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Breeding phenology of rockhopper penguin *Eudyptes chrysocome* (Spheniscidae) by camera monitoring on isla Noir, Chile

Fenología reproductiva del pingüino de penacho amarillo Eudyptes chrysocome (Spheniscidae) por monitoreo de cámara trampa en isla Noir, Chile

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The reproductive phenology in penguin taxa may differ between colonies due to latitudinal and environmental effects as reported in early studies (Gwynn, 1953; Murphy, 1936; Warham, 1972), and the most recent research using newer technologies (Jones *et al*. 2018). In the case of Rockhopper Penguins (*Eudyptes chrysocome* Forster, 1781) in Chile, it appears that the stages of the reproductive period are similar to those in the Falkland/Malvinas Islands (Marín *et al*. 2013; Strange, 1982, 1992; Venegas, 1999). The phenology has not been completely described for Chile and mainly was inferred based on short visits to breeding colonies at different times of the year (Marín *et al*. 2013; Venegas, 1999). Isla Noir (54°28'S, 73°00'W) is located towards the south-occidental portion of the Fuegian Archipelago and is a highly exposed island to the weather conditions of the southern Pacific Ocean. The island of approximately 10 km in length and 2 km at its widest point. The general topography of the island consists of high cliffs on the southwest sections while the northeast portion tends to consist of variable inclines covered with dense vegetation such as *Poa* sp. grassland that gradually gives away at higher elevations on the ridges to native rush *Juncus* sp. and *Nothofagus antarctica* (Pisano & Venegas, 1984; pers. obs.). The population of Rockhopper Penguins on Isla Noir is an estimated 158,200 breeding pairs, divided in several colonies along the island and it is one of the main concentrations of this species in Chile (Marín *et al*. 2013; Oehler *et al*. 2008).

On 14 October 2012, we installed a time-lapse camera (Buckeye-Cam Apollo model RC-5060, Austin, TX, USA) within a Rockhopper Penguin colony on Isla Noir. A Solar panel and a backup battery pack provided the camera with a consistent power supply for a full calendar year. The 3.1-megapixel camera was programmed to capture images at 2:00, 8:00, 14:00 and 20:00h, Chile Standard Time (CST) along with the capability of capturing additional images if a significant motion was detected. Infrared imaging allowed continued operation in low light conditions. The images recorded include data indicating hour (CST), date, moon phase and temperature. The colony itself was large in the order of a few thousand pairs and subdivided into smaller clusters of compact sub-colonies varying from 20 to 50 breeding pairs. Within the colony, the positions of the clusters were in a gradient varying from 20 to 45 degrees angle and from nearly sea level to about 100m above sea level. We placed the camera in one of the highest clusters above sea level at the edge of the compact *Nothofagus* vegetation. All higher clusters were

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recently colonized area for breeding. The camera was installed approximately 2m from the closest nest and included 12 nests within the study site. The camera was removed on 24 November 2013. Due to the vegetation density, we were not able to set the panoramic photographs as were has being done in other studies (*e.g.,* Lynch *et al.* 2015).

Data were categorized by attendance, adult/ or juvenile Rockhopper Penguins. Supplementary observations including the condition of the individual penguins were noted, such as molt. A total of 2,409 images were recorded via the camera trap within the study period of which 647 images were taken during the breeding season.

