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CHAPTER 1

Appreciating and Studying Birds

Irby J. Lovette and Jennifer Walsh
Cornell Lab of Ornithology

Chapter Contents

1.1 Avian form and function
1.2 Observing birds in the field
1.3 Birding techniques and tools
1.4 Museum collections and specimens
1.5 Ornithological research techniques

Birds have a special place in human science and culture: they capture our hearts, arouse our curiosity, and inspire a sense of wonder. We revel in the diversity and beauty of their forms, and birds also spark the curiosity that drives us toward deeper scientific inquiry into their varied ways of life. Every student of ornithology—from recreational birders to career scientists—will find much to learn and appreciate in the extraordinary physical and behavioral adaptations of birds, their rich evolutionary history, and their commanding global presence.

One of the wonderful aspects of enjoying birds is that they are found everywhere (**Figure 1.01**). Their capacity to live in almost every environment is truly remarkable: birds occupy windswept arctic tundra and harsh antarctic ice, fog-shrouded mountaintops and tropical rainforest understories, the world's driest deserts and storm-swept high seas. They live among us in the most urbanized cities, in suburban backyards, and in the most remote wildernesses. Wherever we travel, birds are our constant companions, and by discovering more about the birds we find around us, we can come to understand many other aspects of the natural world and our relationship to it.

Birds are endlessly fascinating in part because they are so diverse. Birds make use of their myriad habitats with a bewildering array of foraging strategies, while performing important ecological functions. Many birds capture and consume other animals, from tiny insects to large vertebrates, sometimes including other birds. Some birds hunt by night, and a few even navigate using echolocation. Others hunt high in the sky with exceptionally keen vision, diving down with remarkable speed and agility at a moment's notice; many are equally skilled in detecting insects on leaves, or worms in the soil. Still others specialize in scavenging, thus speeding up the process of decomposition. Many birds eat nectar, seeds, or fruits, sometimes aiding in plant reproduction by serving as pollinators and seed dispersers.

The breeding strategies of birds are just as varied as their ecological roles. Many engage in displays with complex choreography as a precursor to mating, often accompanied by intricate vocal performances. Some birds pair together for many years or live in extended families, while others mate only for an instant, never to see one another again. Some chicks are raised by groups of relatives, some by both parents, others by only their father or their mother, and a few receive no parental care at all. Some birds attempt to raise just one offspring in every alternate year, while other species can raise large broods of chicks several times within a single season. The nests built by birds come in a dazzling variety of forms, ranging from simple scrapes on the ground, to intricately woven baskets, to messy piles of sticks that may weigh several tons.

Birds flap, hover, soar, glide, stoop, swim, dive, burrow, walk, hop, and even sprint. To us, they often appear—and quickly vanish—as a burst of motion and color. Through their migratory movements, birds create living links among continents, oceans, and hemispheres. Migratory species know the planet as a north–south stage to be traversed twice each year, creating one of the most remarkable migration spectacles on Earth. The annual return of individual birds to their precise breeding or overwintering territory seems miraculous, and this homing ability is a testament to their underlying adaptations

Photo: Birds as entry points into nature. From the intricate textures of their feathers to the intimate details of nesting and parental care, this Hodgson's Frogmouth (*Batrachostomus hodgsoni*) family captures a central theme of this book: birds are at once familiar, enchanting, diverse, and endlessly informative guides to the natural world. (Photo by Ayuwat Jearwattanakanok ML459354181)

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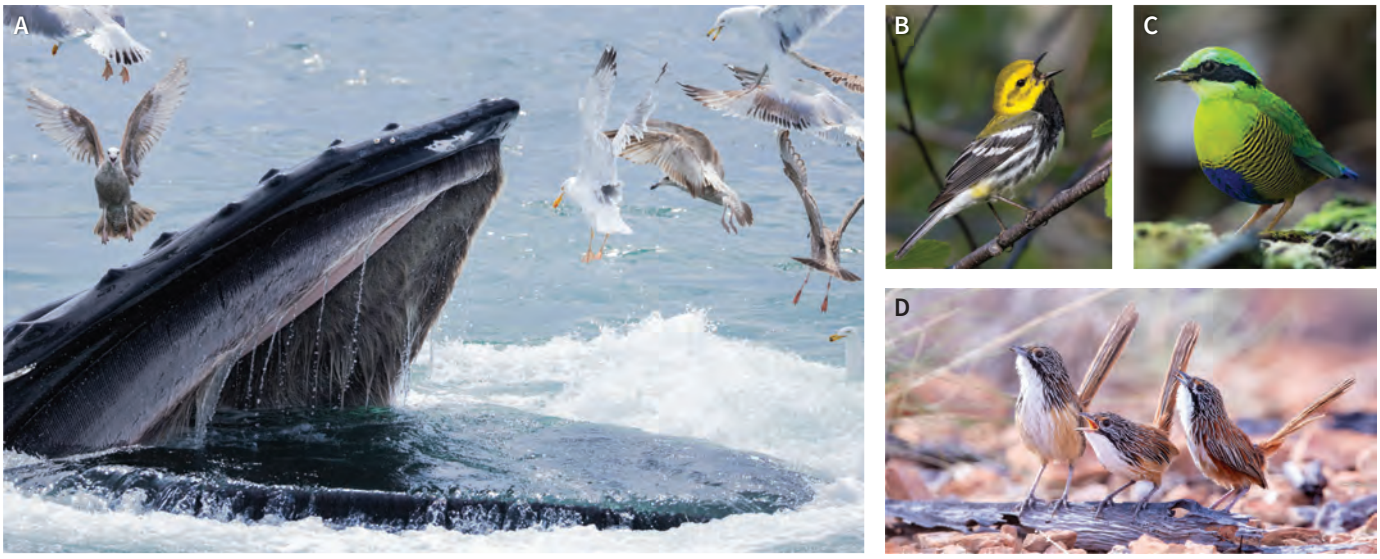


Figure 1.01 Birds are found nearly everywhere on Earth. Shown here are (A) American Herring Gulls (*Larus smithsonianus*) foraging in association with a humpback whale, (B) a Black-throated Green Warbler (*Setophaga virens*) singing on its spring territory in Nova Scotia (Canada), (C) a Bar-bellied Pitta (*Hydrornis elliotii*) photographed on the floor of its rainforest habitat in Vietnam, and (D) a trio of Carpentarian Grasswrens (*Amytornis dorotheae*) in an arid region of Queensland (Australia). (Photos by [A] Macqueen Chen ML656404127, [B] Lyall Bouchard ML453514601, [C] JJ Harrison ML612841703, [D] Laurie Ross ML324074521)

for orientation. Other kinds of birds are nomadic, sometimes wandering in great flocks in search of superabundant food or prime breeding sites; while other birds are homebodies, remaining very close to their hatching site throughout their entire adult lives.

The songs of some birds are among nature's most evocative sounds. Birds vocalize primarily to communicate with other birds, but they do so in a great variety of ways and across a great range of auditory frequencies. For human birders and scientists, learning bird calls and songs is often the key to discovering what species are present in a habitat or location. Going further, we can eavesdrop on the more detailed lives of birds by learning how they use songs to defend territories, advertise to mates, warn of potential dangers, and communicate about their own status.

Beneath all this behavioral and ecological diversity lies a remarkable body plan and a high capacity for physiological adaptability. Birds have unique skeletons: every bird is equipped with specialized forelimbs and fused hand bones that together form a wing. Yet some birds' wings are proportionally too small for flight, while others have wings that are modified into flippers for swimming. All birds have beaks, lay eggs, and breathe via a system of one-way airflow, which permits more efficient capture of oxygen than the in-and-out breathing pattern of mammals. Yet despite these similarities, birds have a wondrous variety of physical forms—from the smallest hummingbirds to the towering ostriches—that are adapted to different ways of life. Their internal body processes are similarly multifarious: some birds can dive deep into water and remain submerged for minutes; others can fly at great heights where the air is thin and the oxygen correspondingly poor. Different birds can extract energy and nutrients by digesting a great range of foods, from tough leaves to fluid nectar, and from tiny invertebrates to rodents swallowed whole. Some birds time their breeding based on subtle shifts in day length that cause cascading effects on their hormones and reproductive systems. Others use specialized areas of their brains to remember the locations of thousands of seeds that they have hidden for later consumption.

The external beauty of birds is enriched by their variety of feathers, which are magnificent in their many functions as well as their array of forms (**Figure 1.02**). Feathers are an adaptation found in no other animal group today, but we now know that birds are the living descendants of otherwise extinct dinosaurs that also sported a great variety of feathered plumage. Feathers provide birds with thermal insulation, waterproofing, and, in many cases, enable their flight. Feathers come in bold or cryptic patterns, ornamental shapes, incredible shades of color, pure tones, impressive lengths, or, in just the right light, brilliant iridescence. Many birds combine these features in ways that play a large role in both mate choice and camouflage.

There are enough species of living birds—11,000 or so—to keep the most ardent birders questing after new sightings throughout their lives. This rich diversity has evolved over 150 million years, creating the diversity of avian orders and families that populates our field guides. Over the smaller

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Figure 1.02 The many functions of feathers. The feathers on the body of this Wine-throated Hummingbird (*Selasphorus ellioti*) perform many functions simultaneously, from insulation and waterproofing, to visual display, to aiding in flight performance. (Photo by Daniel López-Velasco ML500057771)

timescales that can be addressed in field studies, birds have provided some of the best examples of how evolutionary forces play out in nature. Scientists have carefully documented how natural selection can change bird populations in just a few generations, and how intense sexual selection can drive the evolution of gaudy plumage and elaborate displays. Birds have therefore served as model systems for understanding how species of all kinds arise and change through time.

Birds have a similarly influential standing in our efforts to conserve the natural world. Birds serve as flagships for imperiled habitats and ecosystems and as early warning systems for environmental toxins or other destructive forces. Conservation efforts focused on birds often help preserve many other, less-conspicuous organisms. And owing to their charisma and popularity with humans, birds can help inspire all of us to be better stewards of natural systems and biodiversity.

This book is about all such aspects of avian biology, and more. Thanks to a fortuitous combination of diversity, accessibility, and charisma, birds throughout the ages have taught humans an extraordinary amount about natural history. Nearly everyone has seen and wondered about a bird, and this familiarity helps give birds their special inspirational power—birds capture our imagination and curiosity by simply being in our presence. Researchers have long harnessed this same accessibility of birds to answer questions in the laboratory and in the field with relative ease, especially compared with the challenges of studying most other animals. Dozens of principles in evolution, ecology, biogeography, behavior, neurobiology, life history theory, natural resource management, and conservation biology have been—and continue to be—discovered and refined through studies of birds.

1.1 Avian form and function

The visible features of a bird—its plumage, proportions, and body components—offer a visual guide to its identity, behavior, and ecological role. Because these traits are shaped by both evolutionary history and functional demands, they serve as a bridge between how birds look and how they live. Developing fluency in this visual language allows anyone with an interest in birds to achieve a deeper understanding of avian diversity.

Birds are familiar to nearly everyone because they are a truly ubiquitous component of our natural world: there is no place on Earth that humans occupy that is not also frequented by birds. But how do we formally define birds in relation to other animals, both those that occur today and those that existed in the past?

All birds living today are grouped together into a biological entity termed Class Aves. As covered in more depth in Chapter 2, the closest living relatives of today's birds are the crocodilians (like the crocodiles, alligators, and caimans). Yet in the past, a great diversity of dinosaurs were much closer bird relatives, and back then they had a variety of bird-like and non-bird-like traits. If we had perfect knowledge of that biological history, or a time machine to observe it directly in its full and glorious detail, we would discover that there was no one point where a precise ancestor suddenly stopped being a dinosaur and started being a bird. Many kinds of dinosaurs had bird-like attributes, while early birds retained dinosaur-like traits (like teeth) that modern birds now lack. Instead, it is useful to think of birds as the only living representatives of a much broader dinosaur radiation that is otherwise now gone. And since birds are part of the dinosaurs, and dinosaurs are reptiles, it is only via tradition that we often refer to birds being in their own Class Aves separately from the other reptiles in Class Reptilia, since birds are unambiguously a subset of the reptiles.

Among living animals, all modern birds share a suite of distinctive traits. The most outwardly obvious one is that now only birds have feathers. Birds are also among the few living groups that lay hard-shelled eggs; and those others (including some turtles, geckos, and crocodiles) evolved their hard eggshells independently from birds, so some of the physiological processes used by laying birds are unique. The toothless beaks of birds are similarly distinct, in evolutionary terms, from the beak-like mouthparts of other animals like turtles and some kinds of fishes. Birds have bones that are partly hollow that connect with components of their respiratory system; and all birds have wings as their forelimbs, though not all bird species use them to fly.

These traits make it easy to recognize a modern bird as a bird, even when considering forms as radically different

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from each other as an ostrich, hummingbird, sparrow, or albatross. Luckily, today when you see a bird you can be confident that it is part of Aves. The ongoing debates about exactly where to draw the bird boundary instead revolve around the time, long ago, when many other kinds of dinosaurs had feathers and hollow bones, laid hard eggs, and so on.

All birds share the same basic body plan, but the outward expression of that plan varies enormously across species. The same anatomical regions have been modified in different ways in different avian lineages, producing the extraordinary diversity of forms seen among birds. Comparing these features across species reveals how evolution has shaped external structures to meet a wide range of ecological demands.

For observers in the field, these external features of birds enable our visual identification of avian species, sexes, and age classes. These same features often vary dramatically across major avian lineages, making it possible to know at a glance whether a particular bird is a thrush, duck, hawk, or heron. More subtle differences in proportions, shapes, and markings often distinguish the most closely related species that can be harder to separate, and careful attention to these traits is central to their accurate identification. More broadly, many features of avian appearance are linked to how birds move, forage, court, reproduce, and otherwise interact with their surroundings.

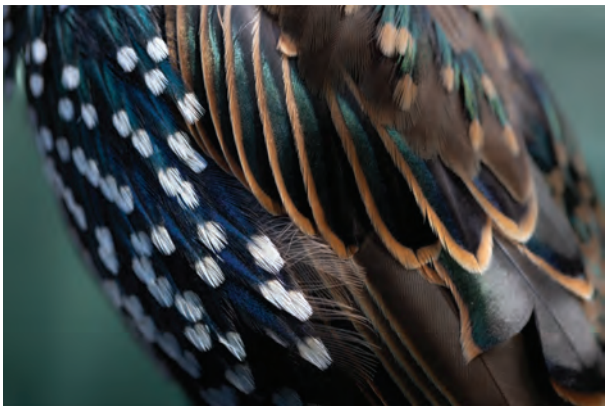


Figure 1.03 Looking closely at familiar birds. The European Starling (*Sturnus vulgaris*) is so common in many parts of the world that it is easy to overlook the subtle beauty of its coloration. (Photo by Michael Stubblefield ML630557450).

1.2 Observing birds in the field

Learning how to find and identify birds is a foundational skill for both birders and ornithological researchers alike. Encountering birds and understanding their behavior all begin in the same place: knowing where and when to look, and how to interpret the distinguishing features of different species. In this respect, the practices of birders and professional field ornithologists rely on the same basic observational approaches.

Birds are distributed unevenly across any landscape, and even the most skilled human observers never encounter all the individual birds that are present in any complex habitat. Instead, every effort to find birds, whether during a casual birding walk or in a highly structured field survey, samples only a subset of the birds that are there. The set of birds that are detected always depends on where and how the search is conducted, how long it is sustained, and the environmental and observational conditions under which it takes place. Some birds are conspicuous and readily observed, whereas others often remain hidden, quiet, or are most active at times when observers are absent. As a result, the birds that are recorded in any given observation period reflect both the underlying avian community and the ability and choices of the person or people looking for them. Recognizing this connection between observation and sampling helps explain why different observers may report different sets of species from the same place. It likewise forms the basis for both developing birding skills and for designing scientific bird surveys.

