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Bats in the City? An Exploration of Acoustic Monitoring of Bats

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ABSTRACT
In this case study and accompanying exercise, students shadow a hypothetical high school student studying the acoustic monitoring of urban bats. Students are introduced to urban biodiversity in New York City, bats in urban areas, bat echolocations/vocalizations, and the monitoring of these species through analyzing acoustic recordings with Kaleidoscope, a specialized software. Students then complete a data analysis exercise where they will be directed on how to visualize the results of the software analysis and summarize the conclusions. Students end the exercise by brainstorming additional questions that may be possible to answer with the type of data they have, while also thinking about how the project could be expanded. This case study and exercise can be used in conjunction with "Our Neighbors, Bats!" and the exercise "A Field Guide to Bats in your Neighborhood," or as a stand-alone activity.

PART 1. "ARE THERE ACTUALLY BATS IN MY NEIGHBORHOOD?"

Maya, a 9th grade student in New York City (NYC) taking the course *Living Environment*, asks herself this question. Her class has just finished reading an article on bats ("Our Neighbors, Bats!") and completed an exercise to determine what species are likely to be in her area. She now knows that, according to the New York State Department of Conservation, nine species of bat are found in New York State; but, she wonders, how many of those are actually in NYC? Maya lives in the Bronx and has never seen a bat before! If bats are in NYC, what other wildlife might also be here?

1.1 NYC Biodiversity

Her teacher assigns a project where each student must pick a topic about bats and do further research. Maya decides to focus on bats in urban areas and to learn about wildlife in urban habitats more generally, especially in NYC. Her teacher suggests Maya reads a bit of background information on NYC nature and gives her this six-page excerpt from a report called: "Biodiversity Assessment Handbook for New York City" by Erik Kiviat and Elizabeth Johnson.

Read the excerpt on pages 68–73 below to see why Maya's teacher thought it would be helpful.

Biodiversity Assessment Handbook for New York City

IntroductIon

Many people assume that biodiversity — nature — only exists in faraway places like tropical rainforests or the Adirondacks. But urban areas support much more than weedy plants like dandelions (*Taraxacum*) and adaptable animals like raccoons (*Procyon lotor*) and house sparrows (*Passer domesticus*).

In fact, a surprising array of uncommon and rare species is found in New York City. Did you know that the peregrine falcon (*Falco peregrinus*), an endangered bird in New York State, nests on high-rise buildings and bridges in the City? That New York City's beaches harbor rare beach-nesting birds like the piping plover (*Charadrius melodus*) and a federally protected plant, the seabeach amaranth (*Amaranthus pumilus*)? That its parks and greenways provide critical resting and feeding habitat for migrating songbirds en route to their northern nesting grounds each spring and returning to their overwintering sites in autumn? That one of only three locations for the New York State-endangered little bluet damselfly (*Enallagma laterale*) is found in Queens? That more than 230 species of bees pollinate crops in community gardens and plants in natural areas, pocket parks, and even window boxes and roof gardens? That beavers (*Castor canadensis*) are now living in the Bronx River, and river otters (*Lontra canadensis*) have recently been seen on Staten Island? Or that scientists recently discovered species entirely new to science in the City, including the dwarf centipede (*Nannarrup hoffmani*) in Central Park, the Gotham bee (*Lasioglossum gotham*) in Brooklyn Botanic Garden, and a new species of leopard frog in Staten Island?

The truth is that New York City is an important ecological crossroads where the presence of a variety of salt- and freshwater habitats, major migratory corridors, and the convergence of three ecological regions prove critical to the survival of many species of fish, birds, and other animals. Biodiversity provides services that are key to the City's quality of life, from clean air, clean water, and flood control to natural beauty. Yet its diversity of plants, animals, and habitats is often underappreciated or ignored. As a consequence, during the past 400 years much of New York City has been built on and paved over, with only a small fraction of its original habitats remaining.

