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Activity rhythms at a gentoo penguin (*Pygoscelis papua*) colony at Cierva Point, Antarctic Peninsula

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Abstract We studied activity rhythms at a gentoo penguin (*Pygoscelis papua*) colony at Cierva Point, Antarctic Peninsula, during the 1992-93 summer. We counted the number of penguins crossing a specific point on their route to and from the colony. Penguins showed a strong daily rhythm of activity, with a two-peak pattern for those leaving the colony and a one-peak pattern for those returning. The peak of penguins departing to sea was at dawn, with a secondary peak in the afternoon which was coincident with the peak of returns. Although this behaviour could be explained by nest relief schedules, the pattern remained once crèches had formed. The main peak of departures strongly correlated with sunrise, which might support the existence of a light signal synchronizing activity. Even though an external factor could be triggering movements, an endogenous circadian clock might drive both patterns.

Quintana, R.D.; Pratolongo, P.D.; Agraz, J.L.; Benitez, O.; Mengual, A.R. 2005. Activity rhythms at a gentoo penguin (*Pygoscelis papua*) colony at Cierva Point, Antarctic Peninsula. *Notornis 52(3)*: 133-137.

Keywords activity rhythms, daily activity, circadian clock, gentoo penguin, *Pygoscelis papua*, Antarctic Peninsula.

INTRODUCTION

Many behavioural features of organisms are adjusted to periodic changes in the environment (Gwinner 1996). In order to improve species fitness, daily routines might couple individuals' behaviour with the time structure of the environment (Aschoff 1981).

Daily activities of free-living birds show clear rhythms, with most species active only during the day. Antarctic penguins maintain their activity rhythms even under the continuous daylight of summer (Cockrem 1990). Although it is believed that an internal circadian pacemaker regulates these rhythms, it has not been experimentally confirmed. Such routines may have an innate component, the product of natural selection and contributions from individual experience with the cycles of the environment (Daan 1981).

Factors like daily physical, climatic and temperature variations, and rhythmic changes in the availability of food and predators are decisive causes of daily patterns of activity. Thus, natural selection may influence the synchronization of behaviour, such as feeding, in order to reduce predation, especially at the most vulnerable stages of the life cycle.

Received 12 December 2004; accepted June 2005
Editor M. Williams

Several studies in penguins, including species of *Pygoscelis*, have shown a nest relief schedule, where one parent remained at the nest while the other foraged at sea (Lishman 1985; Golombek *et al*. 1991). In the case of the gentoo penguin (*Pygoscelis papua*), the species has a diurnal pattern of movements to sea for feeding (Bagshawe 1938).

The objective of the present work was to describe the departure and arrival patterns at a gentoo penguin colony in summer at the Antarctic Peninsula in order to relate activity peaks with behavioural features of the colony and periodic changes in the environment, particularly those related to daily dark-light cycles in Antarctica.

STUDY AREA AND METHODS

Study area

We carried out the study at Cierva Point, Danco Coast, Antarctic Peninsula (64° 09′ S, 60° 57′ W) during the 1992-93 Antarctic summer. Monthly mean temperatures ranged between 1.8 and 2.2°C, relative humidity averaged 79%, and mean wind speed was 7.9 km/h (range 0.0 to 40.6 km/h). During the lapse of time considered in this work, mean daily temperature was 0.6°C with frequent cloudy and snowy days (Quintana *et al.* 2000).

Cierva Point and the adjacent islands on the Danco Coast were declared a Site of Special Scientific Interest (SSSI No. 15) in terms of the Antarctic

Treaty in 1985 since they provide an important example of well-developed maritime vegetation and concentrations of seabird breeding colonies (Anon 1997, 1998). For that reason, tourism is not allowed and human activity is uncommon.

Our study colony consisted of 29 sub-colonies and five isolated areas located between 50 and 150 m above sea level (Quintana *et al.* 2000); at the beginning of the study it comprised 1044 nesting pairs. Average nest density was 0.25 nests/m^2 (range 0.02 - 1.54)(Quintana & Cirelli 2000). The first chicks hatched on 24 December and the first crèches were formed by 20 January. By mid-February chicks from different sub-colonies had formed large crèches, the integrity of sub-colonies was lost and down-free chicks were moving to the coast (Quintana and Cirelli 2000).

Methods

Data collection

The penguins regularly travelled well-defined routes from the colony to the coast. As they used the same routes throughout the day, we used the number of penguins passing a particular point to indicate locomotive activity of the population's breeding birds.