Main events, such as aggregate arrival and departure, molt, egg laying, the presence of nestlings, and general colony attendance were delineated within the breeding and molt cycles from the images recorded by the camera. The arrival of the first penguin occurred early afternoon on 3 October with one penguin (Fig. 1-A) and later that evening four birds arrived. Peak attendance of 21 individual adult penguins was noted on 21 October 2013 (Fig. 1-B). On 29 October the first egg was slightly visible, although judging by the bird´s postures and behavior, egg laying may have occurred days prior on 27-28 October. Postures and placement of birds indicated that incubation commenced slightly past this peak attendance period. Following this peak, adults remained at the nest sites between two to twelve days, leaving the site for two to five days during these twelve days. As of 21 November 2013, the abundance of adult penguins was reduced by 50% and it was possible to see that there was one adult attending each nest respectively (Fig. 1-C). Direct observation of newly hatched chicks was not apparent from these images. During our visitation to the site from the 24 to 28 November, newly hatched Rockhopper Penguins were observed within the sub colonies clusters at lower elevations, closer to the sea, while eggs within the higher elevations had not hatched as of 28 November. This asymmetrical pattern parallels the timing of arriving birds that occupy and begin nesting within the lower elevations first and later expand into the higher elevations. The mass and measurements of nine chicks that hatched on 24 November 2013 had an average hatching mass of 73.6 g, SD = 4.96, n = 9; culmen size: 14.2 mm, SD = 0.80, n = 8; and wing length: 18.8 mm, SD = 0.44, n = 6. In December, the adults reduced the length of stay in the site from two to one day. Images of chicks large enough to be observed on the nest were registered in the middle of December (Fig. 1-D). A maximum number of 24 juvenile birds were observed on 24 January 2013 within a crèche and on the 25 January, nestlings move from the main site. On 1 February 2013, all penguins, adults, and young were absent from the area (Fig. 1-E). Adult penguins start to return to the study site on 19 February 2013. The pre-molt condition was noted on 26 February as feathers begin to protrude and stand out of the body. Groups of up to 17 penguins congregate together during the first week of March and old feathers were shed during that period (Fig. 1-F). As of 28 March 2013, all adult penguins were absent from the study site. The entire cycle from arrival to departure of the colony (Fig. 2, Table 1) lasted approximately six months with a gap of nearly 20 days on a pre-molt feeding trip. The molting period for the subpopulation lasted about 35 days.

Williams (1995) mentioned that birds that breed in more northerly latitudes arrive earlier, however, that correlation could not be defined within the arrival patterns recorded. Williams (1995) gave the following dates, arranged by arrival date, starting in late July on Amsterdam Island (37˚49´S); 3 October, Antipodes Islands (49˚40´S); 7 October, Campbell Island (52˚32´S); 9-10 October, New Island, on Falkland/ Malvinas Islands (51˚43´S); 15-17 October, Macquarie Island (54˚30´S); 27 October, Crozet Island (46˚25´S); and 2-5 November, Heard Island (53˚S) do not fit the correlation of dates with latitude. Clearly, the data from Isla Noir (54˚28´S) do not fit that pattern either, with birds arriving by early October. Based on these dates, rockhopper arrival on Isla Noir is more in line with birds from the Antipodes Islands, which are considerably farther north and by latitude is more in line with birds from Macquarie Island, which arrive at least 12-14 days later.

The trap cameras monitoring system has been proved as a useful tool for seabirds tracking in remote areas (Dodino *et al*. 2018; Hinke *et al*. 2018; Jones *et al.* 2018; Lynch *et al*. 2015), and it may be a method that shows the environmental variability on reproductive phenology in a seabird

