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Breeding Biology of the Crab Plover (*Dromas ardeola*) on the Mond Islands, Northern Persian Gulf, Iran

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Abstract.—The present study describes the breeding biology of Crab Plovers (*Dromas ardeola*), a little-known shorebird species nesting on Nakhilu and Omol-Karam Islands located in the Nakhilu Marine National Park in the northern Persian Gulf, Iran. This study occurred during the breeding seasons of 2009-2011. Colonies had between 500-1,500 nests and were located on sand banks 1-3 m higher than the surrounding ground in non-overlapping areas. Burrow digging began in mid-April, and single nests were built in 2.82 ± 0.1 days (Range = 2-4 days, n = 45) in a period of 10.5 ± 0.76 days (Range = 8-13 days, n = 6), although a spread of digging and laying of 87.50 ± 2.96 days (Range = 82-94 days, n = 4) was recorded primarily due to renesting after human damage to the burrows. Range in nest densities was 0.14-0.26 nest per m^2. The clutch size was 1.01 ± 0.005 (Range = 1-2, n = 421). Egg size (n = 47) was 64.05 × 44.04 mm with an average incubation period of 33 days (Range = 31-35, n = 21). Hatching success was 63-81%, with failures primarily due to egg collecting by local fishermen and tourists. An estimated of 7 weeks passed between hatching and fledging. Fledglings had almost fully developed wings (83% of adult wing length) and feathers, but very low weight (about 55% of adult weight) and smaller bill length (only 60% of adult bill length). A stronger control of visitors and local fishermen would benefit the breeding population of Crab Plovers on the islands. *Received 24 April 2013, accepted 22 August 2013.*

Key words.—breeding biology, chick growth, Crab Plover, *Dromas ardeola*, Persian Gulf.

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Crab Plovers (*Dromas ardeola*) are a little-known shorebird species, the sole representative of the family Dromadidae (Rands 1996) and distantly related to Glareolidae (Pereira and Baker 2010). They breed in colonies on flat or gently sloping sandbanks (Cramp *et al.* 1985; Rands 1996; De Marchi *et al.* 2006; Chiozzi *et al.* 2011). The non-breeding range covers most of the Indian Ocean, while the breeding range is restricted to the Persian Gulf, Gulf of Oman, Gulf of Aden and Red Sea (Cramp *et al.* 1985; Urban *et al.* 1986; Scott 2007; Tayefeh *et al.* 2011). In the Persian Gulf, Crab Plovers breed on offshore islands along the northern coast of the Arabian Peninsula including the United Arab Emirates with 1,400-1,500 pairs (Javed *et al.* 2012), Masirah Island in Oman, and Kuwait, and also on islands in the northern part of the Persian Gulf in the south of Iran (Cramp *et al.* 1985; Scott 2007; Behrouzi-Rad and Behrouzi-Rad 2010;Tayefeh *et al.* 2011). The breeding season extends from April to August (Cramp *et al.* 1985; Rands 1996; Hockey and Aspinall 1997; PERSGA/GEF 2003).

The breeding biology of the Crab Plover incorporates features that are unique among shorebirds. It is the only shorebird that nests in self-dug burrows, the only shorebird that lays a white egg (Rands 1996; Hockey and Aspinall 1997), and the only waterbird species known to provide food to its chicks well after the post-breeding migration and throughout the winter (De Sanctis *et al.* 2005). Crab Plovers normally lay one egg, and the chicks have plain gray down and are fed by their parents in the nest. The chick is semi-nidifugous (Cramp *et al.* 1985; Hockey and Aspinall 1997), remaining within its nest burrow until fledging. As soon as a chick fledges, it leaves the colony in the company of its parents, which may continue to feed the chick for as long as 6 months (Hockey *et al.* 1996; Hockey and Aspinall 1997). Crab Plovers are thought to be primarily monogamous (Cramp *et al.* 1985).

Colonial breeding behavior and the possible advantages to breeding at the hottest and driest time of the year have been discussed by Hockey and Aspinall (1997). These authors suggested that three factors are involved in this behavior: 1) seasonally and regionally patchy food availability; 2) limited availability of suitable substratum for burrowing; and 3) the need to breed on islands that are free of land predators. De Marchi *et al.* (2008) describe an unknown mode of solar-assisted egg development in the Crab Plover. They found that Crab Plover eggs develop with reduced contact incubation, the first case of solar assisted incubation in a species unrelated to the Megapodiidae. Also, they found that the first eggs were laid during the second week of May, and the last eggs hatched during the last week of July. Chiozzi *et al.* (2011) tested the "nest site limitation" hypothesis to explain the high density of Crab Plovers in 21 colonies in Eritrea from 2002-2009. The results showed that at 10 study colonies, nine colonies used no more than 4% of the available nesting area, while one colony occupied 35.6% of the available space.

Information on the breeding biology of the Crab Plover is limited, although there are brief descriptions of some aspects of its breeding biology (Cramp *et al.* 1985; Rands 1996; De Marchi *et al.* 2006, 2008). This study provides new data on the breeding biology of the Crab Plover, including population size, breeding phenology, nest characteristics, egg dimensions, incubation period, breeding success and chick growth rates on the Mond Islands in the Persian Gulf.

METHODS

Study Area

The main study areas (27° 48'– 28° 01' N, 51° 18'– 51° 34' E) were on two Iranian islands known as the Mond Islands: Nakhilu and Omol-Karam (Fig. 1). They are located in the northern part of the Persian Gulf, southern Iran, and are part of the Dayyer-Nakhilu Marine National Park. Climate data from the Dayyer meteorological station during the period 2002-2011 indicate that the area generally has two well defined climatic seasons: the winter months from December to March are comparatively cool (minimum 13.39 ± 0.33 °C – 18.04 ± 16 °C , maximum 21.74 ± 0.15 °C – 27.69 ± 0.17 °C), while the summer months from May to November are hot and dry (minimum 22.46 ± 0.14 °C – 30.82 ± 0.12 °C, maximum 29.57 ± 0.18 °C – 38.38 ± 0.29 °C). The period from June to August is the hottest. Annual precipitation in the area averaged 196.9 mm and was limited almost entirely to the winter months. The maximum and minimum temperatures were 50 °C (5 June 2003) and 6 °C (3 January 2009), respectively. The fastest wind speed 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. Nakhilu Island has an area of about 35 ha, but this varies between 34.2 and 36.2 ha depending on the tide level. Omol-Karam has an area of 75 ha. The highest point of Nakhilu Island is about 3 m above sea level, while Omol-Karam reaches 8 m. Geologically, Nakhilu and Omol-Karam Islands are composed of sediments from the Mond River. The islands have no commercial value at the present time, and they are used by the local fishermen only as resting areas. The main vegetation of Nakhilu Island includes *Atriplex* which often grows in sparse to dense masses. Omol-Karam Island is dominated by *Cyperus conglomeratus*, *Halopyrum mucronatum*, *Suaeda vermiculata* and *Lycium* spp. The fauna on the Nakhilu and Omol-Karam Islands includes a species of rat (probably *Rattus rattus*) that is abundant and reptiles such as *Chalcides occellatus*, *Cyrtopodion scabrum* and sea turtles (superfamily Chelonioidea). Omol-Karam is also inhabited by the saw scale viper (*Echis carinatus*).