Fortunately, the wealth of biodiversity that was once widespread in the City can still be found in resilient pockets of aquatic and terrestrial greenspace (by "greenspace" we mean areas that are not paved or built on, including parks, nature reserves, undeveloped lands, gardens, and vacant lots). Although much has been lost, far-sighted New Yorkers have set aside many signficant greenspaces and even created semi-natural places, like Central Park, Van Cortlandt Park, and the Hudson River Park's Estuarine Sancturay, where nature can flourish.

Seabeach amaranth. Image credit: Stephen M. Young/ NY Natural Heritage Program.

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Urban Biodiversity

The classic definition of "biodiversity" is the variety of life at all its levels, from genes to ecosystems, and also the ecological and evolutionary processes that sustain life. For years, ecologists focused their efforts on managing areas apart from where most people live. Only recently have scientists begun to study the biodiversity of cities, the most human-dominated lands. Without the conservation of urban biodiversity, many habitats and species, and much variation within species would be lost (Noël and Lapointe 2010).

Conserving biodiversity is the key to long-term sustainability and the quality of life for all of us, even urbanites. Species and habitats in distant lands as well as those here in New York City all play an important role in maintaining the ecosystem services on which we depend, such as nutrient cycling and water filtration. Furthermore, cities are refuges for certain rare species that may even do better in urban areas than in the countryside. For example, peregrine falcons (*Falco peregrinus*), a state-protected species, have found a niche in the City, successfully using high-rise buildings, church steeples, and bridges for nesting (NYC Department of Environmental Protection 2012a), and American kestrels (*Falco sparverius*), small cavity-nesting raptors that are declining statewide, are holding their own in the City. Open disturbed habitats in cities often support rare plants, such as the eastern gammagrass (*Tripsacum dactyloides*) in Pelham Bay Park.

The world is rapidly becoming more urbanized. It is projected that by 2050 close to 70 percent of the world's population will be living in urban areas — compared to 60 years ago when the reverse was true and 70 percent were living in rural areas (U.N. 2019). In recognition of this fact, researchers and others gathered in 2008 to explore the best ways to implement the recommendations from the 2002 Convention on Biological Diversity in towns and cities. The Erfurt Declaration, which was developed at this conference to promote the values of urban biodiversity, states in part:

- Urban ecosystems have their own distinctive characteristics;
- Urban areas are centers of evolution and adaptation;
- Urban areas are complex hotspots... for regional biodiversity;
- Urban biodiversity can contribute significantly to the quality of life in an increasingly urban global society;
- Urban biodiversity is the only biodiversity that many people directly experience.

The Declaration further states: "Experiencing urban biodiversity will be the key to halting the loss of global biodiversity, because people are more likely to take action for biodiversity if they have direct contact with nature" (International Conference of the Competence Network Urban Ecology CONTUREC 2008). The ability to experience urban biodiversity will depend on sound research, conservation, and management of the plants, animals, fungi, microbes, and their habitats in cities.

Peregrine falcon in New York City landscape. Image credit: Mike Feller

Biodiversity Assessment Handbook for New York City

The Value of Biodiversity

Diverse terrestrial and aquatic landscapes with a wide range of animals and plants provide natural benefits that are essential to daily life. Often, we have underestimated or even ignored their value when making decisions that affect the land and water, but they are the key to the environmental and economic health of cities as well as suburban and rural areas. And an increasing body of evidence indicates they are also essential to human health.

One effort to calculate the global value of landscapes with rich biodiversity estimated that every year they provide $33 trillion worth of natural services — nearly twice the global gross national product of $18 trillion (Costanza et al. 1997). This estimate, which was based on 1997 dollars, would be much higher today. Among the many benefits that biodiversity provides are:

- **Food, medicine, wood, and other products**
  Many medicines are derived from plants, including aspirin, which comes from the willow tree (*Salix*). Even New York City waters are habitat for fish important for both the commercial and sport fishing industries, such as striped bass (*Morone saxatilis*).

