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Segregation in Timing of Breeding ReducesInter-specific Competition in Tern Species on the Persian Gulf Islands

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Abstract
Several factors such as prey availability, weather, the age and experience of adults, day-length and probably othershave an effect on the timing of breeding in birds. We studied the timing of breeding in the Bridled Tern *Sterna anaethetus*, Lesser Crested Tern *Sterna bengalensis* and Greater Crested Tern *Sterna bergii* as the three most abundantsympatric seabird species on islands in the Persian Gulf. The results showed overlap in the timing of breeding among the three species. However, synchrony was found in individual mixed colonies of Lesser Crested Tern (11.3±0.16 days, range 8-17 days, n=10) and Greater Crested Tern (9.6±0.23 days, range 8-12 days, n=5), while there was a spread of over seven weeks in egglaying in the Bridled Tern. Commencement of nesting during the years of the study correlated closely with the arrival of spring weather and those factors which affected the oceanographic status of the Persian Gulf. High tides and weather conditions mostly affected low-lying nesting areas on the Khan Islands and in the coastal zone of Omol-Karam Island. We conclude that the timing of breeding cannot reduce intra-specific interactions in an assemblage of breeding seabirds in the Persian Gulf. However; asynchrony of breeding between mixed colonies of Lesser Crested Terns and Greater Crested Terns and in the whole colony of Bridled Terns could reduce inter-specific competition.

1. Introduction

Colonial breeding behaviour is obviously an important factor in seabird breeding biology (Coulson 2002; Steinkamp*et al*. 2003). Aggregations of different nesting species have been reported for many birds (Richardson & Bolen 1999; Quinn & Ueta 2008). The majority of these cases involve two or more colonial seabirds located in a particular area (Richardson & Bolen 1999). About 98% of seabird species are colonial and have synchronously timed breeding cycles within colonies (Hamer *et al*. 2002). It is not immediately evident why seabirds should have a higher proportion of colonial species than other bird groups. They use aquatic habitats which do not provide nesting sites, and breeding areas are limited to the coastline closest to the water and mostly to uninhabited islands (Hamer *et al*. 2002). Owing to the spatial variation in feeding and breeding sites in seabirds, many of them move much farther to obtain food for their chicks than other bird species (Weimerskirch *et al*. 2009). This possibly explains why both members of the pair are required to rear the chicks; reaching the

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feeding areas and feeding the chicks may take more time than in other bird species.

Social stimulation arising from colonial breeding is an adjustment that assists faster and more efficient changes of the time of breeding in relation to environmental conditions. There is evidence that social stimulation in concert with environmental factors can act as a proximate mechanism to synchronize reproductive events among colonial breeders (Wilhelm & Storey 2002). Breeding at the correct time is necessary in seasonal climates such as subtropical and temperate regions in order to ensure that the energy demands of reproduction, mainly related to the food requirements of chicks, coincide with peak food availability (Frederiksen *et al.* 2004).

In the Mond Islands in the Persian Gulf, there is pronounced seasonality in food availability which seems to be related to phytoplankton blooms as discussed by Monticelli *et al*. (2007) in the western Indian Ocean. Uninhabited offshore islands in the Mondgroup, including Nakhilu, Omol-Karam and Khan Islands, support many thousands of nesting seabirds (Scott 2007; Tayefeh *et al*. 2011, 2013). The species selected for this study were the three most abundant sympatric seabird species in the Mond Islands, namely the semi-precocial Bridled Tern *Sterna anaethetus*, the precocial Lesser Crested Tern *Sterna bengalensis* and the precocial Greater Crested Tern *Sterna bergii*. In 2009, 2010 and 2011, the most abundant species was Lesser Crested Tern (21,000–23,000 pairs), followed by Bridled Tern (17,000–19,000 pairs), while Greater Crested Tern had the smallest breeding population (2,400–2,500 pairs, Tayefeh *et al*. 2011, 2013). Mixed colonies of Lesser Crested Tern and Greater Crested Tern were present on Omol-Karam Island in the 2009 and 2010 breeding seasons, but were absent in 2011 because of the presence of Golden Jackals *Canis aureus* L., 1758; the birds had presumably shifted to Nakhilu Island. Little information has been published on the breeding phenology of the seabirds of the islands in the northern Persian Gulf. The only study on breeding phenology of seabird species was that reported by Behrouzi-Rad & Tayefeh (2008). These authors reviewed the arrival dates of migrants, the egglaying and hatching periods, and outward migration dates of four species of terns on Nakhilu Island.

