

THERMOBIOLOGY OF GRAY GULL (*Larus modestus*) EMBRYOS AND HATCHLINGS CORRELATES OF NESTING IN THE ATACAMA DESERTTERMOBIOLOGÍA DE EMBRIONES Y RECIÉN NACIDOS DE LA GAVIOTA GARUMA (*Larus modestus*) CONSECUENCIAS DE NIDIFICACION EN EL DESIERTO DE ATACAMARoberto E. Aguilar<sup>1</sup> Carlos G. Guerra<sup>1</sup>, Lloyd C. Fitzpatrick<sup>2</sup>  
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## RESUMEN

Se estudió la tolerancia térmica y la ontogenia de la termorregulación en pollos de garuma *Larus modestus* que nidifican en el Desierto de Atacama. Los puntos termo crítico, máximo y mínimo (42° y 17°C, respectivamente), determinados a partir de la frecuencia cardíaca de los embriones, fueron coincidentes con la temperatura ambiente durante el día, a la cual los huevos son expuestos por parte de los adultos cuando termorregulan o vuelan para distraer a los depredadores, como así mismo, a la temperatura ambiente durante la noche cuando los padres que incuban son reemplazados por aquellos que llegan de la costa. Registros de la temperatura corporal de polluelos expuesto a las condiciones del Desierto de Atacama, mostraron que los polluelos son capaces de termorregular alrededor del sexto día después de haber nacido. Estos resultados coinciden con el período en que los polluelos son dejados solos en sitio de nidificación, mientras ambos padres se alimentan en la costa.

## ABSTRACT

We studied the thermal tolerance of embryos and ontogeny of thermoregulation in chicks of Gray Gulls, *Larus modestus*, in the Atacama Desert of northern Chile. Critical thermal maximum (CT<sub>max</sub> = 42°C) and minimum (CT<sub>min</sub> = 17°C), determined from embryo heart rate, were consistent with the high ambient temperatures to which eggs are exposed when incubating adults stand above nests to thermoregulate or leave nests to distract predators during the day, as well as the low night time temperatures experienced when incubating adults depart to interact with mates. Measurement of body temperatures of chicks exposed to ambient desert conditions showed that chicks were able to thermoregulate 6 days after hatching. This is consistent with the time that chicks are left alone in the desert while both parents forage at the coast.

## INTRODUCTION

Since 1980, we have been studying Gray Gulls, *Larus modestus*, focusing on adaptations and tradeoffs associated with nesting in the desolate Atacama Desert of northern Chile (FITZPATRICK & GUERRA 1988; FITZPATRICK et al. 1988; FITZPATRICK et al. 1989; FITZPATRICK et al. 1992, GUERRA,

1987, 1990; GUERRA et al. 1988a, 1988b, 1988c, 1988d, 1989). Herein, we discuss thermal tolerance of Gray Gull embryos and development of thermoregulation in chicks in terms of adult behavior (see FITZPATRICK et al. 1989) with respect to the severe ambient conditions (see GUERRA et al. 1989) within the Atacama.

Gray Gulls, which nest 30-100 km from the coast,

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lay one to two eggs (mean = 1.56) between November and January. Hatching occurs after an average of 29 days of incubation, significantly longer than for other gulls with similar egg size (see: LACK, 1967; VEMEER, 1970; AR & RAHN, 1980). During incubation, adults alternate daily foraging flights to the coast, making round trips up to 200 km. Hatchlings must be tended by one adult for approximately 7 days while the other forages at the coast. Afterwards, when chicks are able to survive on their own by taking shelter in shallow dry channels and around small scattered rocks, both parents forage (FITZPATRICK & GUERRA 1988).

Energy demands on adults are intense, especially after chicks hatch and must be supplied with food obtained at the coast 30-100 km away. After the first 7 days, when both parents forage and carry food to chicks, the growth rate of Gray Gull chicks is lower than other gulls (GUERRA *et al.* 1988b), which protracts the time the birds remain in the desert. The demands of nesting in the Atacama has led to decreased clutch size and slow growth rates relative to other gulls, and a bet-hedging reproductive tactic (STEARN, 1974), which is adaptive during times of low marine productivity associated with El Niño Southern Oscillation (GUERRA *et al.* 1988d).

During the day, eggs are exposed to air ( $T_A$ ) and ground temperatures (TG) up to 38 and 61°C, respectively, and solar radiation (SR) of 0.15-1.4 Kw/m<sup>2</sup> when adults stand above their nests to thermoregulate convectively (FITZPATRICK *et al.*, 1989), or fly from their nests to distract turkey vultures (*Cathartes aura*) and falcons (*Falco sp*) that prey on eggs and nestlings. At night, eggs are exposed briefly to low temperatures (5°-10°C) when the incubating adult leaves the nest to interact with its mate that has returned from foraging at the coast. HOWELL *et al.* (1974) speculate that the night time exposure to low temperatures results in the long incubation time in Gray Gulls. However, GUERRA *et al.* (1988a) argue that exposure during daytime has selected for decreased egg shell water vapor conductance with attendant reduced cross-sectional pore area relative to similar sized eggs of other gull species. Since pore area also affects CO<sub>2</sub>:O<sub>2</sub> exchange, embryo development is slowed relative to other gulls, resulting in the relatively prolonged incubation time.

