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Breeding Population Biology in Socotra Cormorants (*Phalacrocorax nigrogularis*) in the United Arab Emirates

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Abstract.—Socotra Cormorants (*Phalacrocorax nigrogularis*) are a regionally endemic, locally abundant species restricted primarily to the Arabian Gulf and coastal Oman. The species has declined since the 1980s and is currently categorized as Vulnerable by the International Union for Conservation of Nature. Breeding phenology, breeding performance and variation in breeding population size were studied on Siniya Island, the largest colony in the United Arab Emirates. Laying dates were between 13 September and 6 October during the 2011-2015 breeding seasons. Incubation was estimated to be 24-27 days, and clutch size ranged from 2.21-2.79 eggs/nest. Hatching success ranged from 58.71 ± 5.85 in 2011 to 81.76 ± 4.86% in 2012. The total population varied over the 5 years of study from 28,152 ± 3,780 pairs in 2011 to 41,568 ± 3,761 pairs in 2014. Population estimates using density-area calculations were closely aligned with ground counts. The use of a drone with a mounted camera greatly improved the counts in 2015. The Socotra Cormorant breeding population on Siniya Island appears to be stable over the short term with annual fluctuations comparable to other cormorant species. Thus, our data suggest the breeding population on Siniya Island could have surpassed that of other colonies in the Arabian Gulf, underscoring its global significance. *Received 21 July 2016, accepted 1 December 2016.*

Key words.—age at first breeding, breeding phenology, conservation, *Phalacrocorax nigrogularis*, population trends, Socotra Cormorant.

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Seabirds worldwide are undergoing substantial declines as a result of habitat destruction, invasive species, fisheries bycatch and direct persecution (Zydelis *et al.* 2009; Croxall *et al.* 2012; Paleczny *et al.* 2015). Cormorants (Phalacrocoracidae), many of which are either inland, brackish or marine in their distribution patterns, are especially threatened due to widespread persecution from competition (sometimes putative) with fisheries (Kameda *et al.* 2003; Adkins *et al.* 2014; Wires 2014). The Double-crested Cormorant (*Phalacrocorax auritus*), for example, has undergone major population declines in North America because of persecution by anglers and fish farmers (Adkins *et al.* 2014). Similarly, the Great Cormorant (*P. carbo sinensis*) has also suffered declines in populations in various parts of Europe due to direct persecution, leading to extirpation in some countries (Klenke *et al.* 2013). Management measures in both North America and Europe have helped to restore populations of both species (Klenke *et al.* 2013; Adkins *et al.* 2014; Wires 2014). Shallow gulfs and seas often support substantial fisheries that in turn feed a wealth of seabirds including cormorants (Nelson 2005). Increasing demand for fish has led to increased commercial fish exploitation in these regions (Jabado *et al.* 2015). The Arabian Gulf region has undergone rapid change in the last three decades due to the discovery of oil in most of the Gulf States (Shihab 2001). This has led to environmental degradation, along with increased fishing activities that are supporting the influx of people moving into the region (Jabado *et al.* 2015). Fishing in the Arabian Gulf is mainly targeting pelagic and demersal fish (Carpenter *et al.* 1997; Grandcourt 2012), although the true extent of the fisheries activities may not be fully reported (Jabado *et al.* 2015).

