BATS

A WORLD OF SCIENCE AND MYSTERY

M. BROCK FENTON AND NANCY SIMMONS

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There are more than 1,300 species of bats—or almost a quarter of the world's mammal species. But before you shrink in fear from these furry "creatures of the night," consider the bat's fundamental role in our ecosystem. A single brown bat can eat several thousand insects in a night. Bats also pollinate and disperse the seeds for many of the plants we love, from bananas to mangoes and figs.

Bats: A World of Science and Mystery presents these fascinating nocturnal creatures in a new light. Lush, full-color photographs portray bats in flight, feeding, and mating in views that show them in exceptional detail. The photos also take the reader into the roosts of bats, from caves and mines to the tents some bats build out of leaves. A comprehensive guide to what scientists know about the world of bats, the book begins with a look at bats' origins and evolution. The book goes on to address a host of questions related to flight, diet, habitat, reproduction, and social structure: Why do some bats live alone and others in large colonies? When do bats reproduce and care for their young? How has the ability to fly—unique among mammals—influenced bats' mating behavior? A chapter on biosonar, or echolocation, takes readers through the system of high-pitched calls bats emit to navigate and catch prey. More than half of the world's bat species are either in decline or already considered endangered, and the book concludes with suggestions for what we can do to protect these species for future generations to benefit from and enjoy.

From the tiny "bumblebee bat"—the world's smallest mammal—to the Giant Golden-Crowned Flying Fox, whose wingspan exceeds five feet, Bats presents a panoramic view of one of the world's most fascinating yet least-understood species.

M. Brock Fenton is professor in and chair of the Department of Biology at the University of Western Ontario. He is the author or editor of several books, including *Bat Ecology,* also published by the University of Chicago Press. **Nancy Simmons** is curator-in-charge of the Department of Mammalogy at the American Museum of Natural History, where she is also professor in the Richard Gilder Graduate School.

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MELINDA KENNEDY
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Nancy B. Simmons
Is curator-in-charge of the Department of Mammalogy at the American Museum of Natural History, where she is also professor in the Richard Gilder Graduate School.

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It’s a Bat!

Figure 1.1.
A flying Jamaican Fruit Bat (*Artibeus jamaicensis*) showing the wrist (**w**), thumb (**t**), forearm (**fa**), elbow (**e**), ear (**ea**), knee (**k**), hind foot (**hf**), calcar (**ca**) and tragus (**tr**).

Introduction

The most distinctive features of bats are their wings and nocturnal habits. Fossils show that bats have been around for over fifty-two million years. (See Chapter 2.) If one had a time machine and could stand on the bank of an ancient stream or lake at nightfall, the flying creatures that swooped through the skies would be immediately recognizable as bats. Then, as now, bats would have appeared as quick and mysterious animals. (Figure 1.1)

People have always wondered about bats. From the time of Aesop, there have been stories suggesting that bats are otherworldly, part mammal and part bird. In some folk stories, bats are portrayed as duplicitous because they can alternate between being birds and being mammals. A recurring story recounts a ball game between birds and mammals. In one version, bats are shunned by both sides because they appear to be a mixture of the two. In another, flight allows them to score the winning point and makes them heroes, at which point they are recognized as mammals.

BOX. 1.1

Bats are Mammals

As mammals, each of us can probably think of some key features that we share with other mammals. These could include having hair or fur, giving birth to live young and feeding them with milk and having two generations of teeth (baby or milk teeth and permanent teeth). (See Chapter 7.) Bats meet all of these criteria. The basic anatomy of bats is mammalian, from skeleton to organs. Bats' hearts tend to be larger than those of other mammals of comparable size, no doubt reflecting the demands of powered flight. Bats also have some muscles lacking in other mammals, again related to their flying lifestyle. (See page xx.)

Bats are considered warm-blooded (homoeothermic) because they maintain high body temperatures when active, as do most mammals. Many bats, however, have internal thermostats that allow their body temperature to vary with ambient temperature, a specialization thought to save energy. (See Chapter 6.) This versatile approach is known as heterothermy and is a strategy that also appears in other groups of mammals, such as rodents. Bats of temperate regions especially benefit from this approach to thermoregulation.

Bats have evolved diverse dietary habits including insectivory, carnivory, frugivory, nectarivory, piscivory (fish eating) and even sanguinarivory (blood feeding). (See Chapter 5.) In this respect bats are remarkable: no other group of mammals exhibits such ecological diversity. There are no known toothless bats although a permanent evolutionary loss of teeth has occurred in some other mammals, such as anteaters. There is no evidence that bats or their immediate ancestors laid eggs. Among modern mammals, monotremes (duck-billed platypus, spiny anteater) are the only egg-layers. Bats have a placenta that facilitates exchange of nutrients and wastes between the blood of the mother and that of the fetus. Bats and all other placental mammals give birth to well-developed young. This makes placental mammals (including bats) distinct from the pouched mammals (marsupials such as opossums, kangaroos and their relatives) that bear tiny embryos that must be nurtured attached to the mother's nipple before developing sufficiently to move around alone. There is no evidence of bat-like mammals having evolved from marsupial stock.

Names of Bats

Although bats are mammals, some of the names that humans use for bats reflect the imagined dichotomy between their mammal-like and bird-like aspects. (Box 1.1) The common French name for bat is "chauve souris" or "bald mouse." In German, it is fledermaus or flying mouse. But, as Denise Tupinier pointed out in her excellent book, the French have had other names for bats, such as "souris chaude" (hot mouse), "souris volante" (flying mouse), or "pissarata" (name says it all). In Scotland, bats are sometimes known as "gaucky birds", in Norway as "flaggermaus", in Holland as "viermuis." Other names for bats refer to their nocturnal activity. For example, the Greek "nycteris" refers to night, as does the Polish "nietopyr." Names such as the English "bat" do not refer to other animals or to nocturnality, instead being a unique label for a unique animal. The word "bat" is thought to be derived from the Middle English "bakke" (early 14th century.), which is probably related to Old Swedish "natbakka", Old Danish "nathbakkæ" ("night bat") and Old Norse "leðrblaka" ("leather flapper"). It is clear that humans have almost always had special names for these mysterious flying creatures of the night.

"Common" versus "scientific" names complicate the issue of naming bats. A common name is the one by which the mythical average person knows the animal. Many will recognize the common names of animals such as birds (American Robin, Bald Eagle and Nightingale). The common names of birds are standardized and relatively consistent. This is not the case for living bats, let alone fossil ones.

Scientific names of species are Latinized binomials (two-part names) that describe the organism and its general place in the overall classification of life forms. Although scientific names of larger groups such as families are written as single words in regular fonts, e.g., "Pteropodidae" for Old World Fruit Bats, scientific names of species are always presented as paired names (binomials) in italics. So, *Myotis lucifugus* is the scientific name of what many people know as the Little Brown Myotis and others as the Little Brown Bat. Every species has one unique scientific name, but it may have several common names as in the case of *Myotis lucifugus*–or none at all, for example, *Onychonycteris finneyi*, a fossil bat. Using scientific names increases the precision of communicating about bats, but these names intimidate the non-technical reader. In this book we use common names wherever possible, but the first time we refer to a bat we also provide its scientific name for clarity. Biologists are much more familiar with scientific name, but variation in pronunciations of the Greek and Latin are still a challenge for them. Nobody has asked bats what they think about "common" versus scientific names.

