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The Cattle Egret (*Bubulcus ibis*) on Fernando de Noronha Archipelago: history and population trends

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RESUMO: A garça-vaqueira (*Bubulcus ibis*) no Arquipélago de Fernando de Noronha: história e tendências populacionais. O presente trabalho discorre sobre a colonização da garça-vaqueira (*Bubulcus ibis*) no Arquipélago de Fernando de Noronha, estabelecida na década de 1980, avaliando as tendências populacionais e seus possíveis impactos sobre as espécies nativas. Dados primários e históricos de estimativas populacionais foram ajustados a modelos de regressão não-linear para o cálculo de taxas intrínsecas de crescimento (r) e de incremento anual (λ) para diferentes períodos. Esses apontam que, na primeira década a espécie era irregular no arquipélago, mas nos anos subsequentes apresentou um crescimento exponencial abrupto (r = 0,302 aves/ano e λ = 1,352), chegando a uma população estimada em 655 (DP = 13) indivíduos em 2005. Posteriormente, passaram a ser aplicadas medidas de controle populacional pelo governo local, o que resultou em uma diminuição progressiva em sua abundância, contudo, a eficácia dos métodos diminuiu e a população mostrou sinais de uma acelerada recuperação (r = 1,147; λ = 3,147). Essas experiências sugerem que os esforços descontínuos e pontuais no manejo de garças-vaqueiras, ou sobre apenas uma fração parcial de uma população, tendem a funcionar apenas como medidas mitigatórias, considerando a capacidade na reposição de suas populações.

PALAVRA-CHAVE: Garça-vaqueira, *Bubulcus ibis,* colonização, dinâmica populacional, Fernando de Noronha, Brasil.

ABSTRACT: This paper addresses the colonization of Cattle Egret (*Bubulcus ibis*) on Fernando de Noronha Archipelago, established in the 80's, and evaluate population trends of this species and the potential impacts on native species. Primary and historical data of population estimates were adjusted to nonlinear regression models. Intrinsic growth rate (r) and annual increment rate (λ) for different periods were calculated. The estimates indicate that until the first decade species occurrence on the archipelago was irregular. Nevertheless, it presented an abrupt exponential growth (r = 0.302 birds/year and λ = 1.352) over the following years, reaching an estimated population of 655 individuals (DP = 12.73) in March 2005. Posteriorly, it went through a progressive decrease in abundance when population control measures started being applied by the local government. However, efficacy of these methods decreased and the population presented signs of an accelerated recovery (r = 1.147; λ = 3.147). These experiences suggest that interrupted and sporadic efforts in managing the Cattle Egret population, or simply a portion of it, tend to work only as mitigatory measures, considering the replacement capacity of its population.

KEY-WORDS: Cattle Egret, *Bubulcus ibis,* Colonization, Population dynamics, Fernando de Noronha, Brazil.

The Cattle Egret (*Bubulcus ibis*) is a species with great capacity to invade and occupy new areas in different regions of the world. Its original distribution was restricted to the south of the Iberian Peninsula and parts of sub-saharan and meridional Africa (*B. ibis ibis*), India and southeastern Asia (*B. ibis comodorus*), and Seychelles Islands (*B. ibis seychellarum*) (Martínez-Vilalta and Motis 1992). In the last century, the range of this species expanded enormously and it currently occurs on all continents except for Antarctica (Martínez-Vilalta and Motis 1992). The most remarkable events of this expansion are the rapid invasions of Australia and New Zealand, by *Bubulcus ibis comodorus* (Turbott *et al.* 1963, Morris 1979, Maddock 1990), and the American Continent, by *Bubulcus i. ibis* (Rice 1956; Crosby 1972; Arendt 1988).

In this paper, we address the African Cattle Egret subspecies, *Bubulcus ibis ibis.* The American Continent was naturally colonized by individuals of this subspecies, which possibly came from the Mediterranean or Northwestern Africa (Crosby 1972). Based on early registers, it is deduced that the Cattle Egret had reached the South American Continent several times. This species was first observed in Guyana and Suriname in 1877, and was registered more regularly only since 1937 (Rice 1956; Crosby 1972, Browder 1973). Since then, the Cattle Egret population has been expanding all over America, with

establishment of reproductive colonies (see Crosby 1972; Arendt 1988). This colonization is considered one of the fastest invasions ever registered (Arendt 1988), with an estimated expansion speed of 106.2 km/year (van den Bosch *et al.* 1992).

The Cattle Egret was first reported in Brazil in 1965, on Marajo Island, associated with the presence of buffalos (Sick 1965). Currently, this species occurs extensively in almost every region of the country, and expansion in cattle-raising is supposed to have facilitated this occupation (Sick 1997, Bella and Azevedo-Júnior 2004). In Africa, it follows grazing mammals in order to feed on the invertebrates that are exposed while these animals forage (Siegfried 1971, Thompson *et al.* 1982).

In the 1980s, Cattle Egrets were first reported on Fernando de Noronha Archipelago, 345 km from the Northeastern Brazilian coast. The colonization was apparently natural, with the arrival of individuals coming from the continent dispersed by flight. However, there is no conclusive data on the origin of the Cattle Egret on the Archipelago, and whether they came from the American or African Continent.

Since its arrival on the archipelago, the Cattle Egret population has had a noteworthy increase. Conversely, there is no study that precisely indicates the number of individuals, population tendencies, or possible impact on native species. It is important to know this information, considering that invasion by alien species is one of the main causes of biological diversity loss in insular environments (Vié *et al.* 2009).

The Cattle Egret has also become a risk for aerial navigation on the archipelago due to its occupation at the airport track. Collisions of Cattle Egrets and airplanes have already been registered (reports of the National Center for Investigation and Prevention of Aeronautic Accidents – CENIPA, unpublished data). Therefore, increasing risks of collision and possible ecological impacts motivated Archipelago and Airport administrations to implement some management techniques to control the Cattle Egret population. We present in this paper historical data on the *Bubulcus ibis ibis* population on Fernando de Noronha Archipelago, through the compilation of bibliographical information and data collected by The National Center for Bird Conservation Research (CEMAVE). We also discuss population trends of this species and its responses to measures applied to manage its population.

MATERIAL AND METHODS

Study Site

Fernando de Noronha is a volcanic archipelago isolated in the Southern Equatorial Atlantic Ocean (03°51'S; 32°25'W), approximately 345 km from Cabo de São Roque, Rio Grande do Norte State, Brazil (Figure 1). It is composed of an 18.4 km^2-main island, which represents 91% of the total archipelago area, surrounded by other small islands and islets. Its climate is tropical, oceanic hot, with well established seasons (IBAMA and FUNATURA 1990).

