by surrounding water. Fencing: The site is enclosed by fencing. No fencing: the site is not enclosed. |
| Forage condition              | Quantity and quality of forage.                                                                                           | Good: Sufficient high quality food is available. Moderate: The quantity and quality of the available forage is moderate. Poor: Forage is limited and or of low quality. |
The developed model was also tested in diagnostic and predictive modes to verify if the outputs of the model are in accordance with the experts’ opinions. In diagnostic mode, translocation success was set to a specific state (e.g., excellent) and this information was then propagated through the BBN which updated the probabilities of the other nodes. For the predictive mode, the translocation success of the sites was evaluated using site observation data. An important part of model validation is peer review of the model structure and CPTs which assists in reducing bias and ensuring that the developed model is credible (Marcot et al. 2006).

Fig. 2. Key factors affecting success of Persian fallow deer translocation to new areas. The nodes are displayed in three groups: management type, sites properties and success rate of deer translocation. As an example, predictive model of Persian fallow deer translocation to Zardalan is presented. Failure likelihood of the translocation is predicted as high as 69.1%, which is consistent with the actual extinction of translocated deer population in the area. Descriptions of nodes are provided in Table 2.
RESULTS

Translocation success

The actual population growth rates for the extant populations varied across the sites ranging from 0.26 in Semeskandeh to 0.32 in Tunnel-e-Reno (Table 3). Except for two cases (Tunnel-e-Reno and Kabudan Island), the model’s predicted probability of growth rate was in accordance with the calculated rate. The mortality rate of the transferred populations during the course of transfer or immediately after the release ranged from 0 to 50% (Table 3). According to the definition presented for transfer success, 2 out of 13 transfers were highly successful, and the success of the other 10 transfers was either medium or low. As previously defined, the translocation success is the result of both growth rate and transfer success. Translocation was successful in 4 out of 13 sites (33% of the cases) and failed in the remaining sites (77%).

Modeling

The BBN model.—Using the model in diagnostic mode, it is possible to guide managers in identifying the optimal translocation scenario with respect to available resources and possible constraints. For instance, based on the developed model, achieving complete translocation success demands a complete transfer success (100% high condition) and at least a growth rate of 82% for the translocated population is required. In predictive mode, the model predicted a high probability of failure for reintroducing Persian fallow deer to Zardalan (69.1%) using a scenario of a no fenced area, no hand feeding, no repeated releases and unsuitable sex-age structure (17 males: 5 females) of the translocated population (Fig. 2).

Sensitivity analysis.—As expected the translocation success was mostly influenced by growth rate (Table 4). This node is a function of management scenarios in translocation programs.

| Site          | Calculated growth rate | Mortality within transfer (%) | Transfer success |
|---------------|------------------------|-------------------------------|------------------|
| Dasht-e-Naz   | 0.18                   | 14.29 medium                  | Medium           |
| Tunnel-e-Reno | 0.32                   | 0.00 high                     | High             |
| Miankotal     | 0.06                   | 15.00 medium                  | Medium           |
| Mianrood      | 0.14                   | 5.00 high                     | High             |
| Dena          | 0.02                   | 6.67 high                     | High             |
| Bagh-e-Shadi  | 0.04                   | 16.67 medium                  | Medium           |
| Lavandevil    | –0.11                  | 9.09 high                     | High             |
| Zardalan      | extinct                | 34.78 low                     | Low              |
| Helveh        | 0.2                    | 5.00 high                     | High             |
| Ashk Island   | 0.1                    | 1.92 high                     | High             |
| Kabudan Island| extinct                | 0.00 high                     | Low              |
| Bijar         | 0.17                   | 50.00 low                     | Low              |
| Semeskandeh   | –0.26                  | …                              | …                |

Table 4. The growth rates of the translocated Persian fallow deer calculated using census data versus the predicted percent probability of the growth rates by the BBN model. Percent probability of the translocation success for each site is also given.
(e.g., translocation season, demographic structure, repeat of releases and hand feeding) and habitat suitability (e.g., security, physical resources, forage condition and whether the site is located in historical range of the species).

The relative influence of parent nodes on child nodes is presented in Fig. 3 by the amount of entropy reduction resulting from changing the probability of parent nodes classes. The management scenario is primarily influenced by translocated group structure, and habitat suitability is mainly affected by site security. Translocated group structure is most influenced by sex composition of the translocated population followed by initial female number and age composition. Accessibility is more influenced by site security compared to predator effect, and climate is more important in affecting physical resources than terrain and elevation.

