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Authors: Neinavaz, Elnaz, Barati, Ahmad, Brown, Jessi L., Etezadifar, Farzaneh, and Emami, Besat

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Original article

Effects of nest characteristics and black rat *Rattus rattus* predation on daily survival rates of great egret *Ardea alba* nests in mangrove forest in the Hara Biosphere Reserve, the Persian Gulf

Elnaz Neinavaz, Ahmad Barati, Jessi L. Brown, Farzaneh Etezadifar & Besat Emami

We estimated variations in breeding parameters and daily survival rates (DSR) of nests of the great egret *Ardea alba* during 2008-2009 in the Hara Biosphere Reserve, the Persian Gulf. We modelled and compared nesting success using an information-theoretic approach to assess effects of nest site and temporal covariates on DSR. The mean DSR was 0.9896 (95% CI: 0.9931-0.9842) and the overall nest survival was 0.49 (0.35-0.63). Distance to black rat *Rattus rattus* nest sites was the most important covariate ($\sum\omega_i = 0.96$) affecting the survival of great egret nests whereas distance to other great egret and western reef heron *Egretta gularis* nests was less influential. Neither nest diameter nor nest age effectively explained variation in nesting success. We concluded that black rat predation is the most important factor affecting the breeding performance of great egrets in the Hara Biosphere Reserve, and control measures should be undertaken to reduce the negative effects of this invasive rodent on the heron colonies of mangrove forests in the Persian Gulf.

Key words: Ardea alba, daily survival rate, great egret, nest survival model, Persian Gulf, Program MARK

Elnaz Neinavaz, Farzaneh Etezadifar & Besat Emami, Department of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran - e-mail: elnazneinavaz@gmail.com (Elnaz Neinavaz); f.etezadifar@myune.edu.au (Farzaneh Etezadifar); besat.emami@gmail.com (Besat Emami)
Ahmad Barati, Behavioural and Physiological Ecology Research Centre, Zoology, University of New England, Australia - e-mail: abarati@myune.edu.au
Jessi L. Brown, Department of Natural Resources and Environmental Science, University of Nevada, Reno, USA - e-mail: jessibrown@gmail.com

Corresponding author: Elnaz Neinavaz

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Nest-site selection and nest characteristics are known to influence reproductive success of wild birds (Burger 1985, Burger & Gochfeld 1988). A suitable and secure nesting habitat provides protection against mammalian and avian predators, offers stability and materials to support and construct the nest and is accessible to rich foraging areas within the foraging range (Fasola & Alieri 1992, Hafner 1997, Lamsiri & Gale 2008). Heron species vary in their habitat preferences, diet and behaviour, but they have similar fundamental requirements for nesting (Hilaluddin et al. 2006). The location of a nest may have important consequences for breeding success, potentially influencing predation risk (Regehr et al. 1998) or the probability of the nest being flooded (Lauro & Burger 1989). Interactions between different nest-site selection criteria result in a horizontal and vertical stratification in which vegetation type and structure have been found to be very important in nest-site selection (McCrimmon 1978, Beaver et al. 1980). Hilaluddin et al. (2003) and Kazantzidis et al. (1997) reported that nest site selection critically affected breeding success in certain habitats. Etezadifar et al. (2010) found that the height of nests from the ground was an important factor influencing breeding success of western reef heron *Egretta gularis* in the Hara Biosphere Reserve, the Persian Gulf. A study of grey heron *Ardea cinerea* breeding colonies identified significant relationships

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between nesting success and both tree height and tree species (Ayas 2008). Nest diameter also affects the daily survival rate (DSR) of the nest of some species (Sperry 2006). Thus, different factors may drive conflicting selection criteria so that nest-site selection becomes a compromise between the factors that most strongly influence DSR.