Nancy Makes up Common Names

When I was finishing up writing the Chiroptera chapter for the reference book Mammal Species of the World in 2004, I found myself facing an odd problem. The editors of the book wanted to include common names for every species—yet I found that more than fifty species of bats didn't have common names. They had been described properly in the literature with unique binomial scientific names, e.g., *Myotis lucifugus*, but nobody had ever used common names for them as far as I could tell. What to do? With the permission of the editors, I simply made up names for them! Most often I coined the common name for a bat using a variant of its scientific name, e.g., *Micronycteris brosseti* became "Brosset's Big-eared Bat", after the name of the scientist who originally described it. In other cases, the geographic range of the species helped to provide a common name, e.g., *Leptonycteris curasoae* became the "Curaçoan Long-nosed Bat." It was tempting to make up silly names in some cases—I really wanted to designate a species as the "Common Baseball Bat" just for fun—but I managed to resist the temptation. I have always rather regretted that!

Table 1. The diversity and distribution of modern bats. There are twenty families and >1300 species of living bats recognized today, and about ten new species are described every year. "Laryngeal" under Echolocation means that the sounds used for echolocation are produced in the larynx (voice box).

Common Name	Scientific Name	# of Species	Echolocation	Diet	Distribution
Old World Fruit Bats	*Pteropodidae*	198	absent or tongue clicks	fruit, flowers, leaves	Africa, Asia, Australia, Pacific Islands
Mouse-tailed Bats	*Rhinopomatidae*	6	laryngeal	insects	Africa, southern Asia
Bumblebee Bats	*Crasoncyteridae*	1	laryngeal	insects	Southeast Asia
Horseshoe Bats	*Rhinolophidae*	93	laryngeal	insects	Eurasia, Africa, Southeast Asia, Australia
Old World Leaf-nosed Bats	*Hipposideridae*	9	laryngeal	insects	Africa, Southeast Asia, Australia
False Vampire Bats	*Megadermatidae*	5	laryngeal	insects, small animals	Africa, Southeast Asia, Australia
Slit-faced Bats	*Nycteridae*	16	laryngeal	insects, small animals	Africa, Southeast Asia
Sheath-tailed Bats	*Emballonuridae*	54	laryngeal	insects	Pantropical: Africa, Southeast Asia, Australia, Tropical Americas
New World Leaf-nosed Bats	*Phyllostomidae*	201	laryngeal	fruit, flowers leaves, insects small animals, blood	Tropical Americas, Caribbean Islands
Mustached Bats	*Mormoopidae*	10	laryngeal	insects	Tropical Americas, Caribbean Islands
Bulldog Bats	*Noctilionidae*	2	laryngeal	insects, fish	Tropical Americas, Caribbean Islands
Smoky Smoky Bats	*Furipteridae*	2	laryngeal	insects	Tropical Americas
New World Disk-winged Bats	*Thyropteridae*	5	laryngeal	insects	Tropical Americas
Old World Disk-winged Bats	*Myzopodidae*	2	laryngeal	insects	Madagascar
New Zealand Short-tailed Bats	*Mystacinidae*	2	laryngeal	insects, fruit, flowers	New Zealand
Funnel-eared Bats	*Natalidae*	12	laryngeal	insects	Tropical Americas
Free-tailed Bats	*Molossidae*	113	laryngeal	insects	Eurasia, Africa, Asia, Australia, Americas
Bent-winged Bats	*Miniopteridae*	29	laryngeal	insects	Eurasia, Africa, Asia, Australia
Wing-gland Bats	*Cistugidae*	2	laryngeal	insects	Southern Africa
Vesper Bats	*Vespertilionidae*	451	laryngeal	insects, fish	Worldwide except Arctic & Antarctica

A

B

C

Figure 1.2.
The hand wing of bats. In A the wings of a flying Egyptian Rousette Bat clearly show the basic hand structure which also is obvious in B, the skeletal structure of the hand wing. A CT scan of the skeleton of a Yellow-winged Bat (C) illustrate how wings are the most prominent features of bat skeletons. (See also Figures 2.1, and 2.2.) CT scan (C) courtesy Tim Rowe.

Bats constitute the order Chiroptera, from the Greek *cheiro* meaning hand, and *ptera* meaning wing. (Figure 1.2) They are the second largest group of mammals after rodents, representing about 20 percent of all classified mammal species worldwide. The >1300 species of living bats are arranged in twenty families based on their morphology, DNA and evolutionary history. Each family of bats has a scientific and at least one common name as shown in Table 1. Bats are currently classified in two suborders, the *Yinpterochiroptera* (yinpterochiropterans) and the *Yangochiroptera* (yangochiropterans). In the past scientists divided bats differently, recognizing groups called *Megachiroptera* (megabats = Old World Fruit Bats) and *Microchiroptera* (microbats = echolocating bats). These terms are no longer in use because evolutionary studies of DNA have shown that some "microbats" are actually more closely related to Old World Fruit bats than they are to other echolocating bats. Also, these terms were always misleading in the first place because some "megabats" are quite small, e.g., Long-tongued Fruit Bats (*Macroglossus minimus*) have a wingspan of 15 centimeters (cm.) and weigh only 12 to 18 grams (10 grams = 0.35274 ounces), while some "microbats" are quite large, e.g., Spectral Bats (*Vampyrum spectrum*) can have wing spans of about 1 meter (m.) and weigh nearly 200 grams (g.). Also, at least two "megabats" echolocate using tongue clicks—the Egyptian Rousette (*Rousettus aegyptiacus*) and Geoffroy's Rousette (*Rousettus amplexicaudatus*) —making the distinctions even more confusing. Regardless, most scientists now use tongue-twisting names Yinpterochirotpera and Yangochiroptera—derived from "yin" and "yang" in Chinese philosophy—todescribe the two main groups of bats. The geographic range of families of bats in each group is shown in Table 1.