The Arabian Gulf is a semi-enclosed, shallow, highly saline and relatively warm gulf with rapid turnover that supports species-poor fish communities compared to similar marine systems elsewhere (Sheppard 1993; Grandcourt 2012). The Socotra Cormorant (*Phalacrocorax nigrogularis*) is a regionally endemic cormorant with a geographic range restricted to the Arabian Gulf and Gulf of Oman region (Jennings 2010; BirdLife International 2016). The global breeding population is currently estimated at 110,000 pairs (Jennings 2010), most of which resides within the Arabian Gulf (~86%). The population of Socotra Cormorants in Oman is comparatively small (≤ 10,000 pairs) and is geographically isolated from the Arabian Gulf population (Jennings 2010). Substantial declines throughout their distribution have reduced the global population by ~60% (Symens *et al.* 1993; King 1999; Jennings 2010). This not only included periodic declines from major events, such as the oil spill during the Gulf War in 1991 during which tens of thousands of Socotra Cormorant died (Symens *et al.* 1993), but also the gradual, long-term decline in populations due to degradation or destruction of breeding sites (Symens *et al.* 1993; King 1999; Jennings 2010). The Socotra Cormorant is designated as Vulnerable on the International Union for Conservation of Nature's Red List of Threatened Species (BirdLife International 2016). A total of 14 breeding sites remain within the Arabian Gulf: three in Saudi Arabia, one in Bahrain (on the west of Qatar in the Gulf of Salwa), one in Qatar and nine in the United Arab Emirates (Aspinall 2010). The area of occupancy of the species is very limited, especially considering the breeding habitat, consisting of offshore islands (BirdLife International 2016). Three island complexes (in Saudi Arabia, Bahrain and the United Arab Emirates) hold most of the current global breeding population (Jennings 2010). The United Arab Emirates reportedly holds 38,000 to 39,000 pairs nesting on nine islands, eight of which are in the Abu Dhabi Emirate (Aspinall 2010; Jennings 2010). The Abu Dhabi islands (with breeding populations ranging from a few hundred to a few thousand pairs) have suffered significantly due to oil exploitation and persecution over the last three decades (Environment Agency Abu Dhabi 2014), and 12 colony sites have been abandoned completely by breeding birds (Jennings 2010). The single largest colony in the United Arab Emirates is Siniya Island (an Important Bird Area; Evans 1994), which is located in the Umm Al Quwain Emirate (one of the northern Emirates) on the eastern side of the Arabian Gulf. The Siniya Island population was estimated 15,500 pairs in 1996 (Jennings 2010). In Bahrain, the Hawar Island complex hosts ~20,000 pairs (Pilcher *et al.* 2008; but see Jennings 2010), and islands in the western side of the Gulf of Salwa in Saudi Arabia host ~30,000-40,000 pairs (Jennings 2010). Collectively, these three concentrations make up the bulk of the Arabian Gulf and the global population of the species.

Better understanding of breeding biology and threats of the Socotra Cormorant is essential in strategizing recovery of the species. Limited information exists on the breeding biology of Socotra Cormorants (King 2004; Jennings 2010; Muzaffar *et al.* 2012, 2013; Wilson 2012). Breeding birds nest in dense colonies with a distinct peak nesting period between September and October (King 1999; Jennings 2010; Wilson 2012). Nesting is gregarious with 0.69-1.04 nests/m^2 (King 1999; Muzaffar *et al.* 2012). Clutch sizes vary from 1-4 eggs/nest, and mean clutch size ranges from 2.04-2.43 eggs/nest (Jennings 2010; Muzaffar *et al.* 2012). Muzaffar *et al.* (2012) reported hatching success of 58% and fledging success of 65%, which are comparable to other similar-sized cormorant species (Nelson 2005). Disturbance at the colony from construction activities, illegal egg collection, illegal hunting and predation from introduced or native predators constitute important threats to the species in the remaining breeding areas (Jennings 2010; Muzaffar *et al.* 2012; Wilson 2012; Environment Agency Abu Dhabi 2014).

Muzaffar *et al.* (2013) modeled the Siniya Island breeding population (based on the 1996 estimates from Jennings (2010)) and estimated that mortality of 900 adults per year could reduce the Siniya Island subpopulation to extinction in 20 years. Mortality at Siniya Island was estimated in 2011 to be at least 2,000-3,000 adults per year, primarily due to predation by native red foxes (*Vulpes vulpes*) and introduced feral cats (*Felis catus*) (Muzaffar *et al.* 2013). Thus, there is an urgent need to better assess breeding population size, establish breeding parameters, mitigate threats and identify and implement conservation actions to protect this globally significant breeding colony.

Our objectives for the Siniya Island Socotra Cormorant colony were to: 1) estimate the breeding population size over a 5-year period; 2) determine the breeding phenology; and 3) identify reproductive parameters.

METHODS

Study Area

Siniya Island (25° 36′ 20.63″ N, 55° 36′ 28.85″ E) is a small, nearshore island situated southeast of the Arabian Gulf, ~2 km from Umm Al Quwain Emirate within the United Arab Emirates. The total length of the island is about 14 km from tip to tip and about 3.5 km at its widest point (Fig. 1). Surrounded by shallow water, the colony of Socotra Cormorants on Siniya Island is restricted to the north-central part of the island. The habitat consists of mixed desert scrub (*Haloxylon-Arthrocnemum macrostachyum* complex), loose sandy gravel and plantations of umbrella thorn (*Acacia tortilis*), mesquite (*Prosopis juliflora*) and khejri tree (*Prosopis cineraria*) (Jongbloed 2003). The nearest islands with breeding Socotra Cormorants are 329 km west in Abu Dhabi (Jennings 2010).

