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—Job 39:26

Racing with the Sun: The Forced Migration of the Broad-winged Hawk

I first met the broad-winged hawk as a child in the forests of southern Kentucky. I saw it only occasionally during the breeding season, usually as it slipped quietly from a perch beneath the forest canopy and disappeared into the trees. Like the early naturalists, I knew nothing of its extraordinary migration and assumed, in my ignorance, that it lived in the area all year. Since then I have encountered it at many places on its appointed track. When I lived near the Great Lakes, the arrival of the first push of broad-wings was one of the surest signs of real spring along the south shore of Lake Erie. In high school I occasionally cut classes when my friends and I predicted a big flight based on our consultation with the weather map. Sometimes we were right, and on those days I learned more than I could have in school. A few years ago, in Costa Rica, we watched broad-wings, Swainson's hawks, and turkey vultures stream over the rain forests of La Selva, a seemingly endless procession gliding northward on motionless wings. There, and in the Northeast in both spring and fall, the hawks are seen primarily in the air. At night they disappear into the large forested areas, for the most part unseen until

they arise magically on the next day's thermals. One spring in southern Texas, however, I observed a different facet of the broad-wing's migratory life. Enormous flights were passing over the lower Rio Grande Valley and into the cattle country to the north. Here, woodlands are small and isolated; yet the hawks must put down somewhere when the changes in the atmosphere dictate an end to the day's migration. Early one morning I was birding in some small oak mottes north of the valley. The short trees were literally full of broad-winged hawks, hundreds of them: it was like a blackbird roost. In a couple of hours they were on their way, but I was struck with the importance of these little islands of oak for transient hawks. Even though any one individual broad-wing will probably never spend another night here, for a few days each spring these small woodlands fill up every night like motels along the interstate, providing refuge and rest in an area where the migration stream is particularly constricted.

Among our North American raptors, the Swainson's and broad-winged hawks, osprey, peregrine falcon, Mississippi kite, and turkey vulture are the longest-distance migrants. Performing these journeys places significant time constraints on the birds, and wedging all of the necessary events of the annual cycle into a twelve-month period necessitates a number of evolutionary compromises. Keith Bildstein weaves all of the components together in this chapter, and some of the same themes will run through Chapters 8 and 9 dealing with shorebird migration. —*K.P.-I.*

It is 9:00 A.M., 16 September 1995, Hawk Mountain Sanctuary. Thousands of people from the northeastern United States—others from as far away as Germany, France, and Japan—are streaming into a series of misshapen, gravel parking lots atop a windswept Appalachian ridge 25 miles northwest of Allentown, Pennsylvania. A group of orange-vested, radio-toting volunteers waves on the line of cars. The "vols" are doing their best to unsnarl the rural traffic jam, but Hawk Mountain Sanctuary is in the middle of its crazy season, and controlled pandemonium rules. Many of the impatient drivers have traveled long distances in anticipation of Hawk Mountain's main event, and nothing—including the car in front of them—is going to stop them short of their goal.

Hawk Mountain is venerated ground this time of year. Most of the faithful have come to see the en masse migration of the broad-winged hawk.

The North Lookout (Plate 6.1), the sanctuary's official count site, is three-quarters of a mile up the trail from the parking lots, and the walk is hurried. Nobody is saying so, but "Out of my way, buddy, I'm here to see hawks" fills the air.

Table 6.1 *Annual average counts of migrating raptors at Hawk Mountain Sanctuary, 1934–1991*

Species	*Annual average*
Turkey vulture[a]	143
Black vulture[a]	39
Osprey	342
Bald eagle	47
Northern harrier	223
Sharp-shinned hawk	4,246
Cooper's hawk	283
Northern goshawk	69
Red-shouldered hawk	245
Broad-winged hawk	8,527
Red-tailed hawk	3,208
Rough-legged hawk	9
Golden eagle	45
American kestrel	367
Merlin	33
Peregrine falcon	23
All raptors	17,787

[a]Data for turkey and black vultures are based on counts since 1990.

Founded in the summer of 1934 by the conservationist Rosalie Edge, Hawk Mountain Sanctuary is the world's first refuge for birds of prey. Sanctuary personnel have been recording the movements of migrating raptors at the North Lookout for more than 60 years [1–3]. During that time, more than a million raptors, representing 18 of the continent's 35 species, have been recorded flying past the site. By far, Hawk Mountain's most numerous migrant is a continentally endemic, crow-sized buteo known as the broad-winged hawk (Table 6.1). Hawk Mountain Sanctuary records an average of more than 8,000 broad-wings a year [4]. In most years, the broadwing flight peaks within a day or two of the 16th of September, which explains the crowd this morning.

An exhilarated Doug Wood, the sanctuary's official volunteer counter for the day, had arrived at the North Lookout at 5:30 A.M. Doug was an hour early, in eager anticipation of a great flight. A cold front, the synoptic weather event that Sanctuary Curator Maurice Broun once called "the one and only predictable thing about hawk migrations," advanced through the area 30 hours earlier.

The front had pushed aside a stagnant, late-summer air mass that had been steaming the area for days. Yesterday, 429 broad-wings were recorded at the lookout. The combined count for the previous two days was a paltry 73 birds. If past is prologue, the big broad-wing push is overdue [5, 6]. If not on the 16th, then certainly a day or two later.

Broad-winged hawks, however, can be as fickle as any bird, and only 2 are sighted during the first 90 minutes of the day's vigil. By 9:00 A.M., things began to pick up. The sky—as if unzipped—is pouring forth with raptors, almost all of them broad-wings, and by 11:00 A.M. more than 500 have been recorded. Most of the migrants are sighted far up-ridge, some as many as 3 to 5 miles off, pepper specks scattered against an overcast sky. Eventually, the specks increase in size, sprout wings, and are identified as broad-wings.

There is more to come, however. Between 11:00 A.M. and noon, 3,302 broad-winged hawks—more broad-wings than breed in all of Rhode Island—are counted swirling above 175 rubber-necking birders at the sanctuary's North Lookout. Three-quarters of a mile away, dozens of latecomers are on their backs in the sanctuary's parking lots, binoculars glued to their eye sockets, trying to catch a glimpse of the flight. Although some of the birds are barely visible more than 1,000 feet above the ridge, many others are passing by at treetop level. Those who have seen the flight in previous years are rejuvenated. Those who have never seen it are awestruck. Dozens of lucky novices have discovered a new calling. Everyone is smiling.

Suddenly, almost as quickly as it had started, the raptor parade dribbles to a standstill shortly after noon. The trailing edge of the massive movement, some 241 broad-wings, is counted between noon and 1:00 P.M. Fifty more pass the North Lookout during the remaining 4 hours of the count. By day's end, 4,291 raptors, representing 10 species of hawks, eagles, and falcons, have been counted at Hawk Mountain's North Lookout. The final tally for broad-wings is 4,118.

The date 16 September 1995 will go down in the sanctuary's record book as the sixth-best one-day broad-wing flight in Hawk Mountain history. Not too surprisingly, the biggest—an astounding 11,349-bird flight—had occurred 47 years to the day earlier, on the 16th of September 1948 (Table 6.2).

The hawk-watchers who visited the sanctuary on 16 September 1995 had every reason to expect a great flight. They were, after all, at the right place at the right time, and they had exactly the right kind of weather. Their ability to predict with reasoned confidence the broad-wing migration at Hawk Mountain Sanctuary that day is one of the great birding detective stories of the twentieth century. To appreciate the story fully, however, one first needs to understand three interlocking aspects of broadwing natural history: breeding phenology, migration geography, and flight strategy. Timing is an essential feature of each.

