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[Article begins on next page]

1 **Demography of a stable population of Crab Plovers wintering in Oman**

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18 **Abstract**

19 The monotypic Crab Plover *Dromas ardeola* winters around the shores of the Indian Ocean

20 and breeds in colonies on islands around the Arabian Peninsula. The IUCN lists the world

21 population of Crab Plovers as stable, but long-term survey data or demographic estimates

22 regarding the species status are lacking. Here, we use survey and demographic data collected

23 from 2011-2015 to study the status of the population of Crab Plover at their most important

24 wintering area: the Barr Al Hikman Peninsula in the Sultanate of Oman. Our survey data

25 showed that the population of Crab Plovers initially increased and then stabilized. The overall

26 observed finite rate of population change ($\bar{\lambda}_{obs}$) was estimated at 1.004 (0.995–1.013 95%

27 Bayesian credible interval [BCI]), indicating a stable population (7,000–9,000 birds), that is

28 possibly at carrying capacity. Based on mark-recapture data, the mean annual apparent

29 survival probability of Crab Plovers was estimated to be 0.90 (0.85–0.94 95% BCI). We used

30 counts of adults and yearlings to estimate the mean annual fecundity rate at 0.06 young per

31 pair. Using these demographic values, the overall mean expected finite rate of population

32 change ($\bar{\lambda}_{exp}$) was estimated to be 0.949 (0.899 – 0.996 95% BCI), so there is a low chance

33 that $\bar{\lambda}_{obs}$ and $\bar{\lambda}_{exp}$ overlap. $\bar{\lambda}_{obs}$ and $\bar{\lambda}_{exp}$ would completely match if about 450 Crab Plovers

34 immigrate to Barr Al Hikman each year. Regional surveys show that yearling densities are

35 higher closer to the breeding areas, so immigrants could be birds that during their first winter

36 stayed close to their natal area. Our study support the IUCN listening of Crab Plover as stable,

37 but further population-wide monitoring is required. From a conservation point of view it is

38 important to continue monitoring because Crab Plovers breed and winter in a region that is

39 rapidly developing.

40

41 **Keywords**: apparent survival, Arabian Peninsula, Barr Al Hikman, *Dromas ardeola*,

42 fecundity, finite range of change, Integrated Population Model

43 **Introduction**

44 The coastal areas of the Arabian Peninsula and East-Africa provide essential breeding and

45 wintering habitat for a large number of shorebirds traveling within the Asian–East African

46 Flyway (Delany et al. 2009). In contrast to shorebird populations in other parts of the world

47 (Fernández and Lank 2008; Piersma et al. 2016; van Roomen et al. 2015), the status of

48 shorebirds breeding and wintering along the Arabian and East-African coasts remains largely

49 unknown (Delany et al. 2009). Coasts along the Arabian Peninsula and East-Africa are rapidly

50 changing under increasing human pressure (Halpern et al. 2008), including habitat loss,

51 climate warming, and overfishing (Sale et al. 2011; Sheppard et al. 2010). To understand if

52 shorebirds in this part of the world can keep up with their changing environment, long-term

53 survey data and demographic estimates are urgently needed.

54 The monotypic Crab Plover *Dromas ardeola* is endemic to the coastal areas of the

55 Indian Ocean and the main breeding areas are located in the Arabian/Persian Gulf and the Red

56 Sea (Bom and al-Nasrallah 2015). Crab Plovers breed in colonies on sandy islands where they

57 nest in self-excavated burrows (De Marchi et al. 2008). Suitable breeding habitat seems scarce

58 as only 56 breeding sites are known to exist worldwide (Bom and al-Nasrallah 2015). Crab

59 Plovers are unusual among shorebirds a their modal clutch size is one, or rarely two eggs

60 (Tayefeh *et al.* 2013). Crab Plovers exhibit extended parental care, which is biparental at the

61 breeding areas (Almalki et al., 2015) and probably uniparental at the wintering areas (De

62 Sanctis et al. 2005). Parental care extends up to 8 months, which is longer than any other

63 shorebird (De Sanctis et al. 2005). A small clutch size and extended parental care are life-

64 history characteristics typical of long-lived species with low fecundity rates (Newton 1998;

65 Sæther and Bakke 2000; Sandercock 2003), but the demography of Crab Plovers has not been

66 studied before. Potentially, as Crab Plovers require specific breeding- and wintering habitat,

67 they may suffer from rapid environmental changes in coastal areas. Egg collecting,

68   destruction of burrows, or harvesting of adults may seriously affect breeding success and

69   survival of Crab Plovers at the breeding areas (De Marchi et al 2006; Behrouzi-Rad 2013;

70   Tayefeh et al. 2013), whereas habitat destruction and overexploitation of preferred crab prey

71   may affect the species at the wintering areas (Safaie *et al.*, 2013). Based on counts at the

72   wintering areas, the world population of Crab Plovers has been estimated to be 60,000 to

73   80,000 birds (Wetlands International 2002). The population of Crab Plovers is currently

74   considered to be stable (IUCN 2017), but this has not been substantiated with data (Delany et

75   al. 2009).