Breeding Population Size and Spatial Distribution

During five breeding seasons (September to February 2011-2015) on Siniya Island, we mapped the total area over which Socotra Cormorants nested (area of occupancy) and then estimated the breeding bird population by using nest density estimates. During each breeding season, observers mapped the extent of the colony by walking at a distance of ~20 m adjacent to the colony and taking GPS coordinates at intervals. Additionally, known landmarks (e.g., distance from large tree, distance from lagoon) were also used to validate the area of occupancy manually after entering GPS coordinates into Google Earth. Area of occupancy was estimated using online software that converted shape files in Google Earth to areas. Nesting density was calculated from randomly scattered 5-m x 5-m plots in 2011 (n = 14 plots; Muzaffar *et al.* 2012), 2014 (n = 10) and 2015 (n = 10). In 2012 and 2013, nest densities from 2011 were used. Breeding population was estimated as the product of area of occupancy (m^2) and nest densities (nests/m^2). Standard errors for the mean breeding population for each year were derived by randomization of individual breeding population estimates (n = 14 in 2011, 2012, 2013; n = 10 in 2014, 2015) with 1,000 replications with replacement (McGarigal *et al.* 2000).

In 2012 and 2013, we also carried out ground counts to compare the density-area estimates of the

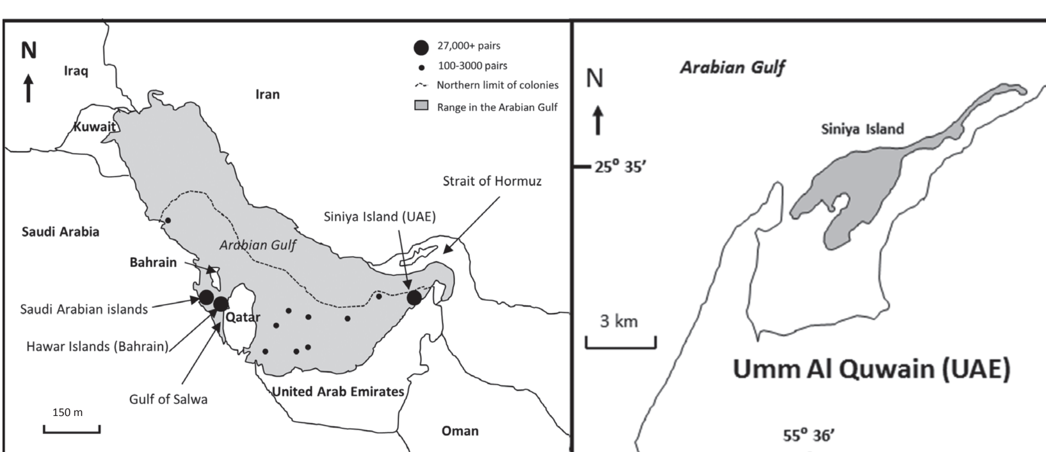

Figure 1. (Left) Geographic locations of Socotra Cormorant colonies in the Arabian Gulf. (Right) Inset map of Siniya Island and mainland Umm Al Quwain Emirate.

breeding population. Ground counts were conducted during peak nesting using a Canon Camcorder (Canon Inc.) to record the birds counted as observers walked along the length of the colony at a distance of ~20 m from the colony. Furthermore, in 2015, we used a drone with a mounted high definition video camera (DJI Phantom 2 Vision Plus v. 3) to more accurately enumerate breeding Socotra Cormorants and their chicks. Breeding birds were counted as the birds were beginning to breed until peak breeding was reached, to account for any additional nests added to the area of occupancy of the breeding birds.

Breeding Performance

We studied breeding activities primarily during the 2011 and 2012 seasons, although some aspects of breeding biology were also monitored during the 2013, 2014 and 2015 breeding seasons. In September 2011, we selected 14 study plots on the breeding colony that were located throughout the colony (see Muzaffar *et al.* 2012). We approached study plots to slowly flush incubating birds and delineated each plot by laying out 5-m x 5-m yellow rope. We then photographed the plot to ensure all nests were clearly visible and included in the photograph. We then visited each plot on 12 and 25 October and 14 and 29 November 2011 to determine hatching success (proportion of eggs that hatched successfully) and used this as an index of breeding performance. Hatching success was compared between years using a Z-test with $\alpha = 0.05$ (Sokal and Rohlf 2012).