The next step after finding birds is to identify them. Many birds are encountered briefly or under imperfect conditions, so identification depends on the setting as well as on aspects of the bird itself. Reliable identification in the field depends on focusing on the most diagnostic observable features, initially the components of bird size and shape, color pattern, behavior, and setting. These features become the evidence for identification. Observers compare them with the attributes of likely species, form a hypothesis about the bird's identity, and test that hypothesis against the available evidence. With experience, this becomes an unconscious process in many situations, but even the most experienced birders and ornithologists encounter bird identification challenges where the evidence available to them is so incomplete or puzzling that their bird identifications remain provisional. This occasional uncertainty is a normal and expected part of observing birds in the wild.

After a bird has been found and identified, careful observation turns attention to how it lives: how it moves, what it is foraging on, how it uses the space around it, and how it interacts with other birds and its surroundings. These details are easy to miss at first (**Figure 1.03**), but they are what link individual encounters to a broader understanding of birds—their behavior, their ecology, and their place in the environments they inhabit. Most of the aspects of bird biology covered throughout the chapters of this book can be witnessed directly in the field through careful observation of wild birds.

1.2.1 Finding birds

Knowing where to look is an important step in finding birds. Some habitats consistently support higher overall numbers

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and diversities of birds than others, while some individual bird species have narrow ecological niches and are only reliably found in certain habitats (Chapter 13). Because different habitats support different bird communities, observers hoping to encounter many species usually do best by visiting several habitat types. **Ecotones** where different habitats meet, such as forest edges or wetland margins, can be especially productive for finding a high diversity of bird species because those ecological boundaries bring together species and resources from multiple environments.

At other times, the primary search target might be a particular bird species, one that is likely tied through its ecology to a specific part of the local landscape, such as dense understory, open canopy, or an exposed shoreline. In these cases, success depends on anticipating the typical behaviors and habitat use of that target species, including where it feeds, perches, or remains concealed. Ornithologists take this approach when studying a focal species, concentrating their search effort in the parts of the habitat where that species is most likely to be found. Birders likewise deploy this same kind of information when searching for a species of interest.

Timing is also important for locating birds. Most birds are easiest to find when they are active, and that activity follows predictable daily and seasonal rhythms that are linked to each species' annual cycle. In many regions, early morning brings a surge of movement and sound as birds forage, defend territories, and communicate. Activity then often declines as the day warms, especially in hot or exposed environments where birds reduce activity and remain in shade. Seasonal changes can be even more pronounced. During the breeding season, birds are often conspicuous as they sing, display, and move frequently within territories. During migration, entirely different species may pass through an area in a matter of days, sometimes appearing in large numbers after favorable winds or weather conditions.

These patterns influence both how many birds are present and how detectable they are. Birders take advantage of these daily and seasonal rhythms by focusing their efforts at times of peak activity, while ornithologists may schedule surveys to coincide with periods when target species are most likely to be active or vocal. In both cases, attention to timing improves the chances of detection, and documenting the search strategy helps ensure that observations are comparable across different visits, locations, or years.

Over time, observers develop a sense of which birds are likely to be present at a given place and time. The birds an observer is likely to encounter in a marsh in early spring differ from those likely to be present there in midwinter; similarly, a tropical forest presents a different set of possibilities than a temperate one. These expectations are shaped by the prior experience of the observer, their knowledge of species' distributions, and their awareness of seasonal movements and cycles. Experienced observers think in terms of which species match their expectations and which do not: a bird that fits those expectations stands out, but so does one that does not. In this way, each field period begins with a working sense of which birds are most likely to be observed, with observations over time gradually refining that expectation through additional experience.

Locating an individual bird often begins with noticing a flicker of motion within vegetation, a silhouette in the distance, a shape that seems slightly out of place, or a vocalization from an unseen individual. In many cases, there is no prolonged view of the bird that allows careful study. Under directed attention, these partial cues become easier to notice, and what once seemed like an empty landscape begins to reveal a steady background of avian activity.

Movement is often the most reliable cue that a bird is present. Birds tend to move in characteristic ways that distinguish them from the surrounding environment. At the same time, observers must sort these signals from background motion such as wind-driven leaves or shifting shadows. This distinction improves with experience, as the eye becomes better at filtering out irrelevant movement and focusing on patterns that indicate a bird. With time, birds simply begin to stand out.

In many settings, most birds are heard before they are seen, especially in densely vegetated habitats and during spring when many birds are vocalizing. This phenomenon is evident in many tropical forests with dense and vertically layered vegetation and limited visibility. In such habitats, many birds are inherently difficult to see: some remain deep within dense vegetation, while others occupy the midstory or canopy, where foliage can obscure them even when they are nearby. First-time visitors to species-rich tropical forests often anticipate seeing large numbers of colorful birds but instead are initially frustrated by encountering a nearly continuous wall of vegetation with very few obvious birds ever in view. A general truism is that most birds in such settings are detected first by voice, and many are rarely seen well at all.

In more open habitats, finding birds often depends on systematic scanning of the surrounding landscape. Birds may be visible at considerable distances in grasslands, shorelines, deserts, and open-water habitats, but they are often small, still, or cryptically colored against their background. Observers therefore sweep the landscape deliberately, using binoculars, spotting scopes, or the unaided eye to search for movement, outline, or contrast. A good strategy is to focus first on likely locations such as fence posts, isolated shrubs, mudflats, or the edges of water, and to revisit these features repeatedly. In the sky, scanning often involves watching for silhouettes or movement, where flight style and shape can be recognized at long range. Even in open settings, detection

Ecotone: a transitional boundary zone where two different ecosystems meet.

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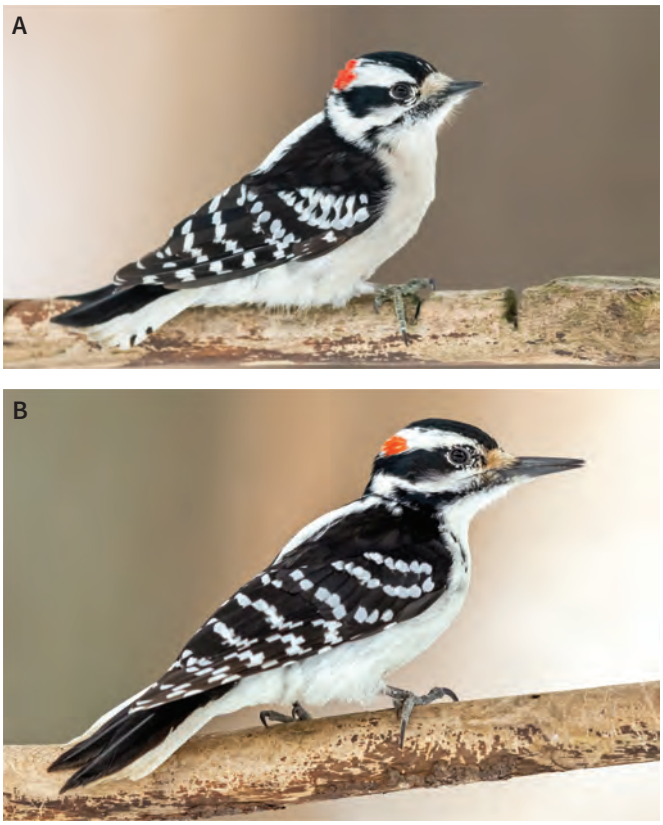


Figure 1.04 Observing size, shape, and proportions. One of the most powerful ways to use a bird's size for identification is to measure the bird against itself. For example, these (A) Downy (*Dryobates pubescens*) and (B) Hairy (*Leuconotopicus villosus*) Woodpeckers look almost identical in terms of their plumage coloration and patterning, and they occur together in many North American habitats. However, compare the length of the bill to the head: the Downy Woodpecker's bill is visually equivalent to only about half the width of its head, whereas the Hairy Woodpecker's bill is about the same width as its head. (Photos by Brad Imhoff ML307170881/ML308764911)

improves greatly with practice as the eye becomes better at picking out subtle anomalies of shape and motion.

1.2.2 The four keys framework: building an identification hypothesis

When you first see a bird, the initial task is to narrow the range of possible identifications as quickly as possible. The most effective way to do this is to focus on a small set of observable features that tend to be both reliable and broadly informative. The four keys framework—size and shape, color pattern, behavior, and habitat—provides one practical way to organize those observations and use them to generate an initial identification hypothesis.

Size and shape are usually the most informative starting point. Even a brief or distant view can reveal proportions—the length of the tail, the thickness of the bill, or the posture of the body—that distinguish broad groups of birds from each other (**Figure 1.04**). A bird with a long neck and long legs suggests something very different from one with a compact body and short bill, regardless of all other attributes. Observers can anchor these impressions by comparison with familiar species, using informal references such as robin-sized or crow-sized. Because these structural features remain relatively consistent across lighting conditions and viewing angles, they often provide the strongest initial constraints on identification.

Color can also be a useful clue to a species' identity, yet it is usually the pattern of colors across the body that carries the most weight (**Figure 1.05**). Rather than trying to match exact hues, experienced bird observers focus on contrasts and arrangements—light underparts against a darker back, bold stripes on the head, or a localized patch of color on the wing or tail. These patterns are more stable than precise coloration, which can change with lighting, distance, or feather wear. Color pattern helps narrow the remaining possibilities after size and shape have suggested the broad category to which the bird belongs.

Behavior provides an additional line of evidence. Birds move through their environments in characteristic ways, and these patterns can be highly distinctive. Some species hop along branches, others walk steadily on the ground; some sally out to catch insects in midair, while others probe methodically for food. Flight style can be equally informative, from the undulating path of many small songbirds to the steady, direct flight of larger species. These behavioral traits can quickly eliminate alternatives that would otherwise remain plausible based on appearance alone.

Habitat acts as a final filter, further constraining the set of possible identifications. Many species are strongly associated with certain environments, and even finer distinctions within those environments can matter. A bird seen wading in shallow water belongs to a different set of possibilities than one swimming in open water or diving into water from above.

By combining habitat with size and shape, color pattern, and behavior, observers can reduce a broad set of possibilities to a short list of candidates. Taken together, these four elements help make sense of a quick or incomplete view. They don't give the answer on their own, but when used in combination they usually point to a shorter, more manageable set of possibilities that can then be refined with closer observation.

1.2.3 Refining identifications: additional lines of evidence

Once an initial bird identification hypothesis is in mind, the next step is to look for and evaluate additional evidence, especially the **field marks** that could either support that

Field marks: distinctive visual features of a bird, such as its size, shape, color pattern, plumage markings, or behavior, that help distinguish it from other species.

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Figure 1.05 Pattern as an identification clue. A birder in western North America might encounter three finch species in the genus *Haemorhous*. On first look, the red coloration of the male's head and breast are likely to stand out as the most prominent field mark. But a closer comparison of the male (A) House Finch (*H. mexicanus*), (B) Cassin's Finch (*H. cassinii*), and (C) Purple Finch (*H. purpureus*) reveals how bird identification often depends more on the pattern of color across the body than on the exact hue. For separating these finch species, the extent of red on the head, breast, back, and rump, together with the streaking and contrast of the facial region and underparts, provides more stable identification clues than does the precise shade of red seen under changing light or viewing conditions. (Photos by [A] Matthew Plante ML305823741, [B] Jeff Dyck ML533832051, [C] Manny Salas ML521031571)

scenario or point to alternative possibilities. Early impressions of a bird are often based on a limited set of features, and adding a few more observations can shift those impressions quickly. A bird that seems to match the field marks of one species at first glance may begin to look different as it moves, forages, or vocalizes. For this reason, identification may not happen all at once, especially for species that are tricky to separate from similar species. Instead, it develops over time as an evolving hypothesis as new information comes in, and earlier impressions are reconsidered. In field settings this process is rarely fully linear; observers may return to earlier impressions as new evidence comes into view.

Sound is usually the most useful additional line of evidence after visual field marks. Many species produce calls or songs that are even more distinctive than their visual appearance, especially when the bird itself is hidden in dense vegetation or obscured by poor lighting conditions. Many birds that cannot be seen at all may still be identified with confidence based solely on their vocalizations. Even when a particular vocalization is unfamiliar, its pitch, rhythm, and repetition can narrow the range of possibilities and guide a listener toward its general avian group. In practice, observers in the field pay attention simultaneously to what they see and what they hear from a bird, using each to check the other.

Time and place provide another powerful set of boundaries on which birds are most likely to be present (**Figure 1.06**). Many migratory species occur in a given location only during certain seasons, and all birds worldwide have their own unique geographic distribution. A bird that is common during migration may therefore be unlikely in midwinter, and a species common in one habitat may be absent from a

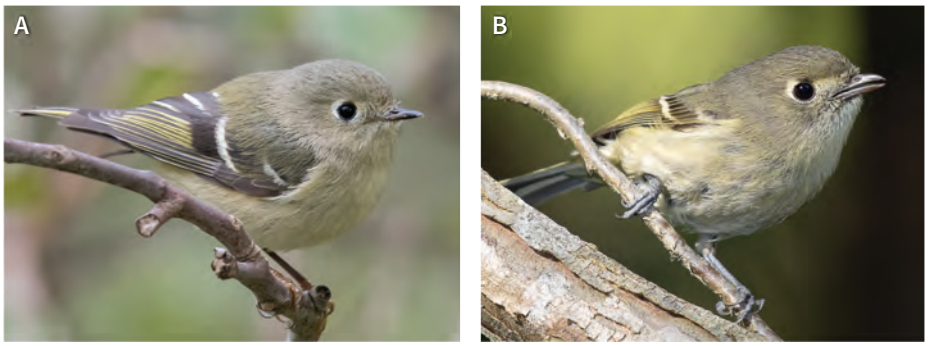


Figure 1.06 Time and place narrow identification possibilities. (A) Ruby-crowned Kinglets (*Corthylio calendula*) and (B) Hutton's Vireos (*Vireo huttoni*) are both small, olive-gray birds with pale wing bars that can look confusingly similar. But in many places in western North America where this vireo is resident, the kinglet occurs mainly as a migrant or winter visitor. Season and location can therefore make one identification much more likely than the other, even before an observer turns to finer details of structure, behavior, and voice. (Photos by [A] Mike Stewart ML122886261, [B] Mark Daly ML339066781)

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different nearby habitat. These patterns do not identify a bird on their own, but they help define which possibilities are most realistic. In practice, this mental filtering often happens quickly and without conscious attention, as observers recognize when a bird does or does not fit what is expected for a given place and time.

Variation within bird species adds an additional layer of complexity. Birds may differ in appearance depending on age, sex, or time of year, and these differences can be substantial. Juveniles often lack the distinctive features of adults, and seasonal molt can alter plumage coloration and pattern (Chapter 4). As a result, some birds are a poor visual match to any field guide depiction of their own species. Recognizing this variation prevents otherwise reasonable identifications from being rejected too quickly or accepted too confidently, and it helps explain why some highly variable birds are consistently more difficult to identify than others.

Occasionally, a strange bird simply does not fit any of the likely possibilities. These field situations are uncommon, but they do occur, and they require a different level of scrutiny. An aberrant individual might be the result of hybridization between closely related species (Chapter 3), or it might be an individual of a species native to a different part of the world that has escaped from captivity. Or it might excitingly be a true **vagrant**, a local rarity that is not among the normally expected species in that location. In these cases, it is especially important to rely on observed details and document the observation carefully, preferably with photographs or recordings so that its identity can be reassessed later.

1.2.4 Similar species and the logic of elimination

In many cases, bird identification ultimately comes down to choosing among a small set of similar species. A bird may match several possibilities in size, shape, and general appearance, leaving only a few realistic options, especially when considering only the species likely to be present in a given location at a certain time of year. At that point, the remaining task is to determine which of those options best fits the available evidence.

