The Challenge of Coping in an Extremely Hot Environment: A Case Study of the Incubation of Lesser Crested Terns (Thalasseus bengalensis)

Author: AlRashidi, Monif

Source: Waterbirds, 39(2) : 215-221

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.039.0214

The Challenge of Coping in an Extremely Hot Environment: a Case Study of the Incubation of Lesser Crested Terns (*Thalasseus bengalensis*)

Monif AlRashidi

Department of Biology, Faculty of Science, University of Ha'il, P.O. Box 2440, Hail, Saudi Arabia

E-mail: m.alrashidi@uoh.edu.sa

Abstract.—The Lesser Crested Tern (*Thalasseus bengalensis*) is a ground-nesting seabird that breeds only on subtropical and tropical islands from northern Africa to northern Australia. Despite their wide distribution, few studies have been conducted on the breeding ecology of this species. On Jana Island, Saudi Arabia, which is northeast of the Saudi Arabia mainland, the midday ground temperature may reach 60 °C during the summer. In this study, two cameras were used to record the incubation behavior of Lesser Crested Terns to evaluate their coping ability in this extremely hot environment. The behavioral mechanism that the seabirds used to maintain optimal egg temperatures was also evaluated. The results show that Lesser Crested Terns attend their eggs continuously during a 24-hr period without leaving the nests, except when a disturbance occurs. This behavior prevents the eggs from reaching lethal temperatures. In addition, position of the sun influenced the incubation behavior. Most incubating Lesser Crested Terns faced west in the morning, and began rotating clockwise until they faced east in the evening. This behavior may play a vital role in preventing both eggs and incubating adults from overheating. *Received 16 November 2015, accepted 31 January 2016.*

Key words.—harsh environments, incubation behavior, Lesser Crested Tern, seabirds, *Thalasseus bengalensis.*

Waterbirds 39(2): 215-221, 2016

The Lesser Crested Tern (*Thalasseus bengalensis*) is a medium, ground-nesting, colony-forming seabird. Its colonies vary in size from a few to up to 20,000 pairs (Gochfeld and Burger 1996; Hamza 2014). This species nests only on subtropical and tropical islands, and inhabits islands primarily near north and east Africa within the Red Sea, the Arabian Gulf, the Indian Ocean, the western Pacific, and near northern Australia (Gochfeld and Burger 1996; Aspinal 2010). As a breeding species, Lesser Crested Terns are very common around the Arabian Peninsula, and the Arabian Gulf colonies contain approximately 59,000 pairs (Aspinal 2010; Jennings 2010). This species is classified as of "Least Concern" by the International Union for Conservation of Nature (IUCN) Red List for birds (BirdLife International 2015). Threats for the colonies include oil pollution, human disturbance, human egg-collection and predation by introduced mammals (Aspinal 2010; Jennings 2010).

Despite their wide distribution, few studies have been conducted on the breeding ecology of the Lesser Crested Tern. This species is an ideal model for studying how extremely hot environments influence incubation behavior since it breeds in nests without any decoration or isolating materials, and egg laying is usually between May and July (Gochfeld and Burger 1996; Jennings 2010), where midday ground temperature may reach 60 °C. Thus, this study is an attempt to investigate how the incubating adults cope with this harsh environment and to evaluate the behavioral mechanism used by incubating adults to maintain the optimal egg temperature to prevent eggs from hyperthermia, using silent trail cameras.