Phenology

The annual waterbird census showed that 19, 22 and 138 Crab Plovers were counted in January 2009, 2010 and 2011, respectively, in the Mond coastal area by personnel of Boushehr Provincial Office of Department of the Environment (DOE). Phenology data was collected in three colonies on Nakhilu Island and three colonies on Omol-Karam Island from 2009 to 2011. The breeding season was divided into phases: first arrival, nest building, egg laying, hatching, chick rearing, fledging and outward migration (O'Leary and Jones 2006). The timing of burrow digging was measured by regularly marking the colony borders using small sticks. To check the content of the burrows, a burrowscope was used; this is a 6" LCD screen connected to a small infrared camera set on a long

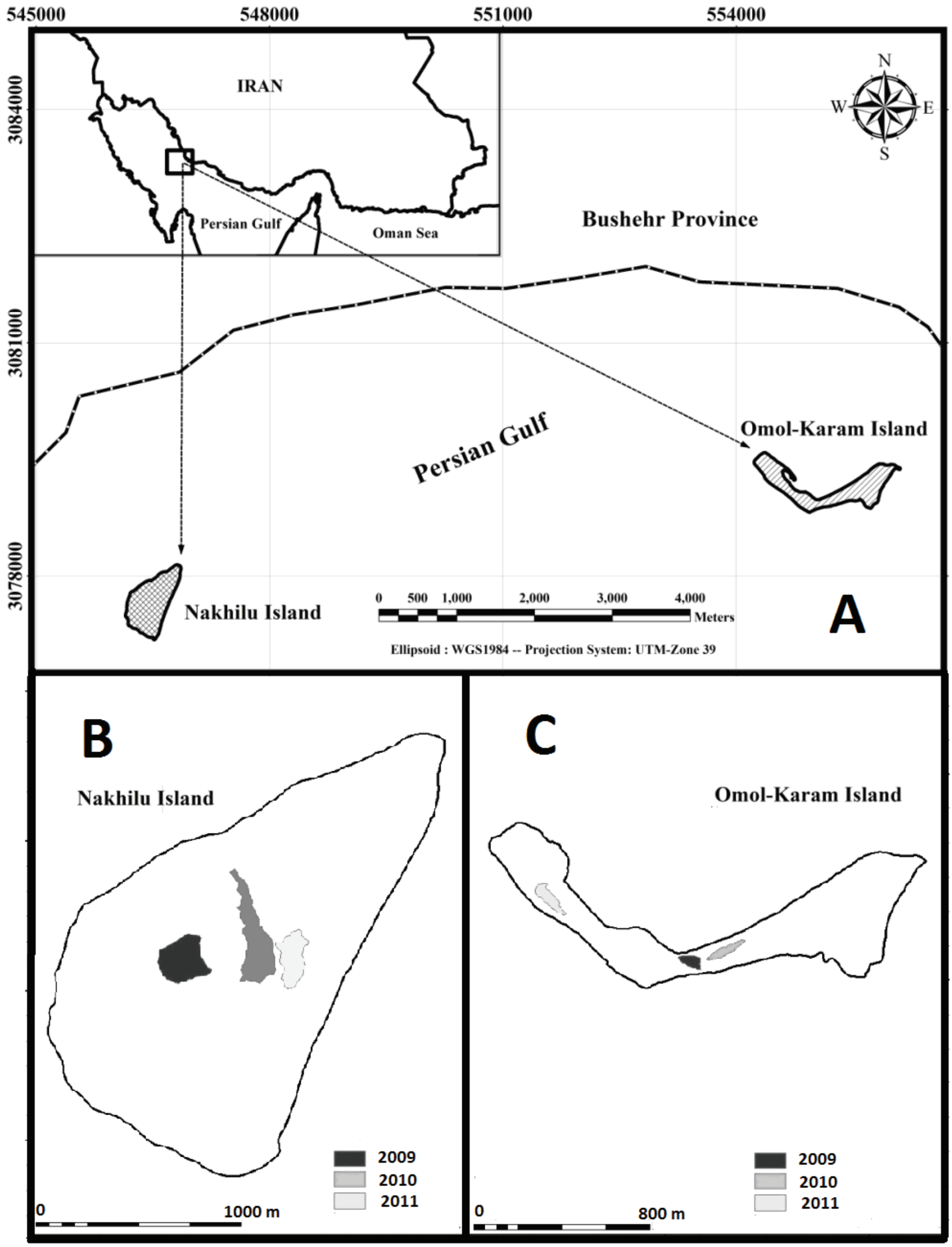

Figure 1. A: study area at Nakhilu and Omol-Karam Islands in the northern Persian Gulf, Iran; B: the location of Crab Plover colonies on Nakhilu Island in 2009, 2010 and 2011; C: the location of Crab Plover colonies on Omol-Karam Island in 2009, 2010 and 2011.

wooden stick that is inserted into the burrows. To determine the timing of egg laying at each colony, 127 burrows in 2010 and 89 burrows in 2011 were marked by numbered wooden sticks and checked by the burrowscope every day to record whether egg laying had taken place or not. Hatching dates were determined by direct observation with the burrowscope or by the presence of the eggshell outside the burrow; eggshells are removed from the burrow by the adults just after hatching (F. H. Tayefeh, pers. obs.).