In 2012, we used four plots that were monitored remotely by high definition Canon Camcorders (Canon Inc.) with optical zoom. Each plot was demarcated using a printed image from the video to ensure that future observations could be associated with known features on the landscape. Hatching success was determined from video footage from 11 and 26 November 2012 of clearly visible nests.

In 2013, 2014 and 2015, hatching success could not be quantified due to logistical challenges preventing regular access to the island. Clutch size was estimated in 2011, 2012, 2013 and 2014 and compared between years using one-way analysis of variance (ANOVA) with $\alpha = 0.05$.

In 2013, eight photos of independent sections of the colony showing the breast plumage of nesting birds clearly ($n = 123$) were examined to determine the proportion of breeding birds exhibiting juvenile plumage in relation to those that exhibited normal adult plumage. This would help to estimate age at first breeding based on known plumage variation in sub-adults in relation to age (Nelson 2005).

RESULTS

Breeding Socotra Cormorants used different parts of the island during the 5 years of study (Fig. 2). In 2011, nesting occurred in a distinct area with scattered trees, but this area was not used in later years as the birds relocated to a sandbank in subsequent years. There was some overlap in nesting areas used in the other years of the study (Fig. 2). The ground counts and the density-area estimates were closely aligned (Fig. 3), and the estimate using the drone enhanced the accuracy of the counts due to the fact that all nesting birds and their nests were clearly visible (Figs. 3 and 4). The breeding populations alternated between high counts in one year followed by a lower count in the subsequent year (Fig. 3). The lowest breeding population was recorded in 2011 with 28,152 ± 3,780 pairs while the highest breeding population was recorded in 2014 with 41,568 ± 3,761 pairs with no overall trend visible.

Incubation period was estimated in 2011 to be 24-27 days. The laying date was 7 days earlier in 2011 compared to both the 2012 and 2013 seasons (Table 1). Likewise, first chicks appeared earlier and fledged earlier in 2011 compared to 2012 and 2013.

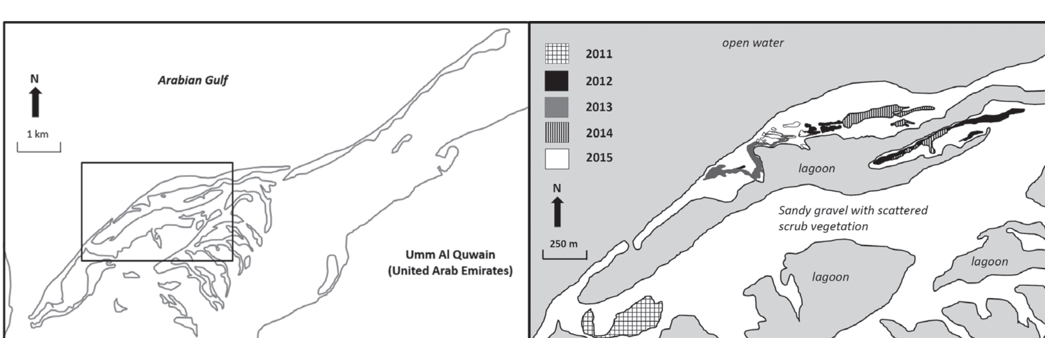

Figure 2. Spatial distribution of Socotra Cormorant breeding sites on Siniya Island, 2011-2015.