Methods

Study Area and Data Collection

This study was conducted from 2-6 June 2015 on Jana Island, Saudi Arabia, which is northeast of the Saudi Arabia mainland. Jana Island (27° 21' N, 49° 54' E) is an offshore coral island in the Arabian Gulf that is approximately 45 km from the Jubail Industrial City. Jana Island is a protected area with a size of approximately 2.6 km^2; it has dense vegetation that is dominated by halophytic shrubs (mainly *Salsola vermiculata* and *Suaeda baryosma*) (Miller *et al.* 2009). Two silent cameras (Bushnell 8 MP Trophy Cam Black Led Trail) were used to record the incubation behavior of adults. The disturbance and any potential threats to the colony were also recorded 24 hr per day for at least 4 days. The cameras were located 1.5 m from the eastern and western parts of the colony. Each camera was set to record one image per minute. A motion sensor was implemented that could take three images per min depending on the movements of objects. The cameras recorded the nocturnal activities of the birds with infrared sensors. Each camera was installed with a minimal amount of disturbance. This allowed the adults to return to the colony only a few minutes after the installation of the cameras with a total time for installation of approximately 10 min. The western camera obtained images for 83 hr and 15 min (from 08:00 hr on 2 June 2015 to 19:15 hr on 5 June 2015), and the eastern camera obtained images for 42 hr and 23 min (from 08:00 hr on 2 June 2015 to 02:23 hr on 4 June 2015). In total, 16,186 images were extracted and analyzed. The ground surface temperature was measured at 1-min intervals on the ground in an open area for at least 24 hr using a data logger (HOBO U10). This open area was 2 m from the western part of the colony. The minimum ground temperature at night was 24.3 °C, and the maximum daytime temperature was 58.4 °C.

Data Analysis

The 24-hr recordings began at midnight (00.00 hr) on 3 June 2015. These recordings were considered to be the unit of analysis for each nest (*n* = 18 nests). Each day was divided into 12 2-hr time periods. Two behavioral variables were calculated for each period: 1) nest attendance – the percentage of nest attendance time by the incubating adults; and 2) orientation – the percentage of the incubating adult's orientation in each direction (north, south, east, and west). The average temperature outside the colony was taken as the ground temperature for each period.

The influence of ground temperature on the incubation behavior was investigated using linear mixed-effect models (Pinheiro and Bates 2000; AlRashidi *et al.* 2010), with nest identity as the grouping structure. The model included a random intercept term for each nest. The ground temperature was included in the model as a second degree orthogonal polynomial covariate. The correlation between the time period and the temperature was also included in the model because the effect of temperature on incubation may vary throughout day (AlRashidi *et al.* 2010). Additionally, the influence of the position of the sun on the incubation behavior was investigated using linear mixed-effect models. The nest identity was included as a random factor. The following fixed effects were included in the initial models: direction (factor with four levels: north, south, east and west), time period, ground temperature as a second degree orthogonal polynomial covariate, and the interaction between the direction, time period and ground temperature. Both response variables were transformed into the arcsine square-root to achieve normality. The statistical package R (R Development Core Team 2015) was used for all statistical analyses. The values are given as the means ± SE.

RESULTS

Daily Routine of Incubation Behavior

The mean total nest attendance was 97.02 ± 1.27% for the entire day (*n* = 18 nests). During the daytime (04:00-18:00 hr), the total nest attendance was 99.77 ± 0.22%. In contrast, at night (18:00-04:00 hr), the nests were attended 93.17 ± 2.84% of the time. Thus, the nests were attended over 98% of the time during each period except for consecutive periods (00:00-02:00; 02:00-04:00; 04:00-06:00 hr). For these time frames, parents incubated 79.07 ± 8.52%, 86.76 ± 6.53% and 98.47 ± 1.53% of the time, respectively (Table 1; Fig. 1). This reduction in attendance was due to disturbances of incubating adults in the western part of the colony. In contrast, no Lesser Crested Terns left their nests during these periods in the eastern part of the colony, as shown by the eastern camera. Moreover, the western camera revealed that nests were attended continuously during these periods during the third night (Table 2).

The position of the sun influenced the incubation behavior. Most incubating Lesser

Table 1. Minimal mixed-effect models of the nest attendance and orientation in the Lesser Crested Tern (*n* = 18) nests. The ground temperature was included in the models as a second degree orthogonal polynomial. The df values are the numerator and denominator degrees of freedom, respectively.

