PETER RYAN

above & beyond

Overachievers in the bird world

TEXT **ANDREW McKECHNIE**

Birds are capable of feats of endurance that beggar the human imagination. They survive and reproduce almost everywhere on earth, from the hottest, most inhospitable deserts to the icy expanses of the Arctic and Antarctic. Some dive hundreds of metres below the ocean's surface, while others migrate over the planet's highest mountains. This article explores the adaptations of those species that push the avian limits of long-distance flight and altitude, heat or cold tolerance, and unpacks some of the physiology that makes these achievements possible.

FLYING HIGH

In late 1973, a Rüppell's Griffon collided with an aircraft over Abidjan on the Ivory Coast. Bird strikes are not uncommon, but what made the abrupt demise of this particular vulture unusual was the altitude at which it happened: 11 kilometres above the ground. That any animal can survive and function at such an altitude is remarkable, even if in this instance the griffon probably reached this height by soaring on thermals rather than in flapping flight.

Birds are inherently better suited to operating at altitude than mammals are. One key factor is the structure of the avian respiratory system. Mammals have a respiratory cycle that involves the inhalation of oxygenated air into the lungs, followed by the exhalation of partially deoxygenated air before the next inhalation. Birds possess a network of air sacs surrounding the lungs, arranged in such a way that oxygenated air flows continuously through the lungs regardless of whether the bird is inhaling or exhaling, providing a far more efficient mechanism for getting oxygen from the atmosphere into the bloodstream.

The best-studied species in terms of performance at high altitude is almost certainly Asia's Bar-headed Goose. This goose breeds in Mongolia and on the Tibetan Plateau and migrates to southern India, flying over the Himalayas to get there. Early explorers of this mountain range were understandably surprised when, even at altitudes above 7000 metres (and anecdotally, above Mt Everest at 8800 metres), they heard the honking of geese flying high overhead. Recent satellite-tracking studies have revealed that most geese pick routes that take them up to between 5000 and 6000 metres, but some individuals fly as high as 7200 metres.

The species' migration represents an incredible feat of performance. The geese flap almost continuously and their heart rates often remain above 400 beats per minute for extended periods.

TREVOR HARDAKER

above *The highest altitude at which a bird has ever been recorded is a Rüppell's Griffon at 11 000 metres.*

opposite *Bar-tailed Godwits are the endurance champions of the bird world, flying non-stop between New Zealand and Alaska.*

When migrating northwards from India back to their breeding grounds, the geese ascend from near sea-level to above 5000 metres in a matter of hours. The capacity of this species to engage in sustained periods of intense exercise in such thin air arises from a suite of adaptations involving every step of the pathway taken by oxygen molecules from inhalation until they reach mitochondria, the 'engines' within individual muscle cells.

THE LONG HAUL

A Boeing 747 flying direct from Johannesburg to Sydney burns about 160 tons of highly combustible jet fuel along the 11 000-kilometre journey. A 500-gram Bar-tailed Godwit migrating from Alaska to New Zealand travels the same distance – also nonstop – by metabolising about 200 grams of fat. The bird's flight typically lasts about eight days, during which time it is on the wing continuously.

One of the major reasons that birds can undertake such long flights involves another fundamental difference between avian and mammalian physiology. In humans, like other mammals, the fuel demands of muscle cells during intense exercise are met primarily by carbohydrates (mainly glycogen stored in muscle cells), with fat reserves elsewhere in the body contributing only approximately 10 per cent. Endurance athletes carbo-load to boost muscle glycogen stores and are all too familiar with 'hitting the wall' when these are depleted. Birds, on the other hand, are able to fuel muscle cells directly from their fat stores, their bloodstream

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RICHARD FLACK

above *Nightjars, like this Rufous-cheeked, are among the most heat-tolerant birds on the planet.*

opposite, above *Scaly-feathered Weavers cope with the brutal cold of a Kalahari midwinter night by roosting communally in insulated nests.*

opposite, below *In even the coldest places on earth, birds like this Alpine Chough are able to eke out an existence.*

continuously conveying fatty acids from fat stores to muscle cells during flight; this is how they sustain continuous flight for days on end.

For both birds and aircraft, the major limitation on how far they can travel in a single flight is the amount of fuel with which they can take off. Long-distance migrants often depart on their journey in a physiological state akin to a flying ball of fat. Bar-tailed Godwits have been recorded leaving on their epic trans-oceanic voyage with fat stores equivalent to 55 per cent of their total mass, which decreases to virtually zero by the time they arrive at their destination. In addition, the godwits minimise unnecessary weight during migration by allowing their digestive systems to atrophy when they set off, because – as memorably expressed by Theunis Piersma and Robert Gill – 'guts don't fly'. The birds then rebuild their guts after arrival so that they can resume feeding and recover.

The physiological processes that enable birds to fly such awe-inspiring distances are also potentially of great interest outside ornithology, in fields such as human nutrition and exercise. Birds, in the words of Scott McWilliams and colleagues, '… repeatedly become morbidly obese, exercise at levels that far surpass elite [human] athletes, and then cure themselves'.