The present study describes the timing of breeding and co-existence of tern species on the Persian Gulf islands. The main objective of this paper was to study the breeding phenology of three tern species to learn how several sympatric breeding species with similar breeding habitats are able to breed together on small islands. In this regard, the comparison of species breeding sympatrically provides valuable information that can address key questions about breeding strategies of colonial seabirds in subtropical regions. The specific objectives were: 1) to investigate the timing of breedingin tern species that bred syntopically in colonies, 2) to explore the variations in timing in order to describe the social interactions and co-existence between tern species, and 3) to investigate the factors affecting the breeding season of the species during the 2009–2011 breeding seasons.

2. Materials and Methods

2.1. Study area

The main study area (from 27º 48´ to 28º 01´ N and from 51º 18´ to 51º 34´ E) was situated on three Iranian islands known as the Mond Islands: Omol-Karam, Nakhilu and Khan (Fig. 1). The Mond Islands are located in the northern part of the Persian Gulf, in south-eastern Bushehr Province, southern Iran. Nakhilu and Omol-Karam Islands are located in Dayyer-Nakhilu Marine National Park and Khan Island is located in the Mond Protected Area. All of these three islands have also been designated as Important Bird Areas (Evans 1994). Because of the suitable soil texture, vegetation cover, nutrient-rich surrounding waters and absence of natural and human predators, these islands are safe and suitable for nesting seabird species and also for sea-turtles. The islands are uninhabited and are only used as resting areas for local fishermen and as shelters during seasonal storms.

Generally, there are two seasons: the winter months of November to March are comparatively cool, while the seven summer months from April to October are hot and dry. From June to August, conditions are harsh because of the extreme heat. Annual precipitation in the area averages 196.9 mm and is limited almost entirely to the winter months.

The maximum and minimum temperatures are 50°C (on 5 June 2003) and 6°C (on 3 January 2009), respectively. The fastest wind speed ever recorded was 25 m/sec on 9 July 2006. Tides in the Persian Gulf are complex and the dominant pattern varies from being primarily semi-diurnal to diurnal. Tidal hydrodynamic simulations predict tidal flows of ~0.9m/s near the Strait of Hormuz and at the head of the Persian Gulf, and 0.3–0.6 m/s elsewhere in the Gulf (Kaempf & Sadrinasab 2006).

2.2. Methods

The surveys were conducted from late March 2009 until the end of August 2011. The breeding season was divided into the following phases: first arrivals, nest building, egg laying, hatching, chick rearing, fledging and outward migration (O'leary & Jones 2006). Based on the breeding phenology of seabird species, the starting date of each breeding phase for each colony was determined as the date on which one of the parents was first observed engaging in a particular phase.

Field visits coincided with the observation of the first arrivals and the first egg laying of a species at the colony. Additional data on the presence or absence of breeding species were obtained from the unpublished records of personnel of Bushehr Provincial Office of DOE. In the case of missing data, the commencement of each breeding phase could be estimated by back-calculating from the start of the next phase using the mean period of each phase (Le Corre 2001; Hamer *et al.* 2002; Villard & Bretagnolle 2010).

During the 2009, 2010 and 2011 breeding seasons, the seabird populations in the vicinity of the Mond Islands were checked daily to find where terns were roosting, and when they moved into their breeding areas on the islands. Colonies of each species were visited from the arrival of the first birds through nest building, egg laying, incubation and chick rearing up to fledging (Nicholson 2002; Hirshman *et al.* 2007).