76   In this study, we assessed the status of the population of Crab Plover wintering at the

77   Barr Al Hikman Peninsula in the Sultanate of Oman (Fig. 1a). The area supports 10-15% of

78   the world population of Crab Plovers and is therefore the most important wintering area for

79   the species (Delany et al. 2009). Based on survey data and demographic estimates collected

80   from 2011 to 2015, we developed an Integrated Population Model (IPM) (Schaub & Abadi

81   2011) in which we estimated observed and expected finite rates of population change (λ_{obs}

82   and λ_{exp}). IPMs combine population counts and demographic data in a single model, and are

83   particularly useful for studies with small datasets (Schaub et al. 2007), or studies where not all

84   demographic parameters could be accounted for by data collected in the field (Schaub &

85   Abadi 2011). Here we estimated λ_{obs} using existing survey data (de Fouw et al. 2017)

86   whereas λ_{exp} was calculated from newly estimated survival and fecundity rates. Apparent

87   annual survival rates were estimated based on sightings of 169 individually colour-marked

88   birds, and annual fecundity rates were based on the percentage of yearlings (first-winter birds)

89   in the population. In addition to survival and fecundity, population dynamics of local

90   populations also depend on immigration and emigration (Newton 1998). We did not measure

91   immigration and emigration directly, but calculated potential immigration rates by matching

92   observed (λ_{obs}) and expected (λ_{exp}) finite rates of population change (e.g., Doxa et al. 2012).

93   We discussed the generality of our results by looking at population dynamics of Crab Plovers

94   at other winter areas.
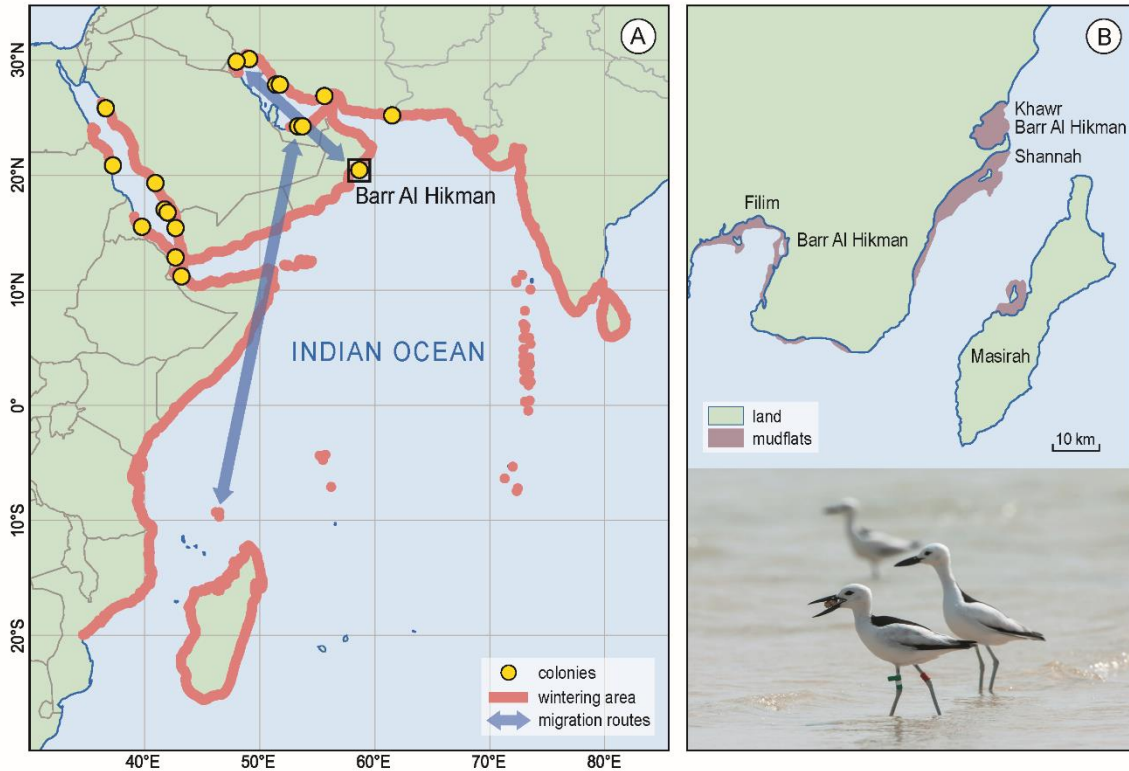
95

96   *Fig. 1. The distribution of Crab Plovers is confined to coastal areas of the Indian Ocean (A).*