The most effective approach is to focus on the field marks that separate the remaining alternatives. Closely related or similar-looking species often differ in consistent ways, such as the proportions of the bill or tail, the presence or absence of a particular marking, or a characteristic pattern of movement. These differences may be subtle, but they tend to be more reliable than broad impressions of color or size. A single, well-observed feature can be more informative than a longer list of uncertain ones. Field guide books, or their digital equivalents, are the primary resource for checking which field marks are diagnostic for each species. Such field guides are now available for the birds of all regions of the world. Not all observed features carry equal weight, and some traits are far more informative than others. In many cases, the absence of expected features—the lack of wing bars, or a tail without white feathers—can be just as informative as their presence.

Comparison of these marks is central to this process of determining a bird's species identification. Rather than asking primarily, "What is this bird's species?," experienced observers consider simultaneously, "What other bird species could it be?" Considering alternatives makes it easier to recognize when an initial impression does not fit the evidence. An identification may seem plausible at first, but comparison with similar species may show that the bird lacks key field marks expected for that species. When that happens, the observer must reconsider the initial identification hypothesis. In this way, everyone identifying a bird is engaged in a version of the general deductive reasoning process that underlies scientific research.

This approach helps prevent overconfidence. When several species remain possible, a standard approach is to first eliminate those that are most clearly inconsistent with the evidence. As the set of possibilities becomes smaller, the remaining possibilities and their most distinctive differences become easier to evaluate, and the ultimate identification becomes more secure.

1.2.5 Limits of observation and identification

Many encounters with birds are frustratingly brief and incomplete, leaving only a limited set of features that can be retained and documented with confidence. A bird may disappear into vegetation, pass overhead, or fall silent before there is time to study it closely. What remains is whatever could be seen, heard, photographed, or recorded during that encounter.

It is surprisingly easy to misremember or misinterpret what was actually seen or heard during a brief encounter with an interesting bird. Human perception and memory are inherently constructive processes that draw on prior experience and expectations to fill in gaps, even when we do not consciously realize that our brains are operating in this way. When a view of a bird is brief or incomplete, the human brain therefore may automatically fill in missing details in ways that can feel accurate but which do not fully reflect what was really observed. Every birder has likely had the experience of spotting a common bird but hoping it might be something rarer. That hope can influence perception, making ambiguous features seem to support the rarer identification, at least initially. For this reason, careful field observers remain aware of this tendency in themselves and make a point of distinguishing between what they directly see or hear and what they only infer, questioning their first

Vagrant: a bird found far beyond the normal range of its species.

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impressions in the moment and focusing on the features they can perceive and recall with confidence.

These limits on observation place clear constraints on identification. When only a few features of a bird are discernable, the number of species that can be ruled out is limited, and multiple identification possibilities may remain. Some useful features may be diagnostic, while others are shared among many species and carry less weight. Identification becomes a matter of evaluating which possibilities are supported by the available evidence and which are not. When the available evidence is insufficient, forcing a definitive answer is a natural but misguided outcome, especially when bird species share many features.

Some birds encountered briefly or distantly are identifiable only to a broader group, such as a genus or other set of related species that are known to be confusing. When faced with this kind of uncertainty, a partial identification becomes the most accurate outcome. Recording that level of identification still conveys useful information consistent with the available evidence. For example, male frigatebirds (genus *Fregata*) in flight are difficult to distinguish from one another, especially at a distance, and in eBird they can be recorded using the predefined tag "frigatebird sp." when they cannot be confidently assigned to a particular frigatebird species (**Figure 1.07**).

Additional lines of evidence can help strengthen or test a tricky bird identification. Comparisons with field guides or other reference materials can clarify which features are truly diagnostic. Photographs and audio recordings may preserve details that were missed or only partly perceived in the moment, allowing closer examination long after the encounter, along with the potential for confirmation by people familiar with the birds in question. Field observations of the same bird made by others can similarly provide valuable confirmation or raise new questions.

Once a bird's identity is known, everything else that can be observed about it becomes easier to interpret. Repeated encounters with the same species begin to reveal consistent aspects of its behavior and ecology. This develops over time into an ever-clearer sense of how those birds live within their environments, and making future identifications of that species easier.



Figure 1.07 The value of partial identifications. Sometimes a bird can be identified confidently to a broader group but not to an exact species. In those cases, the most accurate identification is the most specific one that the available evidence supports. Based on their location, these backlit frigatebirds could be one of two species that are very hard to separate in flight, so tagging them as "frigatebird sp." is better than forcing an unsupported species-level identification. (Photo by Peter Kaestner ML56603671)

1.3 Birding techniques and tools

At its core, birding is the practice of detecting, identifying, and studying birds in the field. Much of our appreciation for birds comes from watching them go about their lives, an activity that requires little more than interest and curiosity. In practice, birders use tools ranging from binoculars to participatory science platforms like eBird to extend their observations. Some of these tools connect individual observations to broader scientific efforts, linking everyday birding with research and conservation, and they also overlap substantially with the methods used by ornithologists to study birds in more formal research contexts.

1.3.1 Binoculars, cameras, and other optics

The stereotypical birder is someone toting a pair of binoculars, staring into the trees in a park to look at distant birds. Binoculars are indeed the most common tool used by all kinds of birders, from the most casual to the most passionate. Binoculars provide a closer view of field marks used for identification and make it easier to observe behavior in detail. Although some binoculars are extremely expensive, binocular manufacturing technology has advanced such that some lower-cost options provide notably high-quality viewing experiences. There are so many binocular options available that it is important to try out a model in person before you purchase it, either in a store or by asking to look through those carried by fellow birders you meet in the field.

Binoculars come in two primary configurations. In Porro prism binoculars, each viewing tube has a Z-shape with the objective lens farther apart than the eyepieces. Birders increasingly rely instead on roof prism binoculars in which the viewing tube is a straight barrel. Roof prism binoculars tend to be lighter and more durable, and many versions are now also waterproof.

Binoculars are categorized by two numbers written in the format 8×42, 10×50, and so on. In this format, the first number indicates the magnification: an 8× binocular will make birds appear eight times closer than without binoculars, a 10× binocular ten times closer. It might seem like the greater the magnification, the better a pair of binoculars will

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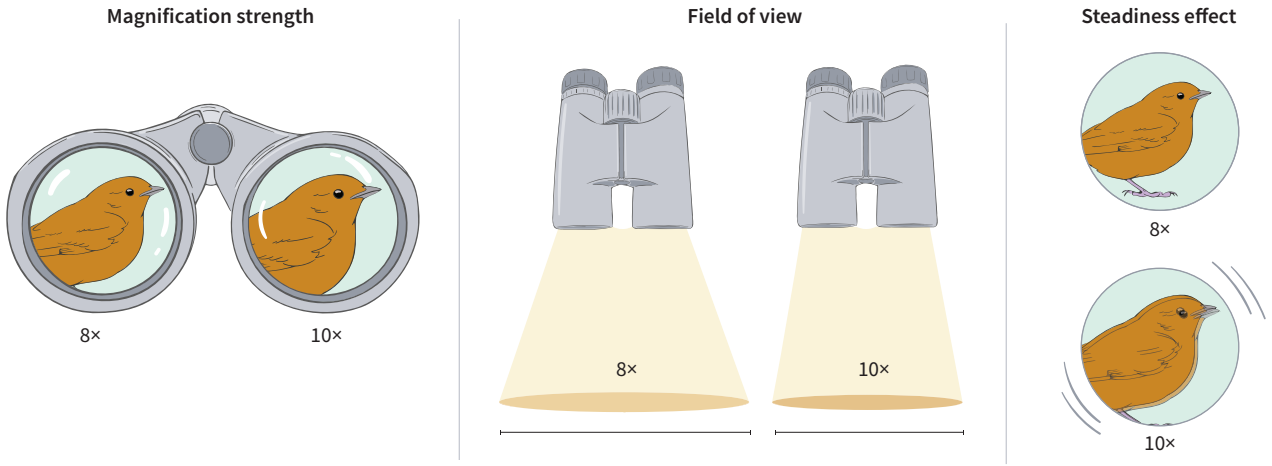


Figure 1.08 Magnification is helpful only when the image remains steady. Binocular labels such as 8×42 and 10×50 begin with the magnification value: an 8× binocular makes a bird appear eight times closer, while a 10× binocular makes it appear ten times closer. Higher magnification produces a larger image, but it also narrows the field of view and exaggerates normal hand-shake. For most birders, a handheld 8× view is easier to keep sharp, while 10× is most effective with very steady hands or added support such as a tripod. (Illustration by Charlotte Holden © Cornell Lab of Ornithology)

be for watching birds. Yet high magnification comes at two real costs: all of us experience inevitable (and sometimes imperceptible) hand-shake that counterbalances the magnification benefits by blurring the image we see, and greater magnification also means a narrower field of view, making it hard to find the birds we want to look at (**Figure 1.08**). Most birders therefore choose binoculars within the 7×–10× range, with 10× being most suitable for people with particularly steady hands.

The second number is the size of the objective lens (the light-gathering lens on the far side from the eyepieces). The larger this number, the brighter the view. The downside of a larger objective lens is that it makes the binoculars heavier. Most binoculars made for birders are therefore in the ×35–×50 range.

When using binoculars, make sure that they are correctly adjusted for your eyes. Start with the eyecups, which might be rubber, or may twist open and shut. If you wear glasses while birding, fold or twist the eyecups to the closed position; if you do not wear glasses, keep them extended. Then hold the binoculars up to your eyes and fold the two barrels to the position where the eyecups are directly in line with the distance between your eyes. You will know that you have this correct when you look through both barrels and see that the resulting image forms a perfect visual circle.

The final and most confusing adjustment step is to set the focus on the two binocular barrels to compensate for any differences in vision between your own left and right eyes, since most people have such a difference. First, find the main focus wheel on the binoculars that you would use routinely when focusing (**Figure 1.09**). Then, look for a separate adjustment knob or setting that changes the focus of only one barrel. It might be on one eyepiece (most often on the right side), or on the center post for Porro prism binoculars. This separate one-side focus setting is called the *diopter ring*. To set this adjustment, look only through the non-adjusting barrel (close or block your other eye while you do this), and use the focus wheel to bring a distant object into perfect focus. Without further touching the focus wheel, switch eyes and switch barrels, and use only the diopter ring to bring the same object into sharp focus. The diopter is now calibrated at your own personal setting. Remember where the diopter ring is set so that you can move it back easily if it drifts away from this set point.

While binoculars were long the classic field mark of a birder, some now prefer to use a camera with a high magnification lens as their primary or only birding optic. Birding with a camera has the advantages of being able to later review a bird's field marks and identification points, and camera shots are great for sharing sightings on participatory science and social media platforms and for documenting rare or unusual birds. Using a camera effectively for birding is typically more difficult than using binoculars and therefore comes with a steeper learning curve.

Birders may also use a small, portable telescope (termed a **spotting scope**) set up on a tripod to view distant birds. Spotting scopes are hard to use for fast-moving birds or those that are in nearby dense vegetation, but they excel in situations where birds are in more open, distant viewing locations, as with shorebirds on a distant mudbank, waterfowl on the other side of an open marsh, or seabirds passing by a coastal promontory.

Spotting scope: a high-powered field telescope used to view birds or other wildlife at greater distances than binoculars allow.

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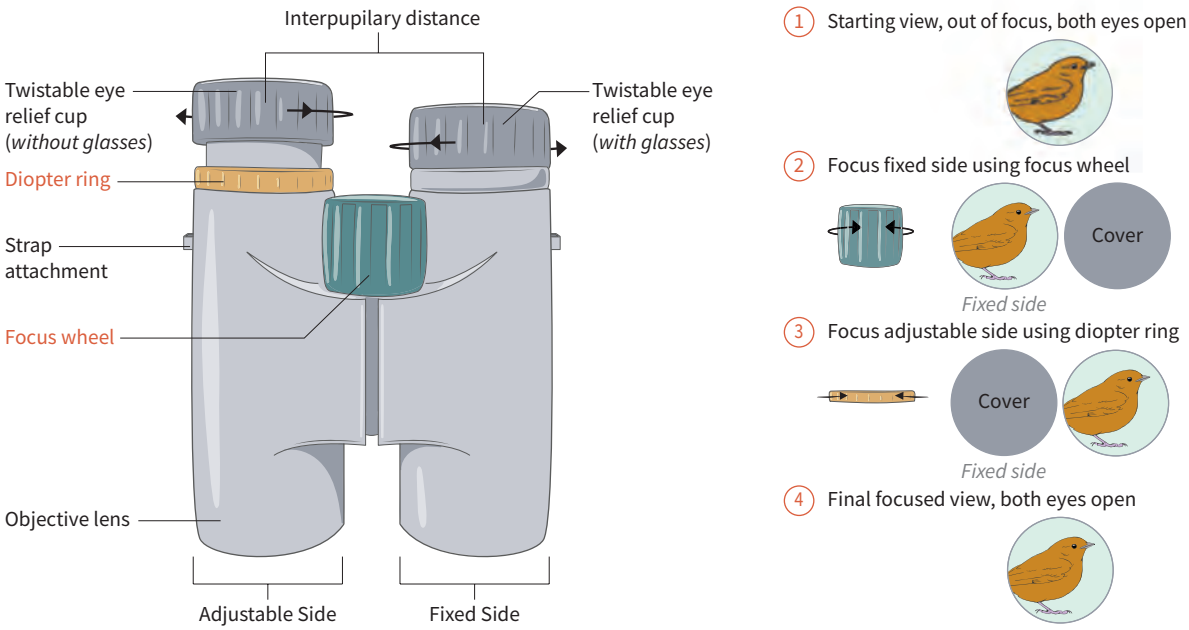


Figure 1.09 Setting the diopter ring calibrates binoculars for differences between your two eyes. First, use the main focus wheel while looking through the non-adjusting barrel to make a distant object sharp. Then, without touching the focus wheel again, switch to the other eye and use only the diopter ring to sharpen the same object through the adjustable barrel. Once set, the diopter adjustment compensates for your personal eye-to-eye focus difference, and the diopter ring should be returned to that mark if it is accidentally moved. (Illustration by Charlotte Holden © Cornell Lab of Ornithology)

1.3.2 Bird vocalizations, song identification, and acoustic techniques

At night everywhere, and in many dense habitats during the day, most birds are far more often heard than seen. Experienced observers rely heavily on sound to determine which species are present. Learning to recognize bird vocalizations greatly expands both the number of birds that can be detected and the depth of information that can be gathered about them.

Bird sounds are broadly divided into songs and calls, which differ in their structure, function, and behavioral context (Chapter 10). Songs tend to be longer and more complex, often associated with territorial defense and mate attraction. Calls are typically shorter and simpler, serving functions such as maintaining contact between individuals, signaling alarm, or coordinating group movements.

Learning to identify bird vocalizations involves recognizing consistent acoustic features in how sounds are structured and produced. Birders may characterize bird sounds in terms of their pitch, tempo, rhythm, repetition, and overall tone quality. Some vocalizations include trills (rapid sequences of repeated notes) or distinctive patterns that can be recognized even after only brief exposure. Many birders use mnemonics to spark their memory, translating songs into human-like phrases that capture their distinctive rhythm or cadence (**Figure 1.10**). With practice, however, most observers shift to recognizing the underlying acoustic patterns directly.

Bird vocalizations vary within species in ways that can reflect their behavioral context, the use of broader repertoires, the sex or age of the singer, or seasonality. Many species also have regional dialects, in which individuals from different areas sing slightly different versions of the same basic song.

Modern tools have expanded the ways in which bird sounds can be learned, visualized, and analyzed. Audio recordings allow repeated listening and comparison across individuals and species, while visual representations of sound, known as spectrograms, translate vocalizations into patterns of frequency over time (Chapter 10). These tools allow observers to "see" differences in pitch, timing, and structure that may be difficult to discern by ear alone. Together, auditory and visual approaches can accelerate the learning process and improve identification accuracy.