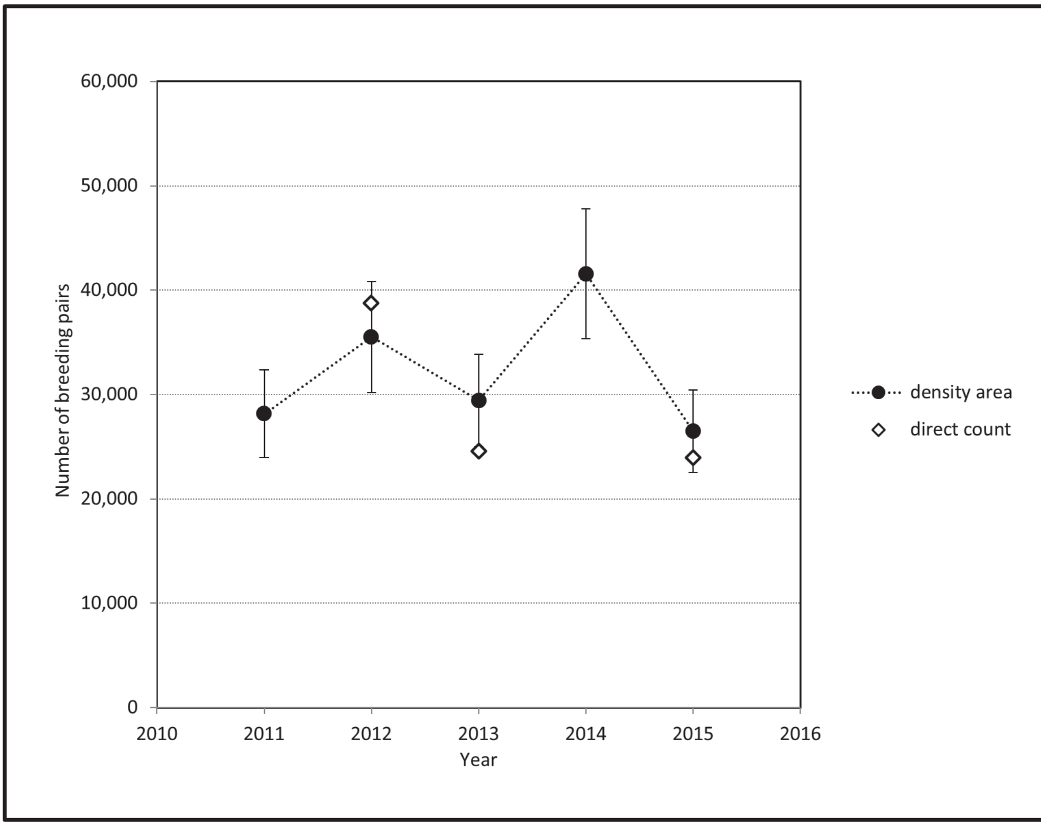

Figure 3. Comparison of total number of Socotra Cormorant breeding pairs estimated from density and area of occupancy (closed circles) and from direct counts (open diamonds). Error bars represent standard errors estimated from bootstrapping methods with resampling.

Clutch size in Socotra Cormorants was between 1 and 4, with annual means being between 2.21 and 2.79 eggs/nest. Clutch size varied significantly between years, with clutch size being larger in 2012 and 2013 compared to 2011 (ANOVA, F = 12.25, $P < 0.001$). Hatching success was significantly higher in 2012 compared to 2011 (Z = -3.655, $P < 0.001$). Parents started abandoning chicks between 10 December and

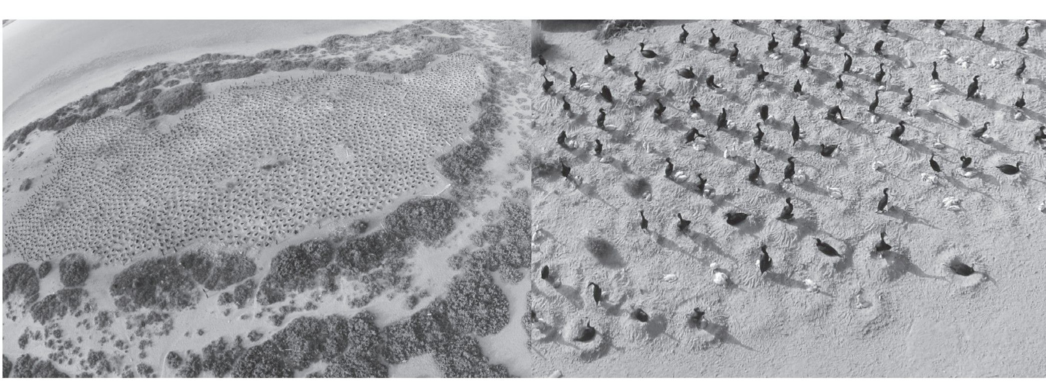

Figure 4. (Left) Image taken from a drone equipped with a camera showing part of the Siniya Island colony of Socotra Cormorants. (Right) Example of zoomed in images that were used in counting nesting Socotra Cormorants in the colony (white chicks are visible in nests without any adults).

Table 1. Timing of breeding and population parameters.