Map to a Bat

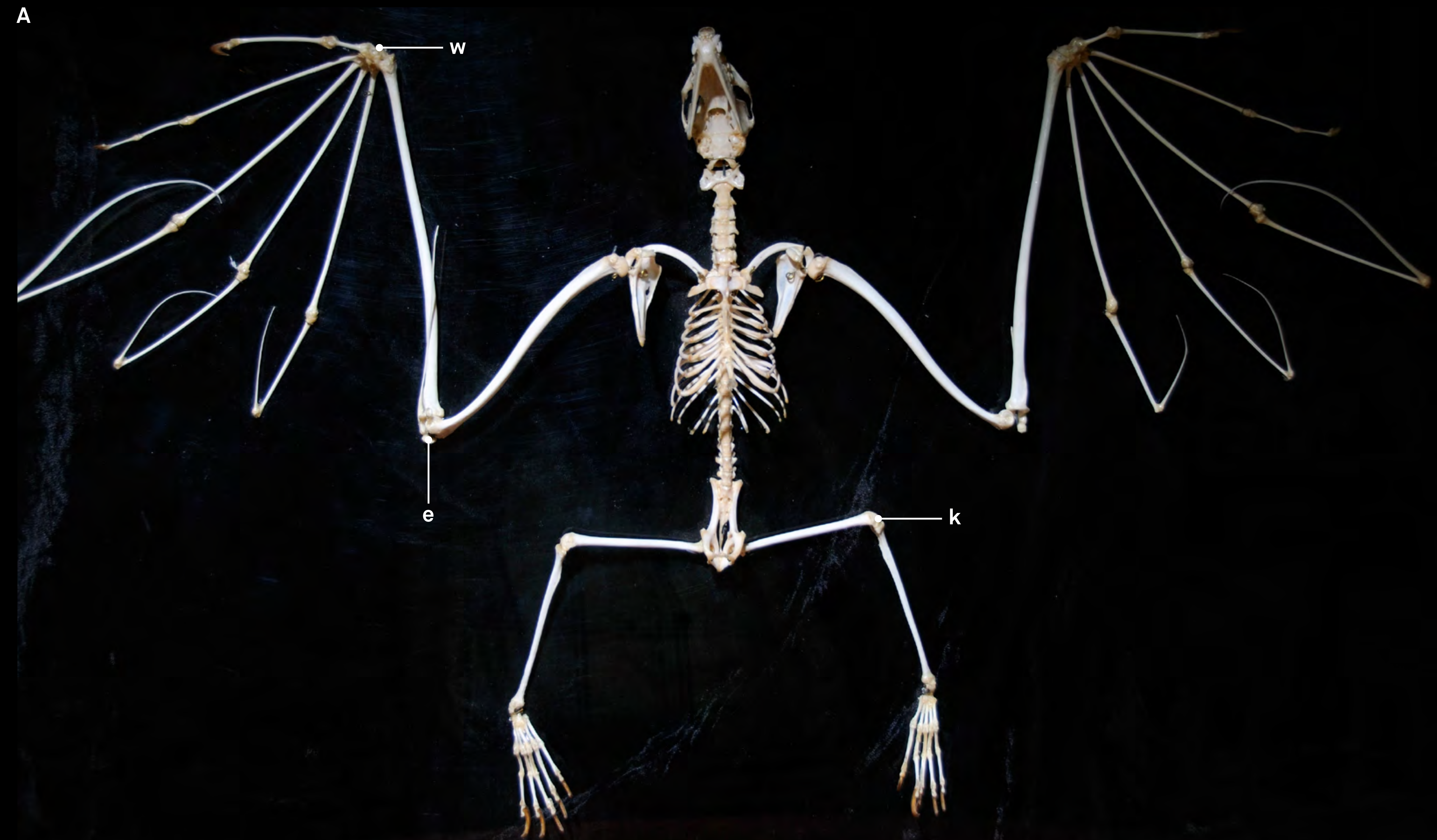
Many of a bat's distinctive features are obvious when the animal is flying (Figures 1.1 and 1.2), but when a bat is roosting, other features become more obvious. (Figure 1.3) We have labeled some of the relatively consistent features in these figures to make them easier to interpret. All bats have two wings with flight membranes (called patagia, singular = patagium), as well as two hind legs with feet. Some bats have a membrane between the legs (uropatagium or interfemoral membrane) but others do not. Bats often have calcars, cartilaginous or bony projections from the ankle towards the tail, which allow control of the shape and stretch of the interfemoral membrane. (Figure 1.3) Tail length varies considerably in bats, spanning the whole range seen in other mammals—from very long to nonexistent.

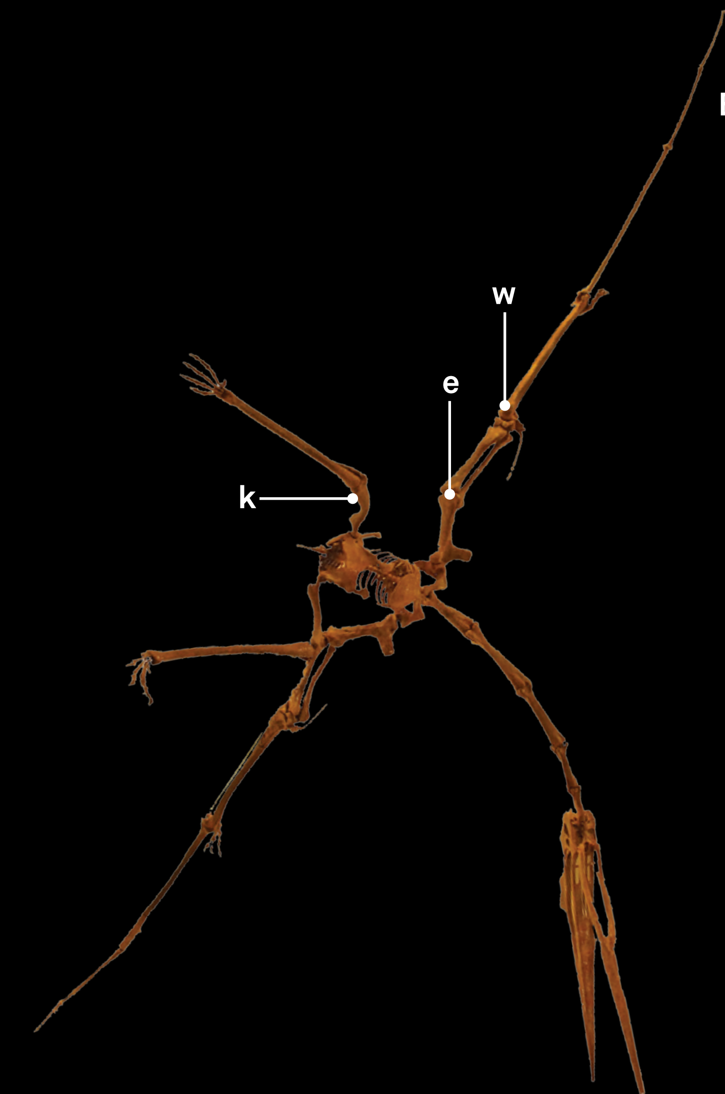
Figure 1.3.
Three roosting bats with wings that are fully folded (A, C), or partly folded (B). The Lesser Mouse-tailed Bat (*Rhinopoma hardwickei*) shown in (A) has an obvious and distinct tail; its feet and thumbs are also clearly visible. (B) The Lesser Short-nosed Fruit Bat (*Cynopterus brachyotis*) partly envelops its body with its wings. Its feet are obvious. (C) The Honduran Ghost Bat (*Ectophylla alba*) hangs by one foot.

Similar Yet Different: Bats Compared to Birds and Pterosaurs

The wing skeletons of bats and those of other flying vertebrates—birds and pterosaurs—are very different from one another although they originated evolutionarily from the same basic set of arm bones common to all terrestrial vertebrates. (Figure 1.5) Ancestrally, the arm skeleton of bird, bat and pterosaur precursors contained the same set of bones that humans have: a single upper arm bone (humerus), a pair of forearm bones (radius and ulna), a group of small bones comprising the wrist (carpals), five hand bones (metacarpals) and five digits each consisting of two to three finger bones (phalanges). The arm and hand skeleton of each flying group evolved to include elongation of different parts of the arm and hand and fusion of different bones to support a wing membrane or airfoil. Note the differences in the positions of elbows and wrists between bats and pterosaurs. The humeri (upper arm bones) of pterosaurs and birds are proportionally much shorter than those of bats. In bats the wing membrane is supported by elongated arm bones (especially those of the forearm) and elongate hand and finger bones in four digits; only the thumb in bats remains relatively small. Pterosaurs, by comparison, had flight membranes supported by a single elongated hand and finger bone.

Figure 1.4.
Tails of bats. (A) Little Yellow-shouldered Fruit Bat (*Sturnira lilium*), a tailless species, (B) long tailed Elegant Myotis (*Myotis elegans*), (C) Sowell's Short-tailed Fruit Bat (*Carollia sowellii*) and (D) Brazilian Free-tailed Bat (*Tadarida brasiliensis*). Arrows point to tails (**t**) and calcars (**ca**). Note the tail in Figure 1.3A.