Colony Sites

To assess colony site selection, some variables were quantified at the colony sites: 1) percentages of clay, silt and sand in the surface layer (top 1 m) were measured by the Hamoon Gostar Soil Laboratory in Borazjan, Boushehr Province; 2) visual estimate of the percentage of vegetation cover around the colony; 3) height of nearest vegetation; 4) presence of other colonial species in the surrounding areas; 5) elevation of the colony above the highest spring tide line (HSTL), i.e., the point recorded when the water reaches its maximum tidal height on each island; and 6) distance of the colony from HSTL (Burger and Gochfeld 1986; Fasola and Canova 1991, 1992; Valle and Scarton 1999).

Nest Density and Population Sizes

The number of breeding pairs was estimated as Apparently Occupied Nest-sites (AONs), i.e., nests with eggs or apparently active nests prior to egg laying (Bibby *et al.* 2000; Gibbons and Gregory 2006; McGowan *et al.* 2008; Seavy and Reynolds 2009). Each AON was considered to indicate a pair of breeding birds. The coordinates of the nesting colonies were taken with a Global Positioning System (GPS) unit, and the total surface area of each colony was measured. The tracks of Crab Plovers at a burrow entrance were used to identify active nests, a method described by (De Marchi *et al.* 2006).

Nest Characteristics

Nest characteristics were measured on Nakhilu Island only, as there are no saw scale vipers on this island, which could be dangerous when checking burrow contents. Entrance width and height, depth of the nest and length of the burrows were measured in the early egg-laying period and at the end of the breeding season, when the chicks had left the burrows, using a steel-thickened retractable measuring tape (De Marchi *et al.* 2008).

Clutch Size

To estimate the mean clutch size, nests were checked using the burrowscope during the nest census and incubation period. The number of eggs at each nest was recorded on Nakhilu and Omol-Karam Islands during the 2010 and 2011 breeding seasons.

Egg Characteristics

Eggs were numbered with a pencil, and their dimensions (length and breadth) were measured with an electronic caliper (± 0.01 mm). Fresh eggs in the study plots were marked and weighed using an electronic balance (± 0.1 g). All eggs were weighed within 48 hr after laying. Moreover, marked eggs were used to determine incubation periods. Incubation period was defined as the number of complete days of incubation that elapsed between the day when incubation started and the day that hatching started (Hamer *et al.* 2002).

Breeding Success

During the breeding seasons of 2010 and 2011, the colonies were visited from the beginning of burrow digging through egg laying, incubation and chick rearing up to fledging a total of 95 days in 2010 and 42 days in 2011. On 2 May 2010 and 8 May 2011, a selection of burrows was checked with the burrowscope. The burrows that contained eggs were numbered with wooden boards and used for monitoring and measuring hatching success. Visitations were continued during the incubation period up to chick rearing.

Chick Growth

Data collection during the Crab Plover chick rearing phase took place from June to August in 2010 and 2011. Morphological characteristics and weights of adults were measured during early incubation but not later since there may be a loss of mass in adults during the nestling period (Chastel *et al.* 1995). Chicks and adults were weighed (± 0.1 g) with a digital electronic weighing balance. The length of the inner tarsus (the length of the tarsometatarsal bone measured from the angle of the foot bent to 90 degrees to the notch of the intertarsal joint), bill length (bill tip to feathering at base of bill), and head to bill length (the distance between the back of the skull and the tip of the bill) of the chicks were measured (± 0.01 mm) with digital calipers. The tail (defined as the distance from the base to the tip of the longest tail feathers) and wing chord (distance from the carpal joint to the tip of the longest primary on the closed wing) were measured (±1 mm) using a stopped stainless-steel ruler (Rising and Somers 1989; Gosler 2004; Goodenough *et al.* 2010; De Marchi *et al.* 2012). To estimate growth rates, newly hatched chicks were marked using plastic colored numbered leg bands. Chicks were classified as “new” when 1-4 days old, “week 1” when 8 ± 3 days old, “week 2” when 15 ± 3 days old, etc. (Keitt *et al.* 2003).

Observations in 2009, based on the collection of eggshells, showed that most chicks hatched almost synchronously over a period of approximately 10 days. During the first weeks after hatching, it was possible to re-catch the marked chicks as they remained in their burrows. However, as the chicks were growing, their parents continued to dig their burrows, which eventually became too long for the marked chicks to be re-caught. In some cases, chicks moved to other burrows because of the disturbance caused by the activities of the researchers. On such occasions, the researchers never had the opportunity to discover whether the chicks returned to their own burrows or not. To solve this problem, we hid at a place near the colony waiting for the banded chicks to appear, and, if they did, we were able to catch them. Every time a chick was caught, it was assigned to a chick category based on its feather development and similarity with the marked chicks (at least 50 were marked with metal rings). Another way to estimate the age of the chicks was based on the feather development of the oldest chicks caught in a single day and back calculation of the hatching date. The age at fledging was confirmed by the observation of week 7 marked chicks in the coastal area far from the colony and by the lack of any week 8 chicks at the colony. Fledged chicks were captured in the coastal area with powerful lights during the night.

Adult Crab Plovers were captured at night in the colony on Nakhilu Island using mist nets. We placed a blind 200 m from the nets, and all trapped individuals were removed from the nets within 1 hr. While body condition should be calculated separately for males and females because pooling the sexes can produce significant intra- and inter-sexual bias (Williams *et al.* 2007; De Marchi *et al.* 2012), we were not able to determine the sex of the Crab Plovers based on morphology (Cramp *et al.* 1985).

Analysis

An Independent Sample t-test was used to test for differences in nest and egg characteristics between 2010 and 2011. The homogeneity of variance was tested by Levene's test, which met the assumption in all characteristics (SPSS, Inc. 2001). Fisher's Exact Test (Crosstabs function) was used to analyze hatching, nestling and breeding success (Williams *et al.* 2007). Several authors have fitted data on chick growth to non-linear models and used parameters of these models to describe the growth rates of chicks (Nisbet *et al.* 1995; Visser 2002; Powell *et al.* 2007). Estimating parameters for individual chicks requires complete growth curves that are calculated from repeated measurements of weight and linear measurements of the same individuals. In this study, it was not possible to catch all marked chicks in the following weeks, and, therefore, growth rates could not be obtained by repeated measurements of the same individuals. Instead, growth curves were determined by plotting weight and linear measurements of different individuals of different ages as described above. The *post hoc* multiple comparisons by Tukey's honestly significant difference (HSD) test were used to compare size and weight values between chick categories. The normality of the data was tested by Skewness, Kolmogorov-Simrnov and Shapiro-Wilk tests. Outliers were searched for by checking box plots and Mahalanobis distances (Tabachnick and Fidell 2007), and outlying data for each of the parameters were removed. All statistical analysis was performed with SPSS (SPSS, Inc. 2001) with the α-level set at 0.05. All values reported are means ± SE.