SOME LIKE IT HOT

Birds inhabiting the world's hottest deserts survive and reproduce in places where air temperatures approach, and increasingly exceed, 50 degrees Celsius. Under these conditions, birds rely on evaporative cooling to avoid heat stroke and may lose upwards of five per cent of their body mass an hour through panting or other avenues. The hazards of living in such extreme environments are dramatically illustrated by occasional mass die-offs of birds during exceptional heat waves, particularly in the arid interior of Australia.

Many desert birds, including sandgrouse, nightjars and larks, nest in locations that are entirely exposed to the sun. The reason for this seemingly paradoxical behaviour seems to relate to predation risk: shady shrubs provide cooler nesting sites but are also good habitat for snakes, mongooses and an assortment of other would-be nest predators. Ground-nesting birds thus face a trade-off: endure brutal conditions and breed in exposed but largely predator-free locations or risk offspring being devoured in cooler, shaded sites. A recent University of Pretoria study of Rufous-cheeked Nightjars revealed that, when solar radiation was taken into account, the temperature experienced by a female breeding in a completely shadeless spot on red Kalahari sand averaged 51 degrees Celsius – and sometimes exceeded 55 degrees – between midday and 15h00. The remarkable heat tolerance of nightjars is made possible by their extremely efficient cooling mechanism that involves the rapid vibration of the membranes of the mouth and throat region, which are far larger in nightjars compared to most other birds. Nightjars can achieve remarkably high rates of evaporation at minimal cost in terms of energy input, whereas groups like passerines must use energy (and generate additional heat) in order to pant.

Although the nightjars' unparalleled cooling capacity enables them to keep their body temperature below lethal levels under some of the hottest conditions imaginable, it exposes them to a second risk: dehydration. Our data suggest that between sunrise and sunset on a hot summer's day, incubating females lose water equivalent to one fifth of their body mass, a level of dehydration well above that thought to be survivable for birds. However, the global heating predicted for this century will push this up to around 26 per cent of body mass, a value probably exceeding what even these unusually heat-tolerant birds can handle.

WARWICK TARBOTON

DAVID ALLAN

HOW LOW CAN YOU GO?

At first glance, most birds appear inherently ill-suited to living in very cold environments. Their body temperatures are several degrees higher than those of similarly sized mammals and consequently they require more energy to keep warm. For species that feed on insects and other animal prey, the availability of food is at its lowest in winter, just when energy requirements are at their highest. Yet even in midwinter in the high Drakensberg or the frigid depths of the northern hemisphere winter, birds remain active.

Many of the ways in which birds cope with cold involve reducing heat loss. Scaly-feathered Weavers, among the smallest avian denizens of the Kalahari, cope with night-time temperatures approaching -10 degrees Celsius by roosting in groups of up to 12 individuals packed tightly into a grass nest, often built in the middle of a blackthorn tree. The combined effect of huddling together and the insulation provided by the nest is a halving of the energy needed by each weaver in the group to stay warm through the night. A >

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White-backed Mousebirds using solar radiation to rewarm on a cold morning.

host of other species, including Acacia Pied Barbet, Rosy-faced Lovebird, waxbills and sparrows, take advantage of the insulation provided by the nests built by other species, most notably Sociable Weavers and White-browed Sparrow-weavers.

A bird's primary physiological defence against cold is the internal heating system that characterises so-called 'warm-blooded' animals. The avian capacity to keep warm while at rest primarily involves shivering, heat production through rapid, involuntary muscle movements. This provides a powerful heating system: most birds can ramp up heat production to more than five times minimal resting levels during cold exposure. Combined with the insulation provided by fluffed-up feathers, internal heat production sometimes enables barely credible feats of cold tolerance; winter-acclimatised Snowy Owls easily handle several hours at air temperatures below -60 degrees Celsius, and in one known instance, -90 degrees.

In addition to internally generated heat and behaviours that reduce heat loss, some birds have a third option. Entering a hibernation-like state and enabling body temperature to fall to nearly that of the surroundings and then warming back up to resume activity at a later stage is an extremely effective way of reducing energy costs while roosting. A short-term form of hibernation (known as torpor) occurs in many groups, including nightjars and mousebirds. Freckled Nightjars in Namaqualand let their body temperature drop to 10 degrees on dark winter nights when they cannot forage and mousebirds occasionally cool to around 15 degrees at night before rewarming the next morning. In this way, birds can greatly reduce the amount of energy they expend to get through the night.

Most groups of birds present on earth today appeared in the aftermath of the asteroid impact that wiped out the dinosaurs 66 million years ago. The adaptability of avian physiology and behaviour made possible the subsequent radiation of birds into virtually every habitat on the planet, as well as the evolution of lifestyles ranging from year-round occupancy of areas a few hectares in extent to annual migrations from pole to pole. But the capacity of birds to adapt to environmental change and novel environments is now being severely challenged by the rapid changes unleashed in the past hundred years by one species of mammal. The accelerating climate change and destruction of natural habitats currently occurring will most likely result in a significant loss of global avian diversity in coming decades and with it the physiological and behavioural adaptations of those species driven to extinction.

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