In this paper, we present results of experiments designed to extend our understanding of: (1) Thermal tolerance of Gray Gull embryos to daytime temperatures when eggs are exposed due to adults standing to thermoregulate or leaving the nests to distract predators; and (2) low night time temperatures when eggs are exposed due to incubating gulls leaving the nest to interact with mates returning from the coast.

### Thermal tolerance of embryos

On 28 and 30 January 1990, we collected 14 eggs from the Lealtad nesting colony (described by GUERRA 1990), determined their ages to be 2-3 weeks old using the flotation technique (BENNETT & DAWSON, 1979) and then transported them within a styrofoam container at ambient temperature and adequate humidity to our laboratory at the Instituto de Investigaciones Oceanológicas-Universidad de Antofagasta (IIO/UA). There, we determined the relation between embryo heart rate (HR = beats per 15 sec) and temperature, following BENNETT & DAWSON (1979). We determined lower and upper critical temperatures (CT<sub>min</sub> and CT<sub>max</sub>) in terms of HR cessation in embryos exposed to  $T_A$  from 0° to 42°C. Response to low temperatures was determined for embryos exposed to 0°-18°C in controlled temperature chambers. Embryos, dissected from the eggs, were immediately placed into petri dishes containing Ringer's solution (GAVIÑO *et al.* 1970). We counted heart beats per 15 sec with aid of a dissecting microscope and stopwatch while temperature was increased slowly using a hot plate.

### Ontogeny of thermoregulation in chicks

We examined the thermoregulatory ability of chicks (0-13 days post hatching) by comparing their body temperature (TB) to air temperature ( $T_A$ ) at the Lealtad nesting site on 25 January and 5 February 1992. We measured TB of hand-captured chicks immediately before placing them into wire mesh confinements (1.20 x 0.50 m). One confinement was shaded, the other exposed to the sun. We then made TB measurements using a fine thermocouple inserted 1-1.5 cm into cloacae hourly between 0700 and 1900 h and every 2 h during the night from 2000 until 0200 h. Simultaneously, TG,  $T_A$  and SR measurements were taken and recorded in a micrologger (Model 21X, Campbell Scientific Inc., Utah).

## RESULTS

### Thermal tolerance of embryos

The CT<sub>min</sub> was 18°C. Hearts stopped beating in Gray Gull embryos exposed for 15-30 min. to temperatures  $\leq$  18°C. Embryos were unable to recover when temperature was increased from exposures at and below 18°C. The mean CT<sub>max</sub> was 41.7°C (SD = 1.2°C; N = 7). Recovery with decreasing temperatures was not tested.

Fig. 1 shows that embryo HR was related linearly to  $T_A$  (HR = 1.45  $T_A$  - 19.79,  $r^2$  = 0.99,  $p$  = 0.0001). Mean HR, within the range of natural incubation



week-old Gray Gull embryos exhibited a 010 of 1.64 and 1.42, respectively. The maximum temperature tolerated ( $41.7^{\circ}\text{C}$ ) by Gray Gull embryos is similar to that reported ( $41.1^{\circ}\text{C}$ ) for Heermann's Gulls (BENNETT & DAWSON 1979), but lower than that ( $46^{\circ}\text{C}$ ) for Western Gulls (BENNETT *et al.* 1981).

Our observations indicate that Gray Gulls only expose their eggs to direct sunlight when they leave to distract humans, turkey vultures, or falcons. Since the highest temperature of viable eggs we have recorded in the desert ( $39.4^{\circ}\text{C}$ ; AGUILAR *et al.* 1995), is lower than the TCMAX, Gray Gulls embryos appear to have sufficient thermal tolerance to enable adults to leave their eggs unattended while defending nests. During the night, the lowest egg temperature we have recorded ( $30^{\circ}\text{C}$ ; AGUILAR *et al.* 1995) is 1.8 times higher than the TCMIN for embryos. Thus, night time exposure to low temperatures appears insufficient to harm embryos, although it may prolong their development as suggested by HOWELL *et al.* (1974), combining with decreased total shell pore area to increase incubation time.

#### Ontogeny of thermoregulation in chicks

Body temperatures of confined 0-3 and 6-13 day-old chicks tracked variation in ambient conditions, principally  $T_A$ . Variation in  $T_B$  of chicks in the shade were not significantly different between age groups and were most strongly correlated to  $T_A$ . Differences in  $T_B$  ranges during exposure to sun and shade ( $5^{\circ}$  vs.  $1.9^{\circ}\text{C}$ ) and differences between age groups suggest that direct exposure to the hot Atacama environment can be stressful to young chicks. However, the absence of differences between age groups during the hottest hours suggests that newly-hatched chicks have an incipient capacity to regulate body temperature, which agrees with the idea that semiprecocial birds rapidly develop the capacity to thermoregulate (DAWSON *et al.* 1976; CHAPPELL *et al.* 1984).