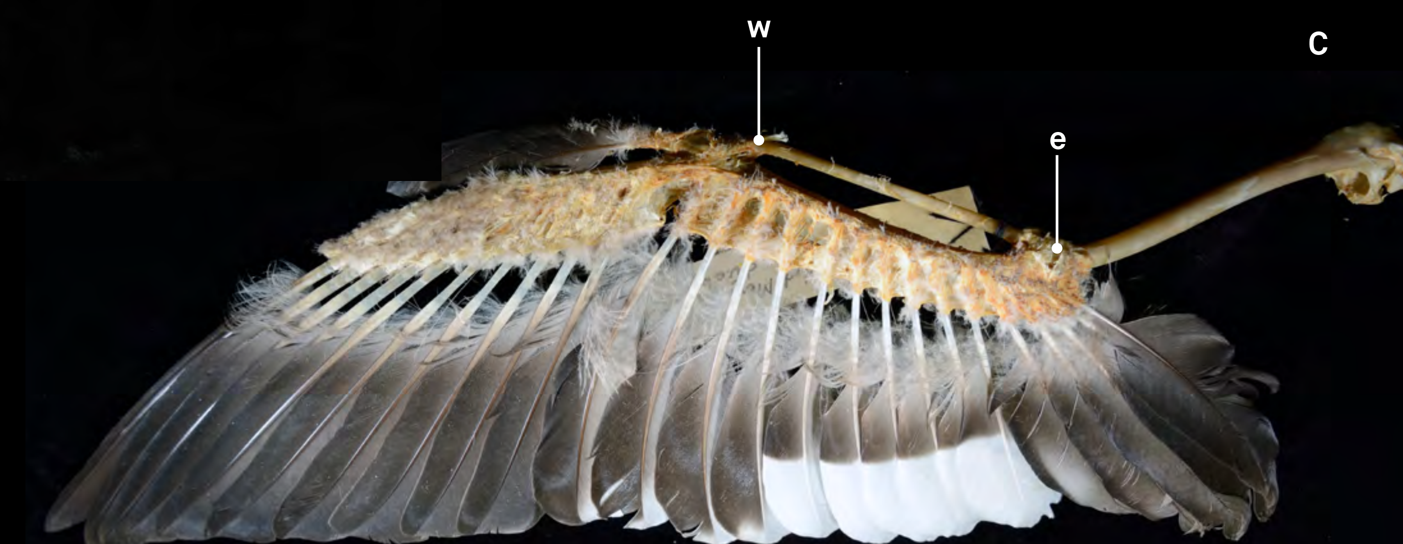


Figure 1.5.
A comparison of (A) the skeleton of a Flying Fox and (B) a reconstruction of the skeleton of a pterosaur, *Quetzalcoatlus northropi*, as well as (C) the wing bones of a bird. The prominent wings of bats and pterosaurs are clear. Arrows show elbows (**e**), wrists (**w**) and knees (**k**). The bird's bones show the points of anchorage of flight feathers.

Pterosaurs may have had wing membranes made of skin like those of bats, but exceptionally well-preserved fossils of pterosaurs from China and elsewhere show that pterosaur wing membranes were filled with parallel fibers arranged perpendicular to the bone of the wing digit. Bat wings have many elastic strips and muscles in their wing membranes, but only some of them are arranged perpendicular to the arm or finger bones. (Figure 1.6)

The precise structure and function of the fibers in pterosaur wings remain a mystery, but doubtless these structures were important for wing function during flight. In birds, feathers comprise the flight surface and the bones of the wrist and hand have become fused to provide a robust attachment site for flight feathers. The fact that three different vertebrate groups achieved powered flight using modified forearms to produce an airfoil (the shape of the wing seen cross-section)—but did so in entirely different ways—is an excellent example of convergent evolution. (See Chapter 3.)

There are other striking differences between bats and birds in addition to their wing structure. In birds that fly, the breastbone (sternum) has a conspicuous keel, while bats typically have only a small keel that is often limited to very anterior end of the breastbone. (Figure 1.7) Birds have a wishbone (furculum) composed of fused collar bones (clavicles), whereas the clavicles in bats remain separate. Special flanges called uncinate processes produce overlap between the ribs of birds and reptiles, but these are not present in bats (or other mammals). The diaphragm and movements of the ribs are important during breathing in mammals. The absence of uncinate processes is correlated with a more flexible chest skeleton in mammals. The lungs of birds are open at either end, allowing air to flow through and resulting in more efficient breathing and cooling. Bat lungs, like our own, are dead-end sacs that cannot be as effectively ventilated as bird lungs. But the blood-gas barrier in the lungs of bats is thinner than that of other mammals, the alveoli are smaller and the lungs proportionally larger than those of mammals that do not fly. Finally, modern birds lack teeth and lay eggs, but all known species of bats have teeth and bear live young.

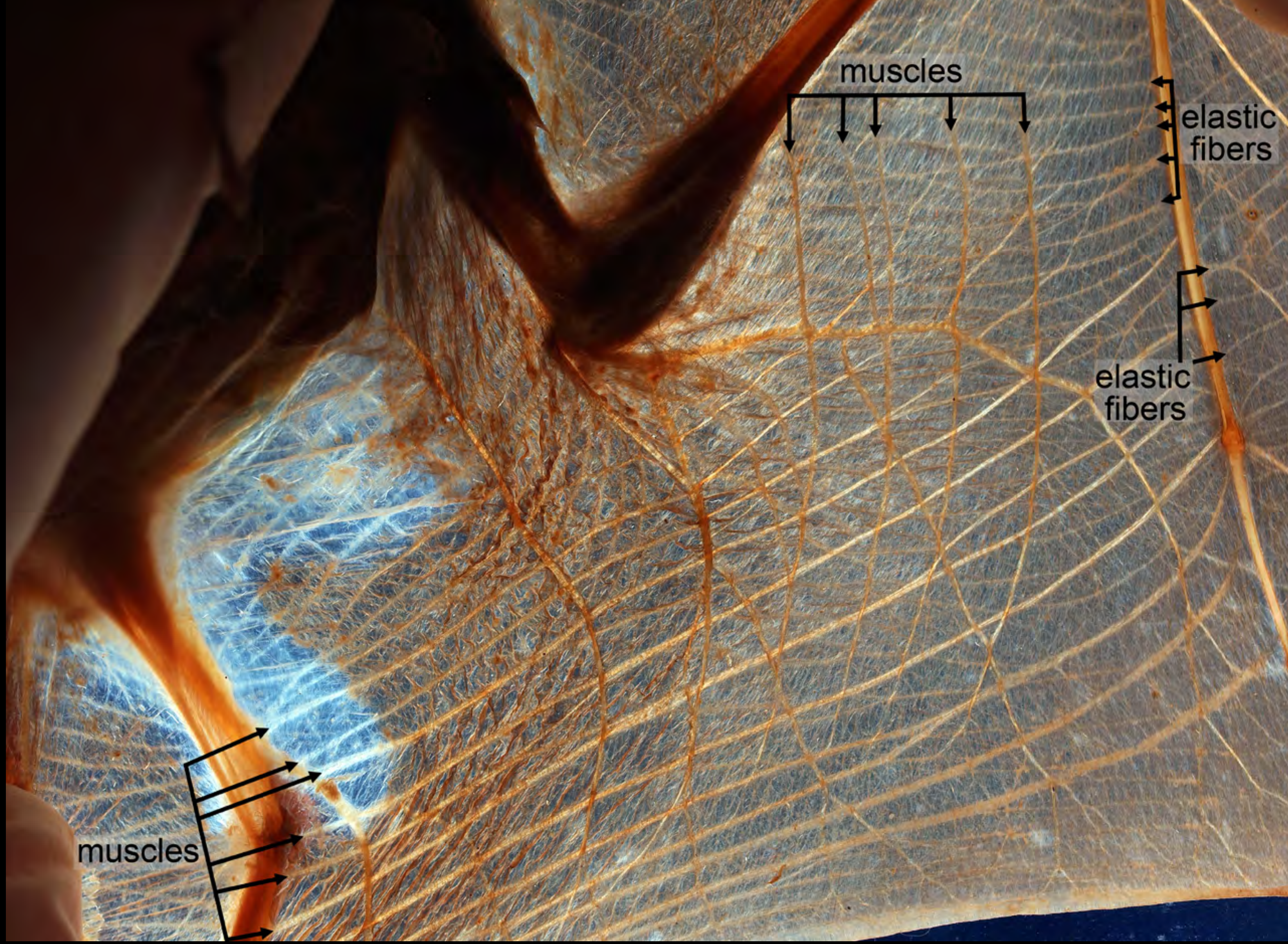
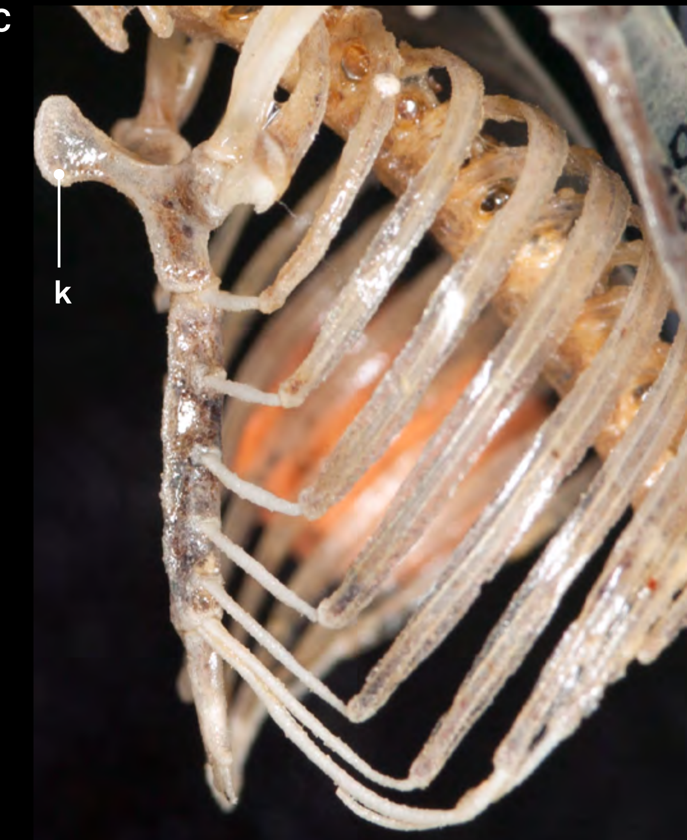