- **Cooler communities**
  Trees and other plants provide cooling shade and help stabilize the global climate by removing carbon dioxide, the major greenhouse gas, from the atmosphere. Vegetation also cools the environment by transpiration (moving water from soils and surface waters through plants to the air).

- **Cleaner air and water**
  Plants, through photosynthesis, provide us with the oxygen we breathe. The cooling effects of shade and transpiration, mentioned above, also reduce the production of ground-level ozone, a major urban pollutant that aggravates asthma and other respiratory illnesses. In coastal systems, Eastern oysters (*Crassostrea virginica*) and ribbed mussels (*Geukensia demissa*) cleanse the water by filtering out suspended sediments and excessive nutrients.

- **Pollination**
  Fully one-third of our food, including apples, tomatoes, and squash, depends on the services of a pollinator — a bee or other animal. As European honey bees (*Apis mellifera*) have been declining due to the affliction known as Colony Collapse Disorder, the value of a diverse community of native bees and other pollinators has become increasingly apparent, whether on rural farms or city rooftops.

Bumble bee on zinnia. Image credit: Elizabeth Johnson.

- **Stormwater control and natural water storage**
  In healthy landscapes, stormwater is absorbed by plants and the soil, in the process removing pollutants and replenishing underground water supplies. In urban areas, where much of the natural landscape has been replaced by concrete and asphalt, contaminated stormwater runoff ends up in local waterways, accounting for 70 percent of water pollution (Loizeaux-Bennett 1999). New York City's combined sewer system compounds the problem, sending both stormwater runoff and untreated municipal sewage into waterways during heavy rainfalls.

- **Erosion control**
  As we witnessed in October 2012 with Hurricane Sandy, the degradation and destruction of coastal ecosystems such as salt marshes and sand dunes, which serve as natural buffers, can lead to increased damage to coastal communities by storm surges (the rise of sea level associated with storms). Often, beaches are rebuilt to save homes and other structures, at an enormous economic cost to the public.

- **Waste decomposition and soil fertility**
  Healthy soil transforms wastes into the nutrients necessary for sustaining life. Small organisms in the soil break down dead plants and animals, and in the process nutrients such as nitrogen and phosphorus are recycled to enrich the soil, enabling growth to continue.

- **Human health and well-being**
  Our connection to nature sustains us physically and mentally. Research shows that encounters with everyday nature restore concentration, calm anxiety, and reduce aggression in adults and children (Louv 2008). Biodiversity can also reduce the risk of disease transmission to humans (Keesing et al. 2010). A more diverse small mammal community — one that includes different species of mice, eastern chipmunks (*Tamias striatus*), gray squirrels (*Sciurus carolinensis*) as well as predators such as red foxes (*Vulpes vulpes*), for example — reduces the spread of tick-borne Lyme disease to humans in rural areas (Ostfeld et al. 2002).

- **A natural insurance policy**
  Ecologists believe that biodiversity makes landscapes more resilient, acting as a kind of insurance policy to cushion them from shocks, such as climate change or new insect pests and diseases. A biologically impoverished world would be unable to support us as effectively, or for as long, as one rich in organisms, biological communities, and ecosystems.

- **A source of inspiration and ideas**
  Scientists and engineers often turn to nature for ideas. The invention of Velcro, for example, was inspired by observation of plants like burdock (*Arctium*), whose seeds are dispersed by tiny hooks that grab onto animal fur (or clothing) (Gebeshuber and Drack 2008).

Perhaps most important, as environmental ethicists point out, biodiversity — species and ecosystems — have intrinsic value, which comes simply from the fact that they exist, not from some benefit they provide to humans or other species.

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How Does Biodiversity Benefit New York City?

New York City residents and visitors benefit from biodiversity in many ways. In 1992, for example, to avoid building a costly drinking water treatment plant, the City began acquiring thousands of acres of land in the New York City water supply watersheds and working with local communities to promote environmentally sensitive development and land management. According to City calculations, its planned investment of approximately $1.5 billion over the course of ten years saved it $4 billion to $6 billion in construction costs and an estimated $300 million per year in operational costs for the new water filtration plant that was no longer necessary (Chichilnisky and Heal 1998; Wilson 2002). The treatment plant would have doubled or tripled water bills; by contrast, the watershed protection plan increased the average New Yorker's water bill by only $7 per year.