RESULTS

Phenology

Crab Plover populations increased in March and excavation of the first burrows began in mid-April in all study years on Omol-Karam Island and a few days later on Nakhilu Island. The areas excavated by Crab Plovers in one year were never reoccupied during the following breeding seasons (Figs. 1B and 1C). Most burrows were dug in 10.5 ± 0.76 days (Range = 8-13 days, n = 6 colonies). The first eggs were recorded on 23 April 2009, 21 April 2010 and 28 April 2011 on Omol-Karam Island and on 23 April 2009, 22 April 2010 and 30 April 2011 on Nakhilu Island. Egg laying began 2 days after the end of burrow digging. It was found that 84% and 87% of the clutches were laid in the third and fourth days after the end of digging in 2010 and 2011, respectively (Fig. 2). While most burrows were dug and most eggs were laid in 10.5 ± 0.76 days, a spread of digging and laying of 87.50 ± 2.96 days (Range = 82-94 days, n = 4) was recorded. The first chicks left their burrows and fledged on 15-24 July (n = 3 years). In early August, groups of hundreds of adults and fledglings formed on the beach and left the islands to move to the feeding areas. The last chicks to fledge were seen on 12-20 August (n = 3 years). Some chicks were observed without parental care in late August.

Colony Sites

The locations of the colonies of Crab Plovers on Nakhilu and Omol-Karam Islands are shown in Figs. 1B and 1C. In 2009, 2010 and 2011, Crab Plovers selected different areas for digging their new burrows on the islands and there was no overlap between the colonies. On Omol-Karam Island, all colonies were located on sand banks 1-3 m higher than the surrounding ground, at distances of between 5 m (2009) and 30 m (2011) from the HSTL. The density of vegetation cover on these sand banks was estimated to range from 5% to 50%. Most burrows were dug in areas dominated by *Cyperus conglomeratus*,

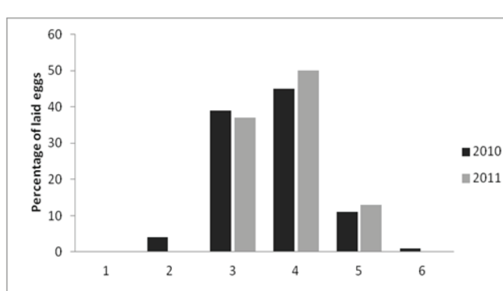

Figure 2. Percentages of Crab Plover eggs laid in the burrows after the end of burrow digging at 1-day intervals on Nakhilu Island in 2010 (n = 126) and 2011 (n = 89).

Halopyrum mucronatum and *Atriplex leucoclada* with a maximum height of 80-110 cm.

On Nakhilu Island, colonies of Crab Plovers were situated in flat or almost flat sand banks, between 45 m and 120 m from the HSTL. In 2010 and 2011, the colonies were contiguous, while the 2009 colony was 48 m from the 2010 and 2011 colonies. However, the nesting areas of Crab Plovers overlapped those of Bridled Terns (*Sterna anaethetus*) with Bridled Terns occupying the empty and ruined burrows of Crab Plovers. Nesting areas were dominated by *Atriplex leucoclada* and *Cyperus conglomeratus* with a maximum height of 80 cm. The 2009 colony was located in areas with 5-25% vegetative cover, while the 2010 and 2011 colonies were in areas with 25-50% vegetative cover. The substrate components were 93% sand, 3% silt and 4% clay on Nakhilu Island, and 84% sand, 15% silt and 1% clay on Omol-Karam Island.

Nest Densities and Population Sizes

Nest counts of the Crab Plover on Nakhilu and Omol-Karam Islands in 2009, 2010 and 2011 are given in Table 1. In mid-July 2010, a new sub-colony with 145 burrows was established 50 m away from the main colony on Nakhilu Island. Of the burrows examined ($n = 50$), 24% contained one egg, 50% contained chicks between 3 and 5 weeks old and 26% were empty. At least 40 new active burrows were counted next to the main colony on Omol-Karam Island on 15 July 2010. In mid-July 2011, a new sub-colony was discovered with 79 burrows, close to the main colony on Nakhilu Island. Of burrows ($n = 50$) that were randomly checked, 44% contained eggs, 6% contained chicks between 4 and 5 weeks old and 50% were empty. On Omol-Karam Island, 112 new burrows were counted on 12 July 2011, 100 m away from the main colony. Although no eggs were recorded in the burrows, some chicks between 2-5 weeks old were found at the new colony (F. H. Tayefeh, pers. obs.).

Nest Characteristics

The measurements of the burrows in the early egg-laying period and at the end of the breeding season are shown in Table 2. There were no significant differences between years for either width ($t = 1.551$, $P = 0.126$) or height ($t = 1.251$, $P = 0.216$). Nests at the beginning of the egg-laying period were significantly shorter in 2010 than in 2011 ($t = -4.813$, $P < 0.001$). Burrows at the end of the breeding season were 23.9% and 20.9% longer than at the beginning of the egg-laying period in 2010 ($t = -10.613$, $P < 0.001$) and 2011 ($t = -4.607$, $P < 0.001$), respectively. The distance of recently laid eggs from the burrow entrance was 59.2 cm in 2010 and 71.1 cm in 2011; there was no significant difference between years ($t = -2.298$, $P = 0.013$). After a few days, the eggs were moved by the parents to the deeper part of the burrow and it was not possible to observe them directly. In 2010, out of 51 nests that were marked on the first day of nest building, six nests were not extended after the first day. In the remaining burrows, excavation continued for a further 2 ($n = 10$), 3 ($n = 33$) and 4 ($n =$

Table 1. Total number of active nests of Crab Plover on the Nakhilu and Omol-Karam Islands, Persian Gulf, 2009-2011.