Aside from Herring et al. (2010), who indicated that nest stage, region, Julian date, water depth and the quadratic form of water recession rate influenced the DSR of great egret nests in Florida Everglades, USA, the influence of nest site variables on the DSR of great egret nests has not been studied in detail. Until recently, the breeding range of this species in Iran spanned the southern provinces of Fars and Hormozgan (Scott 2007). However, the impacts of an ongoing drought (2006-present) and habitat destruction have limited the breeding range of the great egret to the Hara Biosphere Reserve in the Hormozgan Province, the Persian Gulf. The Hara Biosphere Reserve colony is considered the largest breeding colony of great egrets in the Persian Gulf (Porter et al.1996, Bird Life International 2007, Scott 2007) with about 38 and 39 breeding pairs in 2008 and 2009 breeding seasons, respectively. However, in this habitat invasive species are reported to affect breeding success of herons (Etezadifar et al. 2010). The black rat *Rattus rattus*, an invasive species with a high impact on the reproduction of forest birds and breeding seabirds, is the only rodent species that occurs in the mangrove forests of the Hara Biosphere Reserve (King 2005, Pryde et al. 2005, Jones et al. 2008). In our study area, black rats were found to reduce breeding success of western reef heron (Etezadifar et al. 2010, Ghadirian 2007). We examined the nest site and temporal factors related to the daily survival rate of nests in a colony of great egrets in southeastern Iran where the species nest in association with western reef herons (Brown & Sandwith 2007, Gill & Wright 2006). Our primary objective was to evaluate the influence of nest-site variables on the nesting success of great egrets, with particular interest paid to the potential negative impact of black rat predation. There is some evidence of advantages of nest height among Ardeidae (Fasola & Alieri 1992, Ashoori & Barati 2013). Nest diameter is also reported to be influential in nesting success in waterbirds (Childress & Bennun 2000, Barati & Behrouzi-Rad 2010). However, since black rats can easily climb to any of the nests in our study area, it would be expected that nest height and diameter are poor predictors of nesting success.

The ability to distinguish between high- and low-quality nest sites might allow the formulation of effective conservation measures and improved future management of heron nesting colonies.

Material and methods

The Hara Biosphere Reserve (situated at 26°40'-27°N, 55°21'-55°52'E; Fig.1) is a protected area consisting of mangrove *Avicennia marina* forests and is located on the northern shores of the Persian Gulf

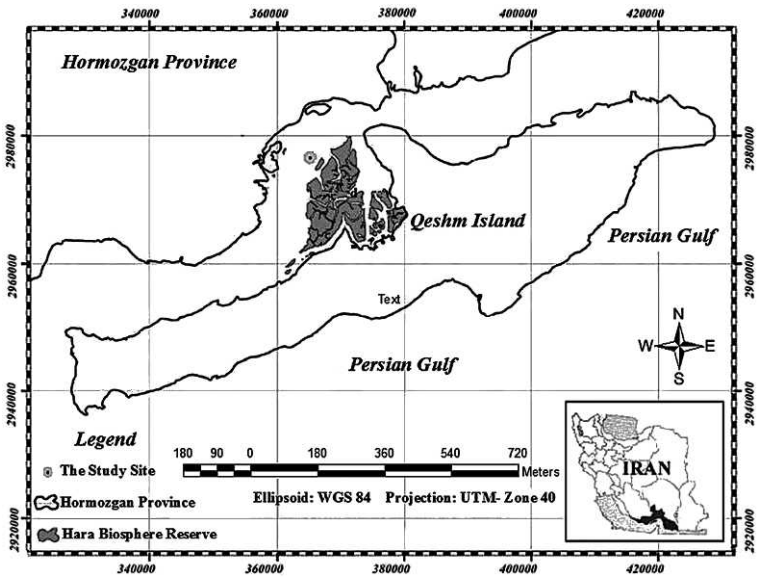


Figure 1. Location of the study area of great egret nesting attempts in southern Iran, Persian Gulf.

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(Neinavaz et al. 2010, Ghasemi et al. 2011). The Hara Biosphere Reserve includes the Khouran Strait, which is situated between Qeshm Island and the mainland of Iran. It covers an area of about 85,000 ha, making up 86% of the total area of mangrove forests in Iran. The whole region has been selected as a wetland of international importance (Dehghani et al. 2010, Ghasemi et al. 2012) and the mangrove forests host one of the largest breeding colonies of grey herons and great egrets in Iran and the Middle East (Evans 1994, Scott 1995). The plant cover in the region is composed of halophyte plant communities which extend to the high-tide zone and mangrove communities which are used as a nesting habitat by herons and egrets (Scott 1995, Etezadifar et al. 2010).