When performing sensitivity analysis separately for each site, management scenario was the most important factor affecting the translocation success (100% of the sites) followed by habitat suitability, and demographic structure of the translocated groups (each c. 70% of the sites) and site security (92% of the sites; Fig. 4).

Model validation.—The BBN model and CPTs were reviewed by two experts and modellers (including one of us: Sandra Johnson) in translocation of other threatened species, and their feedback was incorporated in the model prior to running the different scenarios through the
The BBN model’s predicted probabilities for the translocation success of 11 out of 13 sites were consistent with the actual calculated growth rates of the populations. Thus, the total model error rate is $\frac{2}{13} = 15\%$, and model validation is 85%, which is higher than the minimum accepted threshold (80%; Howes et al. 2010).

**DISCUSSION**

**Translocation success (aim 1)**

Various growth rates have been obtained for Persian fallow deer populations recently translocated to Dez, Karkheh, Bijar, Tunnel-e-Reno, Lavandevil, and Dena and were found to differ across the study sites. These differences may be attributed to the differences in the structure of the translocated populations, the habitat conditions, and security at the sites. McCullough (1982) maintains that if environmental conditions are more favorable, then the population growth rate would be higher. The observed differences in growth rate could therefore be related to environmental differences. However, the differences in population growth rates were observed in both the distantly located sites with different climates as well as those located in the same climatic condition (e.g., Ashk and Kabudan, or Dasht-e-Naz and Semeskandeh). What can be inferred from these wide-ranging differences is a high influence of management activities on the growth rate (as supported by the sensitivity analysis; Fig. 3). Moreover, stochastic events (environmental, genetic and demographic) have the potential to influence the growth rate of the small populations (Caughley 1994), and may have had an influence on the translocation success of these populations. Recently, Ashk Island population, the largest population of the species, has declined dramatically, which has been attributed to the shrinking of Lake Urmia, and the translocated population to Karkheh (Helveh) succumbed to an outbreak of myiasis disease in 2013. Such environmental disasters highlight the importance of successful translocation programs for safeguarding the species.

Almost all the translocated populations of Persian fallow deer are in fenced areas. Initiating programs for releasing the species in large reserves to breed naturally are recommended. To implement such a program, either the protection level of the reintroduction sites must meet IUCN management category II, or educational and awareness programs for local communities should be in place. If future reintroduction programs target large unfenced areas, post-release monitoring will be a necessity.

**The BBN model (aim 2)**

To develop the present model, we collected and applied the available empirical data about populations and habitats of Persian fallow deer in Iran including sites characteristics, demographic information, and management history. However, the available empirical data rarely
sufficed to populate a conditional probability table for different scenarios. Populating CPTs using experiential data introduces additional uncertainty into the model. Employing an adaptive management approach, the uncertainty and variability resulting from lack of data can be reduced as new information emerges (Johnson et al. 2014).

The model structure has been validated by peer review and represents current expert knowledge, which captures the dependencies between the different key factors and the conditional independencies. The model output is generated based on the elicited model structure; should there be major discrepancies between the model output and the site data, it would highlight potential areas of the model that require further scrutiny. The model may be adapted to incorporate new research and lessons learnt from new translocations.

Despite large amounts of uncertainty and incomplete data about rare species, wildlife managers have often been required to make the best possible management decision (Smith et al. 2007, Johnson et al. 2013) to maintain populations of interests. Although it is more than half a century since implementing conservation activities for the endangered Persian fallow deer, there has not yet been a strategic long-term planning or a comprehensive management support system to inform management decisions. Previous management activities have been focused on reintroduction of the species to new areas, but not all the translocation programs have been successful. Efforts have been made to increase the success of reintroduction programs for this taxon through obtaining new knowledge on the performance of the translocated populations (e.g., Saltz 1996, 1998, Bar-David et al. 2005, Rabiei and Saltz 2013). Nevertheless, wildlife managers have not had access to a user friendly tool incorporating the current available knowledge.

The presented model predicts and evaluates the success of reintroducing Persian fallow deer to new selected sites under different scenarios. The accuracy of model predictions was high; hence, it will be possible to make use of the model as a decision support tool to identify best scenarios for translocation of the species. Using the developed BBN model in diagnostic and predictive modes, it is possible to identify translocation strategies that are most likely to secure a successful translocation based on current knowledge. Using an adaptive management approach, data gaps may be identified, and future studies can then be prioritized to eliminate or elucidate these gaps in knowledge (Johnson et al. 2014).