Survey Date	Island	Nesting Area (m^2)	No. Nests	Nest Density/m^2	Total
2009					
6 June	Nakhilu	9,940	1,428	0.14	
7 June	Omol-Karam	5,590	1,313	0.23	2,741
2010					
14 June	Nakhilu	7,827	1,102	0.14	
15 June	Omol-Karam	6,750	1,221	0.18	2,323
2011					
7 June	Nakhilu	3,813	557	0.15	
6 June	Omol-Karam	6,166	1,585	0.26	2,142

Table 2. Width and height of Crab Plover burrow entrance and length of nest burrow during the egg-laying period and the end of breeding seasons, depth and distance of eggs from entrance in the early egglaying period (cm) on Nakhilu Island in 2010, 2011 and combined. Sample sizes are in parentheses.

Year	Burrow Entrance		Length of Burrows		Depth	Distance of Egg from Entrance
	Width (cm)	Height (cm)	Early (cm)	Late (cm)		
2010	16.85 ± 0.27 (31)	13.26 ± 0.17 (31)	126.97 ±1.78 (77)	166.75 ±.94 (36)	48.78 ± 1.65 (36)	59.24 ± 2.39 (25)
2011	16.24 ± 0.29 (29)	12.90 ± 0.23 (29)	143.62 ± 0.46 (37)	181.53 ± 7.2 (19)	64.00 ± 3.02 (19)	71.14 ± 4.4 (14)
Combined 2010-2011	16.56 ± 0.2 (60)	13.08 ± 0.15 (60)	132.38 ± 2.04 (114)	171.85 ± 3.67 (55)	53.66 ± 1.76 (53)	63.51 ± 2.36 (39)

2) days. The mean value of the nest building period was calculated at 2.82 ± 0.1 days (Range = 2-4 days, $n = 45$). Nest lengths on the first, second, third and fourth days were calculated at 64.8 ± 1.6, 100.2 ± 2.1, 123.9 ± 2.5 and 126.1 ± 2.7 cm, respectively.

Clutch Sizes

Clutch size was on average 1.01 ± 0.005 (Range = 1-2, $n = 421$) with only four nests containing two eggs. There were no significant differences between the mean clutch sizes of Crab Plovers on Nakhilu and Omol-Karam Islands or between years (Z = 0.105, $P = 0.746$).

Eggs Characteristics

Overall, the average egg size on Nakhilu Island was 64.05 ± 0.36 × 44.04 ± 0.23 mm and the mean fresh weight was 64.83 ± 0.75g (n = 47). The results of one sample t-test showed that there were no significant differences between 2010 and 2011 in egg length (t = 0.054, $P = 0.962$), width ($t = -0.281$, $P = 0.780$) and fresh weight ($t = 1.498$, $P = 0.141$). The incubation period was calculated at 33.00 ± 0.28 days (Range = 31-35 days) for 21 eggs during the 2010 and 2011 breeding seasons on Nakhilu Island. The incubation period in 2010 was not significantly different from that in 2011 ($t = -0.701$, $P = 0.492$).

Breeding Success

On 2 May 2010, 58.73% of the checked burrows ($n = 126$) contained eggs, while on 10 May 2011, 60.67% of the burrows (n = 89) contained eggs. This small difference in laying success was not significant (Fisher's Exact Test, $P = 0.888$). Hatching success was lower (Fisher's Exact Test, $P = 0.031$) in 2010 (63.51% of 74 nests) than in 2011 (81.48% of 54 nests).

Chick Growth

The mean (± SE) linear dimensions and body weight of chicks grouped in age categories (classified as newborn, 1, 2, 3, 4, 5, 6 and 7 weeks with ± 3 day intervals and adults) measured on Nakhilu Island (combined data of 2010 and 2011; Table 3 and Fig. 3). The *post hoc* multiple comparisons by Tukey (HSD) indicated that the weight of the chicks increased from newborn to 4 weeks of age ($P < 0.001$), but there was no significant difference in weight between 4, 5, 6 and 7 week old chicks ($P = 0.449$). The weight of adults was heavier than all chick categories. The time taken to reach half the adult weight was 4 weeks, which is at least 3 weeks prior to fledging (Table 3). There was no significant difference in wing length between newborn and one week old chicks ($P = 0.335$). However, the length of the wings significantly increased from the second week up to fledging (week 7) when they reached almost adult size. The tail began to grow from the second week after hatching and continued until week 6 after which the growth rate slowed down. The inner tarsus length increased significantly from hatching to the fourth week of development. There were no significant differences between inner tarsus lengths of chicks in weeks 4, 5, 6 and 7.

The results indicated the same trend in the increase in bill length and head to bill length of chicks. While bill length and head to bill length increased significantly between hatching and week 4, there were no significant differences between weeks 4, 5 and 6 and weeks 6 and 7 (bill, $P = 0.192$; head to bill, $P = 0.128$; Table 3). Half the adult bill length was attained between 3 and 4 weeks after hatching.

The appearance of the chicks is shown in Fig. 4. Newborn chicks still have the egg-tooth. Week 1 chicks still have a small bill but no egg-tooth. Week 2 chicks have a longer bill and start to grow the tail. Week 3 chicks start to show the black primaries, have a conspicuous tail and start to grow white feathers on the head. Week 4 chicks have longer primaries and a larger white band of feathers on the head. Week 5 chicks have a largely white head. Week 6 chicks have a fully white head. Fledglings have black feathers on the white head.

DISCUSSION

Our results confirm the importance of Nakhilu and Omol-Karam Islands for breed-

Table 3. Weekly measurements of weight, wing length, tail length, tarsus length, bill length and head to bill length of Crab Plovers on Nakhilu Island. Data for 2010 and 2011 combined. The bottom row for adult birds consists of data from birds caught at night during the study period in the colony during the incubation phase. Statistics are reported for comparisons between each chick category using the post hoc multiple comparisons by Tukey (HSD) of ANOVA. Values are given as mean ± SE.