Plate 5.1 In breeding-plumage, the blackpoll warbler is boldly marked. (Photo by J.Heidecker for Cornell Laboratory of Ornithology)

Plate 5.2 The Allegheny Front Migration Observatory in the mountains of West Virginia. The lines of mist nets in which migrants are captured are in the foreground, and the banding-and-processing building is in the background. The observatory is a popular site for visiting birders. (Photo by Gary Felton)

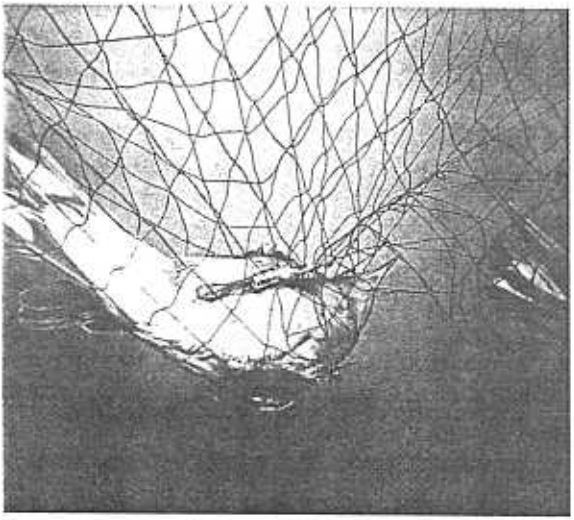


Plate 5.3 A banded blackpoll (note the yellowish feet) has been recaptured. (Photo by C.L. Smith/ Massachusetts Audubon Society)

Plate 5.4 This blackpoll's marathon journey has been interrupted at the Allegheny Front, where it has been weighed, banded, and measured and its age determined. Note the ruffled feathers on the top of its head. The feathers and skin on top of the head have been moistened so that the degree of ossification of the bird's skull can be seen through the skin. Birds hatched during the previous summer still have incompletely ossified skulls during fall migration and can be differentiated thereby from older birds. (Photo by Gary Feltrin)

Plate 5.5 The Connecticut warbler is one of very few passerines that probably makes the long flight over the western Atlantic from North to South America. (Photo by B.D. Cottrille for Cornell Laboratory of Ornithology)

Plate 6.1 The Kittatinny Ridge as seen from Hawk Mountain Sanctuary's North Lookout in mid-September, at the peak of broad-winged hawk migration in the area. (Photo by K.L. Bildstein)

Plate 7.5 The sandhill crane has an extremely varied diet throughout the course of a year. From corn to worms to frogs and baby birds, anything it can get its beak on becomes a meal. (Photo by M. Tremaine for Cornell Laboratory of Ornithology)

Plate 7.6 The Platte River Valley provides vital habitat for many species of midcontinent waterbirds. However, channel shrinkage and loss of wet meadow habitat over the past 60 years have brought the Platte ecosystem to a critical stage. Man's intervention will now be required on a continuing basis to provide appropriate water regimes in order to maintain the existing Platte River ecosystem. (Photo by G. Krapu)

Table 6.2 *The ten best flights of broad-winged hawks at Hawk Mountain Sanctuary, 1934–1995*

Date of flight	*Number of birds counted*
16 September 1948	11,349
14 September 1978	10,066
18 September 1978	7,222
14 September 1963	6,773
17 September 1968	4,863
16 September 1995	4,118
24 September 1938	4,078
14 September 1958	3,522
17 September 1936	3,398
21 September 1960	3,375

Breeding Phenology

As is true for many long-distance migrants, breeding is hurried in broad-winged hawks, especially for those nesting near the northern limits of the species range in New England and eastern Canada. Broad-wings time their arrival on the breeding grounds to coincide with the springtime snowmelt that uncovers the species' vertebrate prey, an event that usually occurs between late April and mid-May each year. The race to breed successfully in time to beat a hasty retreat to the species' wintering grounds in Central and South America begins shortly thereafter [7, 8].

Male broad-wings are territorial within a day or so of arriving on the breeding grounds, and most individuals court and pair within a week of their appearance in the Northeast (Plate 6.2). Nest construction, which begins immediately thereafter, takes two to four weeks to complete. Females then lay one to four eggs—most clutches consist of two or three—at one- to two-day intervals. Across the center of their Canadian and New England breeding range, most females are incubating eggs by late May or early June. A series of downy nestlings hatches *asynchronously* (not at the same time) 28 to 36 days after incubation begins, usually in late June or early July. Throughout most of their range, nestlings are fed a diet of small mammals, nestling birds, amphibians, and insects [7].

Once hatched, nestlings spend their 1st month in the nest fighting with siblings for food (Plate 6.3). In years when food is limited, some nestlings—usually the younger and smaller ones—starve. Those that do fledge are flying within 5 weeks, typically in late July through early August.

For several weeks thereafter, recently fledged young remain within several hun-

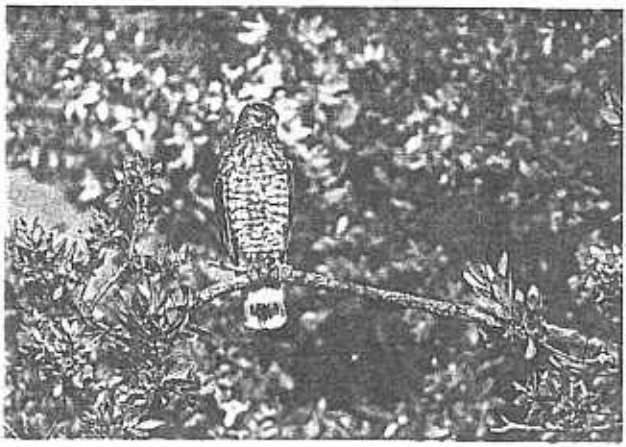


Plate 6.2 Adult broad-winged hawks are often observed perched quietly beneath the canopy of forest trees. (Photo by B.K. Wheeler/Vireo)

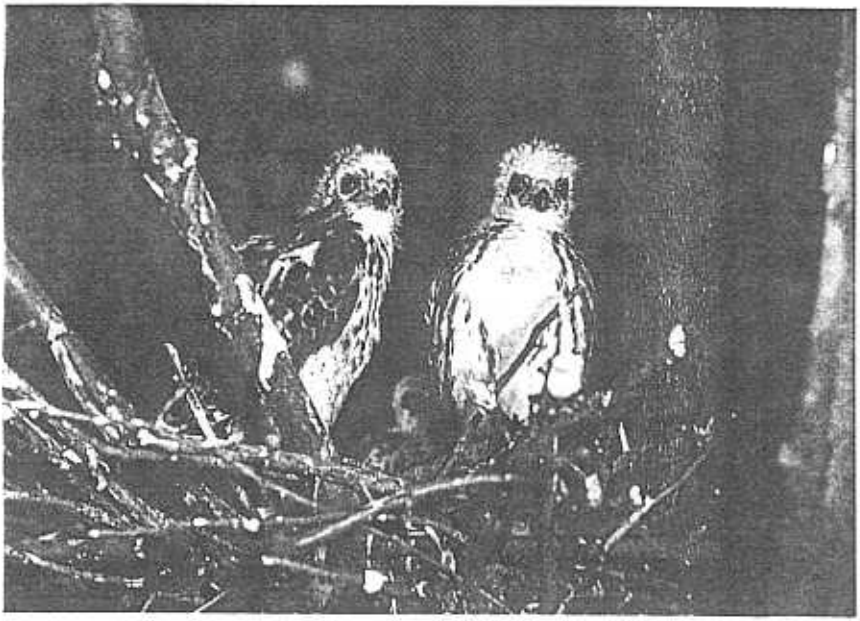


Plate 6.3 Nestling broad-winged hawks near Hawk Mountain Sanctuary in late summer. In less than 2 months these birds will be migrating southward along the Kittatinny Ridge en route to their Central and South American wintering grounds. (Photo by E. Hill/G. Somers Collection, Hawk Mountain Sanctuary)