The colony was located 600 - 800 m from the sea. Observers placed on a route, 80 m from the coast, counted animals passing in either direction. On each date, passing penguins were counted without interruption for 30-min periods, every two hours, starting at 2200 h (local time). Simultaneously, we measured air temperature at the sampling point. Counting started on 21-22 December 1992 and was repeated at 15 different dates until 1-2 March 1993.

Statistical analyses

Our analysis was restricted to the period before chicks began to leave the colony. We hypothesized that during this period the number of birds departing the colony through the day would approximately equal the daily number of penguins arriving. In order to determine the date when this trend changed, we computed the difference between the total number of penguins leaving and those arriving, and we plotted these daily values against Julian date. Using this data set we performed a stepwise linear regression to estimate the point where a discontinuity in the regression line occurred.

The mean number of penguins arriving at and departing from the colony through the day was plotted against local time. We analyzed the number of penguins going to the coast and coming back to the colony separately through Single Spectrum (Fourier) Analysis and Fast Fourier Transformation (FFT). Spectrum analysis is a powerful tool in the exploration of cyclical patterns of data which allows decomposing a complex time series with cyclical components into a few underlying sine and cosine functions of particular wavelengths. By means of applying Fourier analysis, it is possible to uncover just a few recurring cycles of different lengths in the time series of interest (Bloomfield 1976; Elliot and Rao 1982; Wei 1989).

The spectrum analysis identifies the correlation of sine and cosine functions of different frequencies with the observed data. If there is a strong periodicity of a given frequency in the data, a large correlation (sine or cosine coefficient) will result for the respective frequency. As sine and cosine functions are orthogonal, it is possible to sum the squared coefficients for each frequency, and compute periodogram values as:

P_k = sine coefficient $_k^2$ + cosine coefficient $_k^2$ * N/2,

where P_k is the periodogram value at frequency k and N is the overall length of the series.

The periodogram values can be interpreted in terms of variance (sums of squares) of the data at the respective frequency. Customarily, the periodogram values are plotted against the frequencies. However, as periodogram values are commonly subject to substantial random fluctuation, a common approach consist in using, instead of periodogram values, spectral densities (Blackman and Tukey 1958), that is, frequency regions, consisting of many adjacent frequencies. This was accomplished by smoothing the periodogram values via a weighted moving average transformation (since Daniell 1946).

We used main frequency components of the periodograms (those frequencies exhibiting the greatest spectral densities) to determine activity rhythms. As frequency is computed in terms of cycles per unit of time, and each two hour period represents one unit of time, frequency values in periodogram plots represent the fraction of a cycle that can be accomplished in a two hour period.

In order to interpolate values between adjacent sampling times, we fitted the number of penguins departing the colony over time to a sixth-order polynomial function and then determined the first local maximum. To test the relationship between the first activity peak (computed from the fitted polynomial) and the light-dark cycle, we performed a linear regression, taking sunrise for each day as an independent variable.

We also tested the correlation between air temperature and different activity indicators. We correlated the number of penguins departing from and arriving at the colony at each 30-minute period of counting vs air temperature at the start of sampling. We also correlated total number of penguins arriving and departing the colony through each day vs mean daily temperature.

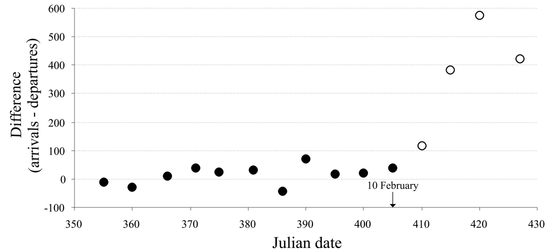

Figure 1 Difference between the number of gentoo penguins departing from and arriving at the colony for each day (Julian date) at Cierva Point, Antarctic Peninsula. Solid dots correspond to values obtained until 10 February (Julian date 406). Positive values show a net loss of penguins from the colony.

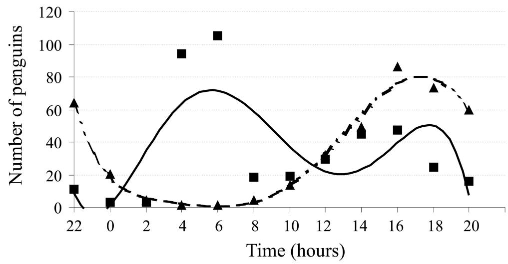

Figure 2 Mean number of gentoo penguins arriving at (triangles) and departing from (squares) the colony throughout the day at Cierva Point, Antarctic Peninsula. Means were computed from data obtained until 10 February. Fitted lines are sixth-order polynomial regressions for departing (filled line) and arriving (dotted line) birds.