According to a 2007 study by the Center for Urban Forest Research, New York City trees intercept almost 890 million gallons of rainwater each year, preventing it from entering storm sewers and saving the City an estimated $35 million annually in stormwater management costs. The cooling effect of all those trees also reduces energy consumption by a whopping $6.9 million (Peper et al. 2007).

Landscapes with a rich variety of habitats and organisms not only save the City money but make it more beautiful and livable. Imagine Manhattan without Central Park. Greenspaces provide an important connection with nature and opportunities for daily recreation for City residents and workers, and are ecotourism destinations for millions of nature-lovers and birders each year — all at "no charge."

In fact, greenspaces actually generate dollars. According to the U.S. Fish and Wildlife Service's 2006 National Survey of Fishing, Hunting, and Wildlife Associated Recreation report, in New York State there are an estimated 3.8 million bird and other wildlife watchers who annually contribute an estimated $1.6 billion to the state economy, including $250 million in state sales tax revenue, and support thousands of jobs across the state, including New York City.

Ashokan Reservoir, part of the New York City water system. Image credit: Helen Forgione.

Birdwatchers at Jamaica Bay. Image credit: Adriana Palmer.

Biodiversity Assessment Handbook for New York City

New York City's greenspaces also enhance property values. Studies show that homes situated near parks, public gardens, rail trails, etc., sell for significantly more money than those with no nearby greenspace (Crompton 2004).

In recognition of the importance of biodiversity, both species and habitats, New York City recently developed a Green Infrastructure Plan. The plan, developed by the Department of Environmental Protection, is a blueprint for stormwater management that complements the City's PlaNYC sustainability initiatives. The goal is to manage runoff from 10 percent of the impervious surfaces in combined sewer watersheds through detention and infiltration over the next 20 years. The New York City Department of Parks and Recreation has been building "greenstreets" for stormwater capture (streets with vegetated median strips or other features that reduce stormwater runoff) for nearly five years. The Parks Department will be working with the New York City Department of Environmental Protection to promote a comprehensive approach to green infrastructure, which will transform neighborhoods from "gray" to "green" through greenstreets, bioswales (typically small landscape elements in which vegetation and soil absorb and treat stormwater runoff), green roofs, stream daylighting (uncovering previously buried streams and restoring natural flow), and natural areas restoration.

The aim of the Green Infrastructure Plan is to change the paradigm of planning in New York City from a site-specific to a landscape approach — strategically designed, engineered, and managed networks of natural and developed lands working in concert to conserve existing landscapes, retain stormwater, and enhance environmental benefits such as natural water filtration and carbon sequestration (the removal and storage of atmospheric carbon in carbon "sinks" such as forest vegetation and soils). While green infrastructure projects are not designed as biodiversity conservation per se, they do in fact protect biodiversity by creating and maintaining greenspace. And conserving biodiversity in turn maintains the City's pool of species that potentially can be used for ecological engineering, such as different kinds of marsh plants for bioswale plantings, or varieties of trees and shrubs that survive with a minimum of care in parks or restored habitats.

Water infiltration swale at Oaktree Place (Bronx) captures stormwater runoff. Image credit: NYC Department of Parks and Recreation.

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1.2 Urban Bats

After reading the introduction to the biodiversity of New York City, Maya decides to start her own research. She finds some helpful websites, an eBook about bats with a chapter on bats and urbanization, and even some scientific articles about bats in cities. From her research, Maya writes her final report.

Read her report on pages 74–77 to see what she found out.

MAYA'S REPORT ON URBAN BATS

I live in the largest city in the United States—New York City. In 2016, the human population of NYC was 8.55 million people (World Population Review 2019); but what else lives in NYC? This report will discuss urban environments and the wildlife that lives in cities, with a special emphasis on bats.