Population Parameter or Timing	2011	2012	2013	2014	2015
Laying date	13-16 Sept[a]	20-25 Sept	22-25 Sept[a]	3-6 Oct	24-27 Sept
First chicks	11 Oct	14-22 Oct	19 Oct	27 Oct	18 Oct
Clutch size (nests)	2.43 ± 0.04 (314)	2.79 ± 0.03 (53)	2.69 (33)	2.21 ± 0.06 (146)	—
Hatching success (%)	58.71 ± 5.85	81.76 ± 4.86	—	—	—
≥ 80% of chicks abandoned by adults	10-25 Dec 2011	15-30 Dec 2012, 12-28 Feb 2013	19 Dec 2013-9 Jan 2014	14 Dec 2014-21 Jan 2015	21 Dec 2014-11 Jan 2016

[a]Back-calculated in years in which first eggs were already laid before first visit on island and based on an incubation period of 24-27 days determined in 2012.

11 January, with more than 80% of chicks being unattended by their parents during this time. All chicks were absent from colonies usually by the end of January. An exceptional year was 2012, when a batch of 1,700 nests was initiated on 21 February 2013. However, no young were successfully raised from any of these nests.

Age at first breeding was determined to be 14 months based on observed breeding of young birds with residual juvenile plumage on the breast (Frontispiece). Juvenile Socotra Cormorants retain the lighter brownish feathers until the beginning of their second year, when the brown coloration is limited to scattered streaks on the breast (M. A. R. Khan, pers. commun.). However, the proportion of second calendar year breeders was estimated at 1.62% (*n* = 123 nests).

DISCUSSION

Siniya Island remains the largest breeding colony in the United Arab Emirates, with robust estimates of breeding birds ranging from 28,152-41,568 pairs over the 5-year period of study. Spatial distribution of the colony varied between years, consistent with other studies in the Arabian Gulf (King 1999; Jennings 2010). Breeding population size seemed to fluctuate annually possibly due to environmental conditions linked with food availability. We suggest that the colony size was larger in 2012 compared to 2013 because of the location of the migrating fish stocks. Nearby fish stocks in 2012 would allow easy access for a larger number of breeding birds compared to the supposedly more distant fish stocks in 2013. This might have forced birds to make longer foraging trips, which in turn could have resulted in fewer breeding birds.

This pattern of an increase in breeding populations in alternate years is consistent with observations in other colonies. For example, Great Cormorants across colonies in England and Wales, U.K., exhibit a similar pattern of high and low breeding colonies suggesting environmental factors could impact breeding numbers (Chamberlain *et al.* 2013). In South Africa, Bank Cormorants (*P. capensis*) and other seabird species delayed breeding by 1 year in response to lowered abundance of anchovies (Crawford and Dyer 1995). Similarly, Socotra Cormorants in Abu Dhabi waters (western Arabian Gulf) also have high and low breeding populations in different years (Environment Agency Abu Dhabi 2014). This supports the idea that environmental factors, including abundance of nearby prey stocks, could influence breeding decisions in seabirds, including many species of cormorants, with individuals opting not to breed in some years (Crawford and Dyer 1995; Hamer *et al* 2001; Nelson 2005). Furthermore, evidence from some species of cormorants indicates that density-dependent regulation may occur in cormorants. Ridgway *et al.* (2006) showed that Double-crested Cormorants in Huron Bay, Canada, experienced density dependent growth, followed by stabilization of the population, whereby populations fluctuated around a carrying capacity of 10,000-11,000 nests. Given that there is a large population of Socotra Cormorants on Siniya Island, we speculate that this population has stabilized recently (perhaps over the last decade), and current fluctuations are consistent with a population at carrying capacity that is periodically influenced by fish abundance. Further studies are required to substantiate this claim.

Socotra Cormorants have been declining throughout their range in recent decades. Compared to other breeding colonies in the Arabian Gulf, Socotra Cormorants breeding on Siniya Island could have surpassed the size of the breeding colony in the Hawar Islands in Bahrain (considered to be the largest breeding colony in the region) and the Saudi Arabian colonies in the Gulf of Salwa (west of Qatar; Fig. 1). King (1999) reported a gradual decline in the Hawar Islands colony size from 28,781 pairs in 1994 to 25,039 pairs in 1998 to 20,539 pairs in 1999. However, more recently, Jennings (2010) suggested that the population size was again around 27,000 pairs in the 2005-2006 breeding season. The Saudi Arabian islands in the western Gulf of Salwa reportedly hosted 30,000-40,000 pairs in 2005-2006, although there is evidence that breeding birds may be switching between nesting colonies between years within the Gulf of Salwa, possibly including the Hawar Islands (Jennings 2010). Compared to these estimates in the Gulf of Salwa, and assuming that further declines have not occurred in the region since the 2005-2006 assessment (Jennings 2010), the Siniya Island colony appears to be the single largest colony in the Arabian Gulf. Thus, the global importance of Siniya Island cannot be overemphasized.