97   *Breeding areas (yellow dots) are adapted from Bom and al-Nasrallah (2015), and wintering*

98   *areas (red coast line) from Delany et al. (2009). Arrows show the known connections between*

99   *breeding and wintering areas (Bom and al-Nasrallah 2015; Javed et al. 2011). The study*

100   *area at Barr Al Hikman is shown in the black square and in (B), with the main localities that*

101   *are mentioned in the text. The inset in (B) shows a colour-ringed Crab Plover.*

102

103   **Methods**

104   **Study area & data collection**

105   Our study was conducted at the intertidal mudflats that surround the Barr Al Hikman

106   Peninsula in the Sultanate of Oman (20.6° N, 58.4° E). The intertidal mudflats encompass 190

5

107 km^2 and can be found south of Shannah, in the Khawr Barr Al Hikman, near Filim and on

108 Masirah Island (Fig. 1b). Local industries included fisheries and salt mining, but the area is

109 relatively pristine. Crab Plovers can be found in the area almost exclusively in winter (Eriksen

110 and Victor 2013). Six GPS tracks and four ring observations show that Crab Plovers

111 wintering in Barr Al Hikman are connected to breeding areas in the Arabian/Persian Gulf in

112 colonies in Kuwait and South-West Iran (Fig. 1a, Bom and al-Nasrallah 2015). Barr Al

113 Hikman was surveyed for shorebirds including Crab Plovers in the four winters of 1989/90

114 (Green et al. 1992), 2007/08, 2013/14 and 2015/16 (de Fouw et al. 2017) (Table 1).

115

116 *Table 1. Survey results on wintering Crab Plovers at Barr Al Hikman, Oman, 1989-2016. In*

117 *the present study, survey results collected over the period 2007/08 – 2015/16 were used to*

118 *estimate the survey-based finite rate of population change.*

Year	No. of Crab Plovers	Source
1989-1990	2943	Green et al. 1992
2007-2008	6901	de Fouw et al. 2017
2013-2014	8759	de Fouw et al. 2017
2015-2016	8462	de Fouw et al. 2017

119

120   We collected mark-recapture data on Crab Plovers at Barr Al Hikman during ten

121 winter expeditions between 2007/08 and 2015/16 (one winter included two expeditions).

122 During seven expeditions, Crab Plovers were caught with mist nets and individually marked

123 with colour rings. All catching took place on the mudflats close to the shore 3 to 22 km south

124 of Shannah in the nights around a new moon. In 2008/2009 and April 2010, all newly

125 captured Crab Plovers received a unique combination of a single colour ring (white or orange)

126 with a single letter inscription on each tibia and a metal ring on the right tarsus. During later

127 years, birds were marked with four coloured rings and a green flag on their tibia, and a metal

128 ring on the tarsus. An initial mark-recapture analysis showed that there was no difference in

129   the resighting probability between the two types of colour rings as the Bayesian credible

130   interval (BCI) for an effect of marker type overlapped zero (BCI 95% [-0.481; 1.459]).

131   Crab Plovers were aged as yearlings (i.e. born in the previous summer) or adults (i.e.

132   birds older than 1 year, Table 2) at first capture. Yearlings of are easy to recognize by their

133   spotted crown and hind neck and their greyish mantle (Cramp and Simmons 2004). We could

134   not confidently age second-winter birds and we suspect that all yearling Crab Plovers had

135   moulted into their adult plumage prior to our catching expeditions (Supplementary Material

136   S1). During all expeditions, observation effort to resight the marked birds was concentrated

137   along the coast south of Shannah, but during most expeditions all other sites in the area were

138   visited and checked as well at least once.

139

140   *Table 2. Number of adult and yearlings Crab Plovers that were individually marked with*

141   *colour rings at Barr Al Hikman per field visit.*

Period	no. of ringed adults	no. of ringed yearlings
Dec 2008- Jan 2009	58	11
Apr 2010	2	4
March 2011	5	6
Nov-Dec 2011	29	3
Nov-Dec 2012	9	0
Nov 2014	22	7
Nov 2015	12	1

142

143

144   From 2011-2015, during early winter (November-December), we collected data on the

145 annual fecundity of Crab Plovers by regularly counting the number of yearlings and adults in

146 foraging or roosting groups all along the coast south of Shannah. Roosting groups were only

147 counted if all birds were visible, because it appeared that birds at flock edges were often

148 foraging yearlings. We counted between 8 and 22 groups per year, and between 10 and 666

149 individuals per group (Table 3).

