# How nest site characteristics influence breeding success in Red-legged Cormorants *Phalacrocorax gaimardi*

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**Abstract.** For seabirds, nest site features are an important factor that determines reproductive success. During three breeding seasons (2010–12), we visited two coastal cliff colonies of Red-legged Cormorants *Phalacrocorax gaimardi* in the Ría Deseado, Argentina, and studied how nest site characteristics influenced their breeding success. We measured six physical characteristics at 46 nest sites, and we counted the number of fledglings produced each year from each nest (breeding success). We also related nest site temperature and wind exposure with nest site orientation. Breeding success was higher at nest sites with a broad base (greater capacity for holding young) and at nests that were less exposed to winds greater than 25 knots (46.25 km/h), which were sites with a north orientation. The lowest breeding success was observed in nest sites that were exposed to the strongest winds (i.e., sites with a south orientation). Strong winds often blow eggs and chicks away from the nests and increase opportunistic predation by gulls *Larus* sp. No significant relationship was found between nest site orientation and nest site temperature. Breeding success decreased with the distance to the nearest nest, which agrees with the idea that higher density of reproductive individuals reduces effectiveness of predators. Nest cover, distance from the top of the cliff, and distance from the tide line had no effect on breeding success at this study scale. Our results suggested that nest site characteristics that were related to protection against adverse weather conditions (e.g., strong winds) and avian predation, in combination with a suitable nest space, determined the breeding success of Red-legged Cormorants.

**Key words:** Red-legged Cormorants, nest site features, nest success, microclimate conditions, Argentina, productivity

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## INTRODUCTION

For birds, the quality of suitable nesting habitat is an important factor that determines breeding success (Buckley & Buckley 1980, Hamer et al. 2002). The site where birds build their nest is the smallest spatial scale of habitat use (Wiens 1986, Cueto 2006). The ultimate factors that determine choice of a breeding site are proximity to food and protection from both predators and from environmental stress (Walsberg 1985, Martin & Roper 1988, Bried & Jouventin 2002). For seabirds, weather affects their survival, so that one short-term weather event can influence their annual nest success. Many species probably select breeding sites based on weather–climate parameters such as wind level and temperature (Schreiber & Burger 2002). Seabirds may also choose their breeding sites to shelter their nests from predators to maximize their reproductive output (Bried &

Jouventin 2002). Colonies that are situated on sea cliffs can reduce or totally exclude predation by mammals and prevent aerial predation (Coulson 2002).

The Red-legged Cormorant *Phalacrocorax gaimardi* occurs along the Pacific coasts of southern South America in Chile and Peru, and it occurs in the Atlantic, where it is restricted to Santa Cruz Province, Argentina (Zavalaga et al. 2002, Frere et al 2004). In Argentina, Red-legged Cormorants breed in 13 localities, with a population of approximately 1800–2000 breeding individuals (Millones et al. 2015). Nests are built on cliffs and consist of fronds of seaweed, feathers, and guano. Habitat use by Red-legged Cormorants was studied at different spatial scales. Red-legged Cormorants nest on steep cliffs with usable surfaces (e.g., cliffs with ledges, outcrops, or caves), mostly in walls that are protected from prevailing winds and the effect of sea waves (Millones et al. 2008). At a local scale

(meso-scale), protection from predators and proximity to abundant food sources were factors involved in breeding habitat selection (Millones et. al 2010). At a regional scale (macro-scale), primary production of the sea, water depths, and climatic features were factors that affected habitat selection by this species (Millones & Frere 2012). Until now, little was known about how microhabitat features could affect breeding success. Frere & Gandini (2001) suggested that avian predation on eggs (by Kelp Gulls *Larus dominicanus* and Dolphin Gulls *Larus scoresbii*) was an important mortality factor for Red-legged Cormorants, and wind, which possibly exacerbated avian predation, also had an important effect on breeding success. In this paper, we studied how nest site characteristics influenced the breeding success in cliff-nesting Red-legged Cormorants.