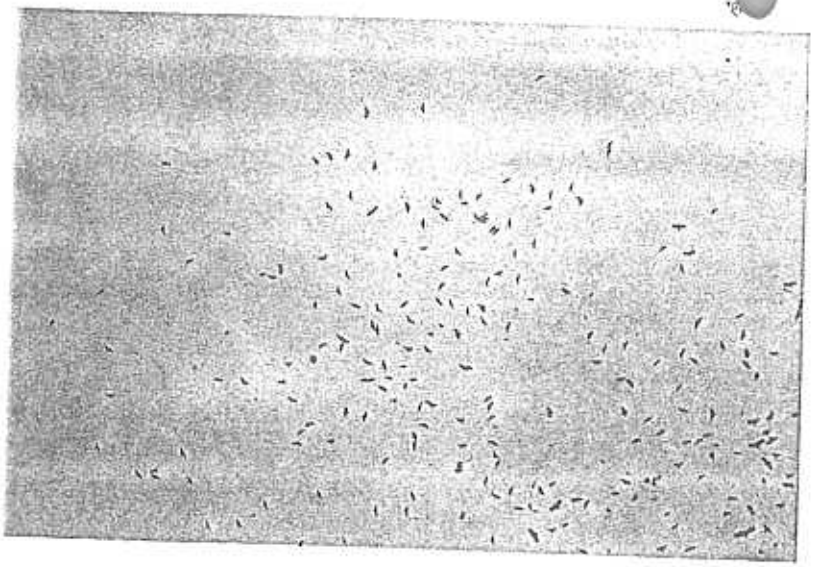


Plate 6.4 A kettle of broad-winged hawks over Cardel, Veracruz, Mexico, in early October 1991. Approximately one million broad-wings are counted at the site each autumn, with peak passage occurring from 27 September through 6 October each year. (Photo by L.J. Goodrich)

Plate 7.1 Sandhill cranes over the Platte River at sunrise. The Platte River Valley provides unparalleled opportunities for viewing sandhill cranes and, along with the adjacent Rainwater Basin Area, hosts one of the largest concentrations of waterfowl in North America in spring. (Photo by J. Eldridge)

dred yards of the nest, waiting to intercept parents returning with prey. Although some young begin hunting within 6 weeks of hatching, most spend little time in the air—usually less than 15 to 20 minutes a day—during their first two to three weeks out of the nest. Almost all of the young broad-wing's limited flight time is spent within the forest canopy. At 8 to 10 weeks of age—typically in late August to early September—most young of the year are independent of their parents and feeding on their own.

Within several days, these same individuals, together with the entire adult population, will be massing by the thousands as the species begins its annual journey to Central and South America.

The Way South

Most broad-wings begin their southbound migrations alone. Shortly thereafter, however, many coalesce into small groups as the flight converges along a series of more-or-less fixed flyways [9]. Some of the routes are more stable than others.

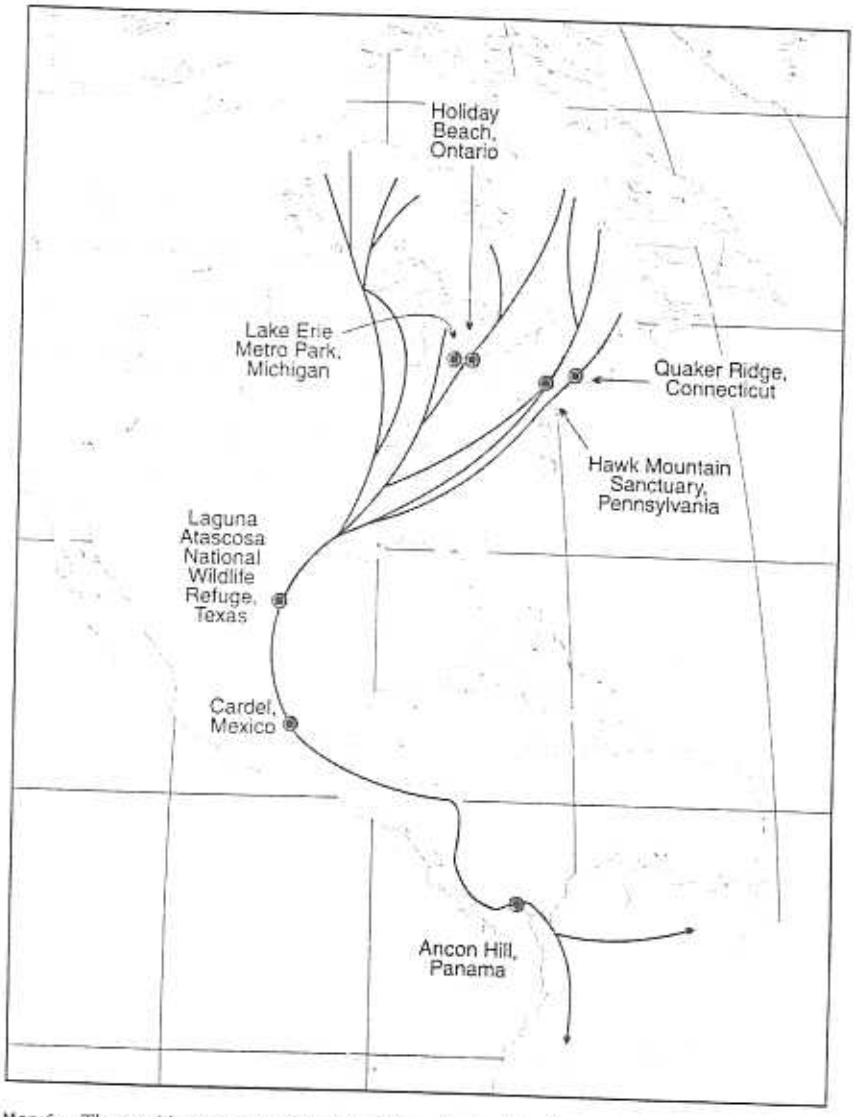
Flyways along *leading lines*, geographic features that serve to funnel the birds around and through particular landscape features, tend to be the most traditional. Hawk Mountain Sanctuary lies along one such route, a weathered ridge more than 200 miles long and 300 million years old that forms the southeastern border of the Central Appalachian Mountains. Known as the Shawangunk Mountains in New York, and as the Kittatinny Ridge in New Jersey and Pennsylvania, this "endless mountain" of the Lenape Indians, attracts thousands of broad-wings to its slopes each and every fall.

In addition to such north–south trending mountains, large bodies of water also funnel the woodland predators south each autumn. Migrating broadwings are figuratively "hydrophobic" on migration, and few, if any, ever make water crossings greater than 25 miles. Those that do, appear to have been forced to undertake the crossing by local weather conditions.

Most broad-winged hawks nest in the eastern United States and southeastern Canada, and the species' migration is best known for birds breeding east of the 100th meridian. With regard to this population, what appears to happen each fall is shown on Map 6.1.

Hundreds of thousands of broad-wings—the bulk of central Canada's breeding population—skirt the northern and western shores of the Great Lakes, en route to a broad Mississippi River flyway that leads them south to the Gulf Coast of Texas and eventually, into Mexico.