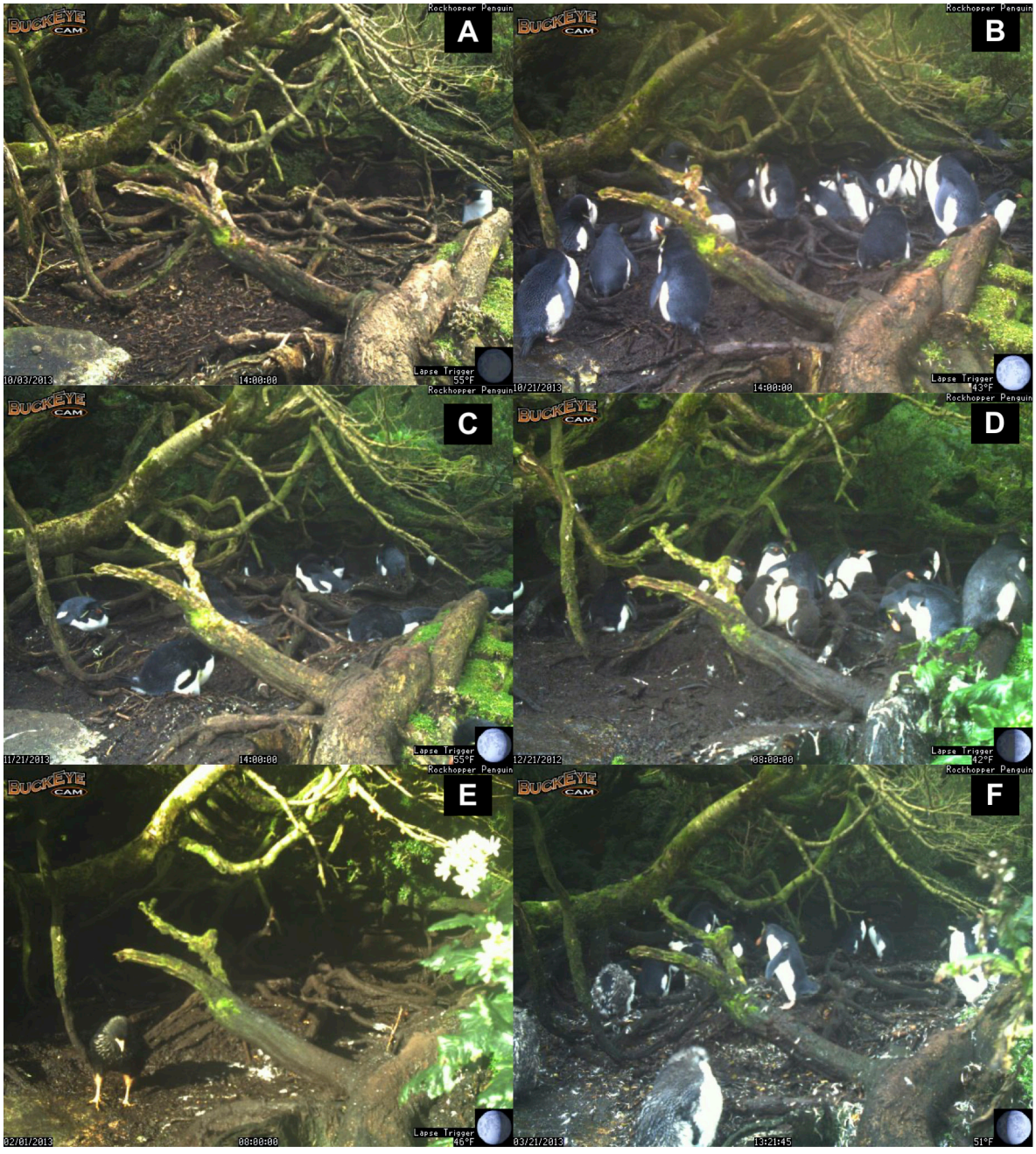

Fig. 1. Images of the study site from a camera trap: A) first adult arrive at the nest, B) peak attendance, C) incubation, D) nestling crèche, E) all penguins absent from the site, F) molting.

colony. In archipelagic sites with vast vegetation of tall grass and dense bushes like Isla Noir, this method can also be giving useful information, but, from a restricted portion of the colony.

In our experience, camera data attuned reproductive phenology dates proposed by Venegas (1999), who generated an approximation based on limited direct observations and previously published information, mainly from colonies within the Falkland/Malvinas Islands. In Isla Noir, combining our observations and those of previous reports (*e.g.,* Marín *et al*. 2013) indicates that the extent of the