RESULTS

Numbers departing and arriving

We estimated that the breakpoint at which there was a difference between the number of penguins departing from the colony and arriving at it was at Julian date 403.3; the closest calendar date being 10 February. Prior to this date the linear trend line of the difference between departures and arrivals plotted against Julian date, was without significant slope (*slope* = 0.85; $P = 0.18$) but thereafter, departures significantly exceeded arrivals (*slope* = 21.65; $P < 0.05$). In both cases, *slope* is the rate at which the difference between departures and arrivals changes over time and P indicates the probability that the slope is not different from cero. Based on these results, we used data recorded until 10 February in later analyses (Fig. 1).

Circadian rhythm

Penguins traveling both from and to the colony revealed a circadian rhythm of activity. Those going to sea showed a daily rhythm with a main activity peak at dawn and a secondary peak in the afternoon (Fig. 2). A periodogram showed a principal frequency component of 0.17 cycles/sampling interval (corresponding to a 12 h period), according with the two daily peaks observed, and secondary components of 0.25 and 0.08 cycles/sampling interval (8 and 24 h periods, respectively; Fig. 3). On the other hand, the periodogram carried out on data from arriving individuals showed a strong frequency component of exactly 0.08 cycles/sampling interval (24 h period, Fig. 4), with negligible secondary components. We observed maximum activity in the afternoon, the same as the secondary peak of departing penguins.

The proportion of individuals that left the colony daily in the afternoon remained almost constant (range: 0.45 – 0.55, n = 10 counts, between

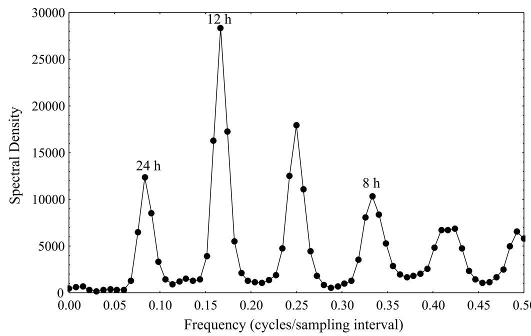

Figure 3 Periodogram for departing activity of Gentoo Penguins at Cierva Point, Antarctic Peninsula, taking into account a sampling interval of two hours. Main frequency components are highlighted, and the period of the main recurring cycles is indicated.

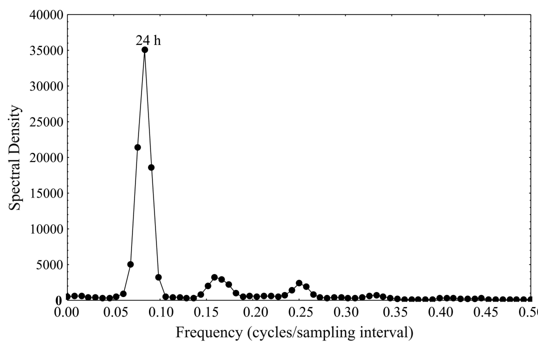

Figure 4 Periodogram for arriving activity of Gentoo Penguins at Cierva Point, Antarctic Peninsula indicating that there is a strong pattern with a recurring cycle of 24 h period.

Table 1 Correlations of different activity indicators with temperature. Activity indicators are defined as: Departing activity - number of penguins departing the colony at each 30-minute period of counting; arriving activity - number of penguins arriving to the colony at each 30-minute period of counting; total activity - departing plus arriving activity; daily activity - total number of penguins departing and arriving through the whole day.

Comparison	Pearson *r* (correlation coefficient)	*P*-value
Departing activity vs. temperature at the moment of sampling	0.11	0.20
Arriving activity vs. temperature at the moment of sampling	0.24	0.05
Total activity vs. temperature at the moment of sampling	0.05	0.54
Daily departing activity vs. mean daily temperature	-0.37	0.26
Daily arriving activity vs. mean daily temperature	-0.34	0.24
Daily total activity vs. mean daily temperature	-0.21	0.45

21 December and 5 February) until 10 February (0.3) and was therefore not affected by crèches formation.

The timing of the first peak of departures and arrivals on sampling days were computed for each sixth order polynomial function and are plotted in Figure 5 in relation to the time of their corresponding sunrise. The performed regression was significant ($r^2 = 0.75$, $P < 0.01$) indicating that there is a strong relationship between sunrise and the first peak of locomotive activity. No correlation was found between temperature and different activity indicators (Table 1).