	Response Variables					
	% Nest Attendance			% Orientation		
Explanatory Variables	df	F	*P*	df	F	*P*
Time period	1, 19	1.12	0.290	—	—	—
Temperature	2, 19	4.41	0.013	2, 83	11.00	< 0.001
Time period x temperature	2, 19	1.90	0.153	—	—	—
Direction	—	—	—	3, 83	14.95	< 0.001
Direction x time period	—	—	—	4, 83	6.74	< 0.001
Direction x temperature	—	—	—	6, 83	16.20	< 0.001

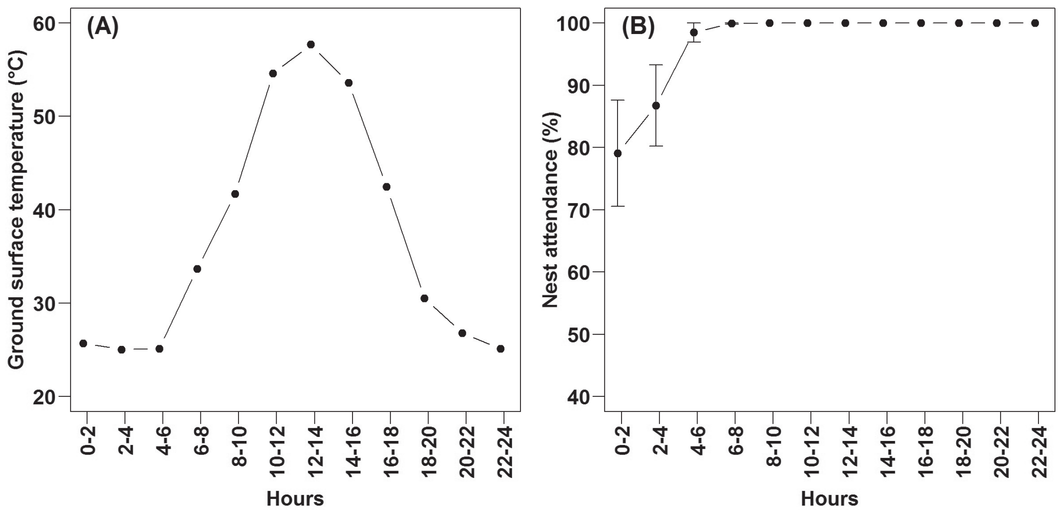

Figure 1. (A) Ground surface temperature of the open area that was approximately 2 m from the western part of the colony (mean ± SE for each 2-hr period). (B) Nest attendance (%) as a function of the ground surface temperature (°C) during 2-hr periods (mean ± SE; *n* = 18 nests).

Crested Terns faced west in the morning and then started rotating themselves clockwise until they faced east in the evening (*n* = 18 incubating birds) (Table 1; Figs. 2 and 3). More than 65% of the incubating individuals faced west during the consecutive periods (06:00-08:00; 08:00-10:00; 10:00-12:00 hr). The highest nest attendance was observed for the period 08:00-10:00 hr (95.83 ± 1.78%). Almost all of the individuals faced west during this period (Figs. 2 and 3). However, the highest nest attendance when the individuals (76.48 ± 6.30%) faced east occurred at 14:00-16:00 hr (Figs. 2 and 3). When the individuals faced north, the nest attendance percentages were all less than 50%, except during the period of 12:00-14:00 hr during which the percentage was 54.03 ± 6.08% (Figs. 2 and 3). However, less than 20% of the birds were recorded facing south during daytime hours. In contrast, at night (18:00-04:00 hr), none of the percentages were more than 50% for either direction (Fig. 2).

Colony Disturbance

The colony was approximately 1-3 m in width and 60 m in length with approximately 1,700 eggs. There was typically one egg per each nest scrape; however, 22 nests had two

Table 2. Colony disturbances that were recorded using the cameras during the 5-day study.