We studied nest-site characteristics and DSR of great egret nests during the 2008-2009 breeding seasons. Great egret nests were concentrated in a single colony on the Gerd-o-Deraz Island (26°53'N, 55°39'E) which is approximately 700 m^2 in area and is situated in the middle of the reserve. We made visits at least twice a week from the beginning of the egg laying season (early April-late June) and all nests found were marked with numbered plastic tags. We monitored all nests within the colony (N = 38 in 2008 and N = 39 in 2009). When a nest was located, the timing of clutch initiation was determined by direct observation or indirectly by back-calculating from the hatching dates in the nests for which clutch initiation dates were unknown. However, in some cases we could not detect the chick's age precisely, so we excluded that kind of nests in analyses of clutch initiating period. After discovery, we checked the nests for failure or success at least every second day. As it was almost impossible to detect and define the fate of young egrets after they fledged, we defined successful nests as those in which at least one chick fledged and/or survived for a minimum of 20 days; this is a measure commonly employed in heron nesting productivity studies (Fasola et al. 2007, Herring et al. 2010). We defined destroyed or failed nests as nesting attempts that were unsuccessful during either the incubation or chick-rearing periods. If we found evidence of predation by black rats (for example rat teeth marks on eggshells or dead chicks) we considered the nest 'depredated'. In some nests, chick mortality occurred or eggs were rolled out of the nest. Otherwise, the cause of egg or chick loss was 'unknown'. We measured the average diameter and the height (distance from the nest bottom to the ground in m) for each nest. The area under the nests was inundated by the tides, so we measured nest height when the water level was at its lowest point. In addition, we measured distances from the center of each nest to the center of nearest western reef heron, great egret and black rat nests. The black rats built their nests among the mangrove forests of the Hara Biosphere Reserve using the foliage of mangrove trees. We could identify black rat nests based on their shapes and the presence of rats, eggshells and bird feathers (Etezadifar et al. 2010). At the colony, we recognised seven rat nests. Because of the dense foliage and the canopy cover, we could not determine the position of each nest by using GPS, so we considered the center of the nest for our measurements. We were unable to use GPS to mark the position of each nest due to the density, canopy cover and dense foliage of vegetation. So, we used a tape to measure the distance from the center of the nest to each other factor.

We tried to reduce the time of our presence in the colony (to ca two hours/visit) to minimise possible disturbance to the nests and chicks. We checked the contents of the nest situated in the lower part on tress without any additional efforts. However, we checked higher nests by climbing the nest tree or adjacent trees when possible. During each visit, we determined the number of eggs or nestlings and their mortality, but we did not mark the nestlings. Following Dinsmore et al. (2002), we recorded: 1) the date that the nest was found; 2) the last day that the nest was occupied; 3) the last date the nest was checked; and 4) the fate of the nest (i.e. successful or unsuccessful).

We analysed data summarising nest survival using nest-survival models in Program MARK to assess the relative influences of the different factors on the DSR of great egret nests within the breeding colony (White & Burnham 1999). We defined DSR as the probability that a nest would survive during a 24-hour interval within the incubation or nestling periods. This considers the 'known fate' of nesting attempts from initiation or time of discovery through fledging of the young ('known fate' because once a nest was discovered, it could be rechecked with detection probability = 1.0). We estimated the nest survival as the product of DSR across the breeding attempt (68 days average duration from the first egg laid to the last chick fledged; Mayfield 1961, 1975, Cooch & White 2007). Our primary aim of modeling the DSR of great egret nests was to better understand the effects of nest-site characteristics on nest productivity, and our secondary aim was to obtain an estimate of nest survival in each study year. We based the model selection on Akaike's information criterion corrected for sample

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Table 1. Results of model selection for daily survival rates (DSR) of great egret nests in the Hara Biosphere Reserve, Persian Gulf, during 2008-2009. AIC_c indicates the Akaike's Information Criterion for small samples; ΔAIC_c the scaled AIC_c relative to the top model; w_i the Akaike model weight; k the number of parameters; Log_eL the log-likelihood; and + indicates additive model terms. Model terms include clutch initiation date (DATE), height of the nest above the ground (HGT), distance of the nest to the nearest great egret nest (DISGE), distance of the nest to the nearest western reef heron nest (DISRH), distance of the nest to the nearest black rat nest (DISBR) and diameter of the nest (DIAM).