Official descriptions of the Fernando de Noronha Archipelago were from the year 1503, by Américo Vespúcio. The islands have been progressively altered since the 18th century, with removal of large trees, introduction of exotic animals and plants, cattle-raising, small crop plantations, mining, logging, and especially urban expansion (Felfili and Silva-Júnior 1990, Teixeira *et al.* 2003). Such interference changed drastically some parts of the islands and it is possible that not much of the original terrestrial ecosystem remains (Felfili and Silva-Júnior 1990).

Shrubs and creeping species predominate in the vegetation of the archipelago (*e.g., Paspalum paniculatum, Cereus insularis, Oxalis insipida*). Arboreal species can be found on irregular terrains (*e.g., Sapium sceleratum, Erythrina velutina* and *Tabebuia roseoalba*) and a small area of white mangrove (*Laguncularia racemosa*) is found on Sueste Beach. However, several of these natural areas are also occupied by invading species, such as *Desmodium* sp., *Leucaena leucocephala, Lantana camara* and *Acacia farnesiana* (Batistella 1996).

The avifauna of the archipelago constitutes one of the greatest diversities of marine birds in Brazil, with important breeding and feeding sites. Seventy-five bird species have already been observed on the archipelago, including marine and terrestrial, as well as migratory birds and sporadic visitors (Silva 2008). Among the native species, only three of them, which are also endemic taxa to the island, are terrestrial: the Noronha Eared Dove (*Zenaida auriculata noronhae*), the Noronha Vireo (*Vireo gracilirostris*) and the Noronha Elaenia (*Elaenia ridleyana*). The Noronha Vireo and the Noronha Elaenia are considered vulnerable to extinction.

The archipelago is considered to be two Conservation Unities: Parque Nacional Marinho de Fernando de Noronha (Marine National Park of Fernando de Noronha), founded in 1988, and the Área de Proteção Ambiental de Fernando de Noronha (Environmental Protection Area of Fernando de Noronha), founded in 1986. The main island is inhabited by 2,500 people, but receives around 800 people per day made up of a "floating population" that includes tourists, service suppliers and researchers (Área de Proteção Ambiental de Fernando de Noronha, unpublished data). Four daily commercial flights and ships are the main link to the continent, bringing supplies and people to Fernando de Noronha.

The main island is serviced by a waste processing and composting plant, located within the Área de Segurança Aeroportuária (Aeroportuary Safety Area, ASA), about 400 meters from the landing headboard of the airport. In

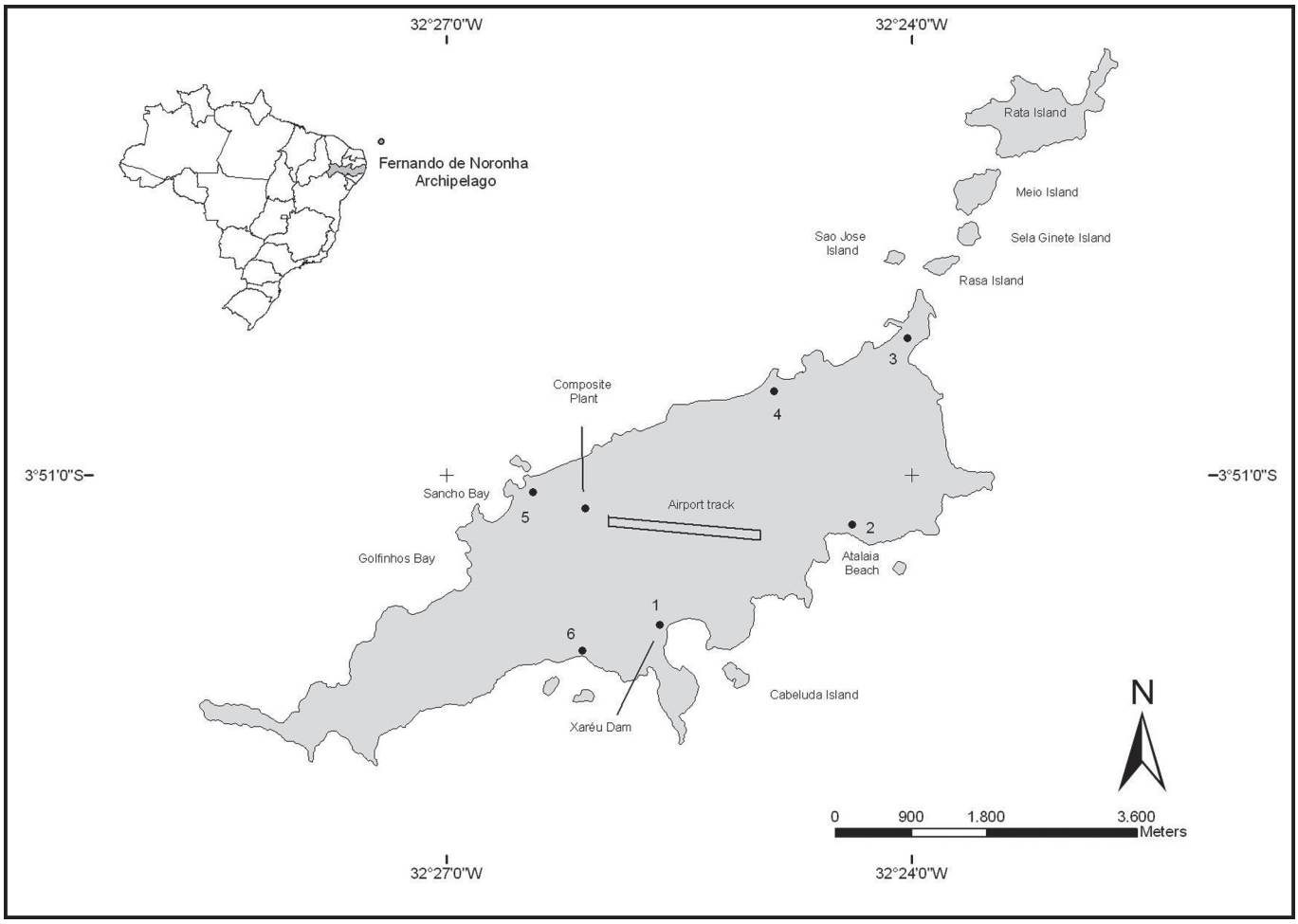

FIGURE 1: Location map of Fernando de Noronha Archipelago. In detail, the position of the six point-counts (black dots) used to survey Cattle Egrets in secondary islands.

the plant there is a conveyor belt for solid waste separation and a meshed structure of approximately 2500 m^2 where organic waste is deposited for composting.

METHODS AND DATA ANALYSIS

We have presented a compilation of historical data on Cattle Egret population registers and on its interaction with local biota on the Fernando de Noronha Archipelago between 1986 and 2003. We have also carried out a series of population estimates from 2005 to 2008, by means of a standardized method to obtain a more accurate measurement on population abundance through time.