Urban environments and wildlife

Cities are dominated by humans and human-made structures, such as buildings, roads, bridges, and parking lots. They are built to be where people live, work, play, and travel, so they are designed with the human population in mind. In comparison to people living in rural areas, individuals living within a dense city might have less impact on the environment because their housing takes up less land (high-rise apartments minimize land use per person) and they use public transit more frequently (i.e., less carbon emissions per person) (Florida 2012). Yet the cities themselves have quite an impact on their surrounding environment. The built environment and the high density of humans living within it leads to large continuous areas covered with buildings, concrete, or asphalt (known as impervious surfaces which keep water from being absorbed into the ground); increased pollution and waste/garbage generation; altered water systems; and increased artificial lighting and sound pollution (Jung and Threlfall 2016). Cities also change the local climate of an area, an impact called the urban heat island effect. Less radiation from the sun is reflected during the day because of the dry, impervious surfaces; the urban infrastructure is also slower to release heat in the night, compared to more vegetated areas (EPA 2019). This means cities are warmer than their rural surroundings; they are "islands" of heat.

Although the construction or expansion of cities leads to a loss of habitat and extirpation (local extinction) for many species that might have once lived in that area, other species remain and occasionally, thrive! Urban wildlife is a term used for species that live in cities. Although some species might struggle in the urban environment, other species can be quite successful because they don't mind (or have adapted to) living with humans. Some even benefit from humans because humans often provide food sources, such as birdfeeders, garbage, or pet food (Urban Wildlife Working Group 2012). Urban wildlife tends to have more generalist tendencies, in terms of their diets and habitats (i.e., less strict, more likely to be omnivorous), and are more flexible with their behaviors (for example, shifting to becoming more active at night when fewer disturbances are present) (Urban Wildlife Working Group 2012).

Bats in cities

On the whole, bats are threatened and declining because of urbanization, but certain bat species have been more able to adapt to urban environments. In the book "Bats in the Anthropocene: Conservation of Bats in a Changing World," a couple of chapters focus on and summarize the scientific research on bats in urban areas (Jung and Threlfall 2016; Rowse et al. 2016). This section will summarize these findings.

Currently, most of the research on urban bats has occurred in Europe and North America. These studies often focus on the response of bats to different aspects of cities, for instance: areas with lots of structures versus areas with few, old cities versus new cites, areas with lots of artificial lights versus dark areas, areas with and without parks, or areas with or without water availability. In general, these studies show that bats use urban habitat less than natural areas. Also, within a city, bats use areas differently—more urbanized areas are used less than those that are moderately urbanized. There is relatively high bat activity and species richness (meaning the number of different bat species) in areas with more vegetation, such as areas with older apartment buildings, as well as around rivers and in parks. Species might also use urban habitat differently throughout a year. For example, European bats (*Eptesicus nilsonii*) spend more time foraging for food in urban areas after the birth of pups (baby bats) compared to before any pups are born. Bats may also migrate through a city and use it for habitat only for a short time.

In one particular case in Chicago, more bats occurred in patches of habitats within the urban area compared to similar patches in rural areas! This might be because Chicago's urban areas provide a different mix of structures and habitat (like buildings, bridges, and forested parks) that bats can use for roosting, while its surrounding rural areas—mainly agricultural lands—don't have the same opportunities for roosting. Therefore, the built environment and large forested parks of Chicago actually help bats in the region.

Bats found in cities differ regionally but are mainly insectivorous (though fruit-eating bats have been observed in cities, especially in areas where residents plant fruit trees, like in Hong Kong). In general, bats that use city habitat most successfully have "high wing loading," which means that their wing surface area is small relative to their body weight (mass). Additionally, these bats tend to have long and narrow wings. Why is this important? These wing characteristics allow the bats to fly fast and they can forage in open areas (areas with low tree cover) without worrying about predators like birds of prey. Slower bats (with different wing characteristics) may avoid open areas like these because of the threat of predation; these bats tend to prefer more covered habitat, like you'd find in a forest outside the city.