Camera Position	Start Time of Disturbance		End Time of Disturbance		Disturbance Duration (min)
	Date	Time	Date	Time	
Eastern part of the colony	2 June 2015	18:00	2 June 2015	18:04	4
	2 June 2015	18:08	2 June 2015	18:11	3
	2 June 2015	18:18	2 June 2015	18:20	2
	2 June 2015	19:26	2 June 2015	19:43	17
	3 June 2015	—	—	—	—
Western part of the colony	2 June 2015	18:00	2 June 2015	18:27	17
	2 June 2015	19:25	2 June 2015	22:40	135
	2 June 2015	23:00	3 June 2015	00:20	80
	3 June 2015	00:38	3 June 2015	01:50	72
	4 June 2015	03:25	4 June 2015	03:58	33
	5 June 2015	—	—	—	—

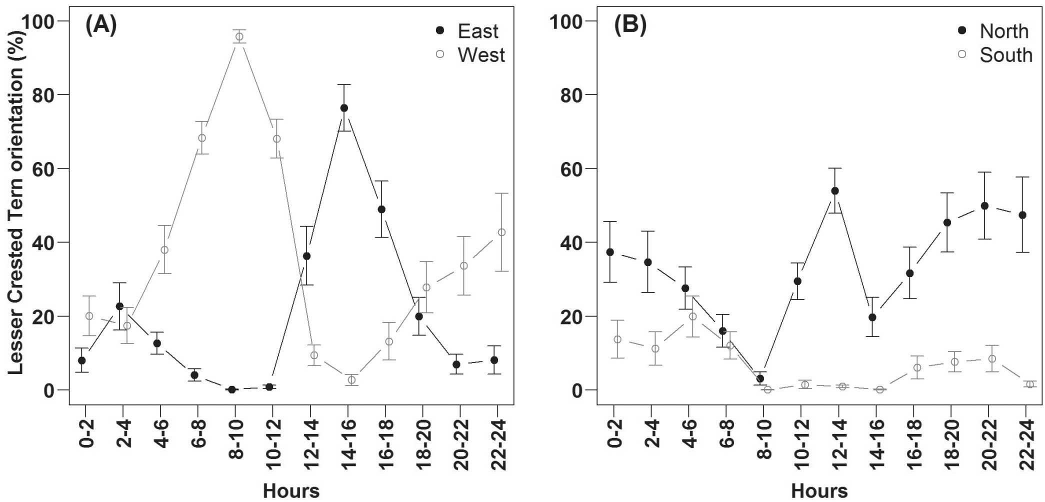

Figure 2. Lesser Crested Tern orientation (%) as a function of the sun direction during 2-hr periods (mean ± SE; *n* = 18 nests). (A) west and east; (B) north and south.

eggs, and one nest had three eggs. The eggs were laid on the barren nest scrape with no isolated materials. I recorded some disturbances among the incubating Lesser Crested Terns during the nighttime but did not record any disturbances during the daytime hours (Table 2). Neither camera showed any predators attacking the nests or eating eggs.

The western camera recoded a small dark animal that may have been a small house mouse (*Mus musculus*) or a darkling beetle (*Pimelia arabica*). It appeared immediately after the flushing of the Lesser Crested Terns during 18:00-02:00 hr on the first night.

DISCUSSION

Incubation may be the most costly phase of the breeding cycle, which is similar to chick rearing in terms of energy expenditure and time limitation. This is particularly the case for ground-nesting avian species that breed in harsh environments (i.e., extreme temperatures, high predation risk and scarcity of food) (Reid *et al.* 2002; Martin and Wiebe 2004; Nord and Williams 2015). The breeding ground-nesting avian species in these harsh environments must balance the demands of their eggs with their own physiological requirements (Carey 2002). Some ground avian species are known to abandon their nests when they cannot withstand extreme daytime temperatures or if they experience a high predation risk (Amat and Masero 2004; Gómez-Serrano and López-López 2014).