150

151 *Table 3. The number of groups in which the percentage yearlings of Crab Plovers were*

152 *counted and the total number of birds counted. The final column give the model estimates of*

153 *the percentage of yearlings in the population per year.*

	no. groups counted	total no. birds counted	% of yearlings (mean ± 95% BCI) 154
2011/12	12	986	6.88 (5.41 – 8.53)
2012/13	12	766	6.77 (5.11 – 8.63)
2013/14	8	479	5.81 (3.89 – 8.14)
2014/15	22	1492	6.23 (5.10 – 7.49)
2015/16	11	2364	3.01 (2.42 – 3.80)

155

156

157 **Integrated population model**

158 We combined survey data and demographic data in a Bayesian Integrated Population Model

159 (IPM) (Schaub and Abadi 2011) to estimate the annual-dependent survey-based finite rate of

160 population change (λ_{obs}) and the annual-dependent demographic-based finite rate of

161 population change (λ_{exp}) for the five-year period 2011/12 – 2015/16.

162

163 *Survey-based finite rate of population change λ_{obs}*

164 λ_{obs} was estimated from population counts as:

165 $\lambda_{obs} = N_{t+1} / N_t$

166 where N_t is the total population size at year t and N_{t+1} is population size in the year t + 1. To

167 calculate N_t for winters in which no surveys were performed we simulated N_t by fitting a

168 quadratic polynomial function with a Poisson distribution through the survey data over the

169 period 2007/08 - 2015/16 in the Markov Chain Monte Carlo (MCMC) framework that we

170 used in our Bayesian model (Fig. 2). We calculated year-specific λ_{obs} and also the geometric

171 mean of $\bar{\lambda}_{obs}$ over all five years. The geometric mean was calculated as:

$$\bar{\lambda}_{obs} = \left(\sum_{t=1}^{T} \lambda_t\right)^{1/T}$$

172

173 (Stevens 2009).

174 Our estimation of λ_{obs} assumes perfect detection or equal probability of detection.

175 Imperfect detection is widespread in surveys of roosting birds (Sutherland 2006) and we

176 cannot guarantee perfect detection during our Crab Plover surveys. Arguably, probability of

177 detection between years is equal, as all surveys reported in Table 1 are comparable in the

178 sense that they covered exactly the same area and that there has been overlap between

179   observers during all surveys (Fouw et al. 2017). In addition, Crab Plovers roost in well-

180   defined congregations at the high-waterline and their conspicuous black-and-white plumage

181   make them hard to miss. Furthermore, tracking data show that Crab Plovers have limited

182   movements in their wintering area (unpublished data), making it unlikely that birds are

183   counted twice when surveys are conducted over subsequent days.
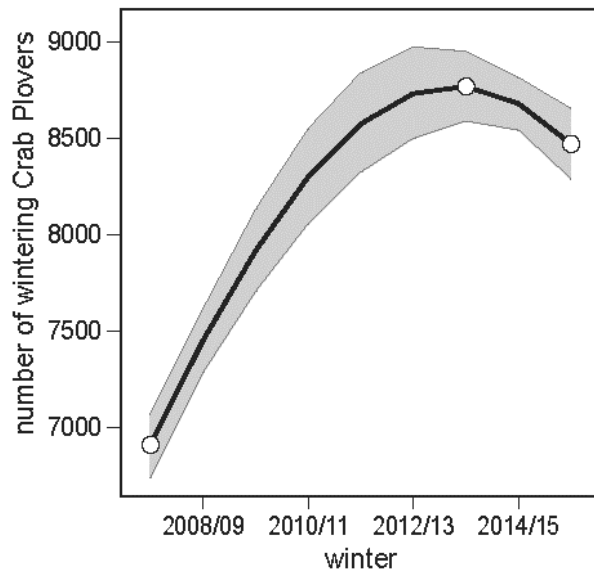

184

185   *Fig. 2. Number of wintering Crab Plovers in Barr Al Hikman in the study period based on*

186   *surveys (open circles) and modelled population estimates. The thick line represents posterior*

187   *means and shaded area represents 95% BCI.*

188

189   *Demographic-based finite rate of population change λ_{exp}*

190   We estimated λ_{exp} following assumptions shown in a post-reproductive census life cycle

191   diagram (Fig. 3). Accordingly, as we could not age second-winter birds, the Crab Plover

192   population at Barr Al Hikman in year t consists of yearlings (Y) and reproducing adults (A).