From March 15-21, 2005, we first identified the sites with higher concentration of Cattle Egret on the archipelago. Two observers walked on trails and roads of the main island and visited some sites where people had previously reported the concentration of these birds (inhabitants *pers. comm.,* Schulz-Neto 2004a). We plotted on maps (by GPS and compass) the localities where the species was abundant, as well as the destination of individuals during nightfall to determine their roost sites.

The secondary islands were sampled from six spots at the border of the main island with telescopes (15 × 60 mm) and long-range binoculars (12 × 50 mm). These islands are small and not too far from the main island (Figure 1). Each one was observed two times, at daybreak and nightfall, when greater dislocation of egrets occurs between roosting and feeding sites.

After this survey, we found two roosting sites for the Cattle Egret located on secondary islets: Cabeluda and Sela Ginete Islands. Simultaneous counting of Cattle Egrets during flight to these two roosting sites at the end of the day (4:40 p.m. – 6:30 p.m.), resulted in estimates of the total population size, since they are social and gather in common areas for breeding and sleeping. It was feasible to determine the size of the flock during flight through direct counting by trained observers. On some occasions when groups made up of dozens or hundreds of individuals arrived at a roosting site, we used techniques suggested by Bibby (1993), such as counting subgroups (*e.g.,* multiples of 2, 3, 4 or 5 individuals).

Each count was made from a cliff or a rocky beach on the main island with good visibility of Cattle Egret roosting sites, using binoculars and spotting scopes. We

assumed that the summation of the two simultaneous counts corresponded to population size of the species on the archipelago for that day of sampling. We did not exclude the possibility of some individuals that slept elsewhere. However, if that were the case, we assumed they were a small group and did not increment substantially the obtained values.

On each expedition, simultaneous counts were repeated two to five times, and the daily estimate mean was considered the closest value of the total egret population on Fernando de Noronha in that period. Between 2005 and 2008, we carried out population estimates for seven different periods (03/17/2005 and 03/18/2005; 10/21/2005 and 10/22/2005; 08/24/2006 and 08/31/2006; 05/15/2007 to 05/17/2007; 04/22/2008 to 04/30/2008; 07/07/2008 to 07/18/2008; and 11/24/2008 to 12/05/2008). Population estimate values through the years were adjusted to nonlinear regression models, according to data variation behavior. Instantaneous or intrinsic growth rate (r) and increment rate (λ) were calculated as in Margalef (1998). The software Statistica (Statsoft 1998) was used for statistical analysis.

During data sampling, two management techniques for controlling the Cattle Egret population were implemented by the Airport and Archipelago administrations. These events were also highlighted in the interpretation of species population trends: 1) In 2004, an isolation cage was built around the composting plant of Fernando de Noronha, considered the main feeding site of the species. However, only after May 2005 was the area properly isolated to deter the entry of birds; 2) In 2008, the administration of the island started to carry out direct management of the species through capture and euthanasia of individuals. The cage at the composting plant was used as a trap for capturing individuals. Such actions are part of the "Management Plan Aiming to Prevent and/or Reduce Collisions with Wild Fauna of the Airport of Fernando de Noronha" and, until the conclusion of this paper, six field expeditions had been carried out (December of 2007 and January, February, April, July and August of 2008), with a total of 385 euthanized individuals (Field reports of the executor team, J. C. R. da silva, *pers. comm.*). To verify alterations in the use of the areas occupied by Cattle Egrets after the implementation of management measures, all sampled areas of the inventory of March 2005, such as secondary islets, interpretative trails, mangroves and dams, were revisited between April 23 and April 29, 2008.

RESULTS

Cattle Egret Occupation History

Information from literature shows that, until the first half of the 1980s, there are no reports of the occurence of this species on Fernando de Noronha Archipelago (Oren 1982, 1984). The first known report of Cattle Egrets refers to two individuals observed on the main island in June 1986 (Nacinovic and Teixeira 1989). Afterwards, 12 individuals were reported in May 1987 and three others in October 1987. However, no Cattle Egrets were found in May 1988 (Antas *et al.* 1990).

Bird censuses were carried out on the archipelago by CEMAVE in 1991, 1992, 1993 and 1996, and few Cattle Egrets were reported: only one individual in November 1992, and 12 in September 1993. In October 1991 and November 1996, the species was not reported (Schulz-Neto 2004a). Due to its sporadic occurrence on the archipelago, the Cattle Egret was classified as an occasional visitor during the decades of 1980 and 1990 (Nacinovic and Teixeira 1989, Schulz-Neto 2004a).

CEMAVE started to carry out bird counts on the archipelago and, in April 2001, reported 54 Cattle Egrets near the airfield track. In February 2003, Silva and Silva (2003) estimated the total Cattle Egret population of the archipelago at approximately 400 individuals. The authors further reported the establishment of colonies on Cabeluda and Sela Gineta Islands (Silva and Silva 2003), as was also observed in our study.

In March 2005, CEMAVE started to carry out simultaneous bird counts at the roosting sites, and reported 655 (SD = 12.73) individuals, the highest number of individuals ever reported on the archipelago. From subsequent months on, species management and population control started being carried out on the islands, and it progressively reduced the abundance of Cattle Egret (Table 1).

Population Trends

We attempted to adjust all the population size estimates from 1986 to 2008 to a nonlinear regression model. However, the population growth tendency was not regular throughout the years. Instead we chose to analyze distinct periods of population growth separately by adjusting the regression models to each period: from June 1986 to March 2005 (period AB); October 2005 to May 2007 (period BC); May 2007 to April 2008 (period CD); April 2008 to July 2008 (period DE); and from July 2008 to November 2008 (EF) (Table 2). Changes in the growth tendencies observed at each period coincided with the beginning of different management treatments applied to the species (Figure 2).

We verified that until March 2005 (period AB, Figure 3), when the Cattle Egret management measures had not been implemented, the estimates indicated an abrupt exponential growth of the species, presenting an intrinsic growth rate (r) of r = 0.302 birds/year and an increment rate (λ) of 1.352. We estimated that, if the growth

TABLE 1: *Bulbucus ibis* population estimates at Fernando de Noronha, between 1986 and 2008, including primary and secondary data.