**Sensitivity analysis and model validation (aim 3)**

We considered, a priori, the joint effect of growth rate and transfer success as a proxy for translocation success. Expectedly, sensitivity analysis recognized these two variables along with management scenario as the most important for achieving translocation success (Table 3). As discussed above, management scenario had much more influence on growth rate than habitat suitability. Transfer success was also affecting translocation success. Standard conditions should be met in transferring deer between sites to dictate the minimum stress and mortality on translocated groups. Ensuring safety and welfare will decrease stress in translocated individuals when transferring them (Adcock et al. 1998).

Translocated group structure was recognized as the most important factor affecting the management scenario, and the lower growth rate of Lavandevil population compared to Tunnel-e-Reno can be attributed to an inappropriate sex ratio. As there has not been any study conducted to inform the optimum group structure for translocation of Persian fallow deer in Iran, we recommend applying the sex-age composition suggested by Saltz (1996) for the translocating population structure. Furthermore, the stress caused by capture, transfer and release of the transferring animals has adverse effects on their persistence (Seddon et al. 2007). All the translocation stages including capture, medical examination, transferring, releasing, adapting to the new environment, monitoring after releasing, and any other source of environmental disturbance may result in increased stress in released individuals. This stress can be one of the important causes of increased mortality of the population in the first year after release (Teixeira et al. 2007).

Habitat suitability is another important factor that should be considered. Habitat quality is mainly determined by site security and adequate plant cover for a species. Similar to other species,
human conflict with Persian fallow deer and its habitat is an important threatening factor (Tsahar et al. 2009) and translocation of Persian fallow deer to new sites need to pay close attention to this aspect of the selected habitats. This is exemplified by failed translocation of Persian fallow deer to Zardalan, which has been mainly attributed to the lack of security of this area. To secure a translocated population in the long term, we therefore recommend the highest available management category of protected areas (e.g., National Park) to be targeted for translocating the species. Fencing has also been proved to be helpful for protecting deer from predators. It is documented that jungle cat (Felis chaus) and even leopard (Panthera pardus) have been preying on Persian fallow deer in a few sites (Ziaie 2008). To ensure a high level of security, appropriate fencing to exclude predators should also be considered. For the fenced areas, hand feeding has been a helpful management option for the maintenance of the translocated populations.

Sensitivity analysis of the BBN model suggests that the most important factors in translocation success are determined by the translocation management program (management scenario node) followed by habitat suitability, reintroduced group structure and site security. The BBN model provides a well-considered and structured means of making informed translocation management decisions while taking uncertainty into account, utilizing the currently available expert knowledge and data of Persian fallow deer. Nonetheless, BBN modelling is an iterative process and a BBN is therefore always a "work in progress" (Johnson et al. 2010). Consequently, this model may be updated as new knowledge and experience are gained at future sites to further improve management decisions for successful translocations of Persian fallow deer.

**ACKNOWLEDGMENTS**

We thank Hushang Ziaie, Bahram Hasanzadeh Kiabi and Abdolrassoul Salman-Mahini who assisted us in populating the CPTs and Bruce Marcot, Bret Collier, and an anonymous reviewer for their valuable comments. We are also grateful to Department of Environment and managers of the Persian fallow deer sites for providing useful information. We also gratefully acknowledge the financial support of Queensland University of Technology, Australia.

**LITERATURE CITED**

Adcock, K., H. B. Hansen, and H. Lindemann. 1998. Lessons from the introduced black rhino population in Pilanesberg National Park. Pachyderm 26:40–51.

Armstrong, D. P., I. Castro, and R. Griffiths. 2007. Using adaptive management to determine requirements of re-introduced populations: the case of the New Zealand hihi. Journal of Applied Ecology 44:953–962.

Armstrong, D. P., and M. H. Reynolds. 2012. Modelling reintroduced populations: the state of the art and future directions. Pages 165–222 in J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction biology: integrating science and management. Wiley-Blackwell, Oxford, UK.

Bar-David, S., D. Saltz, T. Dayan, A. Perelberg, and A. Dolev. 2005. Demographic models and reality in reintroductions: Persian fallow deer in Israel. Conservation Biology 19:131–138.

Barton, D. N., S. Kuikka, O. Varis, L. Uusitalo, H. J. Henriksen, M. Borsuk, A. de la Hera, A. Farani, S. Johnson, and J. D. Linnell. 2012. Bayesian networks in environmental and resource management. Integrated Environmental Assessment and Management 8:418–429.

Bashari, H., and M.-R. Hemami. 2013. A predictive diagnostic model for wild sheep (Ovis orientalis) habitat suitability in Iran. Journal of Nature Conservation 21:319–325.