193   The number of adults that will be in the area at year t+1 depends on age-specific survival

194   probabilities (S_y and S_a) and age-specific site fidelity (ψ_y and ψ_a), and on immigration rate (ω).
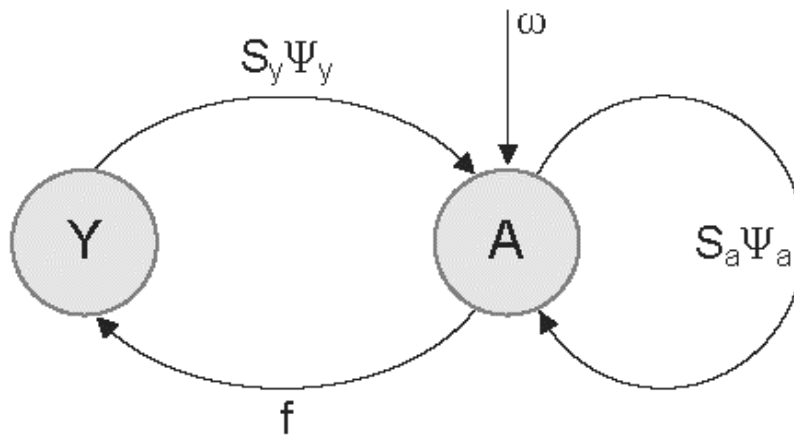
195

196   *Fig 3. The life cycle diagram used for a population model of Crab Plover wintering at Barr Al*

197   *Hikman. The two stages are the yearlings (Y) ≤ 1 year, and adults (A) birds > 1 year. The*

198   *demographic parameters are age-specific survival (S_y, S_a), age-specific site fidelity (ψ_y, ψ_a),*

199   *annual fecundity (f) and immigration of adults (ω).*

200

201   The number of yearlings in the area in year t+1 depends on the annual fecundity rate (f_t),

202   which is the proportion of yearlings per pair. We could not measure side fidelity (ψ) and

203   immigration (ω) directly. Instead we estimated apparent survival (φ) as the product of true

204   survival (S) and ψ (Lebreton et al. 1992) and immigration rate (ω) as the difference between

205   λ_{obs} with λ_{exp} (see below).

206   We used a Cormack-Jolly Seber model to estimate apparent survival (φ), which

207   corrects for the probability that not each bird is seen each year (resighting rate, p) (Lebreton et

208   al. 1992), which we constructed in a Bayesian framework (Kéry and Schaub 2012). We first

209   assessed the Goodness-of-Fit (GOF) in program Release in Mark to ascertain that the

210   underlying assumptions for mark-recapture models are met (Pradel et al. 2005). Test 2, which

211   tests the assumption that all individuals have an equal probability to be resighted and is

212   therefore referred to as a test of trap-dependence, was significant (χ^2 = 40.7049, df = 11, p <

213   0.01), and Test 3, which tests the assumption that all individuals have the same probability of

214   survival to the next time step, was not (χ^2 = 16.4881, df = 9, p = 0.0574). To account for trap-

215   dependence, we therefore used individual as random effect in the resighting probability (Kéry

216   and Schaub 2012). The intensity of fieldwork varied each year, and resighting probability was

217   modelled to vary among years. Test 3 of the GOF was almost significant, which could be

218   caused by a differing apparent survival rate between adults and juveniles. We therefore tested

219   preliminarily if apparent survival between yearlings and adults differed, which was not as the

220   95% BCI of their survival rates overlapped considerably (φ yearlings = 0.867, 95% BCI

221   [0.657-0.994], φ adults = 0.893, 95% BCI [0.844-0.938]). Then, with a time-since-marking

222   test, we tested whether catching influenced survival probability in the first year after catching,

223   which could be caused by higher mortality or permanent emigration after the disturbance of

224   handling, or by age-dependent survival probabilities (Sandercock 2006). We could find a

225   weak effect of catching on apparent survival (φ first year after catching= 0.821, 95% BCI

226   [0.672-0.982], φ years after first year after catching = 0.905, 95% BCI [0.855-0.950]). Given

227   that there was overlap in BCI, all age classes and years after catching were treated as one

228   group. Given our low sample size (Table 2), we did not calculate year-dependent annual

229   apparent survival to avoid over parameterization.

230   We estimated year dependent fecundity (f_t) as the proportion of yearlings within a

231   group (Y/[Y+A]), within the Bayesian framework. Because Crab Plovers lay (mostly) a single

232   egg per year, fecundity could be estimated with a generalized model using a binomial error

233   structure, and hence equals the fraction of success pairs (assuming that sex ratios of yearlings

234   and adults in Barr Al Hikman are equal). As we estimated fecundity over the total number of

235   birds older than one year (see below), we probably slightly underestimated the true fecundity

236   in Crab Plovers, as Crab Plovers probably start breeding after their second winter (Bom and

237   al-Nasrallah 2015). However, given that fecundity rates in Crab Plovers are low (see below),

238   this bias is probably small.