Bats that prefer covered areas also tend to dislike lighted areas. Areas around streetlights are not only open, but also give predators the advantage of making it easier to see their prey. That's bad news for slower moving bats, but good news for other bats that are fast enough to avoid predators: these bats can use artificial lights to assist in their own hunting! Insects such as moths are adapted to use moonlight for orientation while flying; when encountering a street lamp or other source of artificial light, they may get disoriented and circle or collide with the lamp. Other insects can be immobilized or stunned by the light (called the "dazzling effect") and simply rest on the ground or a nearby structure, therefore becoming easy prey for a predator like a bat. Because of this resulting concentration of insects around lamps, some species of bats have used artificial lights found in cities as prime feeding grounds. However, light technologies are changing and not all bats respond the same way to different types of lights. For example, lights that give off ultraviolet (UV) light attract more insects and therefore more bats. Newer light-emitting diode (LED) lamps are increasingly popular because they reduce energy consumption and need to be replaced less frequently, but many species avoid these types of lights; some bats (*Myotis* and *Rhinolophus bats*) have been seen to avoid LED lamps even when the lights are dimmed.

Helping urban bats

Even though there are bats that have adapted to life in cities, they still face challenges and they might not do well enough to reproduce (Goldman 2015). One way to help bats is by creating green areas that could provide additional food sources, darker areas, and roosting habitat. For example, some research suggests that establishing networks of trees could help bats by providing benefits such as roosts; shelter from wind and predators; better foraging opportunities; and reducing the impact of light pollution (Langley 2019).

Another approach might be installing green roofs on the tops of buildings. Green roofs are vegetated spaces found on a building's roof. Although not all wildlife can get up to a roof to use these spaces, bats can! In NYC, Kaitlyn Parkins and Alan Clark from Fordham University in the Bronx studied whether bats used green roofs more than normal "conventional" roofs (Parkins and Clark 2015). Instead of sitting on roofs and watching for bats, these researchers set up audio recorders that recorded the ultrasonic sounds of bats' echolocation calls during the night. These recordings were used to determine how often bats were active over these two types of roofs. Results showed that bats were indeed using green roofs more than normal roofs. Considering approximately 34% of NYC is composed of rooftops, installing more green roofs could be a great way to help bats and other wildlife (like butterflies and birds) that use them (Goldman 2015).

Bat houses, which are wooden box structures that can be attached to buildings to provide roosting locations for bats, are another way to help. On a larger scale, bat friendly architecture can be designed and built. For example, bridges built in Austin, Texas, are now designed to provide bat roosting habitat after an unintentional realization that certain bridges provide better roosting locations than others (PBS 2019).

In terms of light pollution, there are efforts underway to do part-night lighting (meaning lights are turned off for certain portions of the night), light dimming, using lights that illuminate something directly rather than the whole area, and motion-activated lighting. These efforts may help reduce stresses on urban bats and other wildlife in cities.

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REFLECTION QUESTIONS

1. In your opinion, what was the most surprising information in Maya's report?
2. The NYC Biodiversity Handbook excerpt didn't have specific information about the value of bats with regard to ecosystem services. After reading Maya's report, do you think that bats in the city can help people? In what way? (Refer to the synthesis "Our Neighbors, Bats!" if needed.)

PART 2. BATS IN THE BRONX!

2.1 Learning More About Bioacoustics

Maya is excited—through her research she found out that bats are indeed in her area of NYC and that there are scientists studying them not far away! She decides to try and contact the research team at Fordham University to see if she might be able to volunteer with them. She would like to do a project monitoring bats in the Bronx and possibly enter the NYC Science Fair.

She finds Dr. Alan Clark on the Fordham University website and he connects Maya with Kaitlyn Parkins, the lead author of the study. Maya is in luck—the research group was actually looking for help! They decide that Maya can help with a project that monitors bat activity in the Bronx by installing an acoustic recording device (i.e., acoustic monitor) on her school roof, and thereby adding to the research group's data set. Dr. Clark asks Maya to do a bit more reading on how this type of passive recording and analysis works, and why it is a helpful way to study bats. He asks her to review this summary that he wrote for his students.