Figure 1.6.
Taken under polarized light, this photograph of the armwing of a Lesser False Vampire Bat (*Megaderma spasma*) shows both elastin and muscle in the bundles running perpendicular to the bat's bones. Photograph by Jorn Cheney, courtesy Sharon Swartz.

Figure 1.7.
A comparison of the breastbones and rib cages of (A) a bird—Eastern Whip-poor-will (*Antrostomus vociferus*)—and two bats (B) Large Slit Faced Bat (*Nycteris grandis*) and (C) Madagascar Sucker-footed Bat (*Myzopoda aurita*). Note the prominent keel (**k**) on the bird's breastbone (in A), compared to the arrangement of much smaller keels on the breastbones of the bats (**k** in B and in C). In *Myzopoda* there is a single keel at the very top of the breastbone (C), while there are two keels (**k**) in *Nycteris* (B), the anterior most has two projections (two arrows), the posterior one, a single projection. In A, the **u** is an uncinate process, features missing from the bats. (See page xx.)

A

C



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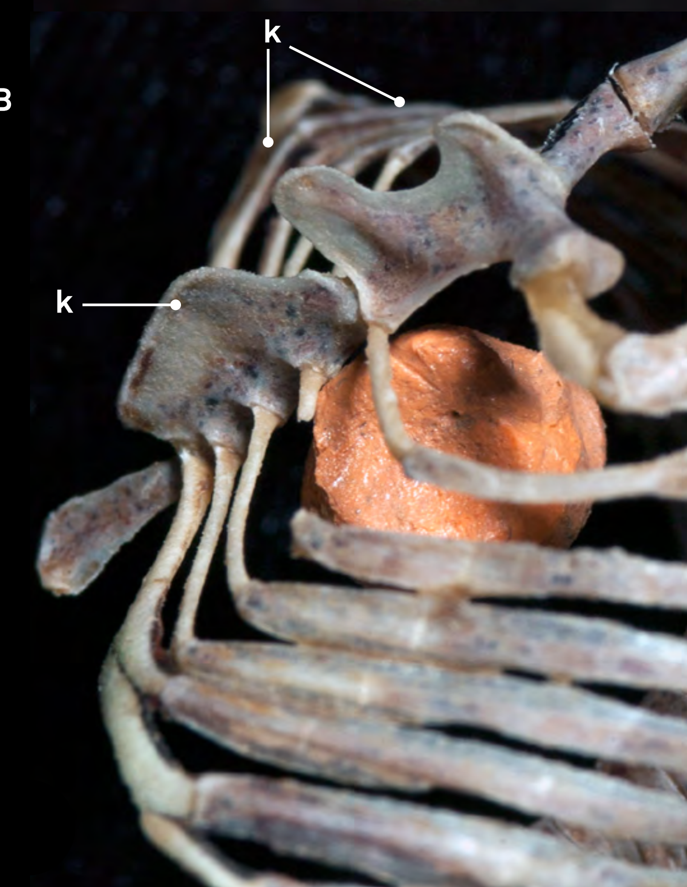
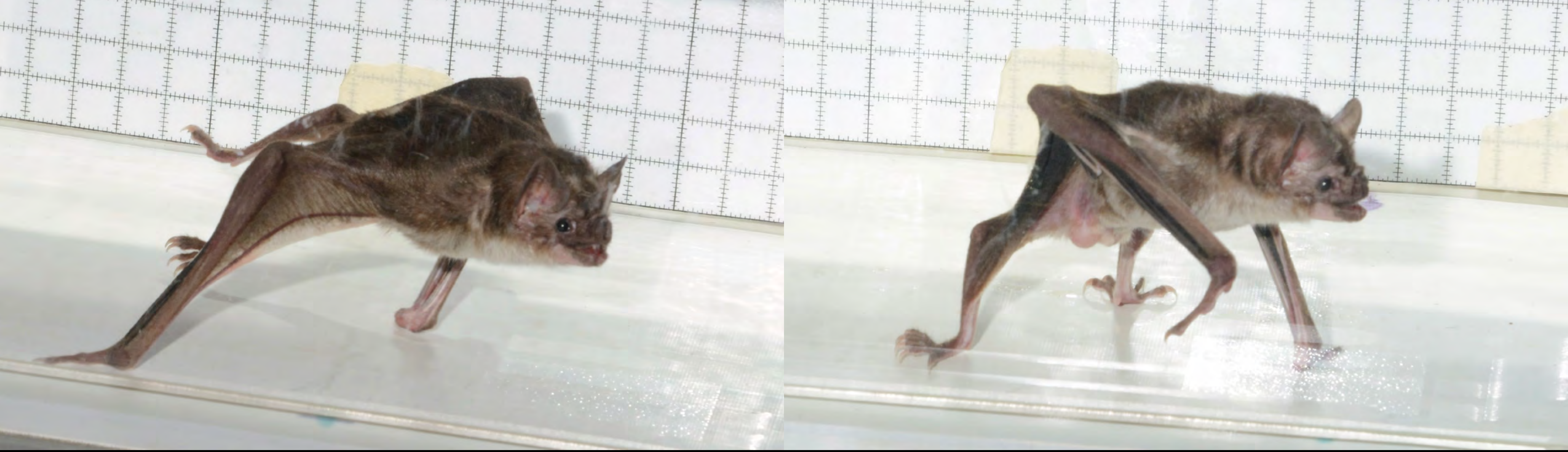


Why should living birds lack teeth and lay eggs? Egg-laying in birds is not a specialization for flight—it is a form of reproduction inherited from ancestral reptiles. Pterosaurs also laid eggs. Egg-laying is a primitive trait also seen in a few mammals (the platypus lays eggs). Most mammals give birth to live young, and this form of reproduction evolved early in the mammalian radiation. Paleontologists have identified fossils from the Early Cretaceous (125–130 million years ago) as members of the large evolutionary group of mammals that today bear live young. Within this group, the placenta, another specialization evolved by roughly the end of the Cretaceous (~66 million years ago). The placenta allows animals to retain a fetus inside the womb until it has grown quite large. Bats inherited a placenta and live birth from such non-flying mammal ancestors. For flying animals, carrying either a large egg internally (prior to laying it) or a fetus can impose energy costs due to the additional body weight that must be supported during flight. Although it only affects females, clearly females must survive for a species to continue! Weight constraints imposed by reproduction are something that all lineages of flying animals have had to overcome to be successful.