One of the best places to observe this portion of the flight is at Hawk Ridge, Minnesota, a windswept, lakeside dune ridge at the western corner of Lake Superior, just



Map 6.1 The southbound migration route of broad-winged hawks in eastern North America. Notable observation points, where large numbers of passing broadwings can be seen, are shown along the route.

outside Duluth. Hawk-watchers at the site, which has been in operation since 1980, have recorded as many as 110,000 broad-wings in a single season. Another major concentration point in the region occurs along the northern shore of Lake Erie, near the mouth of the Detroit River, 20 miles south of Detroit, Michigan. Hawk-watchers at Holiday Beach, Ontario, on the eastern side of the river's mouth, count as many as 110,000 southbound broad-wings each fall; those across the river, at Lake Erie Metro Park, have counted as many as 399,000 in a single season.

Farther east, many of the broad-wings breeding in New England, eastern Quebec, and the Canadian Maritimes travel south to the coastal plains of southern Connecticut. Here, in most years, tens of thousands of birds can be seen at more than a dozen watch sites in the area, including Quaker Ridge, near Greenwich, Connecticut. Many of the birds fly directly over New York City, where counters in Manhattan's Central Park have tallied thousands of broad-wings in recent years.

After the flight crosses the Hudson River, many broad-wings proceed west along a route that eventually positions them over the central Appalachian ridges of northernmost New Jersey and east-central Pennsylvania. There they merge with other individuals that have been following a more inland route to the south. Other broad-wings continue southwest along a more coastal—and decidedly more metropolitan—route which in some years tracks the New Jersey Turnpike to Philadelphia and points beyond.

Throughout eastern North America, the bulk of the season's broad-wing flight passes each established watch site over the course of a few days—usually the same few days—year after year.

Eventually, broad-wings from the eastern and central portions of the species' breeding range converge in massive congregations above the Gulf Coast of Texas, where seasonal tallies at traditional watch sites (stretching from Galveston and Corpus Christi all the way to the Mexican border) approach and exceed 300,000 broad-wings.

Once the migratory stream passes into Mexico, almost every broad-wing in the world continues south in a series of huge flocks (100,000+) along the foothills and coastal slopes of northeastern Mexico's Sierra Madre Oriental (Plate 6.4). By the time the birds reach coastal Veracruz, as many as 1.7 million broad-wings can be seen drifting south above the tiny town of Cardel. A bit farther south, at the 137-mile-wide Isthmus of Tehuantepec, the flight veers to the east along the northern slopes of the Sierra de Tuxtla, en route to the Caribbean coast of Guatemala and the rest of eastern Central America. Although some broad-wings overwinter in Central America, most of the flight squeezes through Middle America's second bottleneck, the 31-mile-wide Isthmus of Panama, where counts from Ancon Hill outside of Panama City range into the hundreds of thousands each year [10].

Once the broad-wings have entered South America, their movements are decidedly less well understood. Anecdotal reports suggest that at least some of the birds proceed south along the western slopes of the Andean Cordillera at least as far as central Colombia, where traditional roost sites include forested slopes of the Combeima Canyon, midway between the Colombian cities of Bogotá and Cali. Although the broad-wings' wintering distribution in South America is not especially well known, they do appear to be common winter residents in portions of forested Colombia, Venezuela, Bolivia, and Amazonian Brazil.

The routes broad-wings take to return to their North American breeding grounds are also considerably less well understood. Most apparently retrace their migratory tracks through Central America and Mexico before fanning across central and eastern North America north of the Rio Grande in late March and early April. Movements across the eastern United States appear to be dispersed relative to those of southbound migrants and, overall, the birds follow a more westerly track in spring than in fall. Tens of thousands of springtime migrants can be expected at traditional watch sites along the southern shores of Lakes Erie and Ontario in late April each year.

Hawk Mountain, by comparison, typically records only a few hundred broad-wings each spring, with most of the flight passing during the third week of April each year.

Flight Behavior

Consider for a minute the challenges facing broad-winged hawks about to embark on fall migration. Successful adults have just completed the burdensome task of raising their young. Young of the year have been on the wing for as little as several hours of their brief lives. The 4,000- to 5,000-mile trip from southern Canada or the northern United States to northern or central South America will take as long as two months to complete, and most of it will be over unfamiliar terrain. The birds need to find energy to fuel their flight. Failure to do so means death.

Migrating birds have several options in regard to fuel for their journey. The first and foremost is to *build up fat*. Because it has a higher caloric content than other potential metabolic fuels and can be stored dry, fat is the metabolic fuel of choice for most migratory birds. Many smaller migrants, including many songbirds and shorebirds, lay down enormous reserves of fat during several weeks of hyperphagia prior to migration each year. Some even double their body mass while doing so (see Chapter 2).

Broad-winged hawks also fatten up prior to migration, but they don't go to extremes. Most add no more than 20% to 40% to their lean body mass; enough to spell

a grounded bird during the several weeks of inclement weather it is likely to encounter during the flight, but hardly enough to fuel the entire intercontinental journey. Broad-wings are limited in their ability to accumulate additional fat for migration both by time and by size.

With a lean body mass of just under a pound, broad-wings are relatively large birds; as such, their metabolism is slower than that of smaller migrants. Although this metabolic rate means that it takes broad-wings—gram for gram—longer to burn energy reserves accumulated for migration, it also means that it takes them longer to deposit these reserves in the first place. And as the broad-wing's rushed breeding phenology suggests, many breeders barely have time to raise their young each summer, let alone spend additional time laying down a massive premigratory fat reserve. Even if they had the time to lay down lots of fat, broad-wings would not be able to do so. The problem is one of scale.

To understand this problem, consider what happens when one changes the size of a two-dimensional square drawn on a piece of paper. When the length of each side is doubled, the area inside the square quadruples. When the sides are tripled, the area inside the square increases by a factor of nine. Now, consider what happens when one increases the size of a three-dimensional object such as a bird. Doubling the linear dimensions squares the object's two-dimensional surface area, while cubing its three-dimensional volume.

Thus, if we compare two birds of the same shape and one is twice as big as the other, the larger of the two will have a wing span that is twice that of its smaller companion, a wing area than is four times as large, and a body that is eight times as massive. As a result, even though larger birds have disproportionately larger wing areas than those of similarly shaped smaller birds, the wings of larger birds are decidedly *more heavily wing-loaded* (i.e., carry more weight per unit area) than those of smaller birds. Because of this physical law, lean-bodied, larger birds tend to be closer to their weight limit for effective long-distance flight than smaller birds and, therefore, less able to fatten up in anticipation of it. The broad-wings' relatively large size all but eliminates fat as the single most important source of power for long-distance flight.

A second fueling option available to birds is to *feed and refuel en route*. Passerines, for example, especially those that are normally active by day but that migrate at night, refuel on an almost daily basis by feeding near their daytime roosts. Other migrants, including shorebirds, break up their long-distance movements by spending several days to several weeks refueling at traditional stopover sites en route (see Chapters 8 and 9). Broad-wings have a difficult time employing either strategy.

Broad-wings are quintessential sit-and-wait predators, energy minimalists that meet their metabolic demands not by actively searching for prey, but by spending long periods of time perching quietly, waiting for prey to come to them. Successful

perch hunting requires a) an exceptional knowledge of the prey populations within a well-known territory and b) a lot of time; neither is readily available to migrating broad-wings. Even so, these constraints don't mean that broadwings forgo feeding entirely while on migration.

During migration, broad-wings are in the air mainly between 10:00 A.M. and 4:00 P.M., providing them with some time to hunt each morning and afternoon. Because they often are traveling through North America at the same time that many forest passerines are making similar journeys, broad-wings sometimes find themselves surrounded by naive young-of-the-year prey as well as adults out of their normal territories, both of which can make for easy pickings.