The Merlin Bird ID app (available free for both Android phones and iPhones) is the most widely used modern tool for identifying bird sounds in the field (**Figure 1.11**). Merlin was created by the Cornell Lab of Ornithology, the same institution that produced this *Handbook*. It includes a popular sound identification feature that listens to ambient bird vocalizations and suggests likely species in real time, using machine-learning approaches trained on large libraries of recorded and curated bird sounds. At the same time, the app displays a real-time spectrogram of incoming sounds, allowing users to see the structure of bird vocalizations as they are detected and to connect their auditory impressions with those visual patterns. For many people, this

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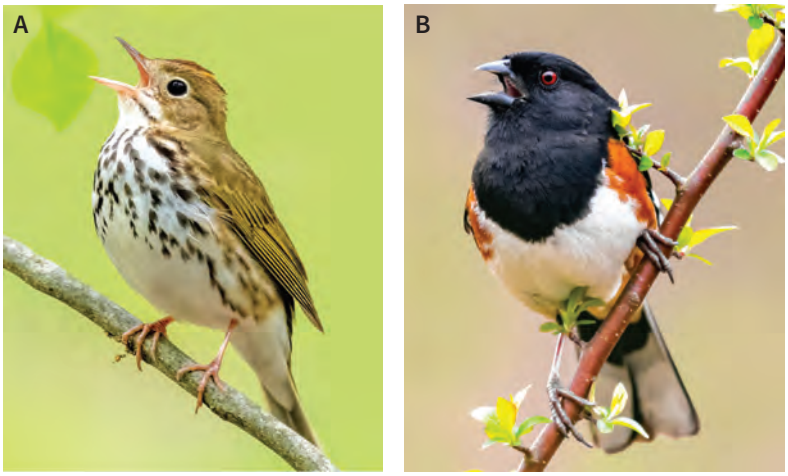


Figure 1.10 Use mnemonics to identify bird songs. Learning bird songs takes practice, but many observers use mnemonics—memorable words or phrases that approximate the rhythm, pitch pattern, or cadence of a vocalization—to help recognize common species. Every region of the world has birds whose songs have inspired local mnemonics; the examples shown here are species often heard in spring around the Cornell Lab of Ornithology. (A) The Ovenbird (*Seiurus aurocapilla*) sings a repeated phrase that grows progressively louder and is often rendered as *teacher-teacher-teacher*. (B) The Eastern Towhee (*Pipilo erythrophthalmus*) gives a distinctive song commonly described as *drink-your-teeeeeeee*, with the final syllable drawn out into a trill. Mnemonics are simplified approximations, but they can help observers remember songs and connect what they hear in the field to a species identification. (Photos by Brad Imhoff ML335096071/ML324396161)

tool provides an accessible and highly engaging entry point into learning bird sounds, allowing them to connect unfamiliar vocalizations with named species while the bird is still vocalizing. All such tools are most effective when used as a complement to careful listening and practice at identifying birds by sound.

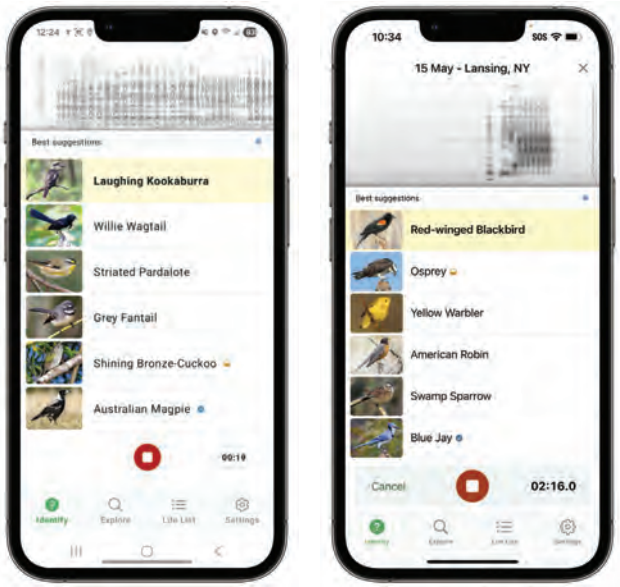


Figure 1.11 Merlin as a birding tool. The Merlin Bird ID application includes a Sound ID feature that displays a real-time spectrogram and suggests likely bird species as it listens. (© Cornell Lab of Ornithology)

Birders and researchers sometimes use acoustic techniques such as playback of recorded songs or calls to attract individual species. These approaches can elicit responses from birds that are otherwise quiet or hidden, particularly during the breeding season when individuals are more likely to react to perceived intruders or threats. As a result, such techniques can be useful for confirming the presence of certain species or for improving survey completeness in challenging environments.

To the uninitiated, few birding behaviors seem stranger than hearing someone stand quietly in the woods while making repeated *pssh* sounds into the vegetation. Birders refer to this technique as **pishing**, in which a series of soft, hissing sounds is used to attract birds and draw them into view. This sound can elicit close approaches by multiple species, especially small passerines, and under the right circumstances it can substantially increase both the number of individuals and species detected during a period of observation (Buchmann and Reynolds 2022). Experimental studies show that pishing most likely functions by resembling the acoustic structure of alarm or scold calls (particularly those of chickadees and titmice in the family Paridae), which trigger generalized mobbing responses in many bird communities (Langham et al. 2006). In regions where parids are common, many birds have evolved to respond to such

Pishing: A birding technique in which a series of soft, hissing sounds is used to attract birds, often eliciting close approach by species responding to perceived alarm or mobbing cues.

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Figure 1.12 Pishing to attract small birds. Pishing uses repeated soft, hissing pssh sounds to draw nearby birds into view, probably because these sounds resemble alarm or scold calls that can trigger mobbing responses. Small passerines are often especially responsive. This male Golden-crowned Kinglet (*Regulus satrapa*), with its crown feathers raised, shows the kind of alert, investigative response that can make pishing useful for detecting foliage-dwelling birds that might otherwise remain hidden. (Photo by David Turgeon ML331031381)



Figure 1.13 Bird feeders create opportunities for close observation. Feeding stations bring birds into places where people can watch them closely, often providing an accessible connection to bird behavior, identification, and natural history. This Rufous Hummingbird (*Selasphorus rufus*) was photographed at a feeder in Ontario (Canada), at a location outside of the normal range of this species. (Photo by Brad Reinhardt ML645193839)

signals by approaching and investigating potential threats, often joining mixed-species mobbing aggregations. As a result, pishing tends to be most effective in the temperate zone and in habitats where birds rely heavily on eavesdropping on other birds' alarm calls, whereas responses to pishing are often weaker or more variable in tropical regions where different alarm systems prevail. In practical terms, pishing is most useful for detecting small, foliage-dwelling insectivores that might otherwise remain hidden (**Figure 1.12**).

A closely related technique termed **mob-taping** involves the playback of recorded alarm or mobbing calls from one or more species to attract birds. Unlike pishing, which uses a generalized sound, mob-taping employs biologically meaningful signals that can trigger strong, coordinated responses from multiple species, sometimes drawing in birds from considerable distances. In practice, this approach is most often used during migration or in dense habitats where birds are otherwise difficult to detect, but its effectiveness depends strongly on local species composition and their behavioral context. Because mob-taping can elicit intense and prolonged responses, it has become a topic of ongoing tension within the birding community about its appropriate use and potential impacts.

More generally, because all these sound-based bird attraction methods intentionally alter bird behavior, their use raises valid ethical considerations. Playback and related techniques can distract birds from essential activities such as feeding, territorial defense, or care of offspring, and repeated use in heavily visited locations can lead to cumulative negative effects. For these reasons, most birding guidelines emphasize restraint and situational awareness, encouraging observers to use such methods sparingly, if at all, and to avoid contexts where disturbance is likely to be consequential. These considerations reflect broader principles of ethical birding.

1.3.3 Bird feeding and attracting

Bird feeding provides a direct way for people to engage with birds while fostering observation, learning, and conservation awareness. Many people first develop their appreciation for birds by viewing the species attracted to local feeding stations (**Figure 1.13**).

Bird feeding takes many forms around the world, but all share the principle of matching food resources to the ecological needs of local bird species. In temperate regions, feeders are often designed to dispense seeds, suet, or other high-energy foods that support birds during colder months when natural resources are limited. These foods primarily attract seed-eating and generalist species, which often dominate feeding sites in these regions (**Figure 1.14A**).

In tropical locations, feeding stations frequently provide fruit or sugar water, attracting species such as tanagers, barbets, hummingbirds, or sunbirds. Feeding sites are common at field stations, lodges, and reserves, where they can draw a remarkable diversity of species into view. In all cases, the types of food provided strongly influence which species are attracted and how they use the site (**Figure 1.14B**).

Mob-taping: The use of recorded alarm or mobbing calls played back in the field to attract birds, typically triggering coordinated responses from multiple species investigating a potential threat.

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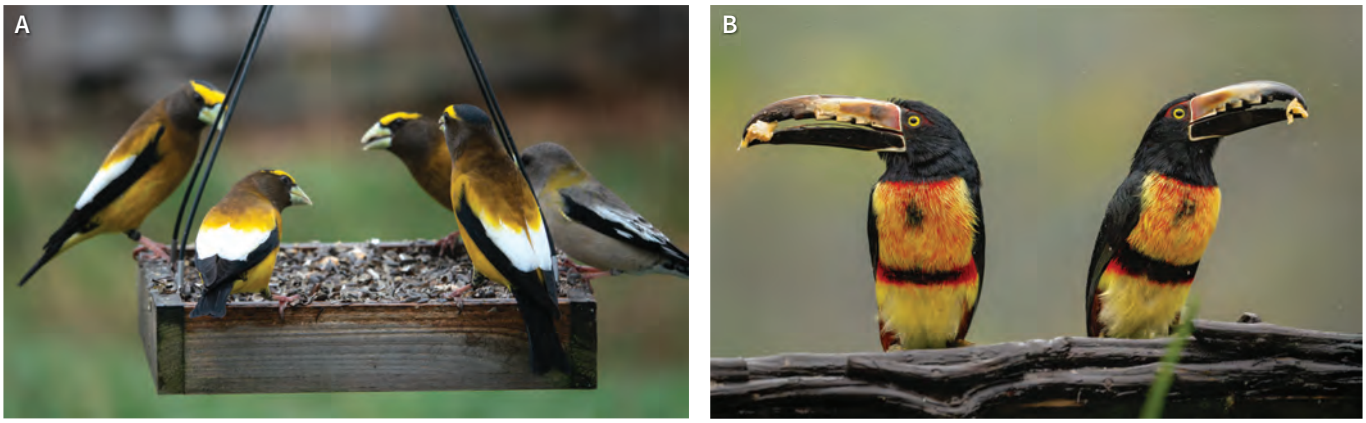


Figure 1.14 Bird feeding in temperate and tropical regions. (A) Bird feeders in colder regions often provide seeds or other energy-rich foods. These Evening Grosbeaks (*Hesperiphona vespertina*) illustrate how winter feeding stations can concentrate seed-eating species. (B) In tropical regions, feeding stations often provide fruit rather than seeds or suet. These Collared Aracaris (*Pteroglossus torquatus*) are visiting a fruit feeder in Costa Rica. (Photos by [A] Andrew Whetten ML655273056, [B] Karen Szafrajda ML638318117)

Water can be an equally important resource for attracting birds. Most birds require reliable access to water for drinking and for maintaining feather condition through bathing. In some environments, water availability can limit bird activity more than food. Even small water features such as shallow basins or birdbaths can attract a wide variety of species, particularly in arid habitats. Moving water, such as drips or small fountains, is especially effective as a bird attractant because it is both more visible and more easily detected by sound.

The placement and maintenance of feeding and watering sites are critical to both their effectiveness and the safety of the birds that visit them. Feeders placed near vegetation can provide birds with refuge from predators, but they should also be positioned to minimize risks such as collisions with nearby windows or structures. Regular cleaning of feeders and water sources is important, as high densities of birds at feeding sites can facilitate the spread of disease.

Birds may take time to discover new feeding sites, but once birds become familiar with a feeding location, they often return regularly and may even adjust their movements or daily routines in response to the availability of food. These predictable aggregations can provide valuable opportunities to observe social interactions, dominance relationships, and foraging strategies among individuals and species.

Feeding birds can alter both the behavior of individual birds and local ecological dynamics. Concentrating birds at feeding sites may change their patterns of movement, increase interactions among species, and in some cases make feeding birds more vulnerable to predators. These effects can be subtle and context-dependent, but they highlight that feeding birds involves actively shaping the environment in which those birds live. For this reason, feeding practices are most effective when implemented thoughtfully, with attention to local conditions and to the potential consequences for the birds involved.

1.3.4 Participatory science

Participatory science connects individual birders and their observations to broader scientific and conservation outcomes. In these projects, volunteer birders contribute data such as species observations, counts, or behavioral notes that can be combined across large spatial and temporal scales. Birds are especially well suited to projects based on this crowd-sourced model: they are conspicuous, widely distributed, and already observed by large numbers of people with varying levels of expertise. As a result, bird-focused participatory science has become one of the most successful examples of how public engagement can directly advance scientific understanding.

Participatory science in ornithology takes many forms. Some projects focus on specific questions, such as monitoring breeding success, tracking migration timing, or documenting changes in local species composition. Others involve coordinated surveys conducted at certain times of year, such as seasonal bird counts. These efforts vary in scale from local to global, but they share a common goal: to gather data that would be difficult or impossible to collect using only professional researchers. Every region of the world hosts bird-focused participatory science projects that welcome contributions from interested non-scientists.

By distributing effort across many observers, participatory science can generate datasets of extraordinary size and resolution. The most widely used global platform for bird-related participatory science is eBird, developed and hosted by the Cornell Lab of Ornithology in partnership with many

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Box 1.1 eBird as a Tool for Birding and Science

eBird is an online platform and mobile app, developed by the Cornell Lab of Ornithology in partnership with many organizations around the world, that allows birders to record, organize, and share their bird observations. Users submit their sightings as checklists, each tied to a particular place, date, and time. An **eBird checklist** might record a few birds seen during a short stop at a pond or all the birds detected during a long walk through a forest, wetland, or neighborhood. For birders, eBird provides a personal archive of observations, life lists, trip records, and local birding history. For science, those same checklists become part of a much larger database documenting where and when birds occur.

The most valuable eBird checklists, both for birders and for science, are those that report all species the observer was able to detect and identify during a birding outing rather than incomplete checklists that note only the rarest or most unusual birds. Complete lists are far more useful to researchers because they help document not only which species were detected and how many individuals were counted but also which potential species went undetected. That information helps researchers distinguish places and times where a species was searched for, but not found, from records that simply report selected highlights. Counts of individuals help birders recognize local abundance patterns, migration pulses, and seasonal changes, while also allowing scientists to study relative abundance and population trends.

Other eBird checklist details have similar value. Date, time, and location help birders learn when and where to find species, and they allow researchers to map seasonal movements, habitat associations, and range shifts. Effort information, such as duration, distance traveled, and number of observers, helps birders compare one outing with another, and it helps scientists account for differences in how intensively people searched for birds.

The option to upload photographs, sound recordings, videos, and field notes adds another layer of value to eBird submissions. For birders, these materials document memorable observations and help confirm identifications. When media are uploaded through eBird, they are archived in the Macaulay Library and become part of a permanent scientific resource. A well-documented checklist therefore serves two purposes at once: it enriches the birder's own record of an encounter with birds, and it adds a more interpretable, verifiable, and useful data point to the broader study of bird distribution, abundance, migration, and environmental change.

organizations and institutions worldwide. Its importance comes from the way it turns individual birding observations into structured records that can be combined across places, seasons, and observers (**Box 1.1**).

For birders, eBird is a powerful tool for organizing and exploring their own past observations. Users can maintain **life lists**, track their sightings over time, and keep detailed records of their past bird encounters. The platform also helps birders explore recent sightings, identify productive **eBird hotspots**, and refine expectations about what species they might encounter, while the same checklist structure also makes these records useful for science.