239   Because apparent survival between adults and yearlings did not differ, we could

240   calculate λ_{exp} as:

241    $\lambda_{exp} = \varphi + \varphi \, f_t$

242   We estimated year specific λ_{exp} and the geometric mean of $\bar{\lambda}_{exp}$ over all the years.

243

244   *Immigration*

245   We regard immigrants as birds that have been in other areas during previous winters (hence,

246   adult birds only). We calculated the per capita immigration rate ω for each year except the

247   first year as

248    $\omega = (N_t - \lambda_{exp} * N_{t-1})/N_t$

249

250   All parameters were estimated in one IPM. MCMC simulations for parameter

251   estimation were obtained by running the JAGS program (Plummer 2003) implemented in the

252   R environment (R Development Core Team 2013) using the *R2JAGS* package (Su and Yajima

253   2012). We used uninformative priors for all parameters. We ran three independent chains of

254   50,000 iterations of which the first 10,000 were discarded, and kept every 6th observation to

255   avoid autocorrelation. We checked the R-hat for convergence of the parameters (in all cases <

256   1.01). Estimates are presented as the posterior means and with a 95% BCI.

257

258   **Results**

259   The geometric mean $\bar{\lambda}_{obs}$ for the five-year period 2011/12 – 2015/16 was 1.004 (0.995–

260   1.013). The yearly λ_{obs} ranged between 0.98 and 1.02 and decreased over the years (Fig. 4).

261   Annual apparent survival probability was 0.895 (0.847–0.940) for the period 2008/09 –

262   2015/16. The annual resighting probability increased from 0.080 (0.025 – 0.169 95% BCI) to

263   0.744 (0.097 – 0.915 95% BCI) over the years 2008/09 – 2015/16 (Supplementary Material

264   S2). The estimated annual fecundity rate varied over the period 2011/12 – 2015/16 between

265   0.03 and 0.07 (proportion of yearlings), with 95% BCI ranging between 0.02 and 0.08. On

266   average, the annual fecundity rate was 0.06 (Table 3). Based on the estimated apparent

267   survival probability and fecundity rate, the geometric mean $\bar{\lambda}_{exp}$ over the period 2012/13 –

268   2015/16 was 0.949 (0.899 – 0.996 95% BCI) and annually ranged between 0.92 and 0.96 (Fig.

269   4). As we did not estimate a yearly dependent apparent survival probability, variation in λ_{exp}

270   was solely due to variation in the estimated fecundity rate, which was particularly low in the

271   last year (Table 3). To explain differences between λ_{obs} and λ_{exp}, we estimated yearly per

272   capita immigration rates of 0.056 (0.006 –0.107 95% BCI) in 2012/13, 0.052 (0.027–0.104

273   95% BCI) in 2013/14, 0.034 (0.026–0.086 95% BCI) in 2014/15 and 0.051 (0.103–0.026 95%

274   BCI) in 2015/16. Our estimated immigration rates correspond to 315-508 individuals per year.

275
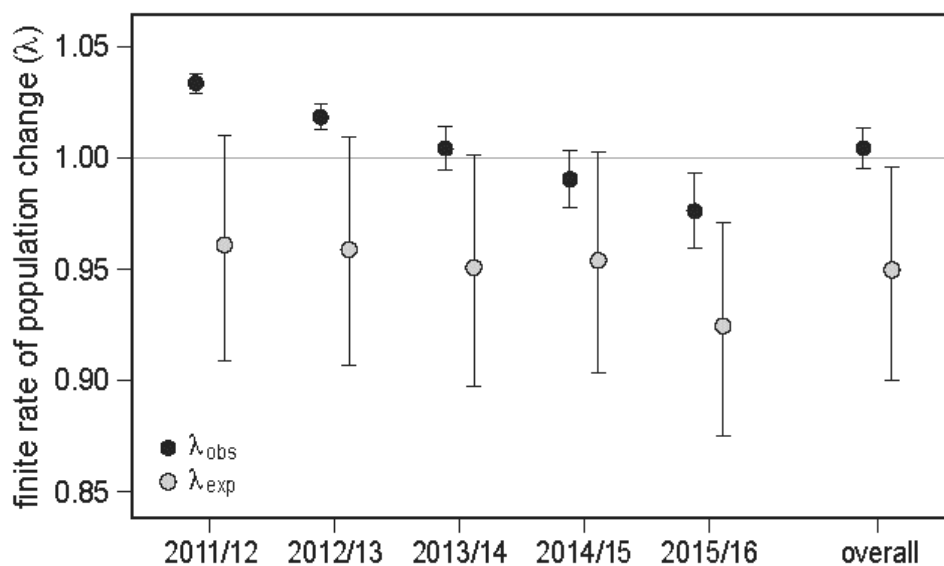
277   *Fig. 4. Annual finite rates of population change based on population surveys (λ_{obs}, black*

278   *dots) and based on demographic estimates (λ_{exp}, grey dots) and the overall $\bar{\lambda}_{obs}$ and $\bar{\lambda}_{exp}$.*

279   *Error bars show 95% BCI. The grey line at λ = 1 indicates the level at which the population*

280   *would be stable. The difference between λ_{obs} and λ_{exp} was used to calculate immigration*