During the fall of 1981, Hawk Mountain counters reported that 8% of the more than 600 broad-wings they had seen at close range had obviously distended crops, suggesting that they had fed earlier in the day. An additional 4% were actually seen catching or feeding on flying insects at the time, most of which were migrating dragonflies [11]. My observations suggest that most of the latter predation is serendipitous: the insects involved are flying too close to the broad-wings for the birds to pass them up. In most instances, a soaring or gliding broad-wing simply folds it wings and "sideswipes" its victim, which within minutes has been dewinged and consumed in flight. Feeding events such as these, however, are not likely to provide sufficient energy to fuel the broad-wing's long-distance migration.

How, then, if not with fat and if not by regularly refueling en route, do broad-wings power their migratory journeys south each fall? Broad-winged hawks manage to fly between North and South America each year by performing a bit of ecological slight of hand. Rather than depending upon predation and metabolic fuels to power their flights, broad-wings extract the energy needed to do so directly from the atmosphere. These extraordinarily energy-efficient raptors hitch what amounts to a free ride to and from the tropics each fall and spring by soaring most of the way. Indeed, soaring is so important to migrating broad-wings that it is safe to say that nothing about the species' migration ecology makes sense except in the light of this flight behavior.

By definition, soaring occurs when a bird extracts the energy needed for flight directly from the atmosphere. Birds can do so in one of three ways: *Slope soaring* takes advantage of the upward deflection of air caused by mountains and hills. *Thermal soaring* takes advantage of the differential heating of the earth's surface that results in pockets of warm air rising through cooler air. *Dynamic soaring* takes advantage of wind shear and the resulting increase in wind speed with height that occurs over large flat surfaces, such as lakes and oceans. Slope and thermal soaring, which occur mainly over land, require vertical air movements. Dynamic soaring, which occurs mainly over large bodies of water, does not. Because soaring can occur only in mov-

ing air, soaring birds (including broad-wings) spend much of their time maneuvering to find this essential aerial habitat [12].

Broad-winged hawks rely on both slope and thermal soaring to achieve their migratory goals. Although they are masters of both, the species is especially dependent upon thermal soaring. Slope soaring serves, more or less, as a backup strategy.

Thermal production depends directly upon the differential heating of the earth's surface that occurs each day as a result of incoming solar radiation. By midmorning on all but the cloudiest of days, the absorption of solar radiation begins to heat the surface of the earth. As it does, air in direct contact with the surface is warmed by conduction. Once sufficiently warmed, this hotter air begins to rise through the colder air above it.

Different land surfaces warm at different rates. Those with *lower surface albedo* (i.e., those that reflect less and absorb more solar radiation—darker surfaces, for example) warm more quickly than those with high surface albedo. Dry surfaces (where evaporative cooling is not possible) warm more quickly than moist surfaces. As a result, landscapes that consist of a patchwork of habitat types, including those that occur throughout most of eastern North America, are likely to produce a series of isolated columns, or thermals, of rising warmer air. Thermals tend to be strongest in late morning through midday—after the sun has risen sufficiently to warm the earth's surface and before strong afternoon winds pull them apart.

In late spring and summer in North America, many thermals rise a mile or so above ground before dissipating. Because they are fueled by sunlight, thermals are far more common on the longer summer days than at other times of the year. My colleagues Paul Kerlinger, Sid Gauthreaux, and Ken Able have used radar to study broad-wings soaring in such updrafts, both in central New York State and in southern Texas. These three biologists recorded broad-wings rising in thermals at rates of 200 to 650 feet per hour; fast enough to allow broad-wings to use this free ride to soar and glide to and from South America each year [13].

Even in summer, however, thermals do not form each and every day. Rainy or cloudy weather, for example, can severely impede the formation of these atmospheric disturbances. Thus, if broad-wings depended solely upon this source of atmospheric energy to fuel their migrations, they might never reach their wintering grounds. For this reason, many broad-wings use slope soaring as a backup. Generally restricted to hilly or to coastal regions, slope soaring allows broadwings to migrate at low cost when thermals are not available.

Slope soaring is possible when sufficiently strong horizontal winds strike an elevated surface—a mountain ridge, for example—and are deflected up and over it. This is exactly what happens along the more-than-200-mile-long Kittatinny Ridge which forms the spine of Hawk Mountain Sanctuary. Each fall tens if not hun-

dreds of thousands of birds use the updrafts associated with this famous ridge, together with the region's thermals, to alternately swirl and surf above the sanctuary's forests—and birders—below.

Broad-wings use several cues to find "good air." Dust and debris are often carried aloft in thermals, and there is every reason to believe that broad-wings, like glider pilots, use such circling masses of reverse detritus to locate vertical air. Because prevailing winds in eastern North America tend to come from the west, mountain ridges that are oriented north–south also are likely to attract broad-wings on migration. The greatest attractant of all, though, appears to be another broad-winged hawk.

More than any other eastern raptor, broad-winged hawks migrate in flocks, the size of which depends upon the magnitude of the day's flight. At Hawk Mountain Sanctuary, for example, "100-broad-wing days" produce flocks of from several birds to several dozen birds, while "1,000-bird days" produce flocks of hundreds of birds. Farther south in Veracruz, Mexico, where a season's broad-wing flight can easily exceed 1 million birds, flock of tens of thousands of the soaring buteos are common.

Broad-wings mass on migration not because the species is more social than other raptors, but rather because doing so enhances the birds' ability to find and use thermals quickly and efficiently. By fanning across the landscape within sight of one another, a group of broad-wings simultaneously samples the atmosphere for pockets of "upwardly mobile" air.

There are no permanent leaders or followers in a flock of migrating broad-winged hawks, simply a series of lucky birds who, having found a column of rising air or a ridge-induced updraft, quickly find themselves surrounded by newfound and decidedly ephemeral friends, eager to take advantage of their "leader's" new resource. In thermals, flocks remain together only until the highest individuals reach the top of the column of rising air, at which point the broad-wings begin to spill out of the vortex and, in hawk-watching parlance, "stream"—tails and wings partially tucked, head-to-tail—to the next available thermal, in which the flock will follow yet another leader to the top.

Groups of spiraling broad-wings are called *kettles*. Although the etymology of the term remains unclear, Hawk Mountain Sanctuary counters have been using it for decades. The term may be derived from the fact that broad-wings lofting in thermals resemble steam rising above a kettle of boiling water. Whatever its origins, calling out an approaching "kettle" of broad-wings at Hawk Mountain's lookout in September electrifies the crowd.

In eastern North America, most of the thermals encountered by migrating broad-wings are relatively narrow columns of rotating air—some measure no more than 10 to 20 yards across—in which soaring broad-wings need to pivot to stay in-

side. Soaring effectively in narrow thermals requires a tight turning radius. Broad-wings can accomplish this feat because they are very lightly wing-loaded (i.e., relatively big-winged for their body mass) compared to other hawks. The average broad-wing, for example, carries about 355 g (12.5 oz) of body mass for each square foot of wing area; approximately 20% less than a Cooper's hawk, and 30% less than a red-tailed hawk. Being lightly wing-loaded gives the birds more lift, which allows them to fly more slowly in thermals, thereby enabling them to circle more tightly.

Light wing-loading, however, is not without cost. Additional lift makes it easy for broad-wings to get caught up and carried away in thermals. As a result, some broad-wings—especially inexperienced, recently fledged young—can be driven off-course. Most of the broad-wings seen at Cape May Point, the southern peninsular tip of coastal New Jersey, for example, are juvenile birds, individuals that are far off-course and that will need to backtrack along the eastern shore of the Delaware Bay—the body of water that separates the Garden State from Pennsylvania and Delaware—until it narrows sufficiently to permit a short-distance water crossing using powered flight. In most circumstances, experienced adults are far less likely to make this type of costly mistake.