We conducted the study from October to December over three consecutive breeding seasons (2010–12) at two colonies of Red-legged Cormorants in the Ría Deseado (Santa Cruz, Argentina): Isla Elena (47°45´S, 65°56´W) and Cañadón del Indio (47°45´S, 65°58´W)(Fig. 1). Colonies were separated from each other by approximately 3 km. Isla Elena had ~113 breeding pairs and Cañadón del Indio had ~ 44 breeding pairs (Millones et al. 2015). Data were collected from 27 active nests at Isla Elena and from 19 active nests at Cañadón del Indio. A greater number of nests were selected during the first breeding season, but only those nests that were active during all three study years were analyzed. Given the inaccessibility to the nests on steep cliffs, nests were selected based on those that we could

observe clearly from the top of the cliff using binoculars.

Each year, we checked nest contents every week (using binoculars) from the beginning of egg laying until clutches were completed in the colony. Because it was not always possible to observe and register the precise contents of the nests at each visit, especially during the incubation stage, we estimated mean clutch size based only on those nests where we could determine the precise contents. For each year we defined breeding success (productivity) as the number of fledglings per nest. Even though the nesting period of the species is calculated in approximately five weeks (Frere & Gandini 2001), we considered chicks to have fledged if they reached 4 weeks of age, just before they start to leave the nests.

At the beginning of the season in 2010, we measured six physical characteristics at each nest site: ledge-size (i.e., total area of the ledge where the nest was built), level of nest coverage, orientation, distance from the top of the cliff, distance from the tide line, and distance to the next nearest nest (both distance from the top of the cliff and distance from the tide line were calculated separately, due to the fact that the same cliff does not have the same height along its entire length, since it is possible to observe differences of several meters between cliff sectors). Before this, for each colony, the entire stretch of the cliff was photographed at a scale of approximately 1.5 cm per meter. This scale gave us sufficient detail to recognize individual sites. Because the height of each cliff was known (Millones et al. 2008, Millones 2009), we assigned a scale to each photo that helped us to determine some of the nest site
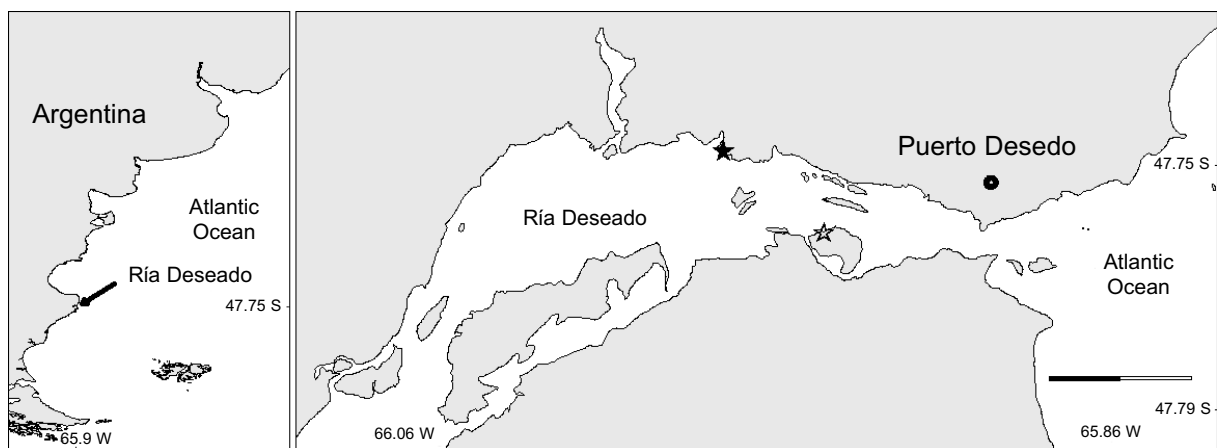


Fig. 1. Location of the two studied colonies of Red-legged Cormorant at Ría Deseado, Argentina. Grey areas correspond to land and white areas correspond to seawater. Black star corresponds to location of Cañadón del Indio and unfilled star correspond to location of Isla Elena

variables (e.g., distance between the nest to the top of the cliff, the distance between the nest to the tide line, and the distance to the nearest nest).