Bats and Bioacoustics

Bats are the only mammals with self-powered flight. The largest bat species generally eat fruit and spend the day flying from tree to tree in their search for fruit. In contrast, most smaller, insectivorous bat species are active at night (nocturnal). Since both fruit and insectivorous bats have vision similar to that of humans, how do nocturnal bats manage to find their way around? The answer is that these bats have evolved an amazing approach to navigation and hunting: sonar and echolocation.

The word “sonar” is an acronym of the phrase “**So**und **Na**vigation and **R**anging.” Sonar is a method of navigation that relies on the production of sound wave pulses and interpreting the echoes of these sound waves as they bounce off nearby objects. Submarines also use sonar, but to navigate through water rather than air. The type of sonar that bats use is called “echolocation.” Using unique morphological features (specially adapted body parts), bats produce a series of sound wave pulses and then listen to the echoes that bounce back. These echoes contain information on the location and size of objects around them—allowing these bats to fly and capture prey they cannot see.

Most echolocating bats produce sound waves through their larynx, the same structure humans use to speak. But bat echolocation calls are usually ultrasonic; that is, they are above the frequency[i] range of human hearing. In other words, most bat echolocation calls are so high in pitch that we cannot hear them—they are “ultra” (above) “sonic” (sound). Most humans can hear sounds ranging from 0.20 to 20 kilohertz (kHz). Sound waves have a frequency (pitch) that can be measured by the number of oscillations, or cycles, per second, and a hertz is a unit of frequency defined as one cycle. So, a 10 kHz sound has 10,000 sound waves/cycles per second. Humans hear sounds best when they are in the 2 to 5 kHz range. Bats, however, can produce sounds ranging from 20 to 200 kHz! That’s why humans cannot usually hear echolocating bats.

Echolocating bats produce a single “pulse” of sound, a series of which make up a “call” or “pass.” They have two main types of ultrasonic vocalizations: 1) calls used primarily to travel, often called “navigation” or “search phase” calls; and 2) calls used to capture prey, usually called “feeding buzzes.” Navigation calls give bats a “picture” of their environment that allows them to avoid hitting objects as they fly in the dark. These navigation vocalizations can be used to identify species or species groups through analyzing the unique characteristics of individual pulses, including a pulse’s frequency range, how fast the frequency of a pulse’s pitch changes (frequency modulation), and a pulse’s “knee” (the point where frequency modulation is at its greatest) (Figure 1). However, the most common character that is used to classify a pulse by species or species group is its fundamental frequency—that is, the lowest frequency of an echolocation pulse (see Figure 1). We can “visualize” ultrasonic sounds through spectrograms, which provide a visual representation, or picture, of

[i]The term “frequency” can be confusing. In everyday use, “frequency” generally means how often. But in the field of bioacoustics, “frequency” refers to a sound’s pitch, i.e., how high or low the sound.