Gray Gull chicks thermoregulate under hot conditions by panting and gaping. However, adults provide shade, protecting chicks from intense direct radiation over their first 7 days (GUERRA *et al.* 1988c; FITZPATRICK *et al.* 1992). Similar behavior has been observed in California Gull chicks (CHAPPELL *et al.* 1984). When Gray Gull chicks are left alone during the day, they take advantage of micro-meteorological conditions of areas adjacent to rocks and in dry channels (GUERRA *et al.* 1988d). According to FITZPATRICK *et al.* (1989), hypothermia in Gray Gulls, which begins at  $T_A 29^{\circ}\text{C}$ , is an important physiological tactic for minimizing both water and energy loss by reducing the  $T_B - T_A$  gradient even below the gulls' upper TNZ limit ( $32^{\circ}\text{C}$ ). In 0-3 day-old chicks, the minimal  $T_B - T_A$  gradient that we observed was  $29^{\circ}\text{C}$ , equivalent to their lower TNZ

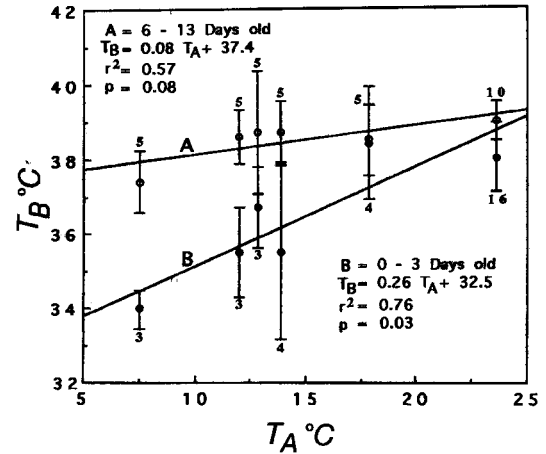


FIG. 3: Linear regression model relating body temperature ( $T_B$ ) of gray gull *Larus modestus* chicks (0-3 and 6-13 days old) to air temperature ( $T_A$ ) at Llealtad nesting colony (The bars represent one standard deviation and the number is the sample size)

limit. Chicks maintained  $T_B$  ca  $41^{\circ}\text{C}$  at  $T_A 22^{\circ}\text{--}29^{\circ}\text{C}$ , which is close to values observed in California Gulls:  $40.1^{\circ}\text{C}$  at  $T_A 20^{\circ}\text{--}30^{\circ}\text{C}$  (CHAPPELL *et al.* 1984). When  $T_A$  was exceeded the maximum tolerated ( $39^{\circ}\text{--}41^{\circ}\text{C}$ ), California Gull chicks become stressed, pant and attempt to escape. Similar behavior occurred in Gray Gull chicks held at  $T_A$  over  $41^{\circ}\text{C}$ .

During the coldest hours, thermoregulation was significantly different between 0-3 and 6-13 day-old Gray Gull chicks. Young chicks were less able to thermoregulate under changing  $T_A$  than older ones:  $T_B$  in 0-3 day-olds fluctuated from  $34$  to  $38^{\circ}\text{C}$ , while in 6-13 day-olds the range was  $37.4$  to  $38.5^{\circ}\text{C}$ . Poor thermoregulation in hatchlings under 5 days at  $T_A$  under  $15^{\circ}\text{C}$  has been shown for Laughing Gulls (DAWSON *et al.* 1972), Western Gulls (DAWSON & BENNETT 1981), Mew Gulls, Lesser Black-Backed Gulls, Greater Black Backed Gulls, and Herring Gulls (DUNN 1976). Between 2400 and 0400 h young Gray Gull chicks and fledglings are active, increasing metabolic heat production as they are fed and interact with adults which have returned from foraging (GUERRA *et al.* 1989). After adults depart for the coast, young gulls are inactive during the coldest hours (0400-0700 h) taking shelter from cold Andean winds next to rocks or within shallow dry channels (FITZPATRICK & GUERRA 1988; GUERRA *et al.* 1988c). During those hours, young gulls may increase heat generation metabolically through post-feeding heat increment associated with digestion (specific dynamic action) and shivering thermogenesis.

Since during our assessment of thermoregulation, all chicks were kept in wire mesh confinements

without protection from the cold wind or the ground, differences in thermoregulation between 0-3 and 6-13 day old chicks indicate that parents must play important roles in stabilizing chick  $T_B$  during their first 6 days. After 6 days, chicks are able to thermoregulate sufficiently to be left alone in the desert while both parents are away, (ca. 0400-2400 h) and not to depend on adults for thermoregulation between 2400-0400 h. Onset of thermoregulation is consistent with our observations that both adults forage ca. 7 days post hatching.

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