In addition to tabulated bird checklist data, many participatory science platforms now incorporate multimedia records that capture different aspects of bird biology. Within eBird, observers can upload photographs, videos, and sound recordings as part of their checklists. These records provide direct documentation of species identity, behavior, vocalizations, and environmental context, and they often serve as verifiable evidence for unusual or rare observations. Because each media file is linked to a specific checklist, it is also accompanied by rich contextual information about when, where, and how the observation was made. This integration allows researchers to use these media resources in ways that extend beyond traditional field notes, enabling studies of vocal variation, molt patterns, behavior, and many other traits that can be extracted from archived recordings and images.

Beyond its utility to individual birders, eBird is structured to generate data that can be used for rigorous scientific analysis. Each checklist records not only which species were observed but also details about how those observations were made, allowing researchers to account for differences in detectability among species and habitats. As millions of checklists have accumulated, they have created a global dataset that documents patterns of bird distribution, abundance, and movement. Because these records are standardized, they can be analyzed using statistical models that account for the variability inherent in human observations.

The scientific and conservation impacts of eBird and similar initiatives have been substantial. Aggregated participatory science data have been used to map migration routes, estimate population trends, identify important habitats, and assess how bird distributions respond to environmental change. Importantly, these contributions arise directly from the efforts of individual observers, whose

eBird checklist: a digital record submitted to eBird that documents the birds observed at a particular place and time, often with associated information about effort and conditions.

Life list: the cumulative record of all bird species an observer has personally identified during his or her lifetime.

eBird hotspot: a publicly shared birding location in eBird where observations from multiple users are aggregated for a single site.

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collective participation connects their local birding activity with this global scientific enterprise.

Participatory science thus represents a convergence of observation, technology, and collaboration. By contributing even a single checklist or media record, a birder adds to a growing body of knowledge that supports research, conservation, and environmental decision-making. These projects enhance the birding experience itself, encouraging observers to be more attentive, systematic, and engaged with the birds around them.

1.3.5 Birding ethics and best practices

The general ethics of birding derive from the same foundations that guide our moral treatment of nature and of one another. Most organizations devoted to birders and birding codify these principles into widely shared guidelines that emphasize minimizing disturbance to birds and habitats, acting with honesty and integrity, and treating both people and places with respect. Although the details vary across contexts, these codes converge on a common set of expectations that place the welfare of birds first while recognizing that birding is embedded within broader ecological and social systems.

Ethical birding also includes a proactive commitment to conservation. Birders can contribute to the well-being of birds by supporting habitat protection, reducing human-caused threats such as window strikes or free-ranging domestic animals, and advocating for policies and practices that benefit bird populations (Chapter 15). In this way, birding becomes a platform for engaging with and supporting the natural systems that sustain birds.

When considering individual birds or bird populations, the ethical birder assigns a very high priority to the welfare of those animals, placing the birds' well-being higher than their own desire to view, photograph, or record them. They avoid disturbances that would cause birds to flush or otherwise deviate from their normal behaviors, especially when the birds are breeding or engaged in essential behaviors like foraging or displaying. Ethical birders also learn to recognize behavioral cues that indicate stress or disturbance, such as alarm calling, repeated flushing, distraction displays, or abrupt changes in posture or movement (**Figure 1.15**); when such responses to humans occur, it is a clear signal that the observer is too close and should withdraw. Birders should further be aware of situations where even brief disturbances might have large detrimental effects on the disturbed birds, such as interruptions to courtship displays, disturbances of nesting birds or at nesting colonies, or interruptions of feeding during unusually cold weather or as birds are fueling for a long migratory flight.

Feelings about the ethical use of audio playbacks of songs or alarm calls vary, but most modern birding guidelines emphasize strong caution. While some birders advocate avoiding playback altogether, others accept limited use under specific conditions, typically involving brief, infrequent playback in low-impact settings. Across these perspectives, there is broad agreement that playback should be used sparingly and with sensitivity to the welfare of the birds being sought. Meanwhile, it is widely acknowledged that audio playbacks should be avoided entirely in contexts where disturbance is likely to be cumulative or consequential, as in intensely birded sites that get a lot of human visitor traffic, or when they target particularly sensitive or endangered birds.



Figure 1.15 Distracting an observer from the nest. An Upland Sandpiper (*Bartramia longicauda*) will perform a broken wing display to draw predators away from her offspring. It also does this when a human observer gets too close. (Photo by Alex Lamoreaux ML29403761)

These same principles extend beyond playback to other aspects of birding technology. Approaching birds too closely to photograph or record them can be especially harmful for rare or threatened species. More broadly, actions taken to photograph birds that alter their behavior can compromise the very features that birding photographers seek to capture. Ethical bird photography and videography therefore require restraint, careful attention to signs of disturbance, and a willingness to forgo an image or clip when obtaining it would come at a cost to the bird.

When considering the habitats of birds, ethical birders are proactive about avoiding damage to that environment. They remain on trails and adopt a "leave no trace" approach to the greatest degree possible, avoiding trampling vegetation, minimizing disturbance to substrates such as beaches or wetlands, and taking care not to degrade sensitive habitats through repeated use or careless movement.

Birding ethics further involves the responsible collection and sharing of information. Birders contribute valuable data to scientific and conservation efforts, but this responsibility requires honesty and care. Observations should be reported accurately and with appropriate attention to identification certainty and documentation. At the same time, birders must consider whether sharing precise locations—especially for rare, threatened, or breeding birds—could lead to excessive disturbance. In such cases, it may be more ethical to

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Figure 1.16 Birding ethics. One aspect of responsible birding is to respect land-access rules and rights, both to avoid disturbing vulnerable birds and to maintain positive relationships with land managers and owners so that they continue to value birds like this Burrowing Owl (*Athene cunicularia*) that may be present on their property. (Photo by Charlie Trent ML640490285)

generalize or withhold location details in order to protect those birds.

In the human dimension, ethical birders consider the ways in which their actions might benefit or harm others. They know and respect laws and regulations related to birds and land use, and they never enter private property without permission (**Figure 1.16**). When birding far from home, they become familiar with and respect local customs and local bird knowledge, and they seek to give back economically to the places and their peoples that they visit. They also recognize that birding activity itself can affect local communities and landscapes; for example, widely publicized rare bird sightings can draw large numbers of observers, potentially creating pressures on access, parking, and landowner relations. They avoid disrupting the outdoor activities of others (birders or otherwise), they make space for fellow birders, and they share their own birding knowledge, sightings, and passion for birds. They also take care to respect personal privacy, for example, by avoiding directing binoculars or other optics toward people, homes, or private spaces.

Ethical birders understand that birding is a shared activity and take steps to make it welcoming and accessible to others, regardless of experience level or background. In group settings, experienced birders and trip leaders have an added responsibility to model best practices, ensure that group behavior does not unduly disturb birds or habitats, and help others understand and follow ethical guidelines. Most broadly, birders act as ambassadors for both birds and the birding community, and their behavior can influence how others perceive and engage with nature and conservation.

1.4 Museum collections and specimens

Museum collections assembled over the past two centuries underpin much of what is known about avian diversity. A few of the largest museum collections each hold more than 1 million bird specimens, others only a handful, but all are important for the record of avian diversity they preserve. These collections have played a major role in shaping our understanding of avian biodiversity. Many types of modern research depend on direct access to the information contained in physical specimens.

Bird specimen collections provide a direct record of biodiversity that documents which birds were present at particular times and places, along with a wide range of information about the birds themselves, such as the habitat they were found in, detailed features of their internal and external anatomy, and sometimes even the DNA content of each bird's entire genome. They enable studies that require comparisons among different types of birds, whether to understand the break points between different species, their evolutionary relationships with other avian groups, or their traits that vary in association with factors like bird age, sex, geographic location, habitat, and species. Bird specimen collections are thereby a resource used by many ornithological researchers and conservation professionals, as well as by students, teachers, and artists.

The creation and use of these collections also raise important ethical considerations. Modern museum curators frequently salvage birds that die from other causes, such as birds that collide with windows or vehicles, or that are caught incidentally in human activities, and convert them into specimens, but historically most specimens were collected intentionally for scientific purposes. The era of intensive scientific collecting, spanning roughly the mid-1800s to the mid-1900s, was sometimes associated with practices and perspectives that are now subject to critical reassessment. Today, the collection and use of bird specimens are governed by strict ethical guidelines, legal protections, and permitting systems that aim to balance scientific value with the welfare of bird populations.

Visitors to large museum research collections frequently ask: "Why do you need so many specimens? Wouldn't one or a few of each species be enough?" For some kinds of research, one specimen is indeed adequate, but for most scientific studies it is important to be able to measure the degree of variation in any trait of interest. For example, this broader sampling is important for any study that uses statistics to test whether two or more groups of birds are different from each other (**Figure 1.17**). Questions about geographic variation in traits require especially large numbers of specimens sampled across broad spatial scales. For example, a global analysis of body size variation in barn owls (genus *Tyto*) used measurements from more than 9,000 museum specimens spanning multiple continents to test whether body size

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Figure 1.17 Variation within a species. This series of round skin museum specimens of Red-winged Blackbirds (*Agelaius phoeniceus*) allows researchers to study how individuals of the same species differ in relation to age, sex, season, breeding location, and other factors. (Specimens from the Cornell University Museum of Vertebrates)



Figure 1.18 Standard research preparations of bird specimens. Unlike lifelike taxidermy mounts made for exhibit, research specimens are prepared in standardized forms that preserve different kinds of information. Shown here are examples including a round skin, a spread wing, skeletal elements, frozen tissue samples, and a whole bird preserved in fluid. (Specimens from the Cornell University Museum of Vertebrates)

follows Bergmann's rule, the tendency for animals to be larger in colder environments and smaller in warmer ones. This extensive sampling showed that the owls' wing length increases predictably with latitude and decreases with temperature (Romano et al. 2021). Similarly, a study of Blue-capped Manakins (*Lepidothrix coronata*) and Velvety Manakins (*L. velutina*) combined genetic data with measurements of plumage coloration taken from hundreds of museum specimens from more than a hundred localities to test how geographic distance and environmental variation shape variation among populations of these widespread and closely related species (Paulo et al. 2023). These kinds of studies depend on access to extensive specimen series that capture the full range of variation within a species.

A related question is: "You have so many specimens already; why do you keep adding more?" One answer is that birds and their distributions both change over time, and regularly adding new specimens allows researchers to study these changes, which is an important goal given how rapidly birds and their environments are changing owing to human causes (Rohwer et al. 2022). Another answer is that we can often glean more and better data from new specimens than from older material. Current specimen preparators are careful to record every aspect they can about a bird they convert into a specimen, whereas a label on a specimen from the 1800s might indicate only the country in which it was obtained. Modern specimens also are accompanied by new types of materials, such as frozen tissue samples, which allow types of analyses that are impossible with older samples. A final reason is that collections made today will empower research done in the future, likely on topics and with methods not yet invented. Just as today's researchers stand on the shoulders of past ornithologists who made collections in their time, future scientists will rely on materials added to collections in our current times.

1.4.1 Skin specimens

When people think of bird specimens in a museum, they often envision the taxidermy mounts in exhibit displays that show birds in realistic poses. These kinds of lifelike specimens are great for public exhibits, but they are difficult to store in large quantities; and they are not standardized in how they are prepared. Specimens made for research purposes do not have this lifelike posture. Instead, scientific bird specimens traditionally have been prepared in several standardized ways, including as skeletons, eggs and nests, or as whole specimens (including internal organs) preserved in alcohol or formalin (**Figure 1.18**). Among these options, **round skin specimens** that preserve the external parts of a bird are the most common in research museum collections. Across the different vertebrate groups, only birds have this preponderance of skin specimens; skeletons are the most abundant type of specimen in mammal collections, and whole animals preserved in alcohol are most numerous in fish, reptile, and amphibian collections.

In making a standard round skin bird specimen, a preparator removes most of the bird's internal parts, including the organs and muscles that would otherwise rot, leaving just the skin with its attached feathers, along with the beak, parts of the skull, and some of the bones of the wings and legs. The removed body parts are replaced with cotton

Round skin specimen: a preserved bird specimen prepared with the body, feathers, legs, wings, and bill intact, usually in a compact form used for study and comparison.

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Figure 1.19 Spread wing specimens. These spread wing specimens from the (top row) yellow-shafted and (bottom row) red-shafted forms of the Northern Flicker (*Colaptes auratus*) reveal details that would be largely hidden in the closed wings of a round skin specimen. For example, the top right wing has a few red-hued primaries feathers while being mostly yellow-shafted, and the top left and bottom right wings both have single molting and regrowing flight feathers. (Specimens from the Cornell University Museum of Vertebrates)

stuffing, and the opening (usually in the breast and belly area) is sewn back together. The specimen then is dried in a standard outstretched orientation, with the wings folded at the side and the bill pointing forward. Advantages of round skins include the ease of taking many standard measurements of structures such as the bill, wing, and tail, and the practical utility of housing many specimens together in one museum drawer.

Making a beautiful round skin requires practice and skill, and it is an artistic endeavor as well as a scientific one. Once dried, round skins are highly stable and can last for centuries: on opening a specimen drawer, it can be difficult to distinguish well-prepared round skins that are many decades old from those that were recently prepared. Moisture and insects are the greatest threats to round skins; and museum curators are careful to keep their specimens dry while being vigilant for any signs of carrion beetles or other insects that might destroy them.

One challenge with traditional round skin specimens is that they become permanently rigid once they are dried, such that wings dried in a closed posture can never be opened again. In a now-popular variant of the round skin specimen type, one wing is removed during preparation and pinned out by itself to dry in an outstretched orientation. These **spread wing specimens** are useful when researchers want to look at details of wing plumage patterning, feather molt sequences, or aspects of the wing shape and size that are important for aerodynamic performance (**Figure 1.19**).

In recent times, round skin specimens have become useful for an entirely different reason: because they were



Figure 1.20 DNA from extinct species. Although Bachman's Warbler (*Vermivora bachmanii*) has been extinct for more than a half-century, a tiny skin sample from this specimen collected in 1890 allowed researchers to sequence its entire genome (Byerly et al. 2024). (Specimens from the Cornell University Museum of Vertebrates)

usually not treated with chemicals or preservation agents, the dried skin still contains the full DNA genome of that individual bird. Using modern genomic methods, researchers can analyze that DNA by taking a tiny skin sample from the specimen. For example, the endangered Crested Ibis (*Nipponia nippon*) of eastern Asia was once numerous, but then declined close to extinction before recovery efforts brought its population numbers to over 2,000 individuals. Conservation biologists were curious about the impacts of this steep decline on the genetics of the species. Using DNA from specimens dating as far back as 1841, as well as DNA samples from living birds, they found that this ibis has lost close to half of the overall genetic variation once present in the species (Feng et al. 2019). While important for ibis conservation planning, this study also showcases a general principle about museum specimens: they frequently end up being used in ways that the original collectors could not have imagined, as with these early ibis specimens that long pre-date the discovery of DNA as the genetic material.

Even more poignantly, specimens of species that are now extinct provide the only genetic sources for studies of these birds that can no longer be sampled in the wild. For example, researchers extracted genomic data from museum skins of the extinct Bachman's Warbler (*Vermivora bachmanii*), which bred in cane thickets in the southeastern United States (**Figure 1.20**). Genomic analyses based on small tissue samples from century-old, preserved specimens revealed that this warbler had little population structure across its former range and likely experienced a rapid population decline just before its extinction (Byerly et al. 2024). Because direct field

Spread wing specimen: a preserved bird wing prepared in an open position so that the arrangement, shape, and condition of the wing feathers can be studied.

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observations of Bachman's Warblers were sparse, the genetic information archived within these museum specimens now provides the only means of reconstructing the species' population history.

Museum specimens can also provide a window into environmental conditions experienced by birds over long periods of time. For example, researchers analyzed methylmercury in the body feathers of Sooty Tern (*Onychoprion fuscatus*) specimens as well as wild birds spanning a 145-year period (Cusset et al. 2023). Through their position at the top of marine food chains (Chapter 14), seabirds like Sooty Terns tend to accumulate mercury in their bodies. Mercury concentrations in the feathers of these terns were almost 60% higher in the 2020s compared to the 1920s, reflecting the human-caused increase in mercury contamination of their environment over that same period.