Bashari, H., and C. S. Smith. 2010. Accommodating uncertainty in grazing land condition assessment using Bayesian Belief Networks. Pages 341–354 in A. Rebai, editor. Bayesian network. SCIYO, Croatia.

Bashari, H., C. Smith, and O. J. H. Bosch. 2009. Developing decision support tools for rangeland management by combining state and transition models and Bayesian belief networks. Agricultural Systems 99:23–34.

Beck, B. B., L. G. Rapaport, M. R. Stanley Price, and A. C. Wilson. 1994. Reintroduction of captive-born animals. Pages 265–286 in P. J. S. Olney, G. M. Mace, and A. T. C. Feistner, editors. Creative conservation: interactive management of wild and captive animals. Chapman and Hall, London, UK.

Cain, J. D. 2001. Planning improvements in natural resources management. Guidelines for using Bayesian networks to support the planning and management of development programmes in the water sector and beyond. Centre for Ecology and Hydrology, Wallingford, UK.

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology 63:215–244.

Conroy, M. J., R. J. Barker, P. W. Dillingham, D. Fletcher, A. M. Gormley, and L. M. Westbrooke.
2008. Application of decision theory to conservation management: recovery of Hector’s dolphin. Wildlife Research 35:93–102.

Dodd, C. K., and R. A. Seigel. 1991. Relocation, repatriation, and translocation of amphibians and reptiles: Are they conservation strategies that work? Herpetologica 47:336–363.

Elmer, J. R., and T. C. S. Morrison-Scott. 1951. Checklist of Palearctic and Indian Mammals, 1758 to 1946. Trustees of the British Museum (Natural History), London, UK.

Feldhämmer, G. A., K. C. Farris-Renner, and C. M. Barker. 1988. Dama dama. Mammalian Species 317:1–8.

Fernández-García, J. L. 2012. The endangered Dama dama mesopotamica Brooke, 1875: genetic variability, allelic loss and hybridization signals. Contributions to Zoology 81:223–233.

Fischer, J., and D. B. Lindenmayer. 2000. An assessment of the published results of animal relocations. Biological Conservation 96:1–11.

Griffith, B., J. M. Scott, J. W. Carpenter, and C. Reed. 1989. Translocation as a species conservation tool: status and strategy. Science 245:477–480.

Harrison, D. L. 1968. The mammals of Arabia. Volume 2. Carnivora, Artiodactyla, Hyracoidea. First edition. Ernest Benn, London, UK.

Holling, C. S. 1978. Adaptive environmental assessment and management. John Wiley and Sons, London, UK.

Howes, A. L., M. Maron, and C. A. Macalpine. 2010. Bayesian networks and adaptive management of wildlife habitat. Conservation Biology 24:974–983.

Ibáñez, B., E. Moreno, and A. Barbosa. 2013. Parity, but not inbreeding, affects juvenile mortality in two captive endangered gazelles. Animal Conservation 16:108–117.

IUCN [International Union for Conservation of Nature]. 2014. The IUCN red list of threatened species. Version 2014.1. www.iucnredlist.org

Jantischke, F. 1990. History of the Persian fallow deer Dama dama mesopotamica at Opel zoo Kronberg. International Zoo Yearbook 29:207–205.

Johnson, S., E. Abal, K. Ahern, and G. Hamilton. 2014. From science to management: using Bayesian networks to learn about Lyngbya. Statistical Science 29:36–41.

Johnson, S., L. Marker, K. Mengersen, C. H. Gordon, J. Melzheimmer, A. Schmidt-Küntzel, M. Nghikembua, E. Fabiano, J. Henghali, and B. Wachter. 2013. Modeling the viability of the free-ranging cheetah population in Namibia: an object-oriented Bayesian network approach. Ecosphere 4art90.

Johnson, S., and K. Mengersen. 2012. Integrated Bayesian network framework for modeling complex ecological issues. Integrated Environmental Assessment and Management 8:480–490.

Johnson, S., K. Mengersen, A. Waal, K. Marnewick, D. Gilliers, A. M. Houser, and L. Boast. 2010. Modelling cheetah relocation success in southern Africa using an iterative Bayesian network development cycle. Ecological Modeling 221:641–651.

King, T., C. Chamberlan, and A. Courage. 2012. Assessing initial reintroduction success in long-lived primates by quantifying survival, reproduction and dispersal parameters: Western Lowland gorillas (Gorilla gorilla gorilla) in Congo and Gabon. International Journal of Primatology 33:134–149.

Kleiman, D. G. 1989. Reintroduction of captive mammals for conservation. BioScience 39:152–161.