281   *rates (ω).*

282

283

284   **Discussion**

285   **Annual survival**

286   We estimated the annual apparent survival rate of Crab Plovers at 90%, which shows that,

287   consistent with our expectations based on low fecundity rates, the Crab Plover is a long-lived

288   shorebird (Sandercock 2003). Similar high survival rates are known from other large-bodied

289   shorebirds including Eurasian Curlew *Numenius arquata*, Bar-tailed Godwit *Limosa*

290   *lapponica*, Black-tailed Godwit *Limosa limosa* and Eurasian Oystercatchers *Haematopus*

291   *ostralegus* (Conklin et al. 2016; Duriez et al. 2012; Kentie et al. 2016; Sandercock 2003;

292   Taylor and Dodd 2013). Compared to other shorebirds, Crab Plovers exhibit more extreme

293   life-history characteristics, including a clutch size of one egg and extended parental care, so it

294   is perhaps remarkable that the annual apparent survival rate was similar high instead of higher

295   than other large-bodied shorebirds. Since we could not separate true survival from permanent

296   emigration, it could be that the true survival estimate is higher than our apparent survival rate

297   (Lebreton et al. 1992). In general, shorebirds are extremely site faithful to their wintering area

298   (Leyrer et al. 2013; Lourenço et al. 2016), but we do not know site fidelity for Crab Plovers as

299   they move around in a part of the world where few observers are out on the shores looking for

300   colour-ringed birds. An observation in winter 2012/13 in south India of a bird that was ringed

301   by us in 2011/12 in Barr Al Hikman as an adult and never seen in the area afterwards, shows

302   that permanent emigration can occur, suggesting that our apparent survival estimates are a

303   conservative estimate of true survival in Crab Plovers. Note that the dispersal event to India

304   could also explain why the apparent survival in the first year was lower (but with overlapping

305   BCI) than the estimated apparent survival over the years after the year of catching.

306

307   **Finite rate of population change and immigration**

308   Survey data suggest that the population of Crab Plovers at Barr Al Hikman over the period of

309   study (2011/12 – 2015/16) was stable, as in this period the overall survey-based finite rate of

310   population change $\bar{\lambda}_{obs}$ did not differ from one (Fig. 4). A finite rate of change close to one

311   indicates that the population at Barr Al Hikman is possibly at carrying capacity (Newton

312   1998). Note that prior to the study period, between 1989/90 - 2007/08, the population

313   increased from 2,943 to 6,901 birds (de Fouw et al 2017; Table 1). As discussed by de Fouw

314   et al (2017), the effort and area covered in 1989/90 did not differ from the more recent

315   surveys; thereby the observed increase is thought to be genuine. Our demographic data did not

316   cover the period 1989/90 - 2007/08, hence the origin of this increase remains unexplained.

317   Based on demographic data over the period of study (2011/12 – 2015/16), we

318   estimated the overall demographic-based finite rate of population change ($\bar{\lambda}_{exp}$) to be 0.95

319   (Fig. 4). The upper value of the 95% BCI of $\bar{\lambda}_{exp}$ (0.996) slightly overlapped with the lower

320   value of the 95% BCI of the overall $\bar{\lambda}_{obs}$ (0.995), indicating that there is a small chance that

321    $\bar{\lambda}_{exp}$ did not differ from $\bar{\lambda}_{obs}$. (Fig. 4). Given the small overlap of the BCI, we reason that it is

322   more likely that the observed population stability cannot be explained by our survival and

323   fecundity estimates alone. Thus our study population likely received immigrants as part of a

324   larger metapopulation, which matches our observation that Crab Plovers emigrate from Barr

325   Al Hikman. The annual means of λ_{obs} and λ_{exp} predict net immigration ranging from 315 to

326   508 Crab Plovers per year. Immigrants could, for instance, originate from areas where the

327   population of Crab Plovers is at carrying capacity, or Crab Plovers may immigrate to Barr Al

328   Hikman when conditions at their original wintering site are deteriorating (de Fouw et al

329   2017). Limited data show that populations in other wintering areas are stable or increasing

330   (Fig. 5), leaving the scenario open that immigrants could originate from other areas that are