To determine the egg laying dates of Bridled Terns, the nesting areas were checked at three-day intervals to find when the first clutches were laid. The synchrony of egg laying and hatching in the Bridled Tern colonies was monitored at five-day intervals in 2010 and 2011 in a section of the colonies with 25%–50% vegetation cover. In the mixed breeding colonies of Lesser Crested and Greater Crested Terns, colonies and sub-colonies were checked daily. Sub-colonies were smaller colonies of the main colony of a species on an island. New nests and the edges of the colonies were marked with small wooden labels. This marking revealed the growth of each colony, and enabled hatching dates and any predation to be recorded (Langham & Hulsman 1986). The low-lying colonies on the Mond Islands were checked for flooding by tidal water at spring high tides, the timing of these being predicted from data extracted from the Iran Hydrology Official Website.

Table 1. Breeding phenology of Bridled, Greater Crested and Lesser Crested Terns on Nakhilu Island, 2009-2011.

Species	Year	First arrivals	Nest building	First egg laying	Hatching date	Chick rearing	Fledging period	Outward migration
Bridled Tern	2009	29 Mar.	Mid-Apr.	02 May	Early June	June–July	End of July	Mid-Aug.
	2010	27 Mar.	Mid-Apr.	05 May	Early June	June–July	End of July	Mid-Aug.
	2011	10 Apr.	End of Apr.	12 May	Mid-June	Mid-Jun to mid-Aug.	Mid-Aug.	Late Aug.
Lesser	2009	04 May	Mid-May	18 May	Early June	June–July	Late July	Mid-Aug.
Crested Tern	2010	02 May	Mid-May	24 May	Mid-June	June–July	End of July	Mid-Aug.
	2011	08 May	Mid-May	23 May	Mid-June	Mid-June to July	Early Aug.	Late Aug.
Greater	2009	04 May	Mid-May	17 May	Early June	June–July	Late July	Mid-Aug.
Crested Tern	2010	02 May	Mid-May	22 May	Mid-June	June–July	Early Aug.	Mid-Aug.
	2011	08 May	Mid-May	25 May	Late June	July– mid-Aug.	Mid-Aug.	Late Aug.

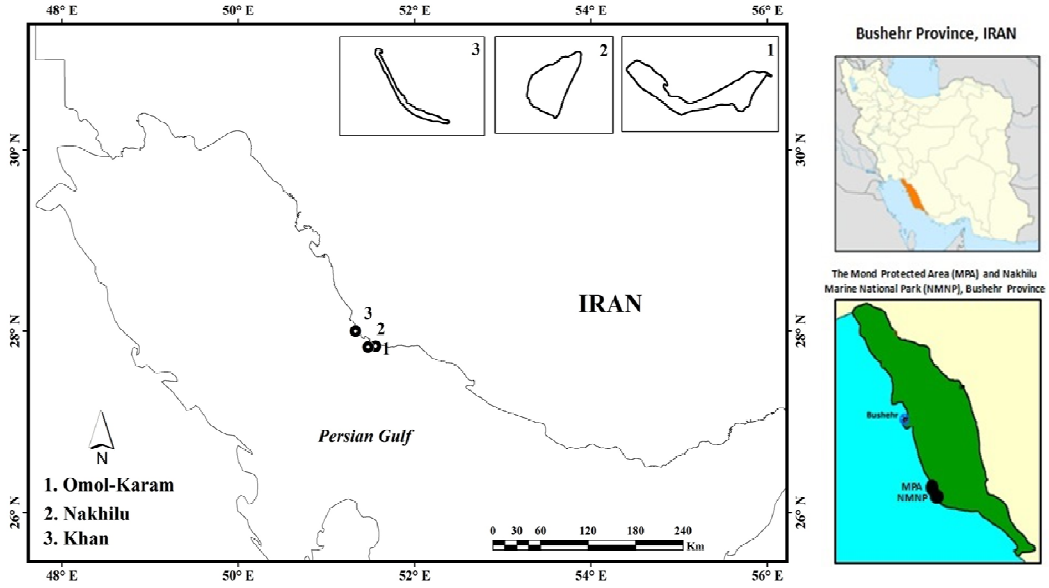

Fig. 1. Location of the Mond Islands in the Mond Protected Area and Nakhilu Marine National Park, Bushehr Province, Iran.