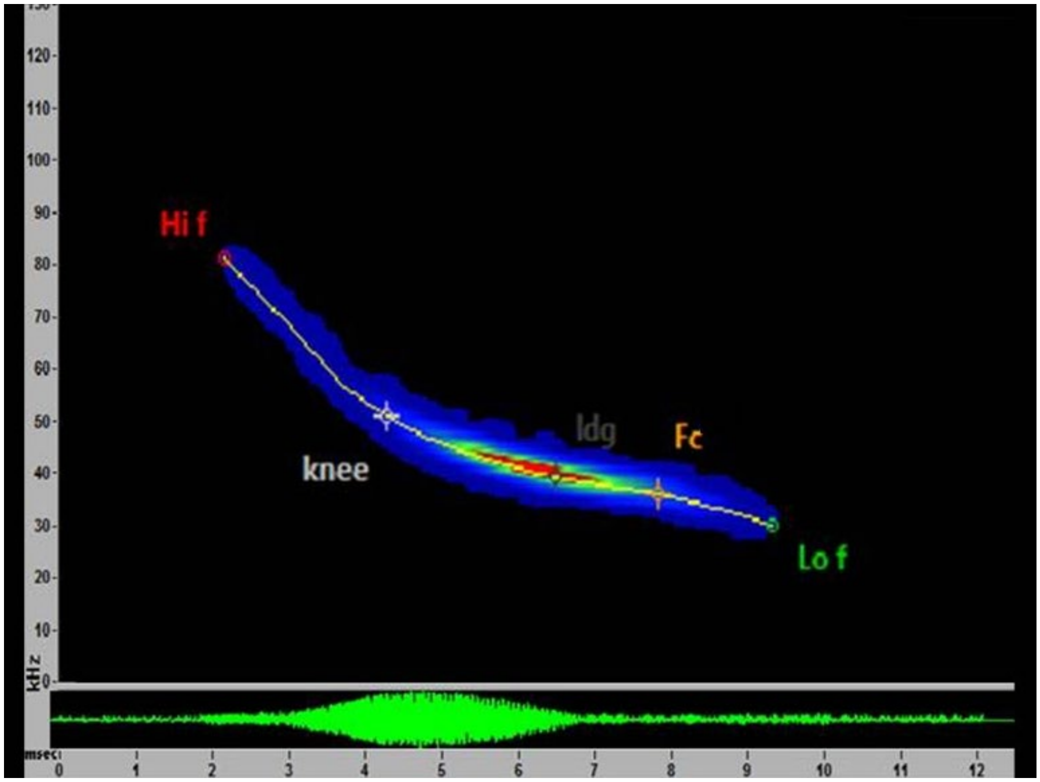


Figure 1. Spectrogram of bat echolocation pulse. Bat call identification is possible through acoustic software programs. Some programs measure multiple parameters of ultrasonic search phase or traveling pulses to identify pulses to the species level. For example, the software program Sonabat uses measurements such as high frequency ("Hi f"), the point of sharpest angle in the slope of the frequency ("knee"), and low frequency ("Lo f"). Other programs, such as Kaleidoscope, use both parameter measurements and an approach similar to that of facial recognition software to identify pulses to the species level.

a sound. In spectrograms, time is on the x-axis and frequency is on the y-axis. Spectrograms can also indicate where the most "power" or energy is found in a sound.

Many animal species can be identified by their vocalizations. The most efficient way to determine which frog, cricket, or bird species is present is to simply listen for their vocalizations. Bat navigation pulses are often species-specific; consequently, we can document the presence of a particular bat species by "listening" to bat navigation pulses in much the same way that scientists and birdwatchers identify birds by their song alone (see Figure 2).

However, compared to most bird songs, bat navigation pulses are much more variable. Bats adjust their pulses to navigate most efficiently in different types of environments. For example, in cluttered environments (like a dense forest), all bat species produce pulses that are faster and cover a wider frequency range. Thus the echolocation pulses of two different bat species pursuing the same prey item in the same type of physical environment will start to look similar (converge), making them more difficult to attribute to a particular species. Consequently, only navigation pulses produced in open environments are used to identify bats to the species level.

A bat will often multitask while traveling, using echolocation calls for locating prey as well as for navigation. When a bat is searching for food, the characteristics of the ultrasonic pulses it produces will begin to change. To improve the chances of finding an insect, bats use pulses with a wider frequency range than the frequency range of navigation pulses and increase the rate they produce these pulses. When pulse echoes indicate potential prey, the bat narrows the frequency range of its pulses and increases the pulse rate even further until the bat narrows its search sufficiently to grab the insect using its wings or feet. A series of food-seeking pulses is called a feeding buzz (see Figure 3). Bats of differing species often eat similarly sized prey items; consequently, the ultrasonic pulses they produce to find and capture those prey items can also be quite similar. Feeding buzzes are therefore not useful in identifying bats to the species level. Feeding buzzes,