Month/Year	Nº of counts	Estimates (x)	S.D.	Min	Max	Source
Jun/1986	—	2	—	—	—	Nacinovic and Teixeira 1989
May/1987	—	3	—	—	—	Antas *et al.* 1988
Oct/1987	—	3	—	—	—	Antas *et al.* 1988
Oct/1988	—	0	—	—	—	Antas *et al.* 1988
Oct/1991	—	0	—	—	—	Schulz-Neto 2004
Nov/1992	—	1	—	—	—	Schulz-Neto 2004
Sep/1993	—	12	—	—	—	Schulz-Neto 2004
Nov/1996	—	0	—	—	—	Schulz-Neto 2004
Apr/2001	—	54	—	—	—	CEMAVE, unpublished data
Feb/2003	—	400	—	—	—	Silva and Silva 2003
Mar/2005	2	655	12.73	646	664	CEMAVE (standardized method)
Oct/2005	2	561	36.77	535	587	CEMAVE (standardized method)
Aug/2006	2	505	13.43	495	514	CEMAVE (standardized method)
May/2007	3	496	36.67	454	523	CEMAVE (standardized method)
Apr/2008	3	236	4.04	234	241	CEMAVE (standardized method)
Jul/2008	5	314	4.69	309	321	CEMAVE (standardized method)
Nov/2008	3	298	8.02	290	306	CEMAVE (standardized method)

TABLE 2: Exponential regression models of Cattle egret population growth on Fernando de Noronha Archipelago between 1986 to 2008, demographic parameters and projections of future abundance for 2 and 5 years (R^2: determination coefficient; r: intrinsic growth rate; λ: annual increment rate).

Period	Model	R^2	r	λ	Estimates 02 years	Estimates 05 years
AB (06/1986 – 03/2005)	y = -5,442+exp(-0,69376+(0,374)*x)	97,3	0,302	1,352	1,413.416	4,354.236
BC (03/2005 – 05/2007)	y = 511,513+exp(57,5243+(-2,731)*x)	76,1	-0,110	0,896	511.515	511.51
CD (05/2007 – 04/2008)	y = 37,653+exp(25,642+(-0,911)*x)	97,3	-0,536	0,585	69.865	39.747
DE (04/2008 – 07/2008)	y = -23,539+exp(-17,778+(1,045)*x)	98,9	1,147	3,147	2,695.680	62,487.597
EF (07/2008 – 11/2008)	y = -11,717+exp(9,131+(-0,148)*x)	67,9	-0,145	0,865	218.743	136.,067

tendency had been maintained, considering an independent growth density, the population could have reached about 1,400 individuals in 2007 and about 4.300 in 2010.

The estimates between October 2005 to May 2007 (period BC, Figure 4) pointed to an exponential reduction of Cattle Egret population size, corresponding to a negative growth rate of r = -0.110 birds/year and an increment rate of λ = 0.896. Just before this period in May 2005, indirect management was implemented by adequately isolating the waste composting plant. This measure reduced the food supply of the Cattle Egret's main foraging site on the archipelago. We estimated that, if this management were maintained under the same conditions, the expected population would stabilize to 511 individuals in 2009.

The population estimate of 236 (SD = 4.04) individuals for April 2008 (period CD, Figure 5) indicated a significant exponential reduction on the number of individuals, corresponding to 52.42% of the population. This decreasing tendency coincided with the period of greatest activity in the execution of direct management promoted by the Airport and Archipelago Administrations between December 2007 and February 2008, when a total of 288 individuals were euthanized (J. C. R. da Silva, *pers. comm.*). The negative growth rate (r = -0,536; λ = 0,585) was five times higher in comparison with those from the previous period (BC), when only indirect management measures were being taken.

In July 2008, the Cattle Egret population was estimated to be 314 (SD = 4.69) individuals, representing a marked recovery tendency of the population (period DE, Figure 6), with a growth rate 3.8 times faster (r = 1.147; λ = 3.147) than in the first period of 1986-2005 (AB). This estimate matched the period of diminishing capture efforts for euthanasia, and later its interruption. Between March and the beginning of July 2008, a total of only seven individuals were euthanized (J. C. R. da Silva, *pers. comm.*). We estimated that if the direct population management, concomitant with indirect population management, had continued with the same intensity of the first semester of 2008, the Cattle Egret population would have been reduced to 70 individuals in two years, and 40 individuals in five yearIn November 2008, a new reduction tendency of the Cattle Egret population was detected (period EF, Figure 7), with an estimate of 298 (SD = 8.02) individuals (r = -0.145; λ = 0.865). This period coincided

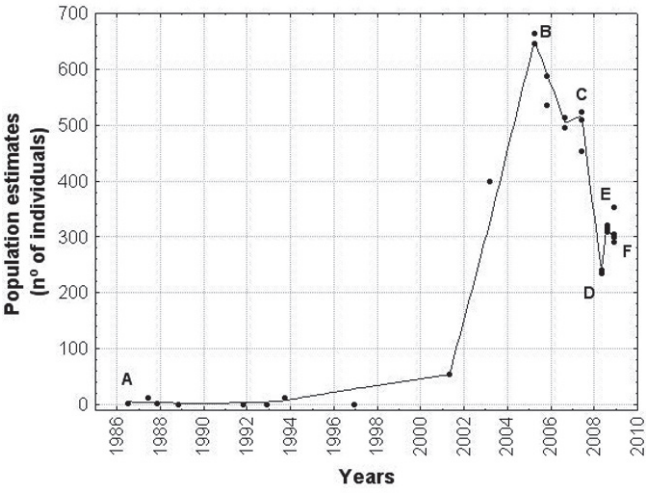

FIGURE 2: *Bubulcus ibis* population estimates at Fernando de Noronha, between 1986 and 2008. AB: exponential growth; BC: indirect management; CD: direct management; DE: direct management interruption; EF: retaking of direct management.

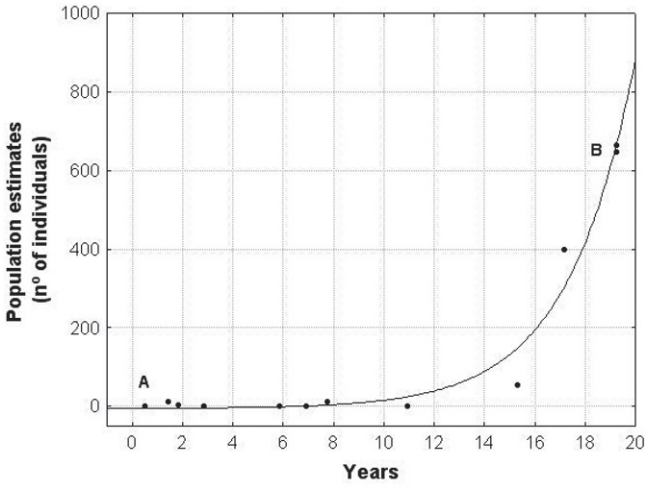

FIGURE 3: Exponential regression model for *Bubulcus ibis* growth at Fernando de Noronha, between June 1986 and March 2005 (AB).

with the retaking of management actions between July and August, when 90 individuals were euthanized (J. C. R. da Silva, *pers. comm.*).