Model	AIC_c	ΔAIC_c	w_i	k	- Log_eL
DISBR	9513	0	0.32	2	4556
DISRH + DISBR	9702	1.88	0.12	3	455
HGT + DISBR	9709	1.96	0.12	3	4553
DISGE + DISBR	971	1.96	0.12	3	4554
DISBR + DIAM	9713	1.99	0.11	3	4555
HGT + DISRH +DISBR	9889	3.75	0.05	4	4542
DISRH +DISGE +DISBR	9900	3.87	0.04	4	4548
HGT +DISGE +DISBR	9908	3.94	0.04	4	4552
CONSTANT	10028	5.14	0.02	1	4913
HGT+ DISRH +DISGE +DISBR	1009	5.77	0.02	5	4542
DATE	10149	6.35	0.01	2	4874
HGT+ DISRH +DISGE +DISBR + DATE	10195	6.82	0.01	6	4897
ALL FACTORS	10438	9.25	0.003	7	4514

size (AIC_c; Akaike 1973, Burnham & Anderson 1998). We used the difference between AIC_c scores (ΔAIC_c) and Akaike weights ($\sum \omega i$) to infer support for different models. Because multiple models had competitive model weights, we generated beta parameter estimates through model averaging. We report all means ± 1 standard error (SE).

Results

Overall, we observed failure of 13 and seven great egret nesting attempts in 2008 and 2009, respectively. Eggs falling out of nests, chick mortality and black rat predation were the most important causes of reproductive failures (accounting for 33, 31 and 20% failures, respectively). The mean height of great egret nests was 2.5 m ± 0.05 and the mean nest diameter was 54.18 cm ± 1.77. The mean distance to nearest great egret, western reef heron and black rat nests was 2.73 m ± 0.21,1.81 m ± 0.17 and 19.97 m ± 2.81, respectively. The mean clutch size was 2.42 (± 0.62 (SD); N = 38) and 2.38 (± 0.61 (SD); N = 39) in 2008 and 2009, respectively.

We identified five competitive nest survival models ($\Delta AIC_c \leq 2$) and three additional plausible models

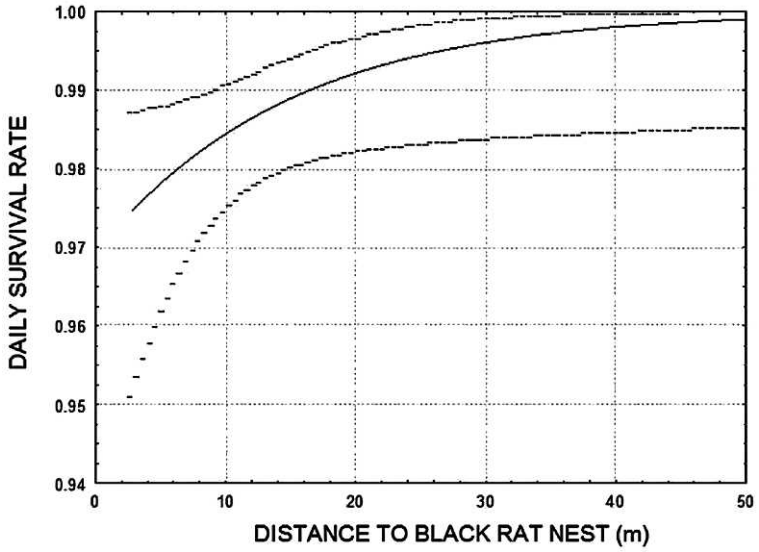


Figure 2. Estimated daily survival rate (DSR) of great egret nests with 95% confidence intervals across a gradient of distances to black rat nests (in m) in the Hara Biosphere Reserve, Persian Gulf.