Table 2. Breeding phenology of Greater Crested and Lesser Crested Terns on Omol-Karam Island, 2009-2011.

Species	Year	First arrivals	Nest building	First egg - laying	Hatching date	Chick rearing	Fledging period	Outward migration
Lesser Crested Tern	2009	03 May	Early May	11 May	Early June	June–July	Late July	Mid-Aug.
	2010	12 Apr.	Early May	08 May	Early June	June–July	Mid July	Early Aug.
	2011	07 May	Late May	No breeding	No breeding	No breeding	No breeding	No breeding
Greater Crested Tern	2009	03 May	Early May	10 May	Early June	June–July	Late July	Mid-Aug.
	2010	12 Apr.	Late Apr.	05 May	Early June	June–July	Mid-July	Early Aug.
	2011	07 May	Late May	No breeding	No breeding	No breeding	No breeding	No breeding

Note: There were no breeding colonies of Lesser Crested Tern and Greater Crested Tern on Omol-Karam Island in 2011 due to the presence of Golden Jackals.

Table 3. Egg laying periods (in days) in colonies of Greater Crested and Lesser Crested Terns on Nakhilu and Omol-Karam Islands, 2009–2011.

Island	Omol-Karam		Nakhilu	
Species / Colony	Lesser Crested Tern	Greater Crested Tern	Lesser Crested Tern	Greater Crested Tern
2009				
Colony 1	13	10	10	9
Colony 2	-	-	13	9
2010				
Colony 1	8	12	17	12
Colony 2	10	-	-	-
2011				
Colony 1	-	-	9	-
Colony 2	-	-	11	-
Colony 3	-	-	8	-
Colony 4	-	-	10	-

3. Results

3.1. Arrival and departure

Bridled Terns were not found around the Mond Islands during the mid-winter censuses from 2009 to 2011.The first Bridled Terns arrived on Nakhilu Island in late March in 2009 and 2010, but not until 10 April in 2011 (Table 1). Nest occupation by Bridled Terns began in mid-April in 2009 and 2010, but in late April in 2011. Adult Bridled Terns and their young left the islands in September during each year of the study. The results of mid-winter censuses by Bushehr Provincial Office of the DOE showed that there were 8, 0 and 1 Lesser Crested Terns in 2009, 2010 and 2011, respectively. No Greater Crested Ternswere recorded during thesethree mid-winter censuses. The Lesser Crested Tern and Greater Crested Tern are normally solitary or occur in small loose groups outside the breeding season in the Mond area, arriving in flocks in early April and reaching a peak in numbers after one to three weeks.

3.2. Comparison between species

The Bridled Tern arrives in late March, about one month earlier than the Lesser Crested and Greater Crested Terns (Table 1). The first clutch of Bridled Tern was laid on 2 May in 2009, on 5 May in 2010, and on 12 May in 2011. The first chick hatched on 1 June in 2009, 5 June in 2010 and 13 June in 2011, and the first fledglings were observed in late July in 2009 and 2010, and in mid-August in 2011.

On Omol-Karam Island, the first breeding colonies of Lesser Crested and Greater Crested Terns were observed simultaneously on 3 May in 2009, on 12 May in 2010 and on 7 May in 2011 (Table 2). In 2009, the first egg was recorded on 10May 2009 when a colony of Greater Crested Terns began egglaying (Table 2). One day later, Lesser Crested Terns commenced egglaying in a mixed colony with Greater Crested Terns.The Greater Crested Terns ceased egglaying on 19 May, but the Lesser Crested Terns continued laying until 24 May. The first case of hatching in 2009 occurred on 5June when some newborn chicks of Lesser Crested Tern were observed. In 2010, Greater Crested Terns began egglaying on 5 May and after three days Lesser Crested Ternsalso started to lay eggs at this colony. On 23 May, Lesser Crested Terns began laying eggs at a second colony and continued until 3 June. Some parts of these colonies were flooded by high spring tides. After this event, re-nesting continued until the middle of July. In 2011, no Lesser Crested Terns or Greater Crested Terns bred on Omol-Karam Island because of the presence of Golden Jackals.

