

failed; on Norsel Point (eight birds), where the birds often loaf near old Palmer Station but do not breed; and on Hermit Island (one bird), where the species breeds occasionally. Carcasses of three giant fulmars (also called giant petrels) (*Macronectes giganteus*) and one south polar skua (*C. maccormicki*) also were found on Litchfield Island. Additional dead south polar skuas were discovered at Norsel Point (eleven birds), Christine Island (one bird), and Bonaparte Point (one bird). Whether or not they died from cholera or other causes is not known. No dead penguins, gulls, or other bird species were observed.

Whether virulent fowl cholera has been previously reported from antarctic regions is not known to us at present. It does strike species that are not far removed. Carlson and Penniford (1961) reported that their diagnostic tests indicated that four captive South American penguins (*Spheniscus humboldti*) died of fowl cholera in Alberta shortly after their arrival from Florida.

We are puzzled why the brown skua (less than 10 percent of the total skua population in the study area) suffered higher mortality than the much more abundant south polar skuas breeding close by (Parmelee, Fraser, and Neilson, 1977; Parmelee et al., 1978). The latter feed on fish and krill and their breeding success fluctuates drastically when ice conditions and other factors prevent efficient foraging at sea. Brown skuas partition the penguin rookeries, and their numbers and breeding success depend on penguins. As unfavorable ice conditions do not inhibit penguin feeding, the brown skuas dependent upon them have not shown the dramatic fluctuations in breeding success experienced by their close relatives.

It is possible the south polar skuas have developed a greater immunity to the disease through more frequent

contacts with the bacteria during the birds' long migrations into temperate and arctic regions of the northern hemisphere. Migrations of brown skuas are not nearly so well known; presumably those birds of the Antarctic Peninsula area do not fly beyond South America. Gulls are known to be important reservoirs of *Pasteurella* in other parts of the world. We do not know, however, whether gulls, skuas, or other species transmitted the disease to the Palmer Station study area.

This unexpected loss of marked brown skuas in the study area presents a rare opportunity to investigate other questions under unique environmental conditions. For example, will the empty territories adjacent to the penguin colonies be filled by brown skuas or south polar skuas? Will surviving brown skuas that were previously banded abandon their present territories for the newly empty and conceivably better territories? Will the reduction in brown skuas, as well as the readjustments within the study area, result in stepped-up cross-matings between the two species?

High priority will be given to these and other issues during the remaining two years of research.

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Cutaneous blood flow in the giant petrel

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Birds living at high latitudes must maintain their body temperatures at levels well above the ambient temperature. Excellent insulation over most of their body helps maintain this gradient. In addition, heat loss through the uninsulated areas of the periphery, such as the feet, legs, and beak, also must be controlled. This control is mediated by the vascular system, primarily by reducing cutaneous blood flow (Scholander et al., 1950; Guard and Murrish, 1974).

The brood patch is an area of skin on the abdomen of adult birds that becomes defeathered, edematous,

and highly vascularized prior to egg laying (Bailey, 1952). It must supply large quantities of heat to the egg during incubation and to the chick after hatching. Although development of such an area is of prime importance for incubation purposes, it is potentially an area of substantial heat loss from the parent. Reducing blood flow to the brood patch to minimize heat loss, although favorable for the parent, would not be beneficial to the egg or to the chick.

We undertook a study of the control of blood flow to the brood patch. Field and laboratory experiments with the giant petrel, *Macronectes giganteus*, showed that brooding adults are able to adjust blood flow to this area in response to different core body and egg temperatures. This suggests a system of neurological controls based on an interaction between central nervous system thermoregulatory centers.

Seven giant petrels were collected from islands near Palmer Station, Palmer Peninsula. The birds were adults, each weighing between 3.3 and 5.2 kilograms, and were kept no more than three days before use. They were held in outdoor cages with snow provided ad libitum.

Surgical anesthesia was induced with pentobarbital sodium (25 milligrams per kilogram of body weight) given

intramuscularly. Sedation was maintained with diazepam (0.2 milligram per kilogram of body weight) given intravenously through either a tibiotarsal or brachial vein cannula.

Temperatures of the brood patch and web were measured with 36-gauge thermocouples placed subcutaneously. Deep body temperature was measured with a thermocouple inserted 10 to 15 centimeters into the esophagus. Heat flow from the brood patch was measured by placement of a heat flow transducer (Thermometrics Corporation) directly onto the brood patch. Heat flow transducers with a thermistor bead were also imbedded against the inside surface of eggs filled with water.