Age (weeks)	*n*	Weight (g)	Wing Length (mm)	Tail Length (mm)	Tarsus Length (mm)	Bill Length (mm)	Head to Bill Length (mm)
Newborn	10	40.84 ± 0.62 a	19.90 ± 0.66 a	0.00 ± 0.00 a	28.87 ± 0.68 a	17.86 ± 0.47 a	47.43 ± 1.09 a
1	7	68.11 ± 2.42 b	27.57 ± 1.04 a	0.00 ± 0.00 a	35.81 ± 0.46 b	22.80 ± 0.45 b	55.05 ± 0.78 b
2	7	105.43 ± 3.79 c	69.43 ± 2.72 b	12.29 ± 0.61 b	46.28 ± 1.07 c	26.12 ± 0.39 c	66.17 ± 0.40 c
3	13	131.08 ± 2.88 d	117.15 ± 3.44 c	26.08 ± 1.31 c	60.88 ± 1.06 d	29.73 ± 0.45 d	70.49 ± 0.43 d
4	16	154.66 ± 3.12 e	140.56 ± 2.24 d	40.50 ± 1.32 d	69.26 ± 1.33 e	33.76 ± 0.28 e	74.24 ± 0.69 e
5	11	162.80 ± 3.29 e	154.55 ± 1.63 e	49.73 ± 1.92 e	76.60 ± 0.69 f	34.10 ± 0.32 e	76.29 ± 0.35 e
6	15	161.50 ± 6.86 e	168.47 ± 1.39 f	55.47 ± 0.85 f	78.18 ± 1.49 f	36.61 ± 0.46 e,f	77.37 ± 1.01 e,f
7	21	167.25 ± 2.78 e	183.62 ± 2.04 g	58.62 ± 0.83 f	81.85 ± 1.06 f	38.32 ± 0.45 f	79.32 ± 0.51 f
Adult	9	304.56 ± 9.58 f	221.22 ± 2.53 h	71.78 ± 1.53 g	102.78 ± 2.00 g	64.40 ± 1.79 g	110.07 ± 0.98 g

Note: Means in the same column followed by the same letter are not significantly different at the P < 0.05 as determined by Tukey (HSD).

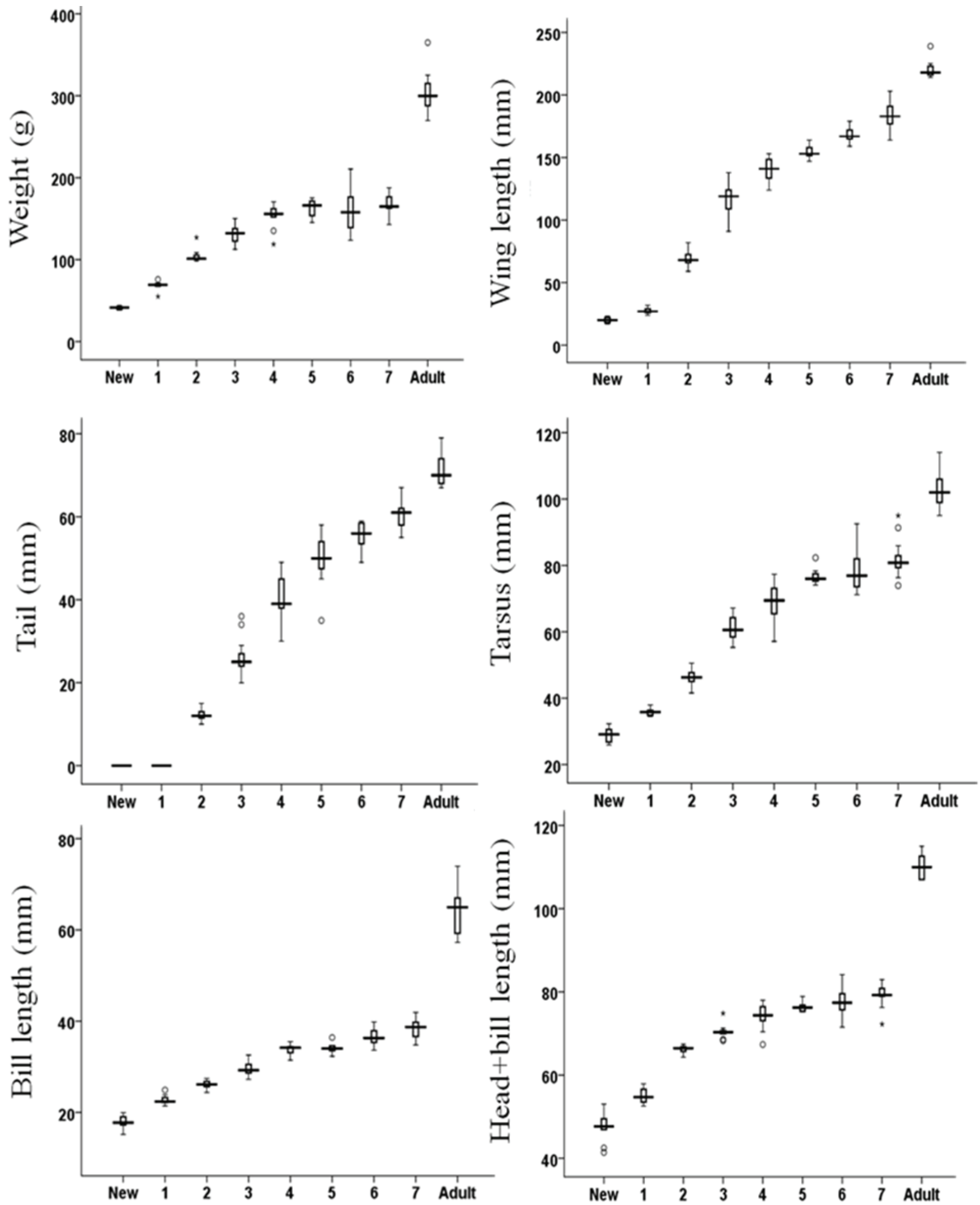

Figure 3. Body weight and wing, tail, tarsus, bill and bill + head lengths for each age category of Crab Plovers on Nakhilu Island (combined data of 2010 and 2011). The box represents the interquartile range; the line across the box indicates the median; bars (whiskers) extend from the box to the highest and lowest values; outliers are indicated with circles.

ing Crab Plovers as they provide suitable and protected breeding sites for about 8% (5,500 birds, Table 1) of the world population of 60,000-80,000 individuals (Wetlands International 2006). During 2009-2011, the breeding population of Crab Plovers on the Mond Islands appeared to be decreasing slowly, with the number of pairs decreasing by 15% between 2009 and 2010 and 8% between 2010 and 2011. However, there is no