Spatial Distribution

During inventory for the search of Cattle Egret concentration spots in March 2005 and April 2008, the species was widely distributed, principally with an association to anthropic environments (Table 3). Dense aggregations of egrets were observed at the airport track and composting plant, and as isolated individuals or in pairs foraging in backyards, squares, corrals, pastures, and other places where there was food available. In more preserved regions of the island, such as the trails inside the National Park that give access to Baia dos Golfinhos (Dolphin Bay) and Baia do Sancho (Sancho Bay), the presence of the species was not reported.

The secondary islands on which individuals were spotted foraging are Rasa, do Meio and Sela Ginete. Cabeluda and Sela Ginete Islands were used as roosting sites, and Cabeluda Island was the preferred destination of individuals that foraged at the airport track, composting plant and Xaréu dam.

Distribution patterns of the Cattle Egret throughout the archipelago in 2005 and 2008, observed by the snapshot survey, are alike. The presence of Cattle Egrets was not modified substantially, mainly concerning their roosting and feeding areas even after direct and indirect management measures. The exception to this is a smaller quantity of individuals at Xaréu dam and the composting plant in 2008, and the significant increase on Atalaia beach, where the species was associated to cattle (Table 3).

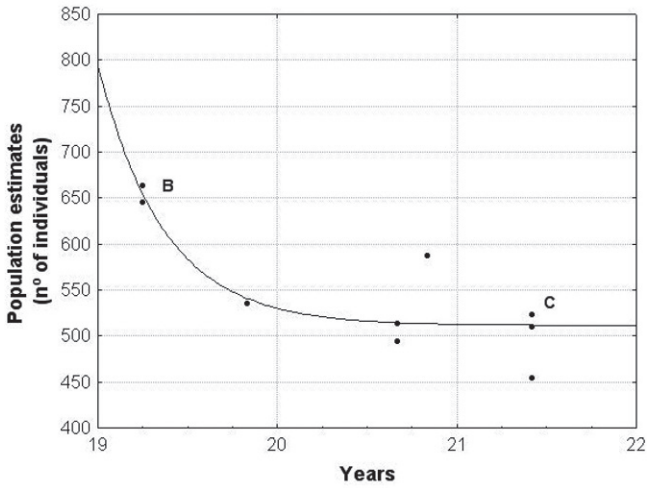

FIGURE 4: *Bubulcus ibis* population exponential decrease model at Fernando de Noronha, between March 2005 and May 2007 (BC).

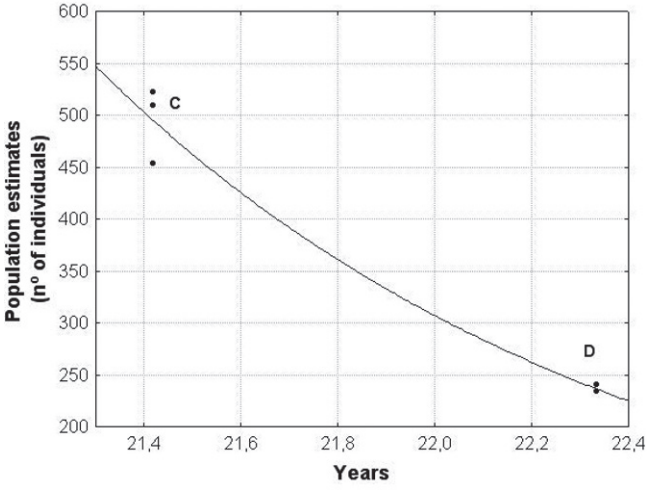

FIGURE 5: *Bubulcus ibis* population exponential decrease model at Fernando de Noronha, between May 2007 and April 2008 (CD).

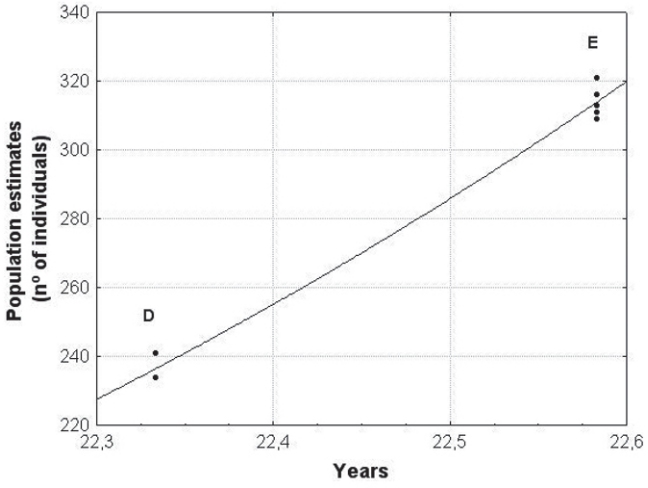

FIGURE 6: Exponential regression model for *Bubulcus ibis* growth at Fernando de Noronha, between April and July 2008 (DE).

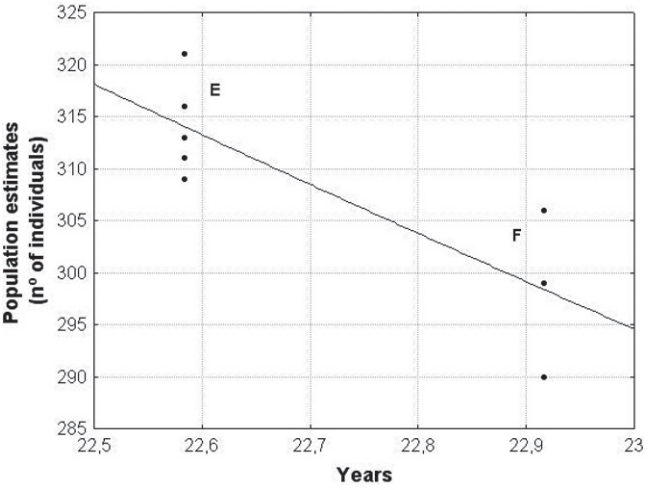

FIGURE 7: *Bubulcus ibis* population exponential decrease model at Fernando de Noronha, between July and November 2008 (EF).

TABLE 3: Numbers and relative frequency of abundance (RF) of Cattle Egret in foraging sites on Fernando de Noronha Archipelago, during snapshot surveys conducted in March 2005 and April 2008.