Kleiman, D. G., B. B. Beck, J. M. Dietz, and L. A. Dietz. 1991. Costs of a re-introduction and criteria for success: accounting and accountability in the Golden Lion Tamarin Conservation Program in Beyond captive breeding: reintroducing endangered mammals to the wild. Symposia of the Zoological Society of London 62:125–142.

MacGillivray, H., J. M. Utts, and R. F. Heckard. 2014. Mind on statistics. Second Australian and New Zealand edition. Victoria Cengage Learning, Melbourne, Australia.

Marcot, B., J. D. Steventon, G. D. Sutherland, and R. K. McCann. 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Canadian Journal of Forest Research 36:3063–3074.

McCann, R. K., B. Marcot, and R. Ellis. 2006. Bayesian belief networks; applications in ecology and natural resource management. Canadian Journal of Forest Research 36:3053–3062.

McCarthy, M. A., D. A. Armstrong, and M. C. Runge. 2012. Adaptive management of reintroduction. Pages 256–289 in J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction biology: integrating science and management. Wiley-Blackwell, Oxford, UK.

McCullough, D. R. 1982. Population growth rate of the George reserve deer herd. Journal of Wildlife Management 46:1079–1083.

Moorhouse, T. P., M. Gelling, and D. W. Macdonald. 2009. Effects of habitat quality upon reintroduction success in water voles: evidence from a replicated experiment. Biological Conservation 142:53–60.

Norsys Software. 2010. Netica 4.16. Norsys Software, Vancouver, British Columbia, Canada.

Nowak, R., and J. Paradiso. 1983. Walker’s mammals of the world. Volume 2. Johns Hopkins University Press, Baltimore, Maryland, USA.

O’Hagan, A., C. E. Buck, A. Daneshkhah, J. R. Eiser, P. H. Garthwaite, D. J. Jenkinson, J. E. Oakley, and T. Rakow. 2006. Uncertain judgments: eliciting experts’ probabilities. John Wiley and Sons, Chichester, UK.

Peterson, J. T., and J. W. Evans. 2003. Quantitative
decision analysis for sport fisheries management. Fisheries 28:10–21.
Rabiei, A., and D. Saltz. 2013. Dama mesopotamica. The IUCN red list of threatened species. Version 2014.1. www.iucnredlist.org
Saltz, D. 1996. Minimizing extinction probability due to demographic stochasticity in a reintroduced herd of Persian fallow deer. Biological Conservation 75:27–33.
Saltz, D. 1998. A long-term systematic approach to planning reintroductions: the Persian fallow deer and the Arabian Oryx in Israel. Animal Conservation 1:245–252.
Sarrazin, F., and R. Barbault. 1996. Reintroduction: challenges and lessons for basic ecology. Trends in Ecology and Evolution 11:474–478.
Seddon, P. J., D. P. Armstrong, and R. F. Maloney. 2007. Developing the science of reintroduction biology. Conservation Biology 21:303–312.
Sinclair, A. R. E., J. M. Fryxell, and G. Caughly. 2006. Wildlife ecology, conservation, and management. Second edition. Blackwell, Oxford, UK.
Smith, C. S., A. L. Howes, B. Price, and C. A. McAlpine. 2007. Using a Bayesian belief network to predict suitable habitat of an endangered mammal—the Julia creek dunnart (Sminthopsis douglasii). Biological Conservation 139:333–347.
Steury, T. D., and D. L. Murray. 2004. Modeling the reintroduction of lynx to the southern portion of its range. Biological Conservation 117:127–141.
Talbot, L. M. 1960. A look at threatened species: a report on sonic animals of the Middle East and Southern Asia which are threatened with extermination. Oryx 5:153–293.
Teixeira, C. P., C. S. de Azevedo, M. Mendl, C. F. Cipreste, and R. J. Young. 2007. Revisiting translocation and reintroduction programmes: the importance of considering stress. Animal Behaviour 3:1–13.
Tsahar, E., I. Izhaki, S. Lev-Yadun, and G. Bar-Oz. 2009. Distribution and extinction of ungulates during the Holocene of the southern Levant. PLoS ONE 4:e5316.
Walsh, J. C., K. A. Wilson, J. Benshemesh, and H. P. Possingham. 2012. Unexpected outcomes of invasive predator control: the importance of evaluating conservation management actions. Animal Conservation 15:319–328.
Walters, C. J. 1986. Adaptive management of renewable resources. Macmillan, New York, New York, USA.
Ziaie, H. 2008. A field guide to the mammals of Iran. Second edition. Wildlife Center, Tehran, Iran.