Teeth are clearly useful for obtaining, handling and chewing food and very important in most vertebrate groups. (See Chapter 5.) Teeth, however, are made of dense materials (enamel and dentine) and are amongst the heaviest structures in the bodies of small vertebrates. Because weight matters during flight, at least some lineages of flying animals—including all modern birds and some groups of pterosaurs—lost their teeth (in an evolutionary sense) after achieving flight. Instead, birds and most pterosaurs have (or had) keratinous beaks, which are lighter. Bats, however, retained a typical mammalian dentition that has been modified in different groups to facilitate processing of different foods. (See Chapter 5.) Teeth are smaller and sometimes fewer in bats that do not need to chew their food, e.g., vampire bats and nectar-feeding bats. This may be due at least in part to the energy savings accrued by reducing the body weight of the animal.

The hind legs of bats also differ from those of birds and pterosaurs. Birds and pterosaurs are bipedal animals with long bones of their hind legs robust enough to bear the weight of a walking or running animal. In contrast, the long bones of the hind legs of most bats are slender and delicate, suitable for supporting a hanging animal but not for bipedal locomotion. Furthermore, the hip and limb structure of bats has been modified so that the hind legs are rotated relative to the pelvis such that the sole of the foot to face forward rather than backwards and downward as in most other animals. In birds, pterosaurs and other mammals the sole of the foot faces down. This difference is clearly reflected in the direction of flexion of knee joints and the position of a bat's feet. (Figure 1.8)

Figure 1.8.
This photograph of a flying Little Brown Myotis shows the position of the knee (arrow) as well as the hind foot. The hind limbs of bats are rotated so that the sole of the foot faces forward—in most other mammals, including humans, the sole of the foot faces backwards.



In birds that fly, two pairs of muscles largely power flight—a set of "elevator" muscles that raise the wings and a set of "depressor" muscles that bring them down. Both pairs of muscles are located on the surface of the chest (these comprise the white meat on a chicken). In contrast, in bats there are nine pairs of muscles involved in powering flight. The elevator muscles are located on the back, and the depressor muscles are on the chest. This difference probably explains why, compared to birds, bats are much thinner in profile through the chest—the flight musculature of bats requires broad areas for attachment to the ribcage, both back and front. The thin profile of the chest may have an added benefit in that it allows bats to squeeze into crevices and through small openings, giving them access to roosts inaccessible to many predators. (See Chapter 6.)

There are flightless species of birds and insects, but no known species of bats or pterosaurs is/were flightless. Flightlessness in birds and insects has often evolved on remote islands where there are few predators; the benefits of flight (in terms of providing access to resources and allowing long-distance movements) are reduced and there are additional dangers to flight, e.g., individuals that fly high may be trapped by wind currents and blown away. But even bats living on remote oceanic islands in the South Pacific have retained their ability to fly. Nobody knows why this is the case. Although the structure of the forelimbs makes it difficult for most bats to walk effectively, strong walking and running behavior has evolved in some bats, e.g,, Common Vampire Bats (*Desmodus rotundus*). (Figure 1.9)

Brock Answers a Question

I'm often asked: "What is your favorite bat?" The problem with answering this is that, like many other bat biologists, I tend to be fickle. Today's favorite is tomorrow's also-ran. Working in the Yucatan Peninsula of Mexico in 1991, I was keen to meet some of the very neat bats that occur there. High on my list were Large-eared Woolly Bats (*Chrotopterus auritus*), Wrinkle-faced Bats (*Centurio senex*) and Tomes's Sword-nosed Bat (*Lonchorhina aurita*). On the third night, I was beside myself when a Wrinkle-faced Bat flew into the mist net. While I was busy with that bat, a Large-eared Woolly Bat flew into the net almost beside me. Within five minutes I also caught a Tomes's Sword-nosed Bat and my colleagues were kidding me about changing the battery in my pacemaker. By 9:00 pm that night, my three favorite bats were all in hand. By midnight, three other species I had not seen before were caught in the nets. So that night I had six favorite species.

Figure 1.9.
Two views of a Common Vampire Bat (A and B) on a treadmill illustrate the difference between the bat's running gait (A) and stance (B). When running, the bat reaches forward with its wrists and thumbs, swings its hind legs forward, plants them and repeats the process. Note that in B the bat is panting.

Figure 1.10.
A sample of faces and noses of bats. Included are (A) a Lesser Mouse-tailed Bat, (B) a Yellow-winged Bat (*Lavia frons*), (C) a Geoffroy's Horseshoe Bat (*Rhinolophus cliveosus*), (D) a Trident Leaf-nosed Bat (*Asellia tridens*), (E) a Bumblebee Bat (*Craseonycteris thonglongyai*) and (F) a Lesser Long-eared Bat (*Nyctophilus geoffroyi*), representing Mouse-tailed Bats (Rhinopomatidae), False Vampire Bats (Megadermatidae), Horseshoe Bats (Rhinolophidae), Old World Leaf-nosed Bats (Hipposideridae), Bumblebee Bats (Craseonycteridae) and Vesper Bats (Vespertilionidae), respectively. Photographs by Brock Fenton, Robert Barclay (B) and Sebastien Puechmaille (C).