Since the Siniya Island colony (eastern Arabian Gulf) is more than 400 km away from the Gulf of Salwa (western Arabian Gulf), exchange between breeding birds in these two regions within the same season is unlikely. However, during the summer, adult birds disperse westward into central/southern Arabian Gulf, when different populations converge in Abu Dhabi waters (S. B. Muzaffar, unpubl. data). It is not known if birds from the Gulf of Salwa merge with the other major concentration in Abu Dhabi waters during the summer. On the other hand, none of satellite tagged birds from our ongoing studies have entered the Gulf of Salwa during the non-breeding summer, suggesting limited mixing between breeding populations. Systematic and synchronous surveys have not been done in recent years in Bahraini and Saudi Arabian colonies, and further monitoring of these colonies as well as those in Abu Dhabi is required.

In 2011-2013 and 2015, Socotra Cormorants on Siniya Island initiated egg laying activities from 13-25 September with an estimated peak on 22 September. However, in 2014, the peak in breeding (maximum number of nests) was observed on 5 October, with the first chicks observed as early as 11 October. Incubation period was comparable to similar sized cormorant species. The Bank Cormorant has an incubation period of 25-31 days (Cooper 1987).

Clutch size was comparable to (slightly higher than) the Bank Cormorant that lays clutches with a mean of 2.02 eggs/nest (Cooper 1987). We suggest that the variation in clutch size could have been influenced by environmental conditions affecting food availability.

Hatching success estimated in 2011 was significantly lower than in 2012. We suggest that 2011 was an unusual year with the birds breeding in a location far away from their usual breeding sites observed in the remaining seasons (Fig. 2) and in earlier years (Umm Al Quwain Municipality, unpubl. data). Fledging success in Socotra Cormorants reported earlier (Muzaffar *et al.* 2012) is likely an overestimate. Socotra Cormorants initiate creche behavior within 2 to 3 weeks of hatching (Gubiani *et al.* 2012; Muzaffar *et al.* 2012). Frederiksen and Bregnballe (2000) found in their long-term study of color banded Great Cormorants that post fledging mortality could be very high (25-58%), making commonly used estimations of fledging success (Hipfner and Greenwood 2009; Muzaffar *et al.* 2012) uninformative.

Age at first breeding was estimated at 14 months based on juvenile plumage (R. Khan, pers. commun.). Only a small portion of the nesting birds exhibited this plumage, and we assume that the majority of fledged birds breed for the first time from when they are 2 years old or later. In many cormorant species, age at first breeding is 2 to 3 years. Muzaffar *et al.* (2013) speculated that breeding occurred on average after 3 years in their modeling-based approach to population demography. Evidence of earlier breeding age of Socotra Cormorants in this study suggests that populations may increase relatively rapidly compared to what was previously believed (Muzaffar *et al.* 2013). On the other hand, lower fledging success compared to that used in Muzaffar *et al.* (2013) could have a negative impact on population growth rates, making them more prone to declines. Further studies to attempt a more systematic robust estimate of fledging success could help better characterize population dynamics of this species.

Our population monitoring data suggest that Socotra Cormorants breeding on Siniya Island appear to be stable over a 5-year time span with annual fluctuations in the breeding population comparable to large colonies of seabirds, including cormorants, and usually associated with food availability (Crawford and Dyer 1995; Ridgway *et al.* 2006; Chamberlain *et al.* 2013). Breeding parameter estimates have improved, and the impact of various activities on populations could be better modeled. We propose that the use of drones is a major advancement in monitoring tools, especially to improve the accuracy of ground counts at relatively low cost. Long-term monitoring of all colonies of Socotra Cormorants could be done reliably and more frequently to generate global population data. We suggest that such assessments of the total population be done in a coordinated manner across range countries. Management of Socotra Cormorants should focus on protection of remaining islands used as breeding colonies, maintenance of habitat quality by removal of wastes, minimizing disturbance or illegal hunting activities, and controlling introduced predators.

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