1.4.2 Skeleton specimens

Skeleton specimens are also common in bird collections (**Figure 1.21**). Bird skeletons are delicate and require careful extraction methods to ensure that all the bones remain intact and undamaged. Specimens selected for skeletonization are often those that are unsuitable for round skins—usually due to decay or damage to feathers and soft tissue—or those that have been specifically requested, either by a researcher or for a collection.

There are many ways to remove the flesh and fat from the bones when making a skeleton specimen. Most institutions that regularly make this type of specimen use carrion beetles in the family Dermestidae to remove the flesh from a skeleton. Colonies of these flesh-eating beetles are easy to maintain and pose the least amount of risk to even the smallest bones. Other methods more suitable for preparing mammal skeletons, such as simmering bones in hot water, may cause damage to the more fragile bones of birds. Ironically, these dermestid beetles that museum curators use to make skeleton specimens are the very same types that they are most concerned about finding munching away in their skin collections.

After the beetles have completely cleaned the skeleton, it is removed from the beetle colony, frozen (to be sure that no live beetles hitch a ride into the museum collection), and placed in a new box. The box and largest bones are labeled with the specimen number, cataloged into the museum database, and placed into the museum collection to make it available to researchers.



Figure 1.21 Skeleton specimens. This skeleton specimen is from an American Flamingo (*Phoenicopterus ruber*). (Specimens from the Cornell University Museum of Vertebrates)

1.4.3 Eggs and nests

The study of eggs and nests is a specialized branch of ornithology termed **oology** (or **oölogy**). Egg collecting by both scientific oologists and amateur collectors was popular in Europe and North America in the late 1800s and early 1900s, leading ultimately to the vast egg collections now held by some major museums. The largest such collections in the world, each with over a million individual eggs, are in the Natural History Museum at Tring (UK) and the Western Foundation of Vertebrate Zoology in California (USA). Egg collecting as a hobby fell out of fashion in the 1930s, and today the collecting or possession of wild bird eggs is illegal everywhere except for scientific purposes under mandatory permits and approvals.

Fresh eggs are preserved as research specimens by drilling a small hole in the side of the egg and carefully blowing out the contents. A similar but more laborious process is used to remove embryos from eggs that have undergone partial development. As with all other types of avian specimens, eggs that are accompanied by detailed information on where and when they were collected are far more scientifically valuable than eggs that lack this contextual information. Egg specimens that are part of the complete natural clutch in which they were laid are also more valuable than single eggs that have become separated from the others in their clutch. Ornithologists use the term *egg sets* to refer to a group of two or more egg specimens that were originally from the same clutch.

One of the historically highest-profile uses of egg collections was in demonstrating how raptor declines in the 1950s and 1960s were caused by the agricultural pesticide DDT (Chapter 15). Ornithologists working with breeding raptors initially observed that these declines were coincident with a large increase in how often eggs broke as they were being incubated. By measuring Peregrine Falcon (*Falco peregrinus*) eggs collected before and after the widespread use of DDT, researchers documented a rapid decline in eggshell thickness

Oology (or **oölogy**): the scientific study of eggs.

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Box 1.2 CT Scanning and the Virtual Dissection of Birds

One of the great strengths of spirit specimens is that they preserve the whole bird, including many internal structures that are lost when a specimen is prepared only as a skin or skeleton. This makes spirit specimens especially valuable for studies based on computed tomography (CT) scanning, where X-rays taken from many angles are used to reconstruct a three-dimensional digital model of a specimen (**Figure 1**). Because spirit specimens retain the skeleton, muscles, organs, and other internal structures largely in place, researchers can use CT scans to examine this internal anatomy in ways that would otherwise require dissection, digitally slicing through the specimen in any plane and separating structures for study without permanently altering the specimen itself.

High-resolution CT scans of hummingbird syrinxes revealed how their vocal anatomy converges in functionally important ways with that of songbirds, including that they have multiple intrinsic syringeal muscles and paired sound sources. These discoveries help explain how hummingbirds produce their complex vocalizations (Riede and Olson 2020). Other studies have used CT scans of museum spirit specimens to investigate avian brain evolution, as in kingfishers where changes in brain shape are associated with lineages that have diversified especially rapidly, suggesting a relationship between brain evolution and lineage diversification (Eliason et al. 2021). CT imaging has similarly expanded the study of avian sensory systems: scans of the middle ears of more than a hundred bird species showed that diving and underwater-foraging birds possess distinctive anatomical modifications associated with amphibious hearing and protection from pressure changes (Zeyl et al. 2022).

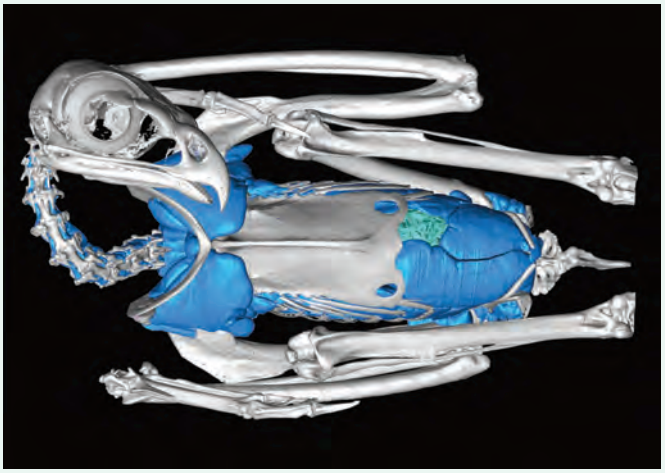


Figure 1 CT scanning of spirit specimens. This segmented 3D digital model depicts the respiratory system of a Red-tailed Hawk (*Buteo jamaicensis*) in blue. It was assembled from microCT scans of a spirit specimen of that species. (Image courtesy of Emma R. Schachner)

Many of the scans from these and hundreds of other studies are now archived in online repositories, where they can be downloaded and reanalyzed by researchers around the world. Because CT scanning creates reusable digital models, these data can also reduce repeated handling of rare or fragile specimens while making anatomical information more widely available to researchers, students, and educators. In this way, spirit specimens prepared for traditional museum collections continue to gain new scientific value.

(Ratcliffe 1967). Later research confirmed that this pesticide interferes with calcium metabolism in many raptors and that eggs with the highest DDT levels had the thinnest shells. This discovery was pivotal to the widespread banning of DDT and the subsequent slow recovery of species like these falcons, multiple species of eagles, and Ospreys (*Pandion halieatus*).

In contrast to the great number of eggs in museum collections, specimens of nests are underrepresented, partly because nests come in so many forms (Chapter 11), some of which are difficult to collect and store: imagine, for example, the challenges of moving and archiving a massive eagle or Hamerkop (*Scopus umbretta*) nest the size of a small car. Nests to be archived in museums are first treated (often by repeated freezing) to kill any insects remaining within the nest, then labeled, and stored in boxes.

1.4.4 Spirit specimens, tissues, and other collection types

Whole birds preserved in alcohol, which are formally termed **spirit specimens** but often informally referred to as *pickles* by museum personnel, are the third common type of bird specimens after skins and skeletons. The primary advantage of spirit specimens is that the entire body of the bird is preserved, making it available for later dissection or scanning to examine anatomical details. Spirit specimens are particularly valuable as subjects for modern three-dimensional imaging studies using computed tomography (CT) scanning technologies, in which the anatomical components of the bird and their physical connections can be reconstructed and viewed in considerable detail (**Box 1.2**).

To make a spirit specimen, a fresh bird carcass is typically treated with a solution of formaldehyde and water (formalin) in a process termed *fixing*. Before submerging the specimen in this same solution, formalin is injected into the major muscles and body cavities using a syringe to ensure that it penetrates the internal tissues before they start to decay. This step of initially fixing the specimen with formalin

Spirit specimen: a whole bird or bird part preserved in fluid, usually alcohol, so that soft tissues and internal structures remain available for study.

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creates chemical cross-links in the proteins within the muscles and other tissues, making them firmer to the touch and far more resistant to degradation over long-term storage. A downside of formalin is that it destroys DNA, so current preparators usually take a separate tissue sample before starting this fixing process. After resting in the formalin solution for a few days, the specimen is washed in water, then moved through a series of solutions of increasing ethanol concentration, ending up for permanent storage in 70% ethanol. Spirit specimens prepared in this way are stable indefinitely for decades or even centuries, with the major risk being drying out if the ethanol solution evaporates.

Starting in the 1980s, it became standard practice to archive a tissue sample from most newly prepared bird specimens in ways designed to preserve the DNA in those materials. Most commonly, tissue samples are initially placed in liquid nitrogen and then archived in very cold (–80°C) freezers, as freezing is the most reliable method of keeping DNA intact. When freezing is not feasible, tissues are instead preserved in ethanol or special liquid buffer solutions. Even though genetic material can be obtained from many dried skin specimens, the DNA in these tissue samples is typically less degraded and far easier to work with in the laboratory. These avian tissue collections have enabled many modern studies of avian relationships, from fine-scale differences among populations of the same species to the grand tree of life that connects all living birds (Chapter 2). All museums with substantial bird collections now maintain a parallel tissue collection, with the largest being curated at the Museum of Natural Science at Louisiana State University (USA).

Additional types of physical specimen materials are sometimes archived in museums, usually in association with targeted research projects. Possibilities include samples of external parasites like feather lice and hippoboscid flies, internal gut parasites such as tapeworms, and blood smears used for detecting avian malaria parasites. The undigested food contents of the crop and gizzard are sometimes preserved in alcohol for diet studies. Individual plucked feathers are useful as DNA sources and for their isotopic signature of the location where they were grown.

1.4.5 Digital and extended specimens

Avian specimens are no longer limited to the manifestations of birds that can be preserved and stored in physical form like skins, skeletons, fluid specimens, and such. These traditional types of specimens are now frequently complemented by digital-only information types that can also be considered specimens, including sound recordings of songs, photographs of birds, videos of bird behavior, and various digital outputs of research methodologies like CT scans and genome sequences. These digital specimens capture aspects of the individual's phenotype, such as communication signals and other behaviors, that are not captured in traditional physical specimens.

These specimen components, both the physical specimens and their digital counterparts, can be integrated together under the concept of an **extended specimen** (in other words, an extended collection of different types of specimen materials all from the same individual bird). For example, a round skin specimen of a songbird (the most traditional bird specimen type) might now be complemented by a separate spread wing specimen, a frozen tissue specimen, parasite specimens collected from the bird at the time of preparation, and the preserved gut contents of what it had recently eaten when it died. Extending into the digital realm, the same specimen also might be augmented by audio files of the songs of that bird that were recorded while it was still alive, photographs or videos of the live bird or of the precise habitat in which it was found, or genomic datasets derived from DNA-based analyses, among many possibilities (Webster 2017).

This extended specimen approach reflects how modern research both relies on and generates a range of specimen materials that collectively contribute to a more comprehensive understanding of bird biology. Integrating across these multifaceted types of specimens enables ornithologists to address complex scientific questions that cannot be addressed using physical or digital specimens alone. It is important to recognize that all components of an extended specimen have potential research value by themselves, but they have even more value when they are linked to other specimen types that provide different types of information. In general, extended specimens that are backed by one or more physical specimens are **vouchered**, as they are associated with materials that can be handled, measured, or assayed in ways that can help confirm their identity. Vouchered specimens remain the gold standard for areas of ornithological research like taxonomy and phylogenetics.

1.5 Ornithological research techniques

People who study birds in a scientific context have developed a powerful and varied set of methods and approaches. Birds themselves are so diverse that no single study technique can ever serve all purposes for all species. This section covers some of the more frequent methods; but new techniques are constantly being invented by creative researchers, and the technologies that underly these approaches are also steadily evolving. We know more about birds now than ever before, but there is still so much to discover.

When considering any scientific project or approach to studying birds, it is essential to know that across the entire

Extended specimen: a preserved specimen linked to additional materials or data, such as tissues, recordings, images, parasites, or ecological metadata, that broaden its research value.

Vouchered: Documented by a preserved specimen, image, recording, or other verifiable evidence that supports the identity or occurrence of an organism.

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world all wild birds are protected by local and national laws, policies, and regulations. Permits (and often more than one) are required to capture, handle, mark, tag, or sample birds; to move birds or bird samples across political boundaries; and often even just to observe birds from a distance, access the places where they are found, purchase ornithological equipment like mist nets, or be in the possession of nests, feathers, eggs, or live or dead birds. The legal penalties for violating these laws can be severe, so an anticipatory early step in any avian research program is to ensure that all requisite approvals and documents are in place and fully compliant.

1.5.1 Capturing, handling, and marking wild birds

Many research questions in ornithology require that wild birds be captured, measured, sampled, marked, and released alive. These activities allow researchers to collect standardized, individual-level data on birds that cannot be obtained in other ways. Because capture and handling involve direct interaction with wild animals, they always require specialized training in proper techniques.

Mist netting is the most widely used method for capturing small and medium-sized birds (**Figure 1.22**). Mist nets are made of a mesh of fine black threads that are nearly invisible when shaded and not moving in the wind. They are stretched between poles so that birds flying into them fall into loose pockets and become temporarily entangled. Nets are often positioned along flight paths, habitat edges, or areas of high bird activity, and they may be used either in standardized, repeated sampling schemes or in targeted efforts focused on capturing particular species or even specific individual birds. Most research projects use mist nets at ground level, but it is also possible to use ropes to suspend them high in a forest canopy to capture birds that stay at that level. Extracting birds tangled in mist nets is a core skill learned by many field ornithologists, one that requires attentive coaching and lots of practice to master.

Many mist-netting efforts are conducted at established banding stations, where standardized protocols are used to capture and process birds. These stations may operate during migration or during breeding seasons and can generate long-term datasets that help researchers track changes in species' abundance across years or decades. One such framework is the Monitoring Avian Productivity and Survivorship (MAPS) program, which coordinates a network of hundreds of banding stations across North America, each using standardized methods to estimate vital rates such as survival and reproductive output. This kind of coordinated survey program allows data collected at individual sites to be integrated into large-scale analyses of population trends.

Many other trapping methods are used to capture birds that are not readily netted. Baited traps are commonly used for ground-feeding birds, while walk-in traps can be effective for some waterfowl and shorebirds. Noose carpets are used to capture raptors, and cannon or rocket nets are sometimes deployed to capture flocks of birds in open habitats. Each such method is designed to match the behavior and ecology of the target species, and researchers select among them based on the goals of their study and the logistical constraints of their field setting.

Once a bird is captured, careful handling allows researchers to collect a wide range of standardized biological measurements from the bird in the hand (**Figure 1.23**).

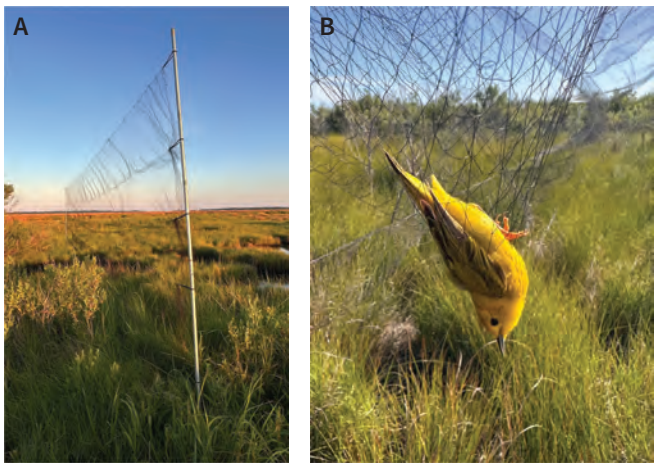


Figure 1.22 Mist netting as an ornithological technique. Many avian research and monitoring projects use mist nets to capture small and medium-sized birds. (A) These nets are stretched between two poles, and under good conditions they are nearly invisible to birds that are flying toward them. (B) Birds that hit the net, like this male Northern Yellow Warbler (*Setophaga aestiva*), fall into a pocket until they are untangled and removed by an experienced field researcher. (Photos by Irby Lovette)



Figure 1.23 Measuring wild birds. The wing length of this male Red-winged Blackbird (*Agelaius phoeniceus*) is being measured after the bird was captured in a mist net. After being measured and banded, it will be released back onto its territory. (Photo by Irby Lovette)

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These measurements commonly include morphometric data such as wing and tarsus length, bill size, and body mass, as well as assessments of fat reserves, muscle condition, and molt status. Because these measurements can be taken consistently across individuals and studies, they provide a basis for comparing variation within and among populations and years.