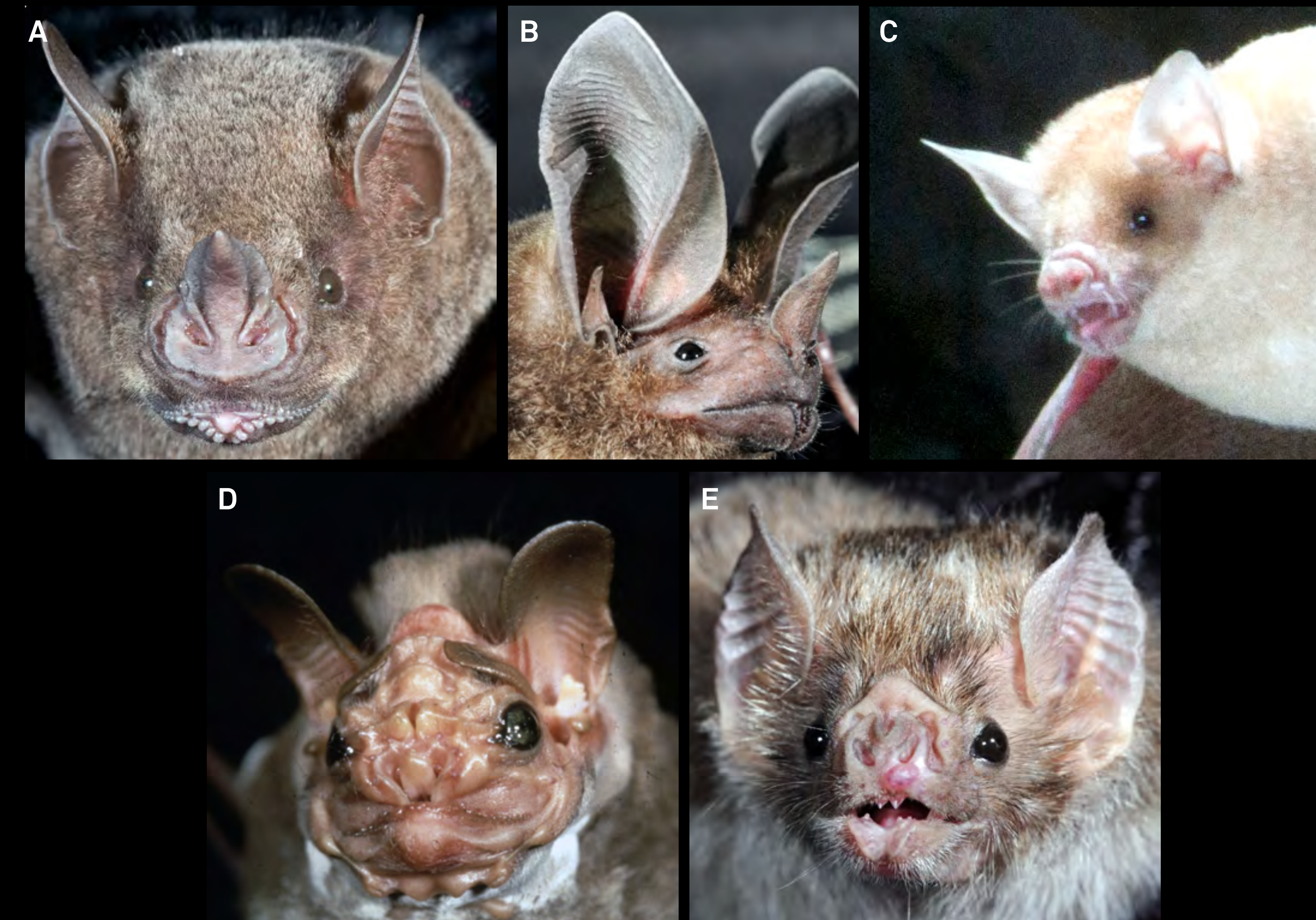


Figure 1.11.
A sampling of noseleaves and ears in New World Leaf-nosed Bats (Phyllostomidae), including (A) a Jamaican Fruit Bat, (B) a Davis' Round-eared Bat (*Tonatia evotis*), (C) a Cuban Flower Bat (*Phyllonycteris poeyi*), (D) a Wrinkle-faced Bat and (E) a Common Vampire Bat.

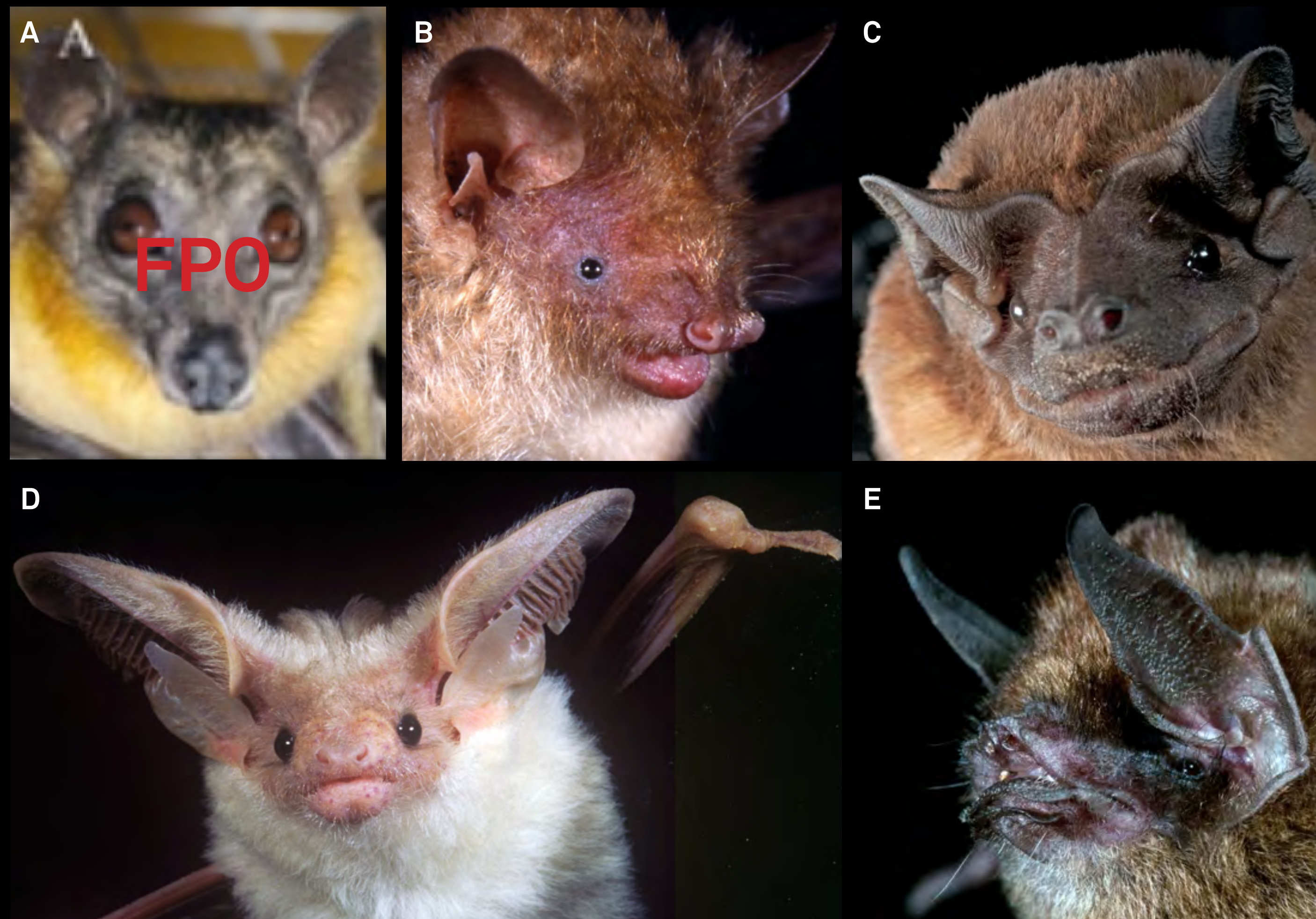


Figure 1.12.
Variations in the faces of bats, including (A) a Straw-colored Fruit Bat (*Eidolon helvum*), (B) a Greater Tube-nosed Bat (*Murina leucogaster*), (C) a Pallas' Mastif Bat (*Molossus molossus*), (D) a Hemprich's Big-eared Bat (*Otonycteris hemprichii*) and (E) a MacLeay's Moustached Bat (*Pteronotus macleayi*). Note variations in ears (A–E) and tragi (C, D and E).

Bats of several families have evolved noseleaves—fleshy projections from the snout around and above the nostrils. (Figures 1.10 and 1.11) Along with noseleaves, ears and related structures such as tragi (singular tragus), an extra spike of cartilage sticking up from the base of each ear, appear to be involved in echolocation. (Figures 1.10 and 1.11 and see Chapter 4.) While noseleaves are involved in sound transmission, ears and tragi play a central role in sound reception. Flaps of skin around the mouth probably direct sounds away from the bat. (Figure 1.6E) Many but not all bat species have a tragus. (Figure 1.12) The tragus is absent in Old World Fruit Bats, Horseshoe Bats and Old World Leaf-nosed Bats. It is large and well developed in False Vampire Bats, Sheath-tailed Bats (Emballonuridae), Mouse-tailed Bats and Vesper Bats. The tragus is small in Slit-faced Bats (Nycteridae) and Free-tailed Bats (Molossidae). Other parts of the ear may serve the function of the tragus in echolocation. (See page xx.)