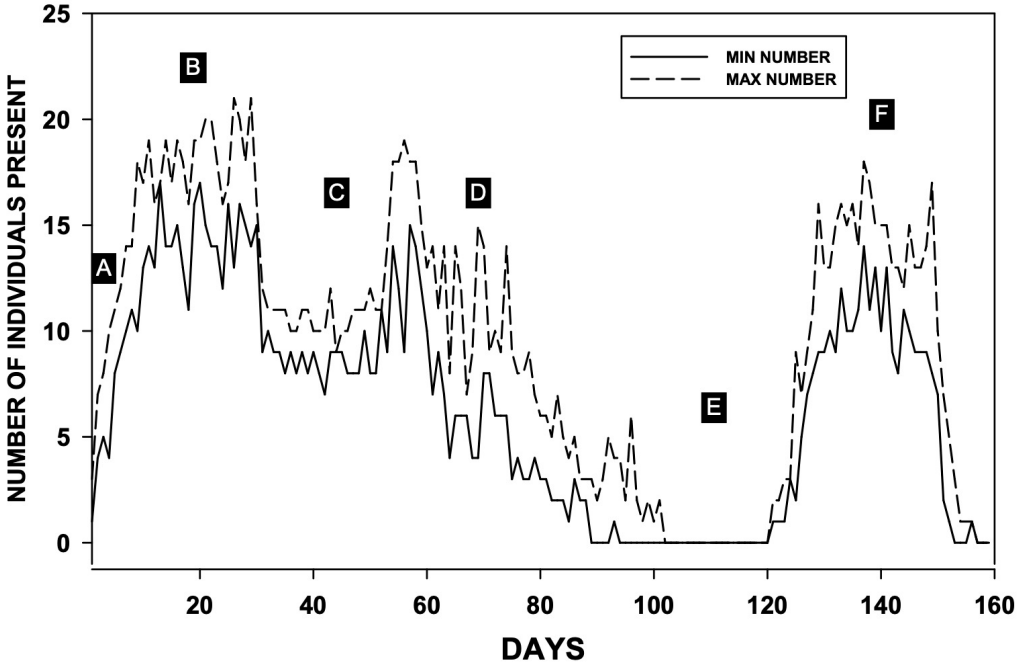

Fig. 2. Colony attendance by number of penguins counted by photographs, at Isla Noir, southern Chile. Days counting from October to March and letters represents main stages, A: arrival to the colony, B: peak attendance, C: incubation, D: crèche, E: absence of penguins, F: molting.

incubation period terminates by early December, and the earliest hatching may commence by mid to late November. With at least 20-25 days of overlap between late incubation and early hatching. We also noted asynchronous hatching periods within the main colony, of 5 to 8 days depending on elevation with earlier hatching observed in nests closer to shore versus nests higher up on the ridge. Despite the small micro fluctuations, in general terms the general phenology agrees with what has been observed in other colonies off South America, *e.g.,* Isla Gonzalo (Cursach *et al*. 2014). However, the entire breeding season is approximately one month shorter than in Falkland/ Malvinas Islands (Strange, 1982, 1992), and the departure of birds at Isla Noir occurs nearly a month before those on Macquarie Island, which is about the same latitude as Isla Noir in the other side of the Pacific Ocean (Hull *et al*. 2004). Nevertheless, the first juveniles were observed in the middle of December cluster in

Table 1. Timing and main events that occurred through the year in the sub-colony of Rockhopper Penguin *Eudyptes chrysocome* at Isla Noir.

Timing	Event
03 October	First birds arrived
29 October	First egg observed, although at least 1-2 days before some birds had insinuating incubation postures
late November	Hatching
25 January	All nestlings move away from colony returning only at night
01 February	All nestlings and adults gone from colony
19 February	Adults start to return to the colony very fatty getting ready for molt
26 February	Several adults molting a few feathers from back
04 March	Heavy molt on head, back, chest and wings visible in all birds
28 March	All birds gone from the colony

crèche a month after hatching, similar to the Hull *et al*. (2004) dates.

The procedure of this tracking involved a minimum population fraction, but it is useful to monitor the phenology of this species indirectly, given that, there might be annual fluctuations or delays of dates, as it is thought to occur in the Falkland/ Malvinas Islands (Crofts & Stanworth, 2017). The use of a long-term remote recording of abundance indices utilizing supplementary power sources provided proof of the concept in accurately recording the behaviors, within the Rockhopper Penguins on Isla Noir. In hard to access sites with low visibility due to limited sight lines caused by dense vegetation, variations in elevation, and other geographical features, additional cameras and observations points would improve this system. Consequently, would increase the data gathering withing the entire colony, and would improve knowledge on the species phenology.

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