Eggs of three temperature ranges—13.6–16.9°, 24.1–28°, and 35–38.8° C, designated as cold, cool, and warm, respectively—were introduced into the brood patch of lightly sedated subjects. Heat flow into the eggs was determined by two methods. First, the area of the shell overlying the heat flow transducer was placed directly against the brood patch and heat flow into this area of the egg surface was determined. Second, total heat flow through the egg was determined by direct calorimetry. Knowing the change in temperature, the volume of water in the egg, and the water's heat capacity allowed us to calculate total heat flow.

Blood pressures were monitored using a heparin- and saline-filled cannula inserted into the carotid artery and connected to a pressure transducer. Relative blood flow to the brood patch was measured with a transcutaneous, doppler-ultrasound flow probe placed over one of the major arteries supplying the area. Temperatures, heat flow, blood pressure, and blood flow were recorded on synchronized oscillographic recorders.

Field measurements of egg temperatures were determined using radio-temperature transmitters inserted into water-filled eggs. Eggs left overnight with an adult on the nest registered incubation temperatures ranging from 29.7° to 31.6° C the following day. These temperatures are lower than those reported for most birds but are similar to the reported incubation temperature of the fork-tailed storm petrel, an Alaskan species (Wheelwright, 1979), and of other high-latitude birds (Eklund and Charlton, 1959; Drent, 1975). Ambient temperatures at the time of our measurements ranged from 3.5° to 8.7° C at nest height.

Field measurements of heat flow to cool eggs were also determined by direct calorimetry and by using heat flow transducers. Values for heat flows measured by direct calorimetry ranged from 1.40 to 2.21 kilogram calories per hour. Laboratory measurements of heat flow by the same method gave a mean value of 2.48 kilogram calories per hour for eight cool eggs. One field measurement of heat flow determined with the heat flow transducer gave a value of 2.20 kilogram calories per hour for a cool egg. These field and laboratory values for rewarming a cool egg represent a heat loss equal to 15–25 percent of the simultaneous standard metabolic rate of the giant petrel as calculated by the equation of King and Farnar (1961).

Control of blood flow to the brood patch was evaluated with cold, cool, and warm eggs introduced into the brood patch. Autonomic nervous system control was evaluated with phenoxybenzamine, an alpha-adrenergic

blocker administered intravenously. Blood flow varied with the deep body temperature of the bird at the time the egg was introduced and with the temperature of the egg itself (figure 1). In almost all procedures, there was an initial sharp drop in blood flow. This decrease is believed to be attributable to disturbance of the brood patch area during the introduction of the experimental egg, since manipulation of the feathers in the absence of an egg had the same effect.

The vascular response of a hyperthermic bird—body temperature (T_B) more than (40° C)—to a cold egg presented to the brood patch was a marked and sustained vasodilation (figure 1a). The relative blood flow increased by almost 100 percent within two minutes and remained at that level until the egg was removed. In contrast, cool eggs had little effect on the amount of blood flowing into the patch, and warm eggs caused a decrease in patch flow of up to 50 percent.

Blood flow into the brood patch in normothermic birds ($T_B = 38.8^\circ$ to 39.4° C) quickly returned to baseline levels after the initial drop, regardless of the temperature of the egg in the patch (figure 1b).

Hypothermic birds ($T_B < 38.5^\circ$ C) generally decreased flow to the brood patch, especially when it was presented with a cold egg (figure 1c). This procedure caused as much as a 75 percent reduction in flow to the patch or a hypothermic adult.