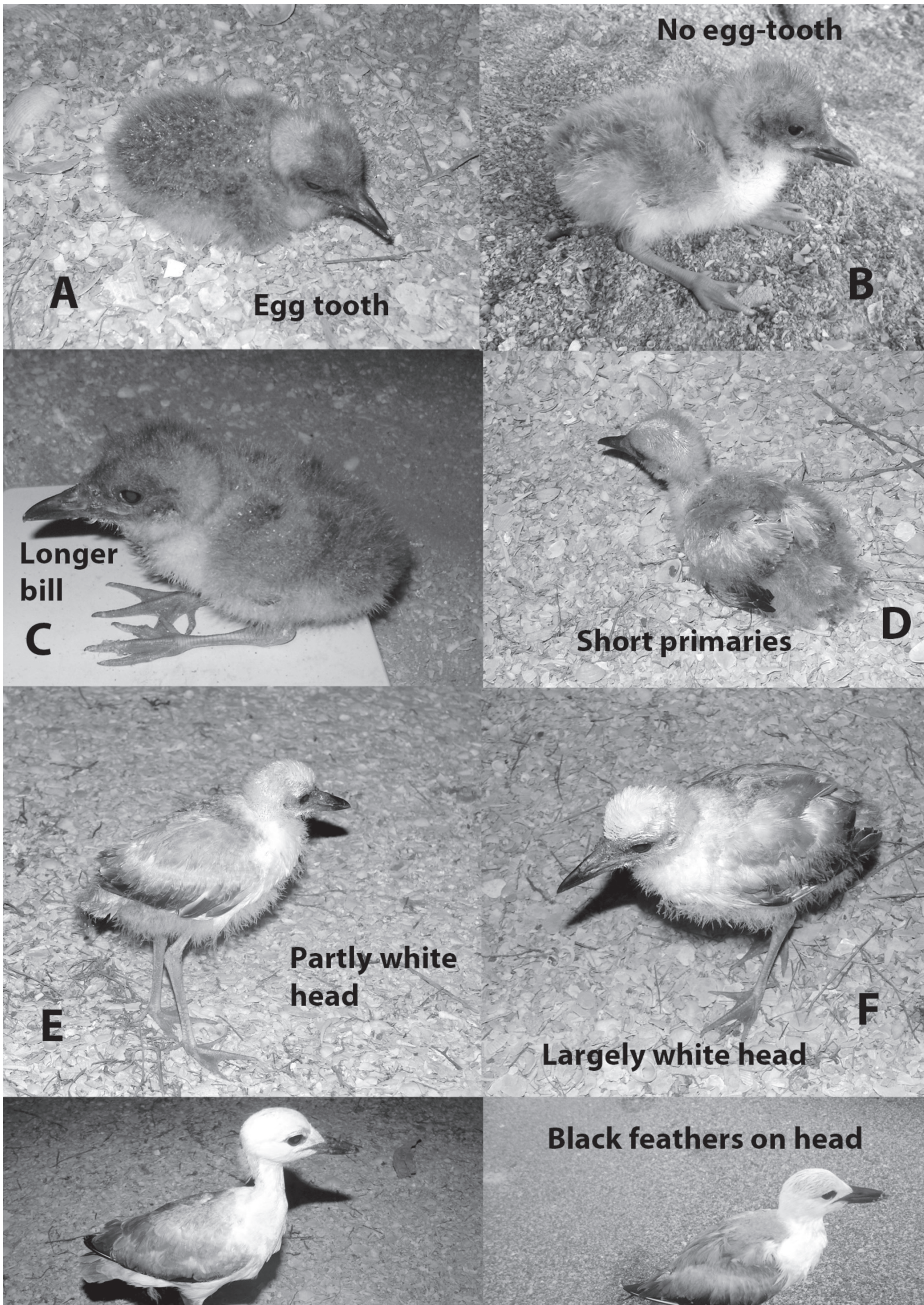

Figure 4. Stages in growth and patterns of feather development in Crab Plover chicks. A: soon after hatching (< 4 days), B: 4-11 days, C: 12-18 days, D: 19-25 days, E: 26-32 days, F: 33-39 days, G: 40-46 days, and H: fledging chick.

evidence of a long-term decline, as the population was lower in the past: the number of nests increased from 2,168 in 2004 to 3,241 in 2007 (DOE Provincial Office, Boushehr, unpubl. data).

Birds select nest sites according to habitat quality, which is the result of both biotic and abiotic factors that increase breeding performance (Stenhouse and Montevecchi 2000). It appears that the two Mond Islands can be used alternatively by Crab Plovers: in 2009 and 2010, the birds shared these islands almost equally to breed, but in 2011 most of the birds left Nakhilu Island to breed on Omol-Karam Island. We do not know why but we suspect that human predation on eggs in the previous year might be a likely explanation.

Breeding starts in April in the Persian Gulf (Cramp *et al.* 1985; Javed *et al.* 2012), while it starts 2-3 weeks later in the Red Sea (De Marchi *et al.* 2006). On a smaller scale, Crab Plovers appear to select colony sites according to three main conditions. First, colony sites must be suitable for burrow digging: deep soil and flat or gently sloping sandbanks (Hockey and Aspinall 1997; Chiozzi *et al.* 2011). Second, access to and departure from colony sites have to be possible. Easy take off and landing is facilitated by flat open areas near to the colonies and can further explain the preference for nest sites near to the sea (Cramp *et al.* 1985) and avoidance of nesting areas that are restricted by dense and tall vegetation (De Marchi *et al.* 2006). Third, vegetative cover is needed in very loose soils to reduce the risk of the burrows collapsing: Crab Plovers frequently dig their burrows under the base of shrubs, the roots of which may stabilize the roof of the burrow entrance. Moreover, the vegetation protects the burrows from wind-blown sand (Bourgeois *et al.* 2008; Chiozzi *et al.* 2011).

In the Mond Islands, the nesting areas are mostly well vegetated, with short halophytic plants, but the vegetation is low and the Crab Plovers can overlook the surrounding area when they are standing outside their burrows. Burrows are important for sheltering eggs and chicks from adverse weather conditions. Years after a breeding season, the old burrows still remain visible and it may not be possible to excavate new burrows in the same area.