The second trade-off is that birds with low wing-loading glide more slowly on fixed wings than do heavily wing-loaded birds. Gliding between thermals at relatively high speeds is important when one is trying to fly across the better part of two continents. Broad-wings circumvent this obstacle by modifying their flight silhouette when gliding. Rather than assuming the species' characteristic soaring silhouette of fully spread wings and tail, broad-wings partially fold their wings and tuck their tails when streaming out of and into thermals, increasing their wing-loading by 10% to 20%, thereby increasing significantly the speed at which they reach the next thermal. Although flexing their wings increases their rate of drop as well, the trade-off of "lost lift" versus "increased speed" is a successful strategy for the species, provided that thermals are plentiful and interthermal distances are not too great. Which brings me back to the 16th of September.

Why Hurry?

Broad-winged hawks are not the Hawk Mountain Sanctuary's earliest migrating raptors. The midpoint of the bald eagle flight is three days earlier than that of the small buteo. But bald eagles—and, for that matter, all of the other 14 raptor species that migrate past the sanctuary—have far more protracted periods of migration at the site than broad-wings. For example, it takes 16 days for the middle third of the sanctuary's bald eagle flight to pass the North Lookout each fall, and an average of two weeks for the sanctuary's other 14 species to do the same. Broad-wings manage the

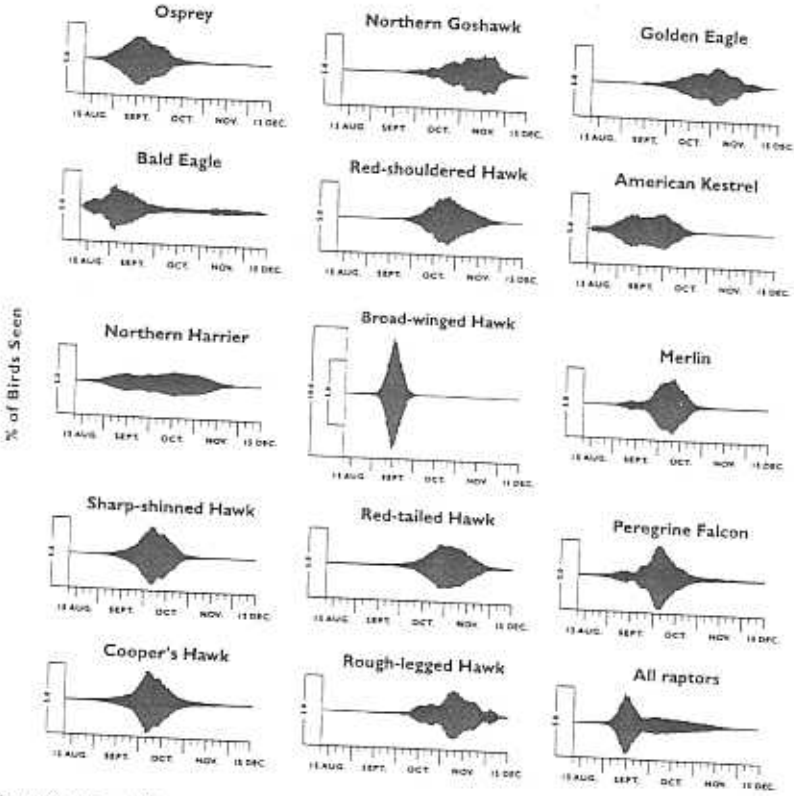


Figure 6.1 Hawk Mountain Sanctuary's migration timetable. Note the exceptionally acute character of the broad-wing flight.

feat in little more than four days each fall (Fig. 6.1). In this respect, at least, broad-wings are exceptionally synchronous migrants.

It is relatively easy to understand why broad-wings don't show up in large numbers at the sanctuary until mid-September each fall. Many broad-wings breeding north and east of Hawk Mountain each year (i.e., those that constitute the sanctuary's annual flight) are still raising young or growing up in mid- to late August. It takes these birds several weeks to acquire their modest fat loads and to complete their journey to central Pennsylvania. Birds that leave earlier than the majority are likely to find themselves searching for thermals on their own, something that may require expensive powered flight and waste precious metabolic fuel.

Why the bulk of the flight passes so quickly, however, is a bit less obvious. In an

average year, half the season's flight has passed the sanctuary's North Lookout by the 16th of September. One week later, 95% of the year's broad-wings will have been counted. And by the end of September, more than 99% of the flight will have passed the North Lookout. No other sanctuary raptor is even close to having completed its flight by late September. Indeed, with the exception of broad-wings, only two of Hawk Mountain's migrant species will have concluded even half of their flights by this date. Those two species, the bald eagle and the osprey, have completed 76% and 80% of their flights, respectively, by the end of September.

Some researchers have suggested that broad-wings need to complete their migration through the region earlier than other raptors because a) their preferred prey on the breeding grounds becomes unavailable earlier in the season than the prey of other migrants or b) they need to travel farther. Neither of the proposed scenarios, however, provides a reasonable explanation for the flight's astonishing synchrony each year, resulting in what appears to be a forced migration across all of North America.

Analysis of 60 years of Hawk Mountain Sanctuary flights has led me to conclude that broad-wings rush past the sanctuary, and out of northeastern North America in mid- to late September each year, not because they are running out of food, or because they have so far to travel, but because they are running out of daylight.

Broad-wings migrating past Hawk Mountain on the 16th of September have 12.5 hours of available sunlight. Those passing the sanctuary two weeks later have less than 11 hours and 50 minutes. This, together with the fact that the sun is considerably lower in the sky in late September than it is earlier in the month, and that maximum daily temperatures in the region have dropped by more than 12° F during this period, means that fewer thermals will be available to the birds. And thermals are the fuel tanks of broad-wing migration.

In a very real sense, broad-wings migrating past Hawk Mountain Sanctuary in mid-September each year are racing with the sun. Those that fail to escape the Northeast before thermals become a not-so-predictable resource will need to spend more time in powered flight to reach their final destination. And powered flight is too expensive for long-distance broad-wing migration.

Aeronautic equations developed by the British ornithologist Colin Pennycuick, together with information on the general metabolic demands of broad-wings and their overall levels of activity, make it possible to estimate the amount of energy an individual broad-wing saves by soaring en route to South America each autumn. By my calculations, nonmigratory broad-wings burn about 65 to 75 calories a day, both during the breeding season and on the wintering grounds. Assuming that the same bird flies all the way from southern Canada to central Brazil at its most efficient air

speed (i.e., 30–35 mph), it would need to travel two to three hours a day to complete its journey of 4,000 to 5,000 miles in two months. Migration using powered flight almost doubles the bird's metabolic needs each and every day of the flight. A broad-wing using this method needs to find more food in less time, and in unfamiliar territory, than it does on either its breeding or its wintering grounds.

On the other hand, assuming the bird uses soaring rather than powered flight to complete 80% of its migration—which seems reasonable given what is known about the species flight behavior en route—then the bird's metabolic needs increase by only about 20%, which, while not inconsequential, can be met.

Because thermals are so important to migrating broad-wings, it seems reasonable to ask why the species doesn't return to its breeding grounds earlier than it does, when doing so would provide individuals with a bit of a "thermal buffer" in case the weather was bad in early September or mid-September. Doing so, however, would require an earlier arrival on the breeding grounds—which, in itself, creates problems. Advancing spring migration by several weeks means that broad-wings would arrive in North America before the time of dependable springtime thermals. And even if the buteos made that journey, many would arrive on their breeding grounds before snowmelt was complete and small mammal prey was readily available.

Watching Hawk Mountain's Broad-wings

Two things combine to make Hawk Mountain a great place to watch large numbers of migrating broad-winged hawks: the mountain itself and the region's weather.