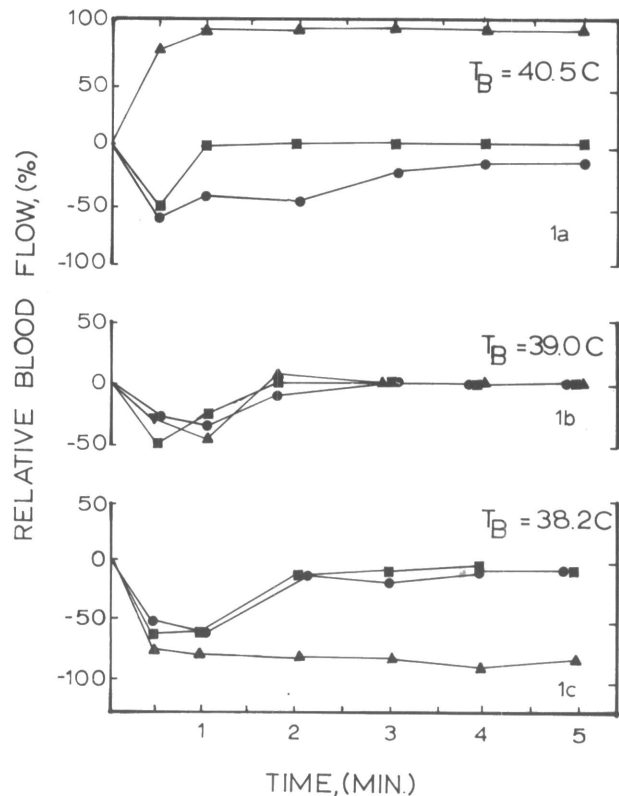


Figure 1. Changes in relative blood flow in the brood patch of hyper-, normo-, and hypothermic adult giant petrels after introduction of eggs and various temperatures. Key: Zero time = flow under control conditions; ▲ = cold egg (13.6–16.9°C); ■ = cool egg (24.1–28°C); ● = warm egg (35–38.8°C).

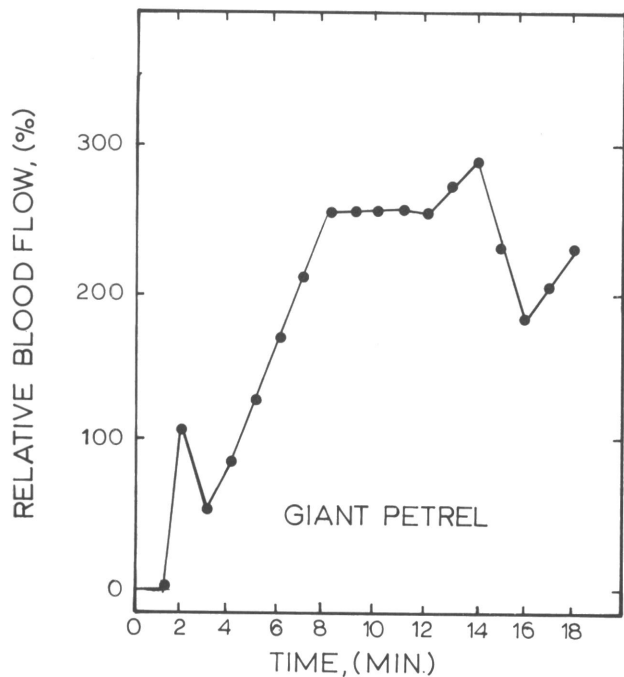


Figure 2. Effect of phenoxybenzamine on relative blood flow in the brood patch of an adult giant petrel. Zero time = flow under control conditions. Alpha blocker infusion initiated at 1½ minutes.

Pharmacological studies gave preliminary evidence favoring the existence of a sympathetic regulatory mechanism of blood flow based on active alpha constrictor control. This control is similar to that found in the skin of the human forearm (Roddie, Shepherd, and Whelan, 1957). Injection of phenoxybenzamine caused an immediate increase in blood flow to the patch, indicating release of alpha constrictor tone (figure 2). Twelve minutes after the alpha antagonist was administered, as the alpha receptors became progressively blocked, brood patch flow increased almost 300 percent over control levels.

Our work with the giant petrel suggests the existence of a control of brood patch flow based on a hierarchy

of central nervous system centers. One center monitors thermal stimuli from the brood patch. This center regulates blood flow to the patch by variation in the degree of alpha constrictor tone. This control, however, can be modified when another center adjusts cutaneous flow to aid in maintaining optimal core body temperatures. For example, when the body temperature of the brooding adult is above normal and a cold egg is introduced into the patch, both systems cooperate to greatly increase blood flow.

In a hypothermic bird, the center monitoring core temperature takes priority over that for the brood patch, and there is a sharp reduction in blood flow to the patch containing a cold egg. This occurs despite the fact that the egg temperature may already be low enough to be harmful for the embryo.

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Vascular anatomy of the brood patch of the giant petrel

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Proper development of avian embryos requires that they be maintained at a relatively constant, warm tem-

perature. In the Antarctic, the thermal gradient between the egg and the environment is often very large. The heat to maintain this gradient must come almost exclusively from the adult, and it is provided by the bird's brood patch, an area of skin on the abdomen between the xiphisternum and the pelvic girdle. Prolactin and estrogen act synergistically to cause defeathering, edema, and increased vascularity of the patch, all of which are conditions that aid in the transfer of heat by conduction to the egg and young (Bailey, 1952).

During the 1979 austral summer, we studied the vascular anatomy of the brood patch of the giant petrel, *Macronectes giganteus*, at Palmer Station. The birds were captured on nearby islands. Only adults without eggs or with non-viable eggs were used for anatomical purposes;