Many captured birds can also be aged and sexed using a combination of anatomical, plumage, and physiological characteristics. Age determination often relies on features such as skull ossification, molt limits, or feather wear. Ages estimated in these ways usually do not generate an exact chronological age but instead can distinguish between birds in their first or second years from older individuals. In many species, sex can also be discerned through plumage differences, body size, or the presence of reproductive structures such as a brood patch or cloacal protuberance (Chapter 6). In some species these distinctions are straightforward to assess, while in others they require considerable experience or may not be possible at all.

Marking individual birds allows researchers to follow them through time and space. By far the most common approach involves placing a lightweight aluminum band (alternatively termed a *ring* in some parts of the world) on the bird's leg. Bands are engraved with a unique numerical code that can be reported if the bird is later recaptured or found dead. In some banding studies of populations that are being followed closely, each bird is also outfitted with unique combinations of plastic, colored bands that allow individuals to be recognized visually from a distance (**Figure 1.24**). Other types of marking tags are sometimes used on large birds, including numbered neck collars for geese and swans, and numbered wing tags on large raptors.

Data derived from marked individuals underpin many long-term and large-scale studies of bird populations. By tracking individuals across years, researchers can estimate factors like survival rates, dispersal distances, individual differences in behaviors, and reproductive success, and can explore how these parameters vary with age, environment, or changing conditions. Large, coordinated efforts, such as continent-wide banding programs, extend these insights across broad geographic scales, revealing patterns that would be difficult to detect through smaller, localized studies.

Handling birds also provides opportunities to assess aspects of health, physiology, and ecological interactions. Researchers may examine birds for external parasites, collect samples to test for pathogens, or evaluate overall condition as an indicator of environmental quality. In some cases, small blood or tissue samples are collected to support genetic or physiological analyses.

Because capturing and handling birds carries risks for birds, these activities are governed by strict ethical guidelines, extensive training requirements, and legal permits. Researchers must be trained in safe extraction and handling techniques to minimize stress and injury, and all capture activities are conducted under regulatory frameworks designed to protect both individual birds and populations. Careful attention to these considerations ensures that the scientific value of capture-based studies is balanced with the welfare of the birds involved.

1.5.2 Scientific bird survey methods

The **point count** is the most widely used traditional survey technique for estimating bird populations and assessing species diversity in communities of landbirds (**Figure 1.25A**).

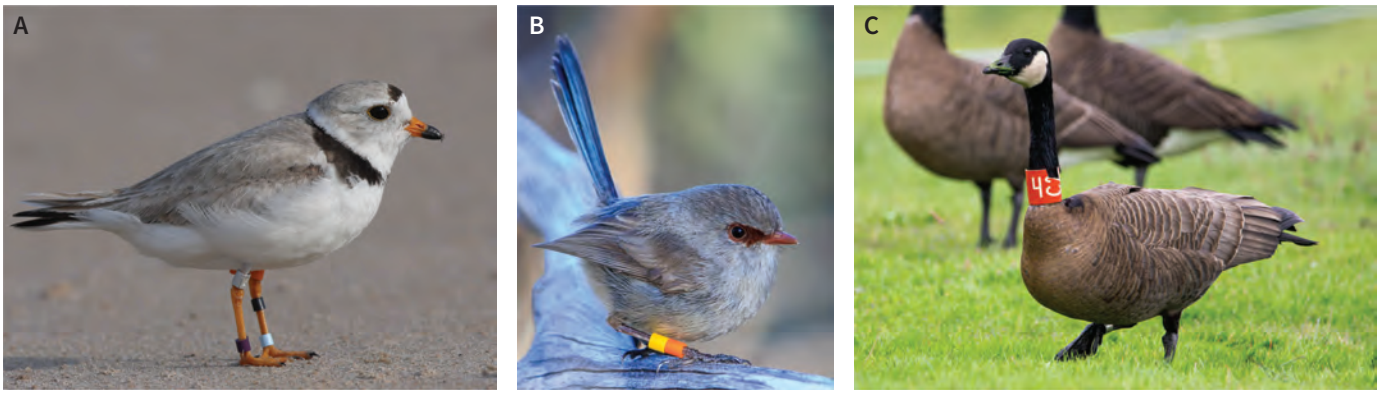


Figure 1.24 Banding and marking. Marking individual birds allows researchers to recognize them after release and to build records of movement, survival, reproduction, and behavior. (A) Lightweight leg bands on a Piping Plover (*Charadrius melodus*) include both a uniquely numbered metal band and colored bands that can be read visually. (B) Color band combinations on other small birds, such as this Purple-backed Fairywren (*Malurus assimilis*), allow individuals to be identified from a distance without recapture. (C) Some larger birds, such as this Canada Goose (*Branta canadensis*), can carry numbered neck collars that are visible at greater distances. Together, these and similar marking methods allow later resightings, recaptures, or recoveries to be linked back to known individuals. (Photos by [A] Matthew Brown ML463973631, [B] Michael Stubblefield ML595706551, [C] Mason Maron ML643579205)

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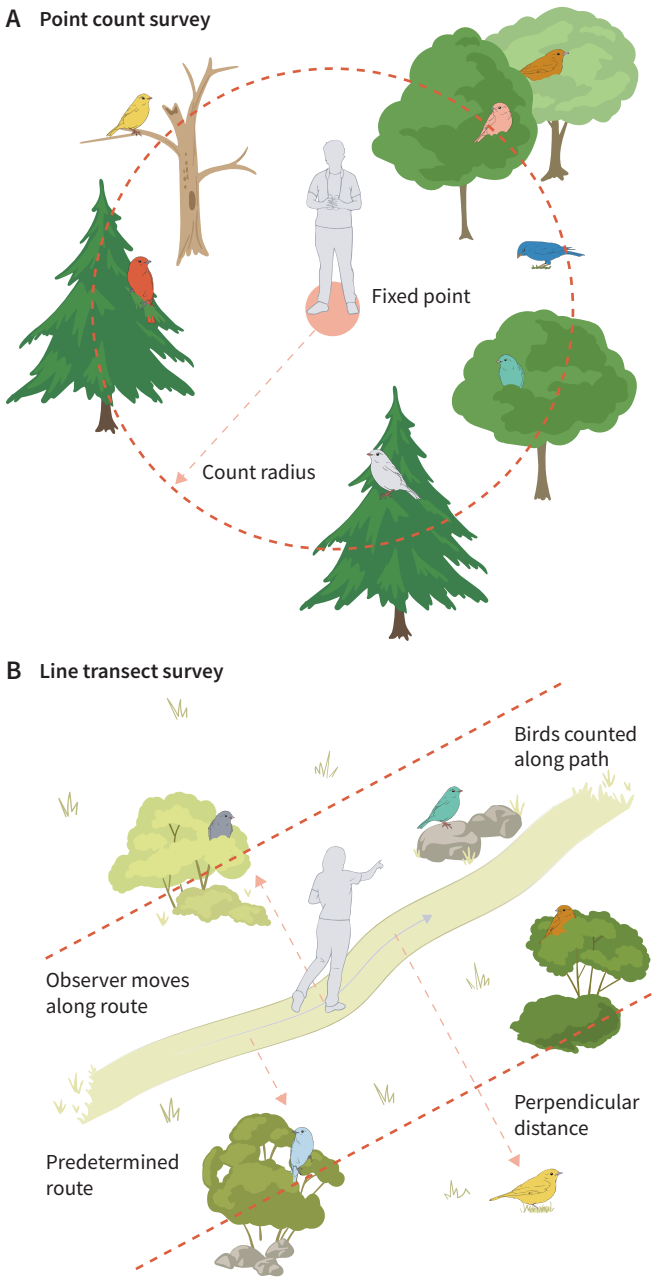


Figure 1.25 Point count and line transect surveys. (A) In a point count survey, an observer records birds seen or heard from a fixed location during a standardized time period, often within a specified count radius. Detection usually declines with distance from the observer. (B) In a line transect survey, the observer moves along a predetermined route and records birds detected on either side of the path, sometimes also measuring each bird's distance from the transect line. (Illustration by Charlotte Holden © Cornell Lab of Ornithology)

Point count: a field survey method in which an observer records birds detected from a fixed location during a standardized period of time.

Line transect: a field survey method in which an observer records birds detected while moving along a defined route.

There are many types of point counts that vary in the nuances of how they are implemented, but fundamentally they all involve an observer recording the birds detected from a fixed location (the *point*) within a predetermined period, which is usually relatively short (observation durations of 5–15 minutes are typical). Point counts are particularly useful in habitats where dense vegetation or rugged terrain makes transect surveys impractical, and where many birds are detected by hearing their songs or calls. Point counts done as part of scientific projects are standardized in duration and the time of day at which they are conducted.

The simplest version of a point count is one where the observer records all birds detected, regardless of their distance. The next level of refinement includes point counts that assess birds only within a predetermined circular area, such as 50 or 100 meters in radius around the observer, within which all birds are recorded; yet this method still does not account fully for how much detection probability usually varies among bird species, even within the same habitat. A species that commonly flies or forages in the open, or that has loud calls or conspicuous display behaviors, is likely to be detected far more often and at a greater distance than a more cryptic species that generally stays hidden in the vegetation or that has inconspicuous songs or displays, even if both species are present in similar numbers. Sophisticated point count methodologies adjust for detection effects by adding in a detection probability scaling factor for each species, or by accounting for the distance to each detected bird, or by varying the count radius depending on the detectability of potential species.

The choice of a particular point count method depends on the kinds of detection biases that are likely to arise for the species, habitats, and research question being studied. A study of bird communities in non-native Norway spruce plantations, for example, used point counts to compare avian assemblages in non-native conifer plantations with those in native forest types in Massachusetts (Ritter et al. 2023). Because apparent differences among forest types could reflect either real differences in bird abundance or differences in detectability, the researchers modeled detection while accounting for covariates such as observer, date, time of day, distance to noise sources such as streams or roads, and habitat type. This approach allowed them to evaluate habitat associations while reducing the risk that patterns in the count data were artifacts of survey conditions. The study found that Norway spruce plantations supported bird richness similar to native forest habitats and were used by several native conifer-associated species, illustrating how carefully designed point counts can connect field detections to broader ecological inference.

Line transect survey methods differ from point counts in that the person conducting the survey moves along a

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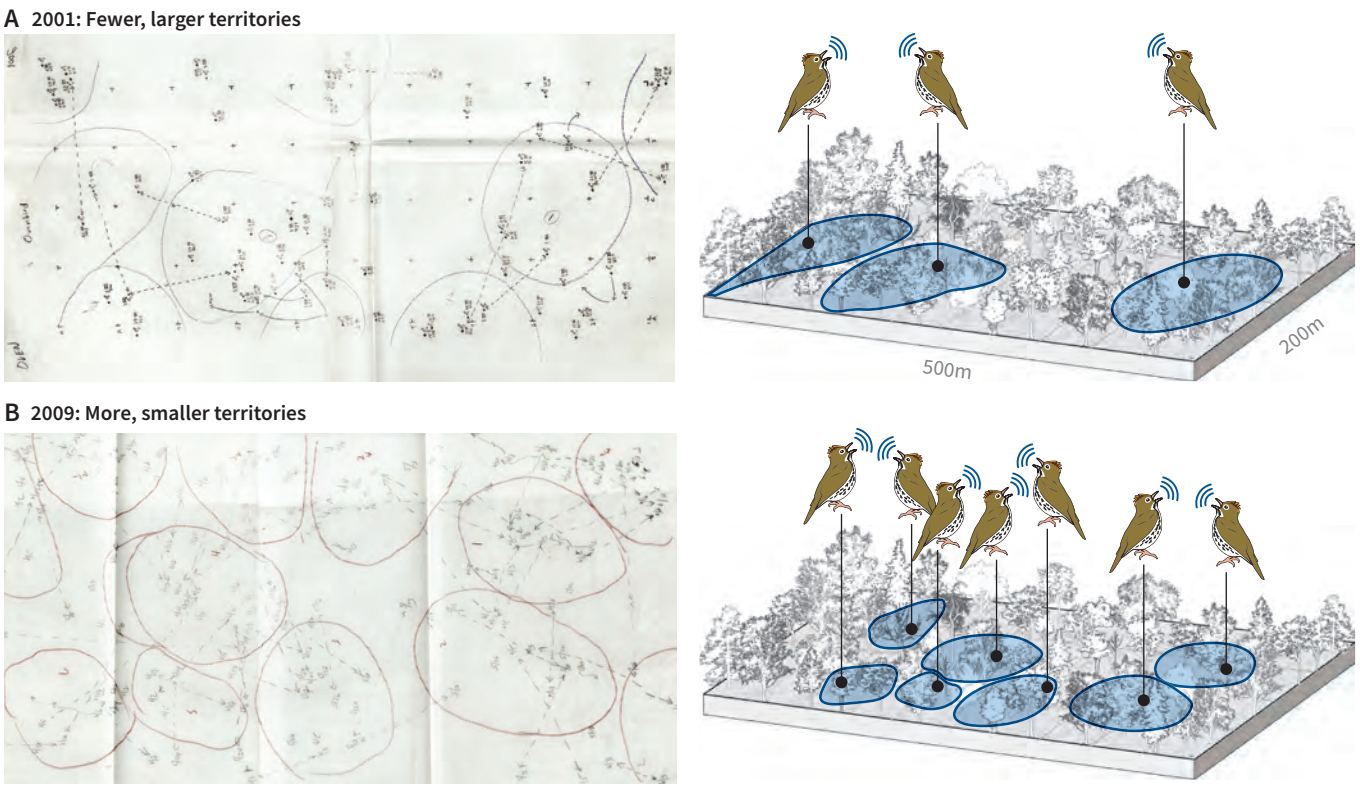


Figure 1.26 Spot mapping. Historical spot-map sheets from the Hubbard Brook Experimental Forest show how observers recorded Ovenbird (*Seiurus aurocapilla*) locations, countersinging interactions, and inferred territory boundaries. The density of this species changed over time from (A) 2001, when Ovenbirds held fewer, larger territories, to (B) 2009, when their higher local abundance was associated with smaller territories. (Photos by Miranda Zammarelli. Illustration by Jillian Ditner © Cornell Lab of Ornithology)

predetermined path during the survey period, counting the birds they detect along the way (**Figure 1.25B**). Most of the analytical considerations that apply to point counts are also relevant to line transects, and researchers use many of the same methods to account for them, such as estimating the distance between the transect line and the location of each detected bird.

Spot mapping is another methodological survey approach where all locations, movements, and interactions of individual birds are marked on a map of the study area (**Figure 1.26**). This is a finer and more detailed type of survey than point counts and transects, with spot mapping allowing researchers to collect density estimates for a species as well as valuable natural history data on topics like territories, nest locations, and intraspecific interactions. The more observer-intensive time demand of spot mapping, however, makes it less feasible on a large scale. Even so, such intensive mapping can generate unusually rich datasets, as in a repeated spot mapping project on a 10-hectare forest plot in New Hampshire (USA) that showed how territory sizes of Ovenbirds (*Seiurus aurocapilla*) decreased as their local abundance increased (Zammarelli et al. 2024).