On Nakhilu Island, there were two colonies in 2009, one colony in 2010 and four colonies in 2011. In 2009, egglaying was first recorded on 16 May for Greater Crested Tern and 17 May for Lesser Crested Tern at the first colony and a few days later in the second colony (Table 1). On 23 May, Lesser Crested Terns began egglaying at the second colony and continued until 3 June. In 2010, Greater Crested Terns laid eggs from 22 May to 3 June and Lesser Crested Terns from 24 May to 10 June. In 2011, the first clutch, that of a Greater Crested Tern, was recorded on 22 May at a sub-colony. Three days later, egglaying of Greater Crested Terns and Lesser Crested Terns was observed at two of the main colonies (Table 1) and six sub-colonies. One week later, egglaying began at a third colony in the east of the island. On 10 June, egglaying was recorded at the fourth colony. Most of the sub-colonies were occupied by Lesser Crested Terns nests and there were not many Greater Crested Tern nests.

On Khan Island, the first groups of Lesser Crested Terns and Greater Crested Terns were observed in early May in 2009 and in mid-April in 2010, but egglaying was unsuccessful because of tidal flooding. In 2011, the first Lesser Crested Tern and Greater Crested Tern clutches were observed on 5 May at two colonies on the island. The first chicks were observed on 9 June. Most parts of the colonies were destroyed by tidal flooding and only 130 chicks were counted at the end of the breeding season.

3.3. Egglaying period

Egg laying in the Bridled Tern was not synchronized, being spread over ~46 days (n=112) in 2010 and ~44 days (n=119) in 2011; however, 75% of eggs were laid during the 15-day period from 17 May to 1 July in 2010, and 84% of eggs were laid during the 15-day period from 27 May to 11 June in 2011 (Fig. 2). The frequency distribution of egglaying dates of this

species shows that egglaying peaked in late May in 2010 and in mid-June in 2011. The egglaying periods of Lesser Crested and Greater Crested Terns are shown in Table 3. The mean egglaying periods were calculated for Nakhilu and Omol-Karam Islands from 2009 to 2011; 10.9±0.16 days (range 8–17 days, n=10) for the Lesser Crested Tern and 10.4±0.23 days (range 8–12 days, n=5) for the Greater Crested Tern (Table 3). The results showed that egglaying in the Lesser Crested Terns and Greater Crested Terns was synchronized, but egglaying in the whole colony was spread over a long period, e.g. 27 days on Omol-Karam Island in 2010 and 28 days on Nakhilu Island in 2011. Part of this long egglaying period was due to replacement clutches being laid in old nests within the colonies.

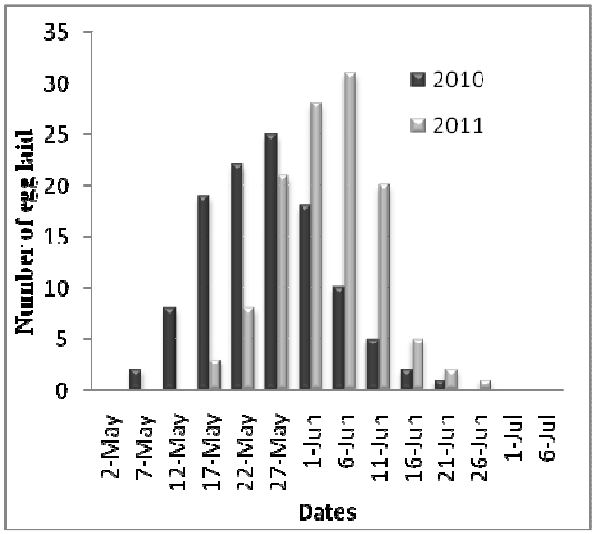

Fig. 2. Number of Bridled Tern eggs laid at five-day intervals within a selected area in the 2010 and 2011 breeding seasons.

4. Discussion

4.1. Asynchrony in the Bridled Tern

In 2011, the first Bridled Terns arrived at the colony two weeks later than in 2009 and 2010. Egglaying was initiated on 12 May, more than one week later than in the two previous years. Therefore, it seems that the arrival of the Bridled Tern on the Nakhilu Island was not as variable between years.