331   already at carrying capacity.
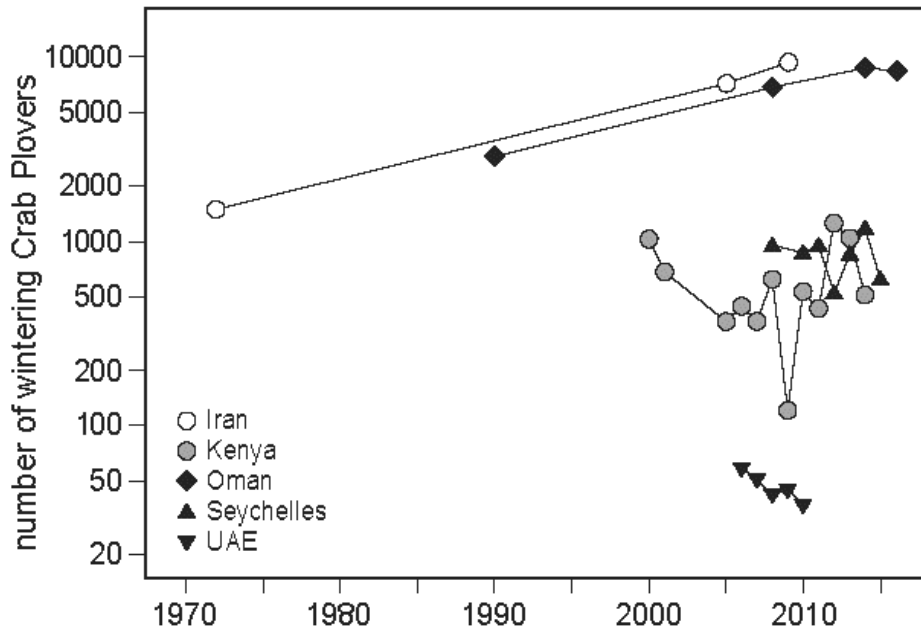
332

333   *Fig. 5. Survey-based population estimates of Crab Plovers in five countries on a $\log_{10}$ scale.*

334   *The large wintering population of Crab Plovers in Iran, which likely have shared breeding*

335   *areas with the Barr Al Hikman population, was observed to increase (data from Amini and*

336   *van Roomen 2009; Summers et al. 1987). A small population of wintering Crab Plovers in the*

337   *United Arab Emirates decreased from 60 to 30 birds from 2006-2010 (Javed et al. 2012).*

338   *Two winter populations along the shores in East-Africa (Miday Creek in Kenya, data C.*

339   *Jackson) and Aldabra in the Seychelles (data: the Seychelles Islands Foundation) were*

340   *apparently stable during the last decade.*

341

342   Immigrants could also be second-year Crab Plovers that during their first winter have

343   stayed close to the breeding areas. Differential migration is widespread among migratory

344   shorebirds (Cristol et al. 1999; Nebel 2007). If this is the case, percentages of yearling Crab

345   Plovers in wintering groups closer to the breeding areas should be higher than the 3-7 % of

346   yearlings found at Bar al Hikman. Only few surveys of Crab Plovers exist, yet these surveys

347   supported this possibility: A winter population near breeding areas in Eritrea consisted on

348   average of 8% of yearlings (18 groups counted during winter over the period 2002-2009, total

349   adults = 1160, yearlings = 99, G. De Marchi, unpublished data). A group of 104 wintering

350   Crab Plovers in January 2016 close to the breeding areas in Kuwait consisted of 16% of

351   yearlings (P. Fagel, pers. comm). Likewise, a group of 550 wintering Crab Plovers in the Gulf

352   of Kutch in India consisted of 17% yearlings, but it is unknown if Crab Plovers breed in this

353   area (Palmes and Briggs 1986). Thus, although the origin of immigrants remain unknown,

354   available data suggest that immigrants are birds that stayed close to their natal area during

355   their first winter.

356

357   **Conclusion**

358   Our results support the current IUCN listing of the world population of Crab Plover as stable

359   (IUCN 2017). Stability may be unexpected given that the species is under human pressure in

360   their wintering grounds and especially in their breeding grounds where colonies remain

361   subject to egg-collecting and harvest of chick and adults (De Marchi et al 2006; Behrouzi-Rad

362   2013; Tayefeh et al. 2013). We emphasize that survival and fecundity estimates indicate that

363   the population of Crab Plovers wintering at Barr Al Hikman received immigrants, but their

364   origin remains speculative. Finding the origin of these immigrants is a prerequisite to better

365   understand the status of Crab Plovers wintering and breeding in the Arabian/Persian Gulf.

366   Moreover, range-wide survey and ringing activities are needed to better understand the *global*

367   status of Crab Plovers.

368   To our knowledge, our study is the first to report demographic parameters of a

369   shorebird population wintering in the coastal areas of the Arabian Peninsula and East-Africa.

370   The observed population stability contrasts with the rapid declining populations of many other

371   shorebird species elsewhere in the world (Fernández and Lank 2008; Piersma et al. 2016; van

372   Roomen et al. 2015); declines that are thought to be caused by environmental change,

373   affecting particularly wintering- and stopover areas of shorebirds (Pearce-Higgins et al. 2017).

374   Thus, shorebirds may still be able to find vital wintering grounds along the coasts of the

375   Arabian Peninsula and East-Africa. From a conservation point of view, it is timely to protect

376   those habitats and to continue monitoring the status of their inhabitants. Only then, unique

377   birds such as the Crab Plover can be safeguarded for the future.

378

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