As a result, Crab Plovers change their colony location every year, clearly showing that the area suitable for digging was only partially used in each single year. In the Mond Islands we report changes of colony locations between 2002 and 2008 (DOE Provincial Office, Boushehr, unpubl. data) and again in 2009 and 2010. The same result was well documented in Eritrea, in particular on Dahret Island, where also the temporal pattern of nest digging (nests close to each other since the start of the nesting season) supports the hypothesis that Crab Plovers nest at high densities because they are truly colonial and not site limited (Chiozzi *et al.* 2011). The annual shift of the colony to a new location on the same island may be a response to previous occupancy that has rendered the former sites less suitable for digging new burrows (Chiozzi *et al.* 2011).

Ashmole (1963) proposed that the populations of colonial seabirds were limited by food availability during the breeding season. In particular, because of over-foraging the area around colonies, adults could not find sufficient food to raise more young or faster-growing young. Specifically then, small clutch sizes and slow growth of young were considered to be adaptations to an imposed low rate of food delivery to chicks. In support of this hypothesis, seabirds that feed offshore generally have smaller clutches than those that feed inshore (Hamer *et al.* 2002). Furthermore, chicks of some waterbird species lay down great amounts of fat during growth, which, it would seem, is necessary to carry them through periods when adults cannot find a sufficient amount of food (Ashmole 1963; Lack 1968). In addition, it has been suggested that in some species breeding asynchrony is a way to reduce intraspecific competition (Fasola and Canova 1991; Valle and Scarton 1999) that is particularly strong during the breeding season in colonial species. Crab Plovers are colonial and might face the same ecological constraints as colonial seabirds. On the Mond Islands, breeding was largely synchronous, suggesting that there was no time segregation that could reduce the overexploitation of food resources around the colonies. The size of the Crab Plover eggs was similar to that found in previous studies (Cramp *et al.* 1985) and corresponds to 21.29% of the mean adult mass, making it one of the largest eggs of any bird compared to the size of the adults. Our data were similar to that recorded in the Red Sea (De Marchi *et al.* 2006). This 31-35 day incubation is a long incubation period compared to that of other bird species with similar sized eggs (Rahn and Ar 1974), but is consistent with that of seabirds, which have nests that are generally well protected from predators (Hamer *et al.* 2002).

As food availability frequently changes, inter-annual variation in breeding investment among seabirds is usual (Croxall *et al.* 1992; Christians 2002), at least for egg quality (Slagsvold *et al.* 1984). Differences in egg size between populations should represent indicators of various environmental stresses and limitations (Christians 2002). We found no variation in egg size, egg mass and incubation period between 2010 and 2011. This can be explained if the same environmental conditions persisted throughout the two breeding seasons, which might be the case as the islands are well protected in Nakhilu National Park. Description of egg variability and its sources can be particularly important for monitoring breeding waterbirds in the Persian Gulf Islands, because this area holds a significant proportion of the world breeding population of several species (Scott 2007; Tayefeh *et al.* 2011) and has come increasingly under pressure from human activities, including industrial development.

Perhaps the most original results of our study are those pertaining to the growth of the chicks; that different characters grow at different speeds. This result is in accordance with the hypothesis that growth rate represents an optimum balance between selection for low rates of energy requirement and short development time. This hypothesis would predict that variation in growth rate between species should be related to rates of predation and patterns of energy consumption (Ricklefs 1979). In the case of the Crab Plover, chicks have almost fully developed wings and feathers at the time of fledging. This can be explained by the need for the chicks to leave the nesting area and follow the parents to the feeding grounds at distance of at least 2.5 km for the colonies of Omol-Karam Island and 5 km away from the Nakhilu Island. The tarsi of Crab Plover chicks are fast growing, possibly because well developed feet are important in a burrowing species for mobility in the burrow and enable chicks to excavate themselves from collapsed burrows. This result is consistent with other burrowing species such as the Short-tailed Shearwater (*Puffinus tenuirostris*; Saffer *et al.* 2000), Wedge-tailed Shearwater (*P. pacificus*; Nicholson 2002) and Flesh-footed Shearwater (*P. carneipes*; Powell *et al.* 2007).

The bills of the chicks are much shorter than in adults; however, Crab Plover chicks are singletons and do not have to compete with siblings, a situation that favors larger bills (Gil *et al.* 2008). Moreover, unlike most shorebird chicks (Colwell 2010), they are not forced to feed by themselves, as they are fed by their parents in the burrow and probably do not require a fully developed bill until after they fledge. Even when the chicks have fledged, the parents continue to feed them for several months (Powell *et al.* 2007).

Chicks attain half the weight of adults after 4 weeks but then add very little weight in the next 3 weeks until fledging. This is in marked contrast to some burrow-nesting seabirds such as shearwaters and puffins that have a peak weight long before they fledge and have to lose weight before fledging (Harris and Wanless 2011). The average ratio of fledging weight to adult weight in Crab Plovers is 0.55 (Table 3), which is below the 0.60-1.84 range measured in 94 species of birds (Ricklefs 1968). Such a low weight at fledging is expected when the life history has evolved under selective pressures to minimize age at fledging. This can happen in the case of heavy predation, high parasite load, or starvation during the chick phase (Miller 2010). Crab Plover chicks have a very low parasite load (F. H. Teyefeh, pers. obs.), possibly as a result of new nests being built every year, and are rarely if ever predated, nesting on islands free of land predators. Therefore, an explanation for the low weight of Crab Plovers at fledging on the Mond Islands is severe food limitation during the latter part of the breeding season, possibly due to colonial life, which forces chicks to allocate the limited food for growth of the body parts (wings and tail) most important for leaving the colony as soon as possible.

The Persian Gulf islands have increasingly come under pressure from development associated with the petroleum industry, since the Persian Gulf together with its coastal zone is known to be the biggest resource of crude oil and associated industries in the world, with a resulting need for sustainable ecological management (Sale *et al.* 2011). Egg collecting and the destruction of burrows as a consequence of human activities were the main causes of nest failure in the Crab Plover colonies in the Mond Islands. These activities may have an adverse effect on the vegetative cover, soil texture and colonial breeding systems especially at the beginning of the breeding season and during the chick rearing period. In addition to human activities, natural events such as very high tides, predation, storms and climate change might also have an adverse effect on large breeding colonies of Crab Plovers. At the Crab Plover colonies investigated during the present study, exploitation by humans resulted in the abandonment of nests and re-nesting attempts at other sites usually close to the original colonies. For the long-term protection of this unique species, we stress that it is necessary to prevent all kinds of disturbance on the nesting islands, particularly egg-collecting and uncontrolled visits by fishermen and tourists.

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