Hawk Mountain's Kittatinny Ridge all but ensures that at least some broad-wings will pass the sanctuary's North Lookout each fall. This ancient corduroy hill—which stretches from the Hudson River Valley of southern New York almost all the way to the Mason-Dixon line just north of Hagerstown, Maryland—is a perfect highway for updraft- and thermal-seeking broad-wings.

The updrafts produced by winds striking the southeasternmost of the central Appalachian corduroy hills, together with local thermals, allow many of the broad-wings that are sighted at the Hawk Mountain Sanctuary to fly for miles at speeds of up to 35 mph without beating a wing. Indeed, it is the juxtaposition of these two sources of free energy—slope and thermal soaring—that all but guarantees that at least a few thousand broad-wings will be counted at the sanctuary's North Lookout each autumn. Just how many will pass each year, and when exactly the flight will occur, depend upon the weather—not only at the sanctuary, but elsewhere as well.

As the region's southernmost ridge of consequence, the Kittatinny is the last chance southbound broad-wings have to fall back on slope soaring during this por-

tion of their southbound migration. Slope soaring, however, is possible only when there are winds; at Hawk Mountain Sanctuary, the best winds come out of the northwest.

The association between northwest winds and good flights at Hawk Mountain Sanctuary has been known for a long time. After a single year at the site, Maurice Broun, the sanctuary's curator, was "guaranteeing good flights" to visitors the day after a cold front had passed. And the passage of a cold front is almost always followed by northwest winds. Several years ago, Paul Allen, Laurie Goodrich, and I decided to quantify Broun's guarantee [6].

The three of us restricted our analysis of the association to the period between 23 August and 30 September each year, the time when 98% of the broad-wings typically pass the sanctuary's North Lookout. We used two data sets in our analyses: the sanctuary's daily counts of broad-winged hawks from 1934 through 1991, and the U.S. Weather Bureau's accounts of cold fronts in the region during that time. Our initial analysis revealed that cold fronts passed the sanctuary once every four and a half days, and that broad-wings were counted at a rate of 283 birds per eight-hour day of observation. Once we combined the two data sets, we discovered that almost twice as many broad-wings—327 birds per day versus 182—were counted during the three days following the passage of a cold front than at any other period. Broun was right: cold fronts do bring good flights.

Over the years Hawk Mountain has had its share of good flights. Indeed, a thousand or more broad-wings have been sighted on a single day 134 times at the sanctuary. And in almost every instance, the flight had been preceded by a cold front. Although thousand-bird broad-wing days have occurred at least once for each and every date from the 8th to the 28th of September, more than half of Hawk Mountain's red-letter broad-wing days have occurred between the 15th and 20th of the month. And with an average passage rate of 95 broad-wings per hour, the 16th of September stands at the top of the list: 46,917 broad-wings—almost 10% of all that have ever been seen at the sanctuary—have been counted on that date alone.

Tropical storms rarely reach the Appalachian Mountains of eastern Pennsylvania. When they do, they can have a dramatic effect on the year's flight of broad-winged hawks. Only once in the sanctuary's 60-year history have more than a thousand broad-wings passed the North Lookout on each of four consecutive days. The single run occurred between 23 and 26 September 1938, shortly after the Great Hurricane of 1938 devastated much of coastal New England. Maurice Broun credited the storm, which had passed several hundred miles east of the sanctuary two days earlier, with the exceptional flight. A somewhat similar six-day flight of more than 6,500 broad-wings, occurred several days after the passage of Tropical Storm David in 1979. Both storms, which passed east of the sanctuary, almost certainly sent many broad-wings,

which would otherwise have passed south and east of the sanctuary, up and over the central Appalachians and onto the Kittatinny Ridge flyway.

Hurricane Fran, on the other hand, which passed west of Hawk Mountain in early September 1996, all but eliminated the sanctuary's broad-wing flight that year. The resulting seasonal total of 1,809 broad-wings—which shattered by more than a thousand birds the previous seasonal low of 2,886 broad-wings set in 1946—amounted to fewer broad-wings than have been reported on 60 single-day counts at the sanctuary. That this cyclonic storm, which had begun as an unpretentious tropical depression off the coast of West Africa several weeks earlier, could so completely dominate the migratory geography of an endemic North American raptor helps demonstrate just how small a planet Earth really is.

The Surprisingly Brief Ornithological History of the Flight

Given what is now known about the fall migration of the broad-winged hawk, it may come as a surprise that this significant avian event eluded ornithologists for most of the nineteenth century. In retrospect, the delayed discovery of the flight is not surprising.

The broad-wing's secretive nature during the breeding season, together with the fact that broad-wings tend to occur at low densities, even in the best of habitats, made it difficult for even experienced nineteenth-century ornithologists to find and study this raptor. As a result, relatively little was known about any aspect of the species' ecology until after the turn of the century.

Alexander Wilson, for example, devoted most of his early nineteenth-century account of the bird to the broad-wing's plumage and associated feather lice. John James Audubon focused a good deal of his text on the idiosyncratic behavior of an orphaned nestling and gunshot adult he had secured as subjects for his paintings. And while both Wilson and Audubon noted the species' habit of circling in flight—now a well-known aspect of the broad-wing's migratory flight—neither of these ornithologists, nor any of their contemporaries, ever hinted at the bird's spectacular migration behavior.

In part, information on the broad-wing's migratory habits was lacking because the birds were difficult to locate during the breeding season, even in areas where they were quite common, making a lack of sightings in winter unsurprising. In part, it was lacking because the species tended to migrate along largely inland corridors, far from the large bodies of water that were then most frequently visited by ornithologists. In part, it was lacking because the flight was concentrated over a few easily missed days each fall and often occurred at heights that would make the flight difficult to see with unaided eyes.

Thus, many local and regional authorities of the day concluded that broad-wings were yearround residents in the ornithologists' geographic areas of expertise. Even Witmer Stone, who in 1937 described the broad-winged hawk as a major participant in the Cape May's "great flights of autumn" [14], had described the species as a nonmigratory "rare resident" in 1894 [15].

In fact, it was not until almost 1880 that the ornithological community "discovered" the broad-wing's migratory behavior. The breakthrough came long after the far less spectacular migratory movements of many other New World raptors had been described in some detail. In retrospect, the delay was understandable. The use of field glasses—and then binoculars—certainly helped, as did the advent of the field guide.

The earliest account of broad-wing migration I have been able to uncover is that of the oil-rig salesman and amateur ornithologist George B. Sennett, published in 1879. Sennett, who at the time was considered "the" authority on the birds of the Rio Grande Valley, described the movements of at least 50 broad-wings on spring migration in Gulf Coast Texas as being "easy, graceful, and at times, quite rapid," quite the opposite of the bird's heavy and sluggish subcanopy flight during the breeding season [16]. This was a different bird than the one most ornithologists who had studied it during the breeding season were familiar with, and George Sennett was one of the first to recognize its migration-period transformation in behavior.

By the mid-1880s, Charles C. Trowbridge was reporting "immense clusters" of hundreds of migrating broad-wings in and around New Haven, Connecticut, including a "great flight" on 16 September 1887 that began shortly after 9:00 A.M., 108 years earlier to the hour than the Hawk Mountain Sanctuary flight described at the beginning of this chapter [17]. Over the next few years, other field-glass-toting ornithologists joined the search, and by century's end the general nature of the species' migratory movements north of the Rio Grande—its movements near Detroit along the northern shores of Lake Erie, and near Rochester, New York, along the southern shores of Lake Ontario, as well as over Montclair, New Jersey, east of New York City, and along the Kittatinny Ridge in the vicinity of the Delaware Water Gap—was well known to ornithologists and bird-watchers of the day. At about the same time, the broad-wings also became known to the region's gunners, an awareness that eventually led to the ornithological discovery of the flight at Hawk Mountain.