Foraging sites	Nº of egrets (RF%) in 2005	Nº of egrets (RF) in 2008
Composting plant	144 (44,86%)	64 (31,07%)
Airport track	77 (23,99%)	40 (19,42%)
Sela Ginete Island	49 (15,26%)	35 (16,99%)
Xareu Dam	36 (11,21%)	5 (2,43%)
Atalaia Beach	9 (2,80%)	50 (24,27%)
Pedreira Dam	3 (0,93%)	0 (0%)
Rasa Island	2 (0,62%)	1 (0,49%)
Leão Beach	1 (0,31%)	4 (1,94%)
Gato Dam	0 (0%)	6 (2,91%)
Quixaba Dam	0 (0%)	1 (0,49%)
São José Island	0 (0%)	1 (0,49%)
Total	321 (100%)	307 (100%)

DISCUSSION

Population Trends

Data presented here indicates that the Cattle Egret population grew quickly after its establishment on the archipelago since 1986. In approximately 15 years, this population reached about 655 individuals in an area not much bigger than 20 km², including the secondary islets, corresponding to an approximate density of 32.75 individuals/km². In fact, its density is even higher in some places because of the gregarious behavior of the species at roosting and major feeding sites. In a short time, the Cattle Egret became one of the most abundant and conspicuous bird species on Fernando de Noronha.

The first growth phase was well represented by an exponential curve model, which is characterized by a constant population growth rate in situations of non-limited resources. However, this is a wild population and it is expected to become saturated in a density threshold, limited by intra and interspecific interactions, for instance: food; shelter or nesting area limitation; predatory or parasitism effects; and others (Pianka 1994). The detected exponential growth seems to be the initial phase of a logistic growth. The logistic model is the most common pattern found in wild populations, because density-dependent effects delay growth rates and stabilize populations (Pianka 1994).

We could not predict the moment when density-dependent effects would have started to regulate the Cattle Egret population, because management measures started being applied before the population reached its carrying capacity. Such measures resulted in a sharp population decrease, preventing the worsening of some problems caused by the Cattle Egret on the islands. According to the estimates under density independent factors, the population would practically double in just two years.

Other authors addressed the difficulty of predicting the carrying capacity of Cattle Egret populations because of their remarkable ecological flexibility – it seems they are always finding empty niches to be explored (Krebs *et al.* 1994). An example is on Barbados, a 431 km²-island in the Antilles. This island was colonized by the Cattle Egret in 1956, and in 34 years it held a population of approximately 11,000 individuals. Even with this large population, no evidence of food and space limitations for the establishment of colonies was found, whereas the population growth continued in exponential tendency (Krebs *et al.* 1994). The exponential growth tendency of Cattle Egret populations was also observed in other areas of the American Continent (Baillie 1963, Bock and Lepthien 1976, Larson 1982), including insular environments (Arendt 1988, Krebs *et al.* 1994). But only Bock and Lepthien (1976), in their study on *Bubulcus ibis* in Florida from 1956 to 1971, calculated the growth rate

(r = 0.21) of the population. This value was close to that observed in the present study (r = 0.30).

Efficient colonization of the Cattle Egret at tropical sites is attributed to its generalist behavior, and also to high recruitment rates, long reproductive seasons and the presence of few predators, especially in the case of islands (Arendt 1988). Several studies have suggested that species with generalist characteristics have a higher probability of establishing themselves and expanding quickly in new environments (Blackburn and Duncan 2001, Cassey 2002, Sol *et al.* 2002).

The Cattle Egret has the capability of surviving in several environmental conditions and demonstrates the ability of changing behavior in order to explore new resources. Currently, it occupies a wide ecological niche in the Americas, and is found inhabiting such different habitats as natural fields, savannas, lowlands, urban areas, pastures, plantations, dense forests (Martínez-Vilalta and Motis 1992) and deserts (McFarlane 1975). There are reports of them feeding in natural terrestrial biomes, solid waste deposits, pastures, agricultural areas (Pomeroy 1975, Martínez-Vilalta and Motis 1992, Yorio and Giaccardi 2002), sea pools on oceanic islands (Bowen and Nicholls 1968) and mud areas (Strange 1979). This species reproduces in environments at sea level and about 4,000 meters high (Frazier 1964). Its roosting sites can be intra- or interspecific, located in dry or humid areas, using small shrubs to 90-meter-high-trees (Lehmann 1959). The Cattle Egret has a diverse diet, composed mostly of insects, but also other terrestrial and aquatic invertebrates, such as fish, amphibians, reptiles, small mammals (Hanebrink 1971, Siegfried 1971, Fogarty and Hetrick 1973, Gassett *et al.* 2000, Bella and Azevedo-Jr. 2007) and birds (Cunningham 1965, Van Ee 1973). There are also records of *B. ibis indicus* eating material of vegetable origin (Heather 1982). Furthermore, this species demonstrates the ability to follow agricultural machines and grazing mammals when foraging in order to maximize the capture rate of prey (Blaker 1969, Thompson *et al.* 1982, Seedikkoya and Shukkur 2005).

There is a limitation in analyzing the factors that influence the fast Cattle Egret population growth in Fernando de Noronha due to the lack of standardization and periodicity of estimation methods applied until 2005. However, it is clear that population establishment and growth were benefited by extensive anthropic occupation on the island, and the Cattle Egret's plasticity to adapt to new environments. Other authors have also suggested that sites with degraded environments tend to have higher probability for *Bubulcus ibis* colonization (Browder 1973).

The largest groups of foraging Cattle Egrets on Fernando de Noronha were found in areas under anthropic influence, and also associated with the presence of cattle or agricultural machinery, such as among the lateral grass from the airport and Atalaia Beach, respectively. These environments and interactions have possibly incremented the abundance of available food for the Cattle Egret on the archipelago, and they were fundamental for its exponential population growth.

We found a continuous decrease in the Cattle Egret population, reaching 24.27%, when food abundance was reduced by isolation of the composting plant (period BC). We presume that these events have a direct cause-effect relationship. We also consider that this indirect management might have affected especially some classes of individuals, such as immature young birds and indirectly, the nestlings. Arendt (1988) suggests that solid waste deposits are important for the foraging of young Cattle Egrets and that the abundant quantity of insects in such places might assure the survival of the inexperienced individuals. Moreover, the decreased offering of this abundant and easily obtained food might also have influenced the nestlings to feed by their parents, and also may have affected the recruiting habits of the species. There are studies in Africa (Siegfried 1972) and Australia (Mackiligan 1985) that identified hunger as the main mortality cause in nestlings of the species (respectively *Bubulcus i. ibis* and *Bubulcus i. comodorus*).

Cattle Egret counts at the composting plant in April 2008 showed that this site continued to be important for attracting a considerable part of the Cattle Egret population, even with the cage around the compost container. Cattle Egrets were observed on top of this structure and surrounding areas, feeding on flying insects over the decomposing organic waste. That fact also indicates that the composting process in the archipelago is being carried out improperly because it should be a controlled and aerobic biological process, and it should not attract insects nor exhale stench (Insam *et al.* 2002). An anaerobic decomposition is probably taking place. We suppose that if this procedure were more efficient, the observed Cattle Egret population decrease, due to isolation of the composting plant, could have been much higher.