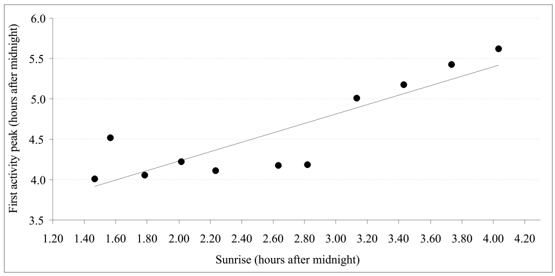

Figure 5 Linear regression between first activity peak of gentoo penguins leaving the colony (dependent variable) and sunrise of corresponding date (independent variable). ($r^2 = 0.75$, $P < 0.01$).

DISCUSSION

The spectrum analysis showed a few recurring cycles of different lengths in the time series considered. Gentoo penguins at Cierva Point had a dual-peak in daily departure activity, as Conroy *et al.* (1975) found in chinstrap penguins (*Pygoscelis antarctica*), with most birds departing for the sea at daybreak and arriving at the colony at dusk. This two-peak pattern was probably related to the birds' nest-relief schedule, a common behavioural feature in penguins (Cockrem 1990), which may involve significant competitive advantages for the species, since the period from hatching to crèching could be critical for chick survival (Quintana & Cirelli 2000). The two-peak activity pattern might be related to a protection strategy against predation, which has been indicated as the main cause of mortality of chicks (Williams 1980, Bost & Jouventin 1991). At Cierva Point, the presence of skuas at nest sites requires the continuous presence of adults to guard eggs and young chicks.

The proportion of penguins leaving the colony at dawn did not change until the first weeks of February, in spite of crèches having been formed by 20 January. Our field observations at this point of change showed that at any one time through the day, a group of penguins foraged at sea while another group remained near the colony. The resulting activity pattern was the same as that of the chick-feeding stage, although the nest-relief schedule was absent once crèches were established.

The trend changed at the beginning of February when the proportion of birds departing from the colony at dawn increased, at the same period in which down-free chicks began to move to the coast (Quintana & Cirelli 2000). A plausible explanation for this increase is that fledgling birds tend to have their activity peak in the morning, and augment adult departing in foraging trips. After 10 February the number of penguins returning to the colony was lower than those departing to the sea, which indicated the beginning of migration as was observed by other authors (Novatti 1978, Jablonsky 1986, Quintana & Cirelli 2000).

Penguin movement activity did not correlate with environmental temperature. Rather, it seemed to be strongly related to daily onset of light, thus indicating light was functioning as a periodic environmental factor synchronizing activity oscillations (Aschoff

1981). Many authors (e.g. Enright 1970; Gwinner 1975; Daan 1981) have provided examples of physical factors with a characteristic 24-hour frequency fluctuations, like temperature and light. However, there are also daily variations influenced by such factors as food species, predators, parasites, and competitors (Hau & Gwinner 1997; Ntiamoa *et al*. 1998).

Several studies have demonstrated the existence of intrinsic rhythms in behaviour in both invertebrate and vertebrate species (e.g. Aschoff 1981; Jacquet & Launay, 1997). These rhythmic phenomena could have evolved in response to temporal patterns in the environment. Although we observed penguin departure activity to be correlated with sunrise, there may be strong selective pressures favouring this arising from both temporal prey availability and avoidance of predation. For example, peak departure times of gentoo penguins, which forage in groups at sea, might be timed to overwhelm awaiting predators like leopard seals (*Hydrurga leptonyx*). We suggest that an endogenous circadian clock fixed within the population throughout its evolutionary history might drive these patterns.

ACKNOWLEDGEMENTS

We are grateful to Javier Calcagno for his useful ideas for this study, to the army personnel of the Primavera Station for logistic support, and to Dr. John Cooper and anonymous reviewers for constructive criticisms of the manuscript. We appreciate the improvements in English usage made by Phil Whitford through the Association of Field Ornithologists' program of editorial assistance. This study was supported by the Instituto Antártico Argentino and the Laboratory of Regional Ecology, University of Buenos Aires, Argentina.

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