The Lesser Crested Terns in this study attended their eggs continuously over 24 hr without leaving the nests except when a disturbance occurred. This result is compared to the Saunders's Tern (*Sternula saundersi*) (AlRashidi and Shobrak 2015) that breeds in a similar hot environment with similar nests to the Lesser Crested Tern. Saunders's Terns did not incubate more than 90% of the entire day. The Saunders's Tern has biparental incubation systems, whereas the Lesser Crested Tern's incubation behavior is still unknown. Cameras did reveal the changeover behavior: in several occasions one Lesser Crested Tern relieved the other from the incubation duties during the hottest part of the day. However, due to the morphological similarities among adults, it is still not clear whether the incubation pattern is biparental or communal incubation. Although some avian species that nest in extremely hot environments have temperature-resistant embryos (Bennett and Dawson 1979; Bennett *et al.* 1981; Aguilar *et al.* 1998), the embryo's optimal developmental temperature in most avian species is typically 36.0-40.5 °C (Webb 1987). The Lesser Crested Terns in this study

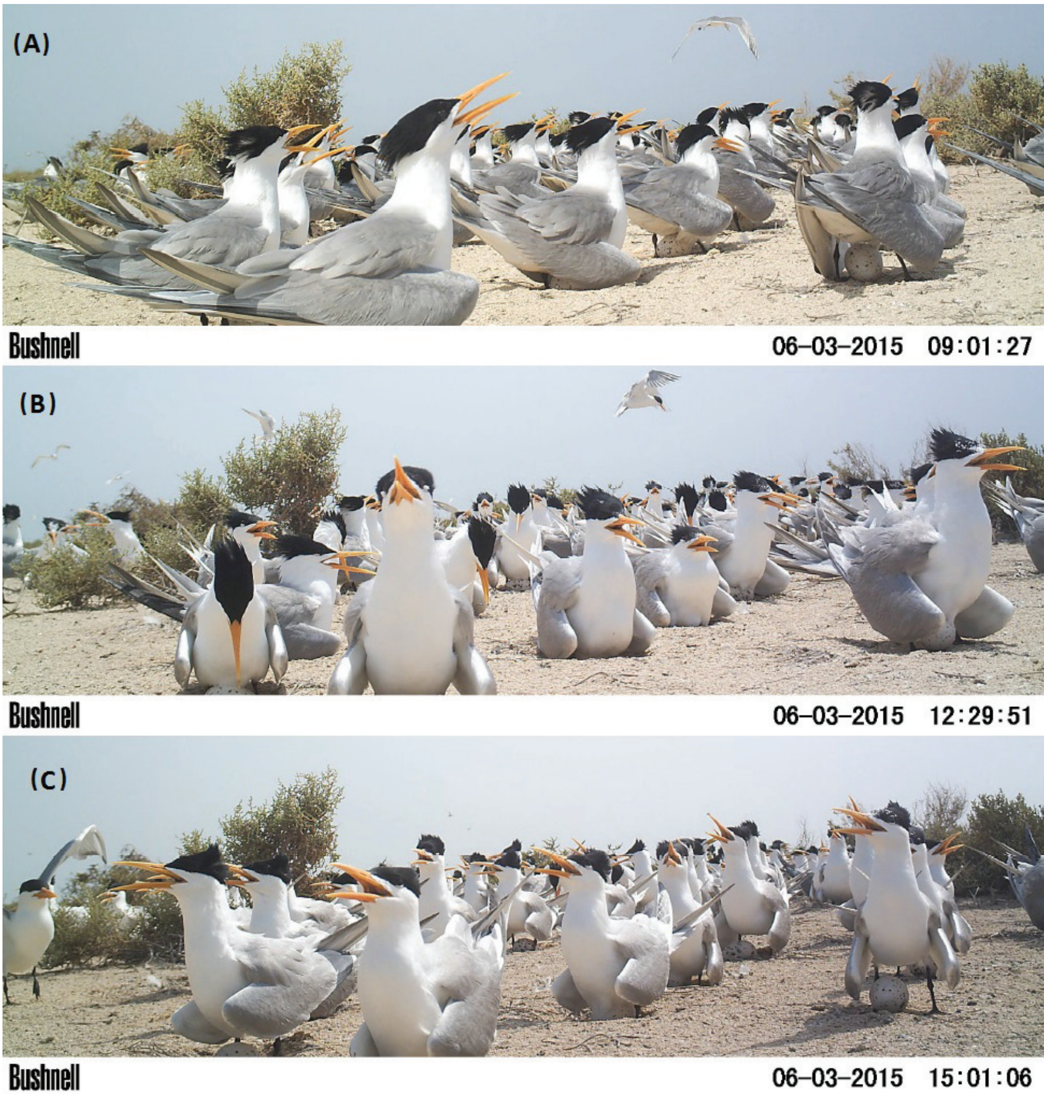

Figure 3. Photos showing Lesser Crested Tern orientation as a function of the sun and time of day: (A) facing west; (B) facing north; (C) facing east.

incubated their eggs incessantly to prevent embryo exposure to the lethal temperatures. This 5-day study period only reflected approximately 20% of the incubation period, which is between 22-25 days. The Lesser Crested Terns did not need to leave their nests for any specific period to avoid predation during the limited term of this study. This was in contrast to Saunders's Terns (AlRashidi and Shobrak 2015), which usually do leave their nests to distract predators and attract them as far as possible from their nests, particularly during the early morning and late evening when predator activity increases.

The incubating Lesser Crested Terns changed their body orientation in relation to the sun. They generally faced opposite the sun, which could be a behavioral mechanism that plays a vital role in preventing both incubating adults and eggs from overheating. This mechanism could minimize the absorption of solar radiation. The heads of these birds are black; thus, they avoided facing the sun by fluffing the crested nape that faces the sun during the hottest part of the day. The fluffed crested nape may