The Cattle Egret population decrease was even sharper when individuals started to be euthanized. However, the efficacy of the method applied diminished when birds started avoiding the traps and capture efforts were reduced. In a short period, the population presented signs of an accelerated recovery. Such an event resembles the experience of Cattle Egret control reported from Hawaii (USA), carried out between 1982 and 1983, also motivated by risks to aerial safety (Fellows and Panton 1988). A population estimated at 547 individuals was managed with euthanasia of hundreds of adult individuals, nestlings and eggs, at foraging and roosting sites. However, an explosive population growth was observed as soon as the control measures ceased and, in only six months the population almost reestablished its original number. This increase could be explained by the effect of high rates of

reproductive success, but also a compensatory reproduction behavior which rapidly restores the losses of eggs and nestlings (Fellows and Panton 1988). Compensatory reproduction was already observed in *Bubulcus ibis* (Kennedy 1991). Other heron species could also restore an ever greater number of eggs than those lost (Kennedy 1991).

Considering the high costs of direct management measures and the ethical questions involved, aside from evaluating the efficiency of population control methods, it is important to reflect on the root and dimension of the problem in order to seek efficacy in actions taken. For that, it is necessary to take into account the impact of the Cattle Egret population on native species of Fernando de Noronha, and whether we are dealing with a closed or opened population. The last question has important implications in the definition of any management plan, because regular and significant inflow of immigrants imply the necessity of continued population control efforts.

Impact on other species

There are only punctual data that indicate negative interactions between the Cattle Egret, the native biota and environments of the archipelago. Anecdotal information about predation events of invertebrates by the Cattle Egret have already been reported, as well as of other bird species (*Anous minutus, Anous stolidus, Gygis alba, Sterna fuscata* and *Zenaida auriculata*) and of Mabuya, a species of lizard endemic to the island (*Euprepis atlanticus*) (Silva-Jr. *et al.* 2005, Barbosa-Filho *et al.* in press; *pess. obs.* of the authors). However, it is not clear if such events are isolated or recurrent, and what the predation impact on the viability of these populations is.

Another possible impact caused by the Cattle Egret was the establishment of their roosting sites among reproductive colonies of the Red-footed Booby (*Sula sula*), on Cabeluda and Sela Ginete Islands. On these islands, the colonies of the two species overlap, and their nests are distributed next to each other in shrub vegetation. Both species may find small and isolated islands like these desirable for the formation of colonies, as they provide safe sites from exotic terrestrial predators, such as the lizard *Tupinambis merianae,* and rodents like *Kerodon rupestris* and *Ratus ratus.* The breeding periods also demonstrate some superposition because the Cattle Egret reproduces on Fernando de Noronha throughout the year (Barbosa-Filho *et al.* in press), with a peak of intensity after the rainy period in June and July. The Red-footed Booby reproduces seasonally in the dry season, from December to April (Barbosa-Filho *et al.* in press).

The impact of this superposition on population recruitment has not been quantified yet, but agonistic interactions were observed between these species (Silva 2008). These interactions imply competition for space (Burger 1978). Such a fact must be examined, because some seabird species can be strongly limited on a local scale by the availability of sites for the establishment of colonies (Furness and Birkhead 1984). The Red-footed Booby builds its nests on low shrubs, and these environments are scarce on the secondary islands of Fernando de Noronha. Moreover, Fernando de Noronha and the Island of Trindade (20°31'S and 29°19'O) are the only reproduction sites for the Red-footed Booby in Brazil (Sick 1997).

Similar to the situation of Fernando de Noronha, the Cattle Egret has been automatically considered a potential threat in many areas of the American Continent, mainly due to its pattern of fast population growth. However, the existing information on its interactions with native species remains generally anecdotal and insufficient. There are few studies evaluating the impact of the Cattle Egret on the American Continent, and the majority was carried out in the Northern Hemisphere, addressing the competition with other Ardeidae species at interspecific nest sites (Dusi and Dusi 1968, Jenni 1969, Fogarty and Hetrick 1973, Weber 1975, Maxwell and Kale 1977). In the USA, the Caribbean and Antilles, the Cattle Egret populations are mostly migratory, and usually gather in mixed colonies with other species of herons and egrets to reproduce (Rice 1956, Buerkle and Mansell 1963, Dickerman 1964, Weber 1975). Authors have suggested that such collective nests are important for the reproductive success of the Cattle Egret because breeding activities of other species would stimulate the beginning of Cattle Egret reproduction (Dusi and Dusi 1968, Belzer and Lombardi 1989).

Among these studies, some indicated negative interactions between the Cattle Egret and other species of Ardeidae. The stealing of nest material (Valentine 1958, Lancaster 1970, Burger 1978, Werschkul 1977, Siegfried 1971, 1972 in Africa), high frequency of interspecific agonistic events (Burger 1978, Werschkul 1977) and exclusion of other species from the best sites in the colony (Dami *et al.* 2006, in France) have been reported. Burger (1978) reported that the Cattle Egret was twice more aggressive than other species, gaining advantage in agonistic events mainly against smaller egret species. There are also studies that addressed the environmental impacts attributed to high mortality of trees in Cattle Egret colonial areas, due to the excess of guano causing stress on vegetation by pH alteration and hyperosmosis (Duse 1978, Arendt 1988).

In contrast, some other studies suggested that impacts of the Cattle Egret on other native egret and heron species are minimal, arguing that there is little superposition in alimentary niches (Jenni 1969, Fogarty and Hetrick 1973) and reproductive periods (Dusi and Dusi 1968, Jenni 1969, Weber 1975, Maxwell and Kale 1977). The arrival of Cattle Egret migratory populations in

interspecific colonies in the northern hemisphere, as well as their reproduction peak, was late in relation to other native species (Dusi and Dusi 1968, Jenni 1969, Weber 1975, Maxwell and Kale 1977). Furthermore, interspecific agonistic events and stealing of nest material involving the Cattle Egrets seem to be rare (Jenni 1969, Weber 1975, Maxwell and Kale 1977), or as frequent as in other species (Maxwell and Kale 1977). Weber (1975) reported that Cattle Egrets were more aggressive with each other than with other egret species.

Colonization and Migratory Movements

There is some evidence indicating a fluctuation of the Cattle Egret population on the archipelago, despite the lack of rigorous systematic data collection. During ten years after the first report of the Cattle Egret on Fernando de Noronha, the species records were irregular, ranging from zero to no more than ten birds. There are also some reports, compiled by National Park inspectors and other biologists (J. M. Silva-Jr., *pers. comm.*), that pointed to a higher occurrence of individuals in the rainy season and the presence of few or none in dryer periods. According to such reports, only at the end of the 1990s did the species become regular and more abundant. These observations raise questions whether there is the possibility of dealing with an open population.