The Diversity of Bats

Most areas of the world support many species of bats, each of which has a slightly different anatomy and lifestyle. Most bat species occur in tropical and subtropical regions, meaning that countries closer to the equator tend to have more species of bats than countries in northern (or southern) temperate regions. Boasting ~180 species (~ = approximately), Colombia has the richest bat fauna (number of distinct species) of any country in the world. This reflects its position astride both the equator and the Andes Mountains. Colombia's equatorial tropical forests, Atlantic and Pacific drainages and desert-like north provide a rich range of climate and environmental conditions for bats.

Bat faunas in the tropics include species with a greater range of diets (fruit, flowers, animals) than bat species in temperate areas (which eat mainly insects). In temperate regions there are also fewer species of bats, for example sixteen species in the United Kingdom, nineteen in Canada and forty-five in the United States. The frigid Atlantic Labrador Current flowing down from the Arctic Ocean passes along the coast of Newfoundland, which has only two species of bats, compared to sixteen in the United Kingdom where the path of the warm Gulf Stream across the Atlantic produces a milder climate. More species of bats live along the west coast of North America than along the east coast.

Perhaps surprisingly, some tropical islands have relatively small bat faunas. There is one living bat species in Hawaii and four on the Galapagos Islands. Even large islands in the West Indies (Cuba, Hispaniola, Jamaica, Puerto Rico) each have modest bat faunas of about twenty-five species, about the same as the twenty-six species that occur on the 6,852 islands that make up the Japanese archipelago.

There is a general pattern to the distribution of families of bats. (Table 1.1) Note that while Old World Disk-winged Bats (Myzopodidae) and New Zealand Short-tailed Bats (Mystacinidae) have a very restricted distribution, Vesper Bats are widespread. Other families, e.g., Horseshoe Bats, Old World Leaf-nosed Bats and False Vampire Bats, occur in the Old World (Eurasia, Africa, Southeast Asia), while others, e.g., Bulldog Bats (Noctilionidae), Mustached Bats (Mormoopidae), New World Leaf-nose Bats, Funnel-eared Bats (Natalidae), Smoky Bats (Furipteridae) and New World Disk-winged Bats (Thyropteridae), occur only in the Western Hemisphere (the Americas).

Although there are a few records of bats from the Arctic, e.g., Southampton Island in the Hudson Bay, there are none from the Antarctic. Mind you, it is only a matter of time before fossil bats are found in both areas, reflecting changes in the distributions of bats that in turn reflect changes in prevailing climates. Over geologic time, climate change has often been brought about by shifts in the positions of the continents relative to each other. We expect that fossil bats may someday be found in Antarctica, which was originally part of Gondwanaland—a continent that included South America, Africa, India and Australia. Gondwanaland began to break apart well before bats evolved, but Antarctica remained connected to South America until the Oligocene (~30 million years ago). During the first twenty million years of bat evolution, parts of Antarctica probably had a much more hospitable climate than today. In Scandinavia, bats occur well north of the Arctic Circle (60o N), surviving and perhaps thriving under the midnight sun. Areas north of the treeline may provide few roost opportunities for bats, perhaps explaining the lack of bats in treeless tundras.

Figure 1.13.
Removing a Little Brown Myotis from a mist net. The fine mesh is obvious against the white wall background.

Figure 1.14.
Nancy Simmons and Deanna Byrnes at a harp trap. Deanna holds a bat, while Nancy records data about its species, gender and age. The vertical monofilament lines are obvious. Set in a bat flyway, bats colliding with the lines slide down them into the bag below. Stand alone harp traps were developed by Bat Conservation International founder Merlin Tuttle and revolutionized the business of catching bats. To many bat biologists they are Tuttle Traps.

How Brock Was Hooked on Bats

At about age six years, I met my first bat at a family cottage north of Toronto in Canada. It was August and the owners of the neighboring cottage were painting its exterior. The Little Brown Myotis that roosted behind the shutters were displaced and one of them ended up in our cottage. After flying about for a while, it landed on the stone mantelpiece.

I decided to catch the bat, but did not realize it was hanging upside down as bats routinely do. So grabbing it low was a mistake—I practically put my fingers into its mouth. I was bitten and immediately released the bat, which took off and continued to fly around the cottage. The amusing part of this was that the only room in the cottage with a low ceiling was the bathroom. So while I watched the bat, my mother and sister took refuge there. These dramatic events, at least to my six-year old eyes, sparked my ongoing curiosity about bats.

Eleven years later, when I was in my second year at Queen's University in Toronto, I had the opportunity to accompany Roland Beschel, whose wide-ranging scientific interests made him an ideal mentor, on a search for hibernating bats. This meant exploring local caves and looking for bats that had been banded in the summer somewhere else. I found bats, but to my disappointment any that were banded had been tagged in the cave where I found them.

At first I was torn between the lure of bats and the lure of caves, but before long the bats won out. How far do bats travel between their summer and winter quarters? How do insects protect themselves against marauding bats? Why are there eight species of bats in Ontario, rather than just one, or twenty?

In the years since then, bats have never disappointed me. They repeatedly challenge me and force me to recognize that what I had thought to be true about them is wrong, or more complicated. In short, the unanswered questions about bats drew me into science and they continue to hold me there. Bats really are the gift that keeps on giving.

Nancy Meets Her First Bats

As a postdoctoral researcher at the American Museum of Natural History, I began working on bat anatomy in 1989. My goal was to develop a better understanding of the evolutionary origins of bats and their amazing specializations for flight and echolocation. The research was fascinating, but it involved only museum specimens—skeletons and dried skins of bats collected by bat researchers in the past, sometimes over a hundred years ago. I had never held a live bat in my hands when I began working on bat evolution. But that all changed in 1991 when my husband and I started a faunal inventory project at Paracou, a forestry research station in French Guiana.

The goal was deceptively simple: document all the mammals that lived in one patch of rainforest. My husband, an expert on rodents and marsupials, would handle those parts of the fauna as well as the other larger mammals; the bats were my job. I researched everything I could find about capturing bats, bought mist nets (imagine giant volleyball nets made of nylon thread) and poured over books and papers about how to identify Neotropical bats. I bought field equipment and plane tickets, and off we went to spend two months in the rainforest.

My first night of netting bats was a comedy of errors. I didn't know how to cut poles for the nets, and I had no idea how tangled a mist net could become if you dropped it. (Figure 1.13) But I learned quickly, and immediately became hooked on the mystery and excitement of catching bats. I put up a series of mist nets along a trail and waited for the bats to arrive. Seeing that first small, struggling form in the net was a thrill I'll never forget. Carefully grasping the bat in one hand while using the other to untangle the threads, I was unprepared for how beautiful and beguiling a live bat could be. Warm and wiggling, with soft and flexible wings, and its tiny heart beating a mile a minute! And the diversity in that small patch of rainforest was completely unexpected (at least to me). So many species—all different—and I loved the challenge of trying to figure out the identity of each bat we caught. If I hadn't been totally hooked on bats before then, I was after that first field trip, and have spent my life ever since studying these endlessly intriguing animals. Recently I have started using harp traps which capture bats without entangling them, and which therefore can be left open all night. (Figure 1.14) I always feel a thrill of anticipation when I walk out to check a harp trap, wondering what new bats I may find in it. It's rather like Christmas morning with the undiscovered bats being like unopened presents!