Although hawk-shooting apparently was widespread along much of the Kittatinny Ridge in the late 1920s and early 1930s, reports from that time indicate that the most popular location for this mainly Sunday sport was the place the gunners called Hawk Mountain, an easily approached escarpment along a mountaintop road connecting Eckville and Drehersville, Pennsylvania (Fig. 6.2).

Many of the shooters were anthracite coal miners, who visited the ridge each Sun-

day after having worked in the mines for six days. Although the Pennsylvania Game Commission prohibited game-hunting on the Sabbath, there was no such restriction on "vermin." And raptors—especially those suspected of taking ruffed grouse, the state's premiere upland game bird—were then considered vermin. A $5 Game Commission bounty on the northern goshawk made that species an especially lucrative target. Estimates from the era suggest that hundreds of raptors, including eagles, ospreys, falcons, accipiters, and harriers, as well as broad-wings and other buteos, were being shot on single weekends. By the early 1930s, shooting at the site was so extensive that brass from discharged cartridges was being collected and sold for scrap metal.

All of this changed in June of 1934, when the conservationist Rosalie Edge, having seen photographs of the events that previous fall, traveled to the site and purchased an option on the property (Fig. 6.3). That August, Edge hired the Vermont naturalist Maurice Broun as "ornithologist-in-charge" of the newly established refuge for birds of prey, the first of its kind anywhere. Broun spent part of his first

Figure 6.2 Prior to the Hawk Mountain Sanctuary's founding in 1934, shooting hawks was a common weekend practice at Hawk Mountain during fall migration. (Photo by R.H. Pough)

Figure 6.3 Hawk Mountain Sanctuary founder Rosalie Edge. (Hawk Mountain Sanctuary)

fall at the site posting the newly named Hawk Mountain Sanctuary and confronting local shooters. He also began recording the migration.

There was much publicity surrounding the sanctuary's formation, and that fall 500 bird-watchers and naturalists flocked to the "newly discovered" wildlife refuge. By 1950, Hawk Mountain was attracting more than 10,000 visitors annually. By the mid-1990s, the number of visitors had increased to 80,000. The sanctuary, which was once known mainly for the numbers of birds counted at its lookouts, is now equally famous for the numbers of people that visit each fall.

Today, Hawk Mountain Sanctuary—110 miles west of New York City and 85 miles northwest of Philadelphia—is a member-supported, not-for-profit international center for conservation, education, and research. Throughout its history, Hawk Mountain has been a leader in science-based raptor conservation. The sanctuary currently maintains the longest and most complete record of raptor migration in the

world. This extensive database played a key role in exposing first-generation organochlorine pesticides, including DDT, as causative agents in the precipitous decline in populations of bald eagles, peregrine falcons, and other species of birds of prey that occurred earlier in the twentieth century, as well as in recording subsequent rebounds in these populations following decreases in the use of the pesticides.

Recognizing the need to protect raptors throughout their migratory journeys, in 1988 the sanctuary launched "Hawks Aloft Worldwide," a cooperative global-conservation initiative that uses the plight of threatened raptors, together with the spectacle of their migrations, to engender local support for raptor conservation worldwide. One of the project's earliest successes was with the broad-winged hawk. Although the species is no longer hunted in Canada and the United States, it is not so lucky elsewhere in its range. This is particularly so in the western cordillera of the Colombian Andes, where local lore suggest that killing broad-wings hastens the passage of Lent and that fat rendered from their carcasses has medicinal value. As a result, as recently as the early 1990s, large numbers of North American–bound broad-wings were being killed each spring by local campesinos who were shooting the birds at traditional nocturnal roost sites. Today, thanks to a major education campaign led by local Hawks Aloft Worldwide cooperators from Bogotá and Tolima, the annual slaughter has all but been eliminated, and local residents now celebrate the birds' passage each April with a festival.

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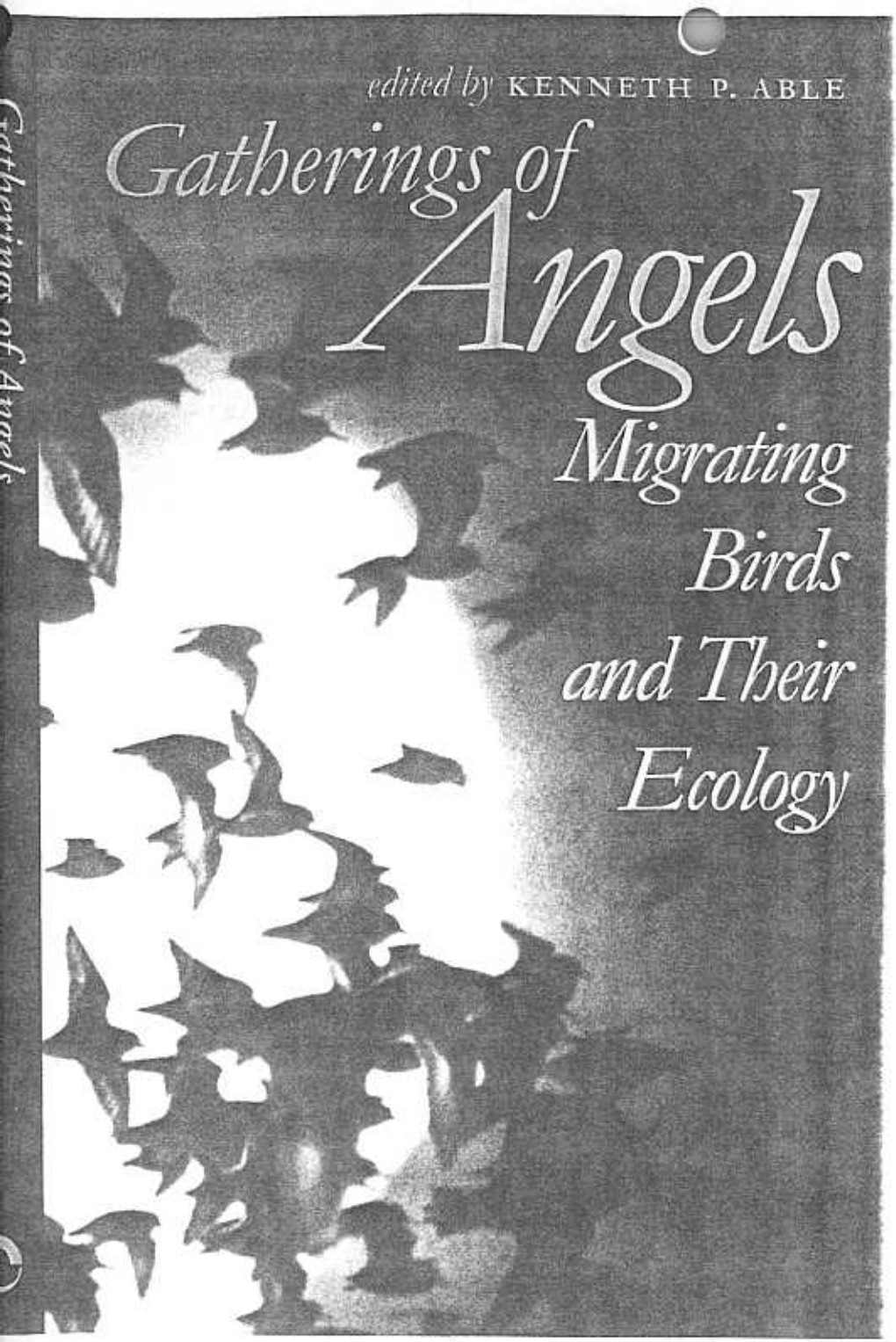
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