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(ΔAIC_c = 2-4; Table 1). The variables in the competitive and plausible models were distance to black rat nest, the height of the nest from the ground, distance to nearest great egret nest, distance to nearest western reef heron nest and nest diameter. However, a model with all nest-site characteristics as covariates had a relatively low AIC_c score compared to the competitive models. Similarly, our model with nest age at discovery received low support. The most important covariate indicated that DSR varied with the distance to black rat nests (sum of model weight, $\sum\omega_i = 0.96$; see Table 1). DSR of nests improved as the distance between nest sites and black rat nests increased (Fig. 2). The distance between nest sites and proximate great egret and western reef heron nests did not significantly affect the DSR ($\sum\omega_i = 0.23$ and $\sum\omega_i = 0.24$). Nest diameter and nest initiation date received the least support ($\sum\omega_i = 0.11$ and $\sum\omega_i = 0.03$). Because the multiple models were competitive, we generated beta parameter estimates through model averaging (Table 2). Overall, the DSR from egg hatching to fledging was 0.98960 ± 0.002 (95% LCI: 0.99314, UCI: 0.98425), for the constant model equivalent to a Mayfield nest survival of 0.49 ± 0.07 (95% LCI: 0.35, UCI: 0.63; Table 3).

Table 2. Model-averaged coefficients (with 95% CI) from nest survival models for great egret nests in the Hara Biosphere Reserve, Persian Gulf, during 2008-2009. Italics indicate parameter estimate with confidence intervals that do not overlap zero.

Variable	Coefficient	LCI	UCI
Intercept	*3.515*	*1.496*	*5.535*
Clutch initiation date	0.0036	-0.005	0.013
Nest height from the ground	-0.045	-0.384	0.292
Distance to western-reef heron nest	-0.013	-0.084	0.057
Distance to great egret nest	0.0047	-0.205	0.209
Distance to black rat nest	*0.0662*	*0.0016*	*0*
Nest diameter	-0.00038	-0.007	0.0062

Discussion

The distance between nests of great egret and black rat was a reasonable indicator of nest-site quality. Although there is little information on the black rat's distribution, habitat, food habits and population density in the Hara Biosphere Reserve, predation by the black rat was found to be an important factor affecting the nesting success of the western reef heron and was responsible for 50.9% of nest failures (Etezadifar et al. 2010). Considering the impact of black rats on the breeding success of great egrets, nest site selection by the herons and food preferences of the black rat appear to be the most important factors involved in this relationship. In the Hara Biosphere Reserve, black rats build their nests within mangrove trees that are above average in height and in the densest areas of the forest. Similar trees within densely forested areas are also used by herons for nesting (Etezadifar et al. 2010). Such a coexistence of the rats and herons subsequently increased the rate of black rat's predation on great egret's eggs/chicks.

In general, the diet of the black rat depends on the availability of food resources in their habitat (Harrison & Bates 1991, Kern 2002, King 2005). In mangrove forests, black rats primarily feed on crabs (especially *Uca* spp.), bivalves, fish and insects. Eggs and chicks are increasingly consumed in March and April, when egrets are breeding. Field observations have revealed that black rats feed on the eggs and chicks of the western reef heron and Indian pond heron *Ardeola grayii* in the Hara mangrove forests (Etezadifar et al. 2010), and we concluded that the predation on eggs and chicks is a major factor in reducing the breeding success of these herons. Moreover, results of our study illustrate that the most important factor threatening great egrets in the Hara Biosphere Reserve colony is egg/chick predation by black rats.

The distance of nests to nests of western reef herons and the nesting density of great egrets (defined as mean distance among nests) did not clearly affect

Table 3. Model-averaged daily survival rate (DSR) and overall survival of nests in a breeding colony of great egrets in the Hara Biosphere Reserve, Persian Gulf.