Some powerful bird survey approaches combine the point count and line transect methods by stringing a series of individual point counts along a predetermined transect route. This combined method underlies the influential North American Breeding Bird Survey (BBS), a continent-wide survey program that has been ongoing since 1966 in Canada and the United States (**Box 1.3**).

Point counts and transects are most often applied to terrestrial birds; other types of birds are censused using a wide variety of other methods. Birds that nest in the open in large colonies—like some penguins, albatrosses, gannets, and terns—can sometimes be counted from photographs or videos taken from above the colony, these days often by a flying drone (**Figure 1.27**). Cranes, geese, swans, and other waterfowl are often censused by human observers flying in planes or helicopters. Migratory raptors are counted at locations where the topography tends to concentrate them during their annual movements. Meanwhile, motivated researchers

Spot mapping: a field method in which repeated observations of individual birds or territories are plotted on a map to estimate territory locations, breeding density, or local distribution.

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Box 1.3 The North American Breeding Bird Survey

The North American Breeding Bird Survey (BBS) is one of the longest-running and most influential bird monitoring programs in the world. Coordinated jointly by the US Geological Survey and the Canadian Wildlife Service, the BBS was established in 1966 to provide a standardized approach to tracking changes in the abundance and distribution of breeding birds. The survey was designed around a relatively simple but highly repeatable protocol: skilled observers conduct fixed roadside surveys during the breeding season, recording all birds detected by sight or sound at a series of standardized stops. The BBS has generated one of the most valuable long-term datasets in ecology by combining broad geographic coverage with consistent methods repeated annually over decades.

Each BBS route follows a fixed roadside transect of 25 miles (approximately 40 kilometers). Along that route, observers stop at 50 designated survey points spaced a half mile (0.8 kilometers) apart. At each stop, the observer conducts a three-minute point count during which every bird heard, and every bird seen within a 400-meter radius, is recorded. Surveys begin 30 minutes before local sunrise and take about five hours to complete. Routes are surveyed once each year during the local breeding season, and many routes have now been surveyed annually for decades. Because most detections involve birds heard rather than seen, observer skill in identifying bird vocalizations is essential for maintaining data quality and consistency.

The BBS combines elements of both point count and line transect methods. The observer travels continuously along a transect route, but data collection occurs through a sequence of stationary point counts. This design allows the survey to sample many habitats efficiently across large areas while maintaining standardized observations at each stop. Because the survey uses roads as access corridors, however, it also introduces potential sampling biases. Roads may pass disproportionately through developed habitats or habitat edges, and some bird species avoid roads while others may be attracted to them. Researchers therefore must account for these limitations when interpreting BBS results, often combining BBS analyses with additional survey methods or statistical approaches that factor in aspects of detectability and habitat representation.

One of the major strengths of the BBS is its emphasis on long-term standardization. Each three-minute count provides only a brief and incomplete sample of the birds present near that stop, and individual counts vary with weather, observer skill, habitat structure, time of season, and bird detectability. Yet the enormous spatial and temporal replication of the BBS allows researchers to identify broad-scale trends with considerable statistical power. Modern analyses of BBS data often use hierarchical models and other advanced statistical methods to estimate population trajectories, while accounting for sources of variation among routes, years, regions, species, and observers. Because this same survey framework has now been repeated annually for more than half a century, the BBS provides an unusually powerful record of ecological change at a continental scale.

The long-term consistency and broad scale of the BBS have made it a foundational resource for studying broad patterns of ecological change in North American birds. For example, analyses that combined BBS population trajectories with additional demographic and population-size data estimated that North America has lost nearly 3 billion breeding birds since 1970, including substantial declines among many once-common species (Rosenberg et al. 2019). Other studies have used increasingly sophisticated analytical approaches applied to BBS data to examine not only whether bird populations are declining but also whether the rates of declines are changing through time. These analyses identified regions in which bird losses appear to be accelerating, particularly in parts of the Midwest, mid-Atlantic, and California associated with intensive agricultural land use and warming temperatures (Leroy et al. 2026). These and the many other scientific contributions made using BBS data reflect the broader importance of long-term ecological monitoring programs for understanding how bird populations respond to environmental change.

around the world have devised many innovative ways of censusing and monitoring birds with traits that make the more standard methods unreliable.

The analytical toolbox for understanding bird distributions, abundances, and population trends is also becoming ever more powerful. Data on birds derived from many sources—citizen science inputs like eBird, traditional scientific survey approaches, and bioacoustic or other sensors—can now be analyzed in concert with many other types of habitat and environmental information, using a variety of sophisticated modeling approaches. These advanced models are becoming highly accurate at predicting where bird species are found. In situations where information has been gathered over decades, these models are becoming similarly powerful at discerning trends in where particular bird species are increasing or declining.

Bioacoustic sensors are rapidly becoming an important extension of traditional bird survey methods (**Box 1.4**). **Autonomous recording units** (**ARU**) can be programmed to record sound at a fixed location, allowing researchers to sample vocal activity for far longer periods than a human observer could remain in the field. This makes them especially useful in remote areas, at night, and in habitats where many birds are more often heard than seen. When deployed singly or in

Autonomous recording unit (or **ARU**)**:** a field-deployed acoustic device used to record bird vocalizations and other environmental sounds for later identification, monitoring, and analysis.

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Figure 1.27 Aerial surveys of colonial seabirds. Photos taken from above can be used to count the number of active nests or breeders in colonies of seabirds that aggregate in open areas. In this image taken via a drone, the regularly spaced black-and-white birds are adult King Penguins (*Aptenodytes patagonicus*), each incubating an egg on its feet while standing just out of pecking range of adjacent birds. The brown individuals are King Penguin juveniles hatched the previous year that have not yet left this nesting area. (Photo by Gemma Clucas)

arrays, ARUs can help document species presence, seasonal activity, occupancy, and population change; although estimates of abundance and density require careful interpretation because the recorders detect sounds rather than birds directly. Rapid advances in automated sound classification are making it possible to process increasingly large acoustic datasets, while also underscoring the need to validate automated identifications against field knowledge and expert review.

1.5.3 Monitoring reproduction

Many ornithologists closely monitor the reproduction of their study species as a core aspect of their field projects. Variation in reproductive success is a major determinant of avian fitness and thereby central to many questions about bird behavior and ecology (Chapter 3). It also plays a key role in population dynamics, which depend on how many young birds are produced each year (Chapter 13).

Methods for monitoring reproduction vary depending on the species and its breeding system, along with the needs and goals of a given research project. Researchers generally monitor reproduction at one of three levels: nest-based, territory-based, or colony-based. Nest-based studies usually yield the most detailed data on individual breeding attempts, while territory- and colony-based approaches allow researchers to scale up to broader estimates of breeding density and population-level reproductive output.

Nest monitoring is the most direct way to quantify reproductive success. Many of the most extensive and long-running studies of nesting songbirds focus on secondary cavity-nesting species that readily nest in artificial nest boxes (**Figure 1.28**). Artificial nest boxes make it possible to locate and revisit nests with ease, which is why they underpin many of the most detailed long-term studies of breeding birds. Researchers can access these boxes to track each breeding attempt and to monitor entire local nest-box-breeding populations consistently across years. Nest-box-based studies have provided some of the most detailed insights into clutch size, hatching success, parental care, and fledging success. Birds that have become model study species partly for this practical reason include the three species of bluebirds (genus *Sialia*), Tree Swallows (*Tachycineta bicolor*), and several chickadees (genus *Poecile*) in North America, and the Great Tit (*Parus major*), Eurasian Blue Tit (*Cyanistes caeruleus*), and European Pied Flycatcher (*Ficedula hypoleuca*) in Eurasia.

For species that do not use nest boxes, monitoring reproduction requires first locating active nests, a field task that can range from straightforward to extremely difficult depending on the species and its habitat. This is easiest for species that nest conspicuously. Examples include raptors like Ospreys (*Pandion haliaetus*) that build large stick nests in open sites such as treetops, poles, or platforms; thornbirds (family Furnariidae) that construct huge or well-defended nests; and Northern Gannets (*Morus bassanus*) and many other seabirds that breed colonially on islands with few land predators.

Because nest predation is such a strong selective pressure, many species nest in ways that make their nests difficult to find, both in location and in behavior. To find these better-hidden nests, parent birds can be followed as they carry nesting material while building or as they carry

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Box 1.4 Acoustic Monitoring as a Bird Survey Tool

To understand the ecology of a bird population, ornithologists often need to know where the birds occur, how many are present, and which species are part the local avian community. This information helps researchers track population changes, identify important habitats, and inform conservation decisions. Because many bird species are easier to detect through their songs or calls, point counts conducted by human field biologists have traditionally been used to survey bird communities. Standard point counts also have limitations: they require skilled observers and listeners, they are usually restricted to short sampling periods, and they depend on which birds are detectable during the brief interval when an observer is present. They also tend to be implemented in more easily accessed places, as along roads or trails.

Autonomous recording units, or ARUs, are a core tool in an alternative approach termed passive acoustic monitoring (PAM). ARUs allow researchers to record sound automatically at fixed locations. These weatherproof devices can be programmed to record on a set schedule, making it possible to sample bird communities for many days or weeks without a human observer being present at all.

ARUs reduce some of the logistical constraints of traditional surveys, but they also introduce new analytical challenges. The use of these recording units can minimize immediate human disturbance, the units themselves can be placed in more remote locations and other places that are difficult to monitor, they increase the spatial and temporal scale of population monitoring, and they offer a level of data-collection repeatability and scope that would be impossible to achieve using individual human observers. Data from the recordings can additionally be archived for future use and reanalyzed later. All these features make ARUs especially useful for documenting vocal activity and estimating species presence, occupancy, seasonal timing, and species richness. But, they are less straightforward for estimating abundance and density, because an ARU records sounds rather than counting individual singing birds. ARU detections also depend on whether birds vocalize and on the accuracy of human or automated species identification based on sounds made by those birds. Automated classifiers can help process large archives, but their outputs still require human calibration and validation because false positives and false negatives can vary among species, habitats, seasons, and recording conditions.

A study of arctic-breeding shorebirds illustrates both the value and the trade-offs of this approach. Researchers compared data from ARUs deployed in remote regions of Alaska's Arctic Coastal Plain with those collected through more traditional surveys of shorebird populations. They found that ARUs detected 33–50% higher species richness compared to the human surveys and that the recorders required fewer plots to detect the maximum number of species. These results reflect one of the main strengths of ARUs: they can sample repeatedly at fixed sites, increasing the chance of recording vocal species. Yet some rare species were detected in the visual surveys and not in the ARU surveys. These differences highlight some of the trade-offs with ARUs: they can increase survey coverage in remote landscapes, but they do not entirely replace the value of trained observers, especially for species that are quiet, rarely vocal, or more easily detected by sight.

Perhaps the most significant ongoing challenge with ARUs is that while identifying bird species based on sound alone is itself a complex analytical puzzle, differentiating acoustically among individual birds of the same species is even harder. ARUs can provide a census of bird species in an area, but estimates of the density of each such species require that those individuals be identified acoustically. Overcoming this limitation is a frontier in ARU-based research. One approach to counting individuals is based on how each bird's position in space influences how its sounds are recorded by an ARU, building models to account for distance, background noise, and song rate. Researchers are also developing and validating methods that use individual differences in vocalizations, multiple microphones, sound levels, call rates, and the timing of sound arrival at different recorders to estimate the locations and identities of vocalizing birds.

For example, one study of Eurasian Bitterns (*Botaurus stellaris*) employed an array of recorders during five years of continuous monitoring (Frommolt and Tauchert 2014). By estimating the time difference of arrival of acoustic signals to each ARU, the researchers mapped the location of each calling bittern and tracked changes in the number and spatial distribution of vocalizing males through time.

food for their nestlings later in the season. Researchers may also position themselves near likely nesting areas and watch for birds that repeatedly disappear into the same area of vegetation. Finding nests during the incubation period can be especially difficult, as incubating birds generally remain still for long periods. Some birds have subtle behavioral cues, such as vocalizations when leaving the nest or during food transfers between mates, that can aid in locating their nests.

Once nests are located, repeated monitoring allows researchers to quantify key components of reproductive success, including clutch size, hatching success, and fledging success (Chapter 13). Nests found early in the nesting cycle provide the most complete information on these patterns of success or failure. Most such studies employ standardized monitoring protocols, including regular but carefully timed nest checks, to allow consistent comparisons across studies and years. Tools like temperature data loggers can also be

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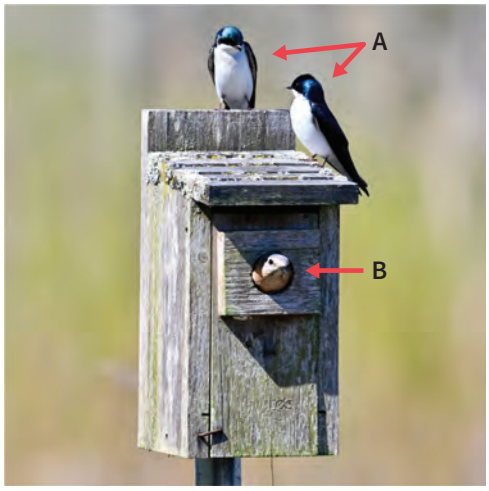


Figure 1.28 Nest monitoring using artificial nest boxes. Artificial nest boxes make the breeding attempts of secondary cavity-nesting birds easier to locate and monitor throughout the nesting cycle. They also create opportunities to study competition for limited nest sites, as in interactions between (A) Tree Swallows (*Tachycineta bicolor*) and (B) Eastern Bluebirds (*Sialia sialis*), two North American species that commonly use and compete for the same nest boxes. (Photo by Michele Carnerie ML634625963)

placed in the nest to collect information on a finer scale, including female incubation times and more precise estimates of when the nest fledged (or was predated/abandoned) (Chapter 7).

In species where nests are extremely difficult to locate, researchers may instead monitor reproduction indirectly through territory-based approaches. By mapping the locations of singing males, observing pair formation, and tracking repeated use of specific areas, it is possible to estimate the number of breeding pairs within a site even without finding their nests. Additional observations, such as adults carrying food or the presence of fledglings, can provide evidence of active or successful reproduction.

In colonial species where large numbers of birds nest together in tightly packed aggregations, reproduction is often monitored at the level of the colony rather than at individual nests (**Figure 1.29**). Researchers may count active nests, eggs, or breeding pairs and repeat these counts over time to track changes in colony size and estimate its overall reproductive output. An additional practical reason for observing colonially nesting birds from a distance is that in dense colonies, even brief disturbances by a visiting researcher can trigger flushing and mobbing responses that expose eggs or chicks to heat stress, cold, or predation, or that increase the risk of nest abandonment. This consideration is especially important in species where communal responses to disturbance can propagate through large areas of a colony.

In some settings, researchers use technological tools to extend traditional approaches to monitoring reproduction. Photographs or videos taken during drone overflights can survey colonial birds such as penguins, allowing accurate counts of nesting adults or, later in the season, dependent young. From an even farther vantage point, satellite imagery has been used to pinpoint the location of Emperor Penguin (*Aptenodytes forsteri*) colonies in otherwise inaccessible regions of Antarctica (Fretwell 2024). Video cameras placed near nests can record parental attendance, feeding rates, and the causes of nest failure, including predation or environmental disturbance. Automated acoustic recorders can be used to detect vocalizations associated with breeding activity, such as mate attraction, territorial interactions, or provisioning behavior.

No single method captures all aspects of reproduction equally well, and each introduces its own sources of bias. Detectability of nests and breeding activity varies across habitats, species, and stages of the nesting cycle. Repeated visits to nests by researchers can, if not carefully managed, increase the risk of disturbance or predation. Differences in



Figure 1.29 Colony-based reproductive monitoring. In dense colonies such as this Northern Gannet (*Morus bassanus*) colony, researchers can monitor reproduction by counting active nests or breeding pairs from a distance, minimizing disturbance while tracking colony size and reproductive output. (Photo by David Turgeon ML475559671)

(continued...)

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