Certainly it is possible that fluctuations in abundance could be a result of birth and death dynamics of the Cattle Egret population already established on the island. Cattle Egret reproduction is generally stimulated by the arrival of rain (Werschkul 1977, Dusi and Dusi 1968), which coincides with reports of higher abundance of individuals spotted by local inhabitants. Events like short flights on a local scale, or other factors influencing conspicuousness through time, could also have affected the observers' perception of species abundance. However, it is unlikely that the species passed unnoticed during the dry season within the boundaries of such a small archipelago. This would only be possible with low population levels.

We consider the possibility of the irregular addition of some new individuals to the population by immigration. The Cattle Egret's arrival on the American Continent was a natural occurrence (Crosby 1972), and it is likely that the same has happened on Fernando de Noronha with successive influx of individuals, vagrant or regular, until it finally succeeded in establishing its presence. The Cattle Egret currently has a wider geographic distribution and a higher population abundance, so it is still possible that the arrival rate would be higher than in the past because of the greater number of source population. Long distance vagrant dislocations are commonly observed in *Bubulcus ibis,* and occur especially with young birds dispersing in different directions to find new food sources (Bowder 1973). It serves as a mechanism of new area colonization and population control within the colony (Bowder 1973).

There is a report of the Cattle Egret on the Archipelago of São Pedro and São Paulo (Bowen and Nicholls 1968), a group of small oceanic islands situated 870 km northeast of Fernando de Noronha, which confirms the existence of vagrant individuals originating in Africa that crossed the Atlantic Ocean. There are also reports of other species or subspecies of birds from the Old World found on oceanic islands in the Brazilian Northeast (Fernando de Noronha, Rocas Atoll or Archipelago of São Pedro and São Paulo). Some of them are egrets as well: *Ardea purpurea, Ardeolla ralloides, Egretta garzetta, Falco tinnunculus, Platalea leucorodia, Tringa totanus, Glareola pratincola, Gallinula angulata, Numenius p. phaeopus* and *Hirundo r. rustica* (Nacinovic and Teixeira 1989, Antas *et al.* 1990, Soto and Filippini 2003, Both and Freitas 2004, Schulz-Neto 2004a,b, Bencke *et al.* 2005).

The arrival of these vagrant individuals might have been facilitated by the Alisian Winds from the North during the period of greater approximation to the Inter-tropical Convergence Zone (ITCZ) at the same latitude as Fernando de Noronha. The ITCZ is the region where the Alisian Winds coming from the Southern Hemisphere and the Alisian Winds coming from the North Hemisphere meet. This is a zone predominantly of weak winds, located approximately at the latitude of the Equator Line. However, it varies some degrees of latitude throughout the year. In the period of March – April, it reaches its most southern positions, the extremes being between 5° and 6°S. It constitutes the main system that generates precipitation in the most northern States of the Brazilian Northeast (Uvo and Nobre 1989a,b). We suppose that in this rainy period there is a possibility of vagrant individuals arriving from the Old World.

On the other hand, a regular migratory route of Cattle Egrets between Fernando de Noronha and northern Africa or the Mediterranean is unlikely because such displacements seem to be too costly to be established as cyclic. Great distances separate these regions (the closest point, Liberia, is 2600 km away), and strong Alisian Winds from the North and South are not favorable during most of the route, and during most of the year in both directions. It is known that egrets do not tend to fly against strong winds (Browder 1973). There are regular dislocations of a few seabird populations between Europe and South America (Hays *et al.* 2002, Neves *et al.* 2002, Ringing National System-CEMAVE, unpublished data), but they are adapted to thousand-mile migrations and exhibit great flight capacity (Martínez-Vilalta and Motis 1992). Cyclic routes from the Brazilian northeastern coast to Fernando de Noronha (the closest point is 345 km away) are also costly to be established due to the presence of Alisian Winds from the South that are unfavorable.

Due to such considerations, we suppose the presence of a regular migrant population of Cattle Egret to be unlikely on the Archipelago of Fernando de Noronha, despite the fact that this species has a partially migratory status according to literature (Martínez-Vilalta and Motis 1992). There are many examples of Cattle Egret migratory populations, like the ones that dislocate between North America and the Antilles (Arendt 1988, Bowder 1973), or between the northwest and the south of Africa (Chapin 1932). In Fernando de Noronha a total of 83 Cattle Egrets were already banded since 2005, but they have never been recovered out of the archipelago (Ringing National System-CEMAVE, unpublished data).

Conclusion and Future Directions

Control measures are already being carried out to reduce the Cattle Egret population on Fernando de Noronha. However, such experiences suggest that efforts in direct management (euthanasia) over a fraction of the Cattle Egret population tend to work only as mitigatory measures, considering the high population growth rate and recovery capability demonstrated by this species. Strategies in this sense may signify a waste of resources and energy, yielding short-termed results with little effect. This species will possibly reestablish its managed population in the short or medium term.

Additionally, even if the eradication of this population is possible, a new colonization is not unlikely to occur as a result of the arrival and establishment of migrant or vagrant individuals. Colonization occurs if there is a sufficient number of founding birds and proper environmental conditions in the new area. The possibility of such establishment is even higher if there are anthropic areas with high food availability (Browder 1973), and such a scenario still remains on the archipelago. Indirect management of the environment seems to be especially important for population control. It must be applied continuously and, if necessary, simultaneously with direct management measures.

We recommend that the composting process be revised at the solid waste treatment plant so as not to attract as many insects. It would also be advisable to implement an educational program for local inhabitants regarding the domestic management of waste, since several individual egrets can be seen in the yards of small properties, benefiting from the availability of easily obtained food. The beaches where horses and cattle were seen pasturing associated with groups of egrets must be the target of more severe and frequent supervision, as such activities are in disagreement with the objectives of these protected areas. Changes in airport structure and routines are also needed. Measures, like changing the time of day for mowing the lawn around the airfield track, or even substituting it for gravel or artificial grass, could be tested to verify if the action would reduce bird concentration in the area.

In parallel, an investigation of the impact of Cattle Egrets on native fauna, focusing on possible competition with the Red-footed Booby and the effects of native birds and reptile predation, would be of great relevance. It would help to define with higher precision the spatial amplitude necessary for management actions. This can turn out to be necessary only in the location of the airport or rather the eradication of the species on the whole island may be required. It is worthwhile to emphasize that any direct management measures involving sacrifice of individuals must be carried out intensively and preferentially before the reproductive peak of the species during the rainy season. This is due to the demonstrated intrinsic growth rates of the species as well as the possibility of the Cattle Egret presenting compensatory reproduction behavior.

Finally, maintaining regular population monitoring is important in identifying population fluctuations and the effects of management measures, aside from aiding in the investigation of newly arrived migrants. Studies using molecular markers from the populations of the islands and continent, as well as bird-ringing and radio-telemetry, can be efficient in elucidating this question.

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