	DSR			Survival		
Year	Mean ± SE	UCI	LCI	Mean ± SE	UCI	LCI
2008	0.9928 ± 0.002	0.9842	0.9967	0.61 ± 0.12	0.37	0.81
2009	0.9874 ± 0.003	0.9795	0.9922	0.42 ± 0.09	0.26	60
Mean	0.9896 ± 0.002	0.9843	0.9931	0.49 ± 0.07	0.35	63

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the DSR of great egret nests based on model-averaged beta parameters (see Table 2). However, this result is inconsistent with the western reef heron study in the same area (Etezadifar et al. 2010). We suggest that this lack of effect should be considered as tentative, because we studied only one colony in which the effect of black rat predation on breeding performance was clearly stronger than other factors. Density-dependence effects also may not be strong enough to detect in a heron colony with moderately few nests. Nest height has been found to be an important factor affecting breeding success in some tree-nesting birds, but did not influence DSR of great egret nests in that case (Ludvig et al. 1995).

Egg-laying date frequently influences reproductive success in birds. For most bird species, a seasonal decline in breeding success has been shown (Rodgers & Schwikert 1997) so that late-season broods usually have lower reproductive success than early-season broods (Moreno 1998, Morrison 1998, Price et al. 1988, Verboven & Visser 1998). However, laying date was not an important covariate for great egret DSR in the Hara Biosphere Reserve, unlike the pattern found in this area for western reef herons (Etezadifar et al. 2010), or for little egrets *Egretta garzetta* in Italy (Fasola 1998). Laying date may not be an important covariate in the Hara Biosphere Reserve because of the large number of black rat nests within the Reserve, overlapping temporally with the great egret nesting period.

Conservation measures

The Hara Biosphere Reserve host many waterbirds and provide suitable breeding habitat for some waterbirds species including wading birds and herons (Ghasemi et al. 2012, Etezadifar et al. 2010, Neinavaz et al. 2010). In particular, mangrove forests host the largest breeding colonies of great egret and western reef heron and herons and egrets in Iran and the Middle East (Evans 1994, Scott 1995, Etezadifar et al. 2010, Neinavaz et al. 2010). This implies that conversation and management plans aimed at enhancing the habitat quality are of great priority in this area. We recommend, as a priority, that efforts be made to study trends in the population of black rats in the Hara Biosphere Reserve, to investigate how to limit the effects of black rat predation on other breeding bird species within the Reserve, and to investigate appropriate methods to reduce the number of black rats in mangrove forests. It would seem that understanding both the population structure and distribution of black rats would be important information to make suitable decisions regarding the control or eradication of black rats, and to understand where efforts should be focused to maximise the probability of nesting success for great egrets.

To reduce the deleterious effects of rat predation on the great egret colony, we suggest using mechanical control methods, in particular traps before the onset of the great egret breeding season. This management technique was also suggested by Etezadifar et al. (2010) for the conservation of western reef herons. However, other methods have been applied for the eradication of rats in different parts of the world. For successful rat eradications, the fundamental requirement is that every rat is removed. Barnett (1988) reported that invasive rat eradication is only possible if each individual rat makes the transition from local food sources to bait containing rodenticide. The appropriate use of rodenticides can eliminate 100% of an island rat population (Taylor & Thomas 1989, 1993, Taylor et al. 2000). These techniques are powerful tools for preventing avian extinctions and they have recently been improved with the advent of new rodenticide delivery techniques, such as aerial broadcast. Using these techniques, invasive rats have been removed from > 90 islands worldwide, most recently including islands in North America (Towns & Ballantine 1993, Donlan et al. 2000, Dunlevy et al. 2000, Taylor et al. 2000, Atkinson 2001).

However, before these techniques are applied in the Hara Biosphere reserve, the effects of rodenticides on other species, particularly breeding waterbird species, needs to be investigated. To enhance our understanding of the breeding ecology of great egrets in the Middle East, other aspects of its ecology should be investigated, such as the diet of adults and local movement patterns. A study of the relationship between the breeding parameters and weather and hydrological conditions is also necessary to understand how to best manage the species throughout the region.

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