Because it was difficult to determine ledge-size (i.e., total area of the ledge where the nest was built), we decided to measure it as "birds space". We considered ledge-size equal to 1 when the space was only sufficient for a parent sitting, but not space for another upright bird; equal to 2 when there was just enough space for the parent sitting and one upright bird; equal to 3 when there was just enough space for the parent sitting and two upright birds; and so on. Level of cover (lateral + overhead) was calculated as the number of lateral walls and the presence of overhead protection (from 1 = totally exposed to 4 = three lateral walls plus presence of overhead cover). We determined the principal orientation of each nest site using a compass.

To explain differences in breeding success among nest site orientations, we analyzed two microclimate conditions, which could be affected by the nest orientations: nest site wind exposure and nest site temperature. Nest site exposure to winds was monitored by obtaining daily data (i.e., six-hourly archive data with one degree spatial resolution) of wind direction and wind speed from the Archived Meteorology at NOAA's Air Resources Laboratory (Ready Web Server). Nevertheless, to analyze which nest site orientation had the coldest temperatures, we carried out an experiment during 2013. From November 2013 until end-December 2014, we fixed a thermochron temperature data loggers (iButton DS1921G#F50; $\pm$ 0.5°C, size: 17.35 mm $\times$ 5.89 mm, Maxim Integrated, San José CA, USA) on the bottom wall of 28 selected nest sites (four nest sites for each orientation: N, NE, E, SE, S, W, and NW). There were no nests with a southwest orientation. With the aim to minimize the effect of the presence of the incubating bird, data loggers were fixed on the bottom wall of the nest and at a height of approximately 50–70 cm from the base. We programmed iButtons to log the temperature every three hours.

To test the effects of explanatory variables (year, ledge-size, level of cover, orientation, distance from the top of the cliff, distance from the tide line, and distance to the nearest nest) on breeding success (number of chicks fledged per nest), we employed generalized linear mixed models with Poisson family distribution and the log-link function (Crawley 2007). We found no significant correlation between the explanatory variables (all

p values for Pearson correlations > 0.05). To avoid pseudoreplication, we introduced colony and nest site identity (nested in colony) as random factors in this analysis. Model selection was based on Akaike's information criterion corrected for small sample size (AICc) (Burnham & Anderson 2002). We selected the models with the lowest AICc score as the best models.

Given the Beaufort Wind Scale, which is an empirical measure that relates wind speed to observed conditions at sea or on land, we considered winds to be strong when their speed reached >25 knots (46.25 km/h). Because breeding success can be affected by winds coming from the front or sides, wind orientations were assigned to quadrants and, therefore, we analyzed the frequency of occurrence of strong winds ($\geq$ 25 knots) from the north, east, south, and west.

To detect differences in temperature according to nest site orientation, we employed generalized linear mixed models with a normal family distribution and the log-link function. We used nest site temperature as the response variable, and nest site orientation and time (Julian date) as explanatory variables. To avoid pseudoreplication, we introduced nest site identity as a random factor in this analysis. As we expected, time series were significantly positively autocorrelated with one time period of lag (autocorrelation function: $p < 0.05$). To account for autocorrelation, we included an autocorrelation structure of order 1 into each model. We used a backwards selection procedure to remove the terms one by one according to a decreasing p value, and we compared the models with and without the eliminated variable with an ANOVA test using the goodness-of-fit, chi-squared test ($\chi^2$ parameter).

We used the R software version 2.15.1 (R Development Core Team 2012), the package "lme4" and "nlme" for running generalized linear mixed models and the package "multcomp" for Dunnett's Multiple comparisons. All the other statistical analyses were performed with Statistica v. 7 (Statsoft Inc. 2004).