The results of this study confirm that egglaying in the Bridled Tern is not synchronized, being spread over seven weeks from mid-May until the end of June (Fig. 2), although part of this spread may be a result of the replacement of failed clutches. This finding is consistent with Bridled Tern breeding phenology on Tree Island (Hulsman & Langham 1985) and Penguin Island (Garavanta & Wooller 2000) in Australia and in New Caledonia (Bretagnolle & Benoit 1997; Villard & Bretagnolle 2010).

Non-synchronous laying and hatching spread the availability of prey over a longer period of time and thereby enable predators to take more prey but no potential predator of the Bridled Tern was found on the Mond Islands. It has been suggested that in some species breeding asynchrony is a way to reduce intra-specific competition (Fasola & Canova 1991; Valle & Scarton 1999) which is particularly strong during the breeding season in colonial species.

4.2. Synchrony of Greater Crested Terns and Lesser Crested Terns at each colony

Egglaying in the whole colony of Lesser Crested Terns and Greater Crested Terns was not synchronized, but egglaying in individual colonies was highly synchronized. Synchrony in egglaying assists in the formationof crèches. Evolutionary theory proposes that crèching is likely to develop when the chicks reared in a group have a better chance of surviving than those reared alone (Coulson 2002). Chick-crèching usually occurs among birds that breed in large, loose colonies and whose eggs all hatch at about the same time. The day-care system permits a fledging to lose itself in a crowd and decreases the risk of predation. In the case of chicks remaining dependent on parents for food, crèching permits the parents to spend more time foraging away fromthe colony (Ehrlich *et al.* 1988).

4.3. Fine asynchrony of Greater Crested and Lesser Crested Terns between colonies

There was no clear annual variation in the timing of breeding of theLesser Crested and Greater Crested Ternson each island, but the timing of breeding of these two terns showed some variation between the different islands. On Khan Island, egglaying in both species took place sooner than on the other islands. A possible reason for this early nesting on Khan is to avoid the loss of nests by high spring tides (took place in the area in June). On Omol-

Karam Island, first arrival, nesting and egglaying took place one to three weeks earlier than on Nakhilu Island. It can be due to the proximity of Omol-Karam to feeding areas and the availability of large areas of the preferred nesting habitat.

4.4. Food segregation when breeding is synchronized

Commencement of nesting during the three years of this study correlated closely with the arrival of spring weather. However, determining the effects of weather on breeding seabirds requires long-term monitoring of populations and individuals (Schreiber 2002).

It seems that as in tropical and subtropical breeding locations elsewhere (Lack 1968), prey availability plays an important role in the breeding phenology of seabirds in the Persian Gulf islands. The terns examined in this study mostly consumed the larval and juvenile stages of fish species (Tayefeh *et al*. 2014). In the Persian Gulf region, food availability for terns was characterized by marked seasonality; abundance and richness were generally higher in the warmer seasons than inthe cooler seasons (Burt *et al*. 2012). The reproductive cycle of fishes in the Persian Gulf is such that the abundance of fish larvae is highest in spring and early summer (Vosoughi*et al*. 2010; Hakimelahi *et al*. 2011), which coincides with the breeding of seabirds. Lesser and Greater Crested Terns foraging at sea in the vicinity of Nakhilu and Omol-Karam Islands or far offshore return to the islands at night. Bridled Terns roost in the vegetation along the southern side of the island which is located closest to the feeding areas.

Conclusions

Despite the variation in egglaying dates between years, the breeding periods of the abundant tern species on the Mond Islands were synchronized in each year, with the breeding phases, and especially the chick-rearing period, largely overlapping in the three breeding species. There was no time segregation that could reduce the over-exploitation of resources around the colonies on the Mond Islands. Synchronization in an assemblage of breeding species in this study showed that the timing of breeding could not reduce intra-specific interactions. However, asynchrony of breeding within the colony of Bridled Terns and also within different colonies of Lesser Crested Terns and Greater Crested Terns could probably reduce inter-specific competition between the three species.

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