disperse the solar radiation and cool the individuals' heads (Oswald and Arnold 2012). Also, this behavior maximized the shading of the eggs by keeping their bodies between the eggs and the direct sunlight (i.e., under the direct shade of their ventral feathers). In addition, this behavior minimized the water evaporation rate of their soaked bellies. The cameras showed that the incubating adults usually wet their ventral feathers, especially during the hottest part of the day. This result partially agrees with the results of Lustick *et al.* (1978), who reported that Herring Gulls (*Larus argentatus*) rotated themselves 180 degrees during the day to face the sun to expose their white surfaces to the direct sunlight to reduce overheating of their bodies.

In conclusion, the results of this study show some of the behavioral mechanisms used by this seabird species that breeds in a harsh environment to protect their eggs and/or themselves from overheating. However, with changes in global climate, which may result in ground temperatures exceeding the tolerable maxima for eggs and incubating adults, implications on breeding systems are anticipated. Future studies should focus on collecting detailed behavioral and ecological data on this species and other seabird species to predict the likely behavioral responses of seabirds to global warming.

Acknowledgments

This work was supported by the University of Ha'il under grant number 150453. I thank the Saudi Wildlife Authority (SWA), which is represented by the SWA Secretary-General, H. H. Prince Bandar bin Saud, for providing assistance regarding logistics and field facilities. I also thank everyone that contributed to the fieldwork, particularly Khalid Al-Shaikh, Tareq AlQhtani, Faris AlAnazi, and Jaber Haressi. I am also grateful to Dr. Steve Oswald and an anonymous reviewer for their critical comments on an earlier draft of this manuscript. I would also like to express my appreciation to Dr. Denis A. Sokolov, Director of Falcon Scientific Editing, for the immense help with the English language editing of the draft.

Literature Cited

Aguilar, R. E., C. G. Guerra, L. C. Fitzpatrick and G. S. Luna. 1998. Thermobiology of Gray Gull (*Larus modestus*) embryos and hatchlings: correlates of nesting in the Atacama Desert. Estudios Oceanológicos 17: 7-12.

AlRashidi, M. and M. Shobrak. 2015. Incubation routine of Saunders's Tern (*Sternula saundersi*) in a harsh environment. Avian Biology Research 8: 113-116.

AlRashidi, M., A. Kosztolányi, C. Küpper, I. C. Cuthill, S. Javed and T. Székely. 2010. The influence of a hot environment on parental cooperation of a ground-nesting shorebird, the Kentish Plover (*Charadrius alexandrines*). Frontiers in Zoology 7: 1.

Amat, J. A. and J. A. Masero. 2004. How Kentish Plovers (*Charadrius alexandrines*) cope with heat stress during incubation. Behavioral Ecology and Sociobiology 56: 26-33.

Aspinal, S. 2010. Breeding birds of the United Arab Emirates. Unpublished report, Environment Agency Abu Dhabi, Abu Dhabi, United Arab Emirates.

Bennett, A. F. and W. R. Dawson. 1979. Physiological response of embryonic Heermann's Gull to temperature. Physiological Zoology 52: 413-421.

Bennett, A. F., W. R. Dawson and R. W. Putnam.1981. Thermal environment and tolerance of embryonic Western Gull. Physiological Zoology 54: 146-159

BirdLife International. 2015. Species factsheet: *Thalasseus bengalensis*. BirdLife International, Cambridge, U.K. http://www.birdlife.org/datazone/speciesfactsheet.php?id=3262, accessed 15 November 2015.

Carey, C. 2002. Incubation in extreme environments. Pages 238-253 *in* Avian Incubation: Behavior, Environment, and Evolution (D. C. Deeming, Ed.). Oxford University Press, Oxford, U.K.

Gochfeld, M. and J. Burger. 1996. Family Sternidae (terns). Pages 624-667 *in* Handbook of the Birds of the World, vol. 3: Hoatzin to Auks (J. del Hoyo, A. Elliott and J. Sargatal, Eds.). Lynx Edicions, Barcelona, Spain.

Gómez-Serrano, M. Á. and P. López-López. 2014. Nest site selection by Kentish Plover suggests a trade-off between nest-crypsis and predator detection strategies. PLOS ONE 9: e107121.

Hamza, A. A. 2014. Breeding ecology, migration and population genetics of Lesser Crested Terns (*Thalasseus bengalensis emigrate*). Ph.D. Thesis, University of Hull, Hull, U.K.

Jennings, M. C. 2010. Atlas of the breeding birds in the Arabia Peninsula. Fauna of Arabia 25: 339-341.

Lustick, S., B. Battersby and M. Kelty. 1978. Behavioral thermoregulation: orientation toward the sun in Herring Gulls. Science 200: 81-83.

Martin, K. and K. L. Wiebe. 2004. Coping mechanisms of alpine and Arctic breeding birds: extreme weather and limitations to reproductive resilience. Integrative and Comparative Biology 44: 177-185.

Miller, J., R. Loughland and K. A. Al-Abdulkader. 2009. Island biodiversity in the Western Arabian Gulf. Unpublished report, Environmental Protection Department, Saudi Aramco, Dhahran, Saudi Arabia.

Nord, A. and J. Williams. 2015. The energetic costs of incubation. Pages 152-170 *in* Nests, Eggs, and Incubation: New Ideas About Avian Reproduction (D. C. Deeming and S. J. Reynolds, Eds.). Oxford University Press, Oxford, U.K.

Oswald, S. A. and J. M. Arnold. 2012. Direct impacts of climatic warming on heat stress in endothermic species: seabirds as bioindicators of changing thermoregulatory constraints. Integrative Zoology 7: 121-136.

Pinheiro, J. C. and D. M. Bates. 2000. Mixed-effects models in S and S-PLUS. Springer, New York, New York.

R Development Core Team. 2015. R: a language and environment for statistical computing v. 3.2.3. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/, accessed 15 November 2015.

Reid, J. M., P. Monaghan and R. G. Nager. 2002. Incubation and the costs of reproduction. Pages 314-325 *in* Avian Incubation: Behavior, Environment, and Evolution (D. C. Deeming, Ed.). Oxford University Press, Oxford, U.K.

Webb, D. R. 1987. Thermal tolerance of avian embryos: a review. Condor 89: 874-898.