For those nests in which the precise contents were determined at the beginning of each breeding season (N = 38), 3% contained four eggs, 66% contained three eggs, and 31% contained two eggs (mean clutch size = 2.7 $\pm$ 0.62). Of the 46 monitored nests that we were able to monitor through all three breeding seasons, average breeding success was 0.68 $\pm$ 0.87 fledglings per nest (n = 138), and the range was 0 to 3 fledglings (Table 1).

Table 1. Mean (± SE) breeding success calculated as the number of fledglings per nest of each colony during the studied breeding seasons.

| Colony | 2010 | 2011 | 2012 |
|---|---|---|---|
| Isla Elena (N = 27) | 0.33 ± 0.68 | 0.81 ± 0.79 | 1.15 ± 1.06 |
| Cañadón del Indio (N = 19) | 0.63 ± 0.90 | 0.53 ± 0.70 | 0.53 ± 0.84 |

The model that best explained the variation in breeding success included year, ledge-size, orientation, and distance to the nearest nest (Table 2). The second ranked model had substantial support with $\Delta AICc < 1$. This model also included ledge-size, orientation, and distance to the nearest nest, but it did not include year (Table 2). The rest of the models showed a $\Delta AICc > 2$. According to the best model, the breeding success of Red-legged Cormorants increased with an increase in ledge-size (parameter estimate = 0.11 ± 0.04, p = 0.011), but breeding success decreased as the distance to the nearest nest increased (parameter estimate = -0.29 ± 0.11, p = 0.014) (Fig. 2). Mean breeding success (both colonies pooled) was different among years: 2010 = 0.45 ± 0.78; 2011 = 0.69 ± 0.75; and 2012 = 0.89 ± 1.01.

Significant differences in breeding success were only observed between north and south orientations (Dunnett's Multiple comparisons, p < 0.05). Median breeding success at sites with a north orientation was equal to 1.66 ± 0.42 (N = 6), and median breeding success at sites with a south orientation was equal to 0.05 ± 0.06 (N = 18) (Fig. 2). To explain the differences among nest orientations, we related nest site orientation with nest site wind exposure and nest site temperature. In the study area, no significant differences in wind intensity were found between years (Kruskal Wallis test, p = 0.57). During the study period, the frequency of occurrence of strong winds (≥ 25 knots) from south and west quadrants was higher than those from north and east quadrants ($\chi^2_C$ = 15.37, df = 3, p < 0.05). There was not a significant relationship between nest site orientation and nest site temperature. The best model only included time (Julian date) as a response variable (time t-value = -6.498; p < 0.0001).

A few nest site characteristics seemed to determine the breeding success of Red-legged Cormorants. The capacity of a nest site to hold young, which we measured as the size of the ledge where nest was built, may be important when birds relieve each other from incubation and for feeding of chicks. Chicks of Red-legged Cormorants have been seen falling from the nests to the sea because of movements of their parents inside the nest and during strong winds (Frere & Gandini 2001, Millones pers. observ.). In this study, we observed that Red-legged Cormorants had a higher nest success when they used sites with a broad base on which to build their nests.

In seabirds, in addition to other factors such as quality of adult birds, protection from environmental stress and predators are important factors that determine the selection of the nesting site (Walsberg 1985, Martin & Roper 1988) and, therefore, their breeding success (Buckley & Buckley 1980, Hamer et al. 2002). The Patagonian coast is characterized by strong winds, especially during spring and summer. Strong winds can blow eggs and chicks away from the nests (Frere & Gandini 2001), and storms can even wash away entire nests of this species (Millones 2009). We observed the highest breeding success in nests that were located on sites less exposed to strong winds (i.e., sites with a north orientation), and the lowest breeding success was observed in nest sites exposed to the strongest winds (i.e., sites with a south orientation). Some difference, although it was not statistically significant, was also observed between the median breeding success at sites with a north orientation and the median breeding success at sites with a west orientation, which is also exposed to strong winds (Fig. 2).

Table 2. Model selection results for the two highest-ranked generalized linear mixed models that explain the variation in the breeding success (i.e. number of fledglings) of Red-legged Cormorants. The rest of the models showed a $\Delta AICc > 2$.

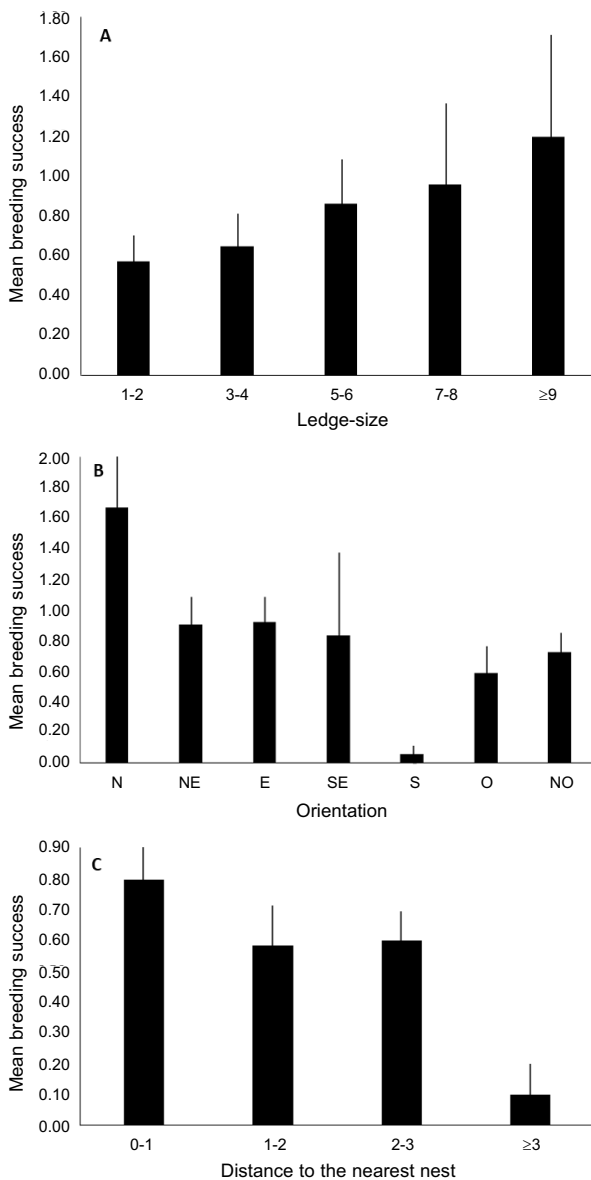| Explanatory variables | Parameters | Δ AICc | AICc Weight |
|---|---|---|---|
| Year + ledge-size + orientation + distance to the nearest nest | 7 | 0.0 | 0.223 |
| Ledge-size + orientation + distance to the nearest nest | 6 | 0.02 | 0.221 |

Fig. 2. Mean number of fledglings per nest related to: A) ledge-size, measured as "birds space" (equal to 1 when the space was only sufficient for a parent sitting, but not space for another upright bird; equal to 2 when there was just enough space for the parent sitting and one upright bird; equal to 3 when there was just enough space for the parent sitting and two upright birds; and so on); B) orientation; C) distance to the nearest nest.

Innate selection of a beneficial nest-site microclimate by birds can moderate extreme environmental conditions, and it has the potential to improve reproductive success (Walsberg 1985). Microclimate may affect nest site quality, especially in relation to the chilling of the chicks. Thermal properties of the nest depend, among other factors, on its orientation and cover, which are important determinants of breeding success in many seabird species (Walsberg 1985, Stokes & Boersma 1998). In our case, we did not observe differences in nest site temperature among different orientations. As it was expected, we observed a relationship between nest site temperature and Julian date, since the passage from spring to summer occurs. It seems that differences observed in breeding success among different nest site orientations could be explained mainly by exposure to wind. Frere & Gandini (2001) also suggested that greater exposure to strong winds, in addition to blowing eggs and chicks away from the nests, increased opportunistic predation by gulls on eggs and chicks of Red-legged Cormorants.

Egg and chick predation by avian predators seem to be an important mortality factor for this species (Vilina & González 1994, Frere & Gandini 2001). Although in our visits to the colonies we did not observe direct attacks over the studied nests, we always observed Kelp Gulls and Dolphin Gulls stalking cormorant nests. A high density of reproductive individuals in a seabird colony reduced the effectiveness of predators (Coulson 2002). Our results showed that when Red-legged Cormorants have close neighbors, their breeding success was higher. Millones et al. (2008) observed, on a larger study scale, that higher densities of active nests of this species were located on cliff faces with a general orientation that was protected from predominant winds and where suitable surfaces (e.g., ledges, small outcrops, or caves) were a limiting factor. Millones et al. (2008) suggested that the use of cliffs with few outcrops and ledges can make the movements and attacks of predators more difficult.

Our results suggested that in a microhabitat cliff scale characteristics that protected the birds against adverse weather conditions (strong winds) and avian predation, in combination with suitable nest space, determined the breeding success of Red-legged Cormorants. The differences observed in breeding success among years were probably due to environmental factors that acted on a greater scale, such as variation in food availability.

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## STRESZCZENIE

**[Wpływ charakterystyki miejsca gniazdowania na sukces lęgowy kormoranów czerwononogich]** W przypadku ptaków morskich cechy miejsca gniazdowego są ważnym czynnikiem decydującym o sukcesie reprodukcyjnym. Badania prowadzono podczas trzech sezonów lęgowych (2010–12) w dwóch koloniach kormoranów zlokalizowanych na nadmorskich klifach w estuarium rzeki Deseado w Argentynie (Fig. 1, Tab. 1). Dla 46 miejsc gniazdowych zajętych przez wszystkie sezony określono sześć cech: wielkość półki skalnej, na której zbudowane było gniazdo, stopień osłonięcia gniazda, ekspozycję, oraz odległości: do szczytu klifu, do linii przyboju i do najbliższego innego gniazda. Zmierzono także temperaturę powietrza w miejscu gniazdowym oraz określono kierunki wiejących wiatrów. Jako sukces lęgowy określono liczbę piskląt gotowych do wylotu.

Sukces lęgowy był wyższy w gniazdach zlokalizowanych na szerszych półkach skalnych oraz w gniazdach, które były mniej narażone na wiatry o sile większej niż 25 węzłów (46,25 km/h) (głównie miejsca o ekspozycji północnej) (Fig. 2A, B). Najniższy sukces obserwowano w gniazdach narażonych na najsilniejsze wiatry (tj. o ekspozycji południowej), gdyż silne wiatry często wyrzucają jaja i pisklęta z gniazd, zwiększając presję drapieżniczą mew (Fig. 2B). Sukces lęgowy zmniejszał się wraz ze wzrostem odległości do gniazda najbliższego sąsiada (Fig 2C), co wskazuje, że większe zagęszczenie kormoranów zmniejsza presję drapieżników. Stopień osłonięcia gniazda, odległość od wierzchołka urwiska i odległość od linii przyboju nie miały wpływu na sukces lęgowy (Tab. 2). Nie stwierdzono istotnej zależności pomiędzy ekspozycją miejsca gniazdowego a temperaturą.

Uzyskane wyniki sugerują, że cechy miejsca gniazdowego, które są związane z ochroną przed niekorzystnymi warunkami pogodowymi (np. silnymi wiatrami) oraz drapieżnikami w połączeniu z odpowiednią przestrzenią gniazdową, decydują o sukcesie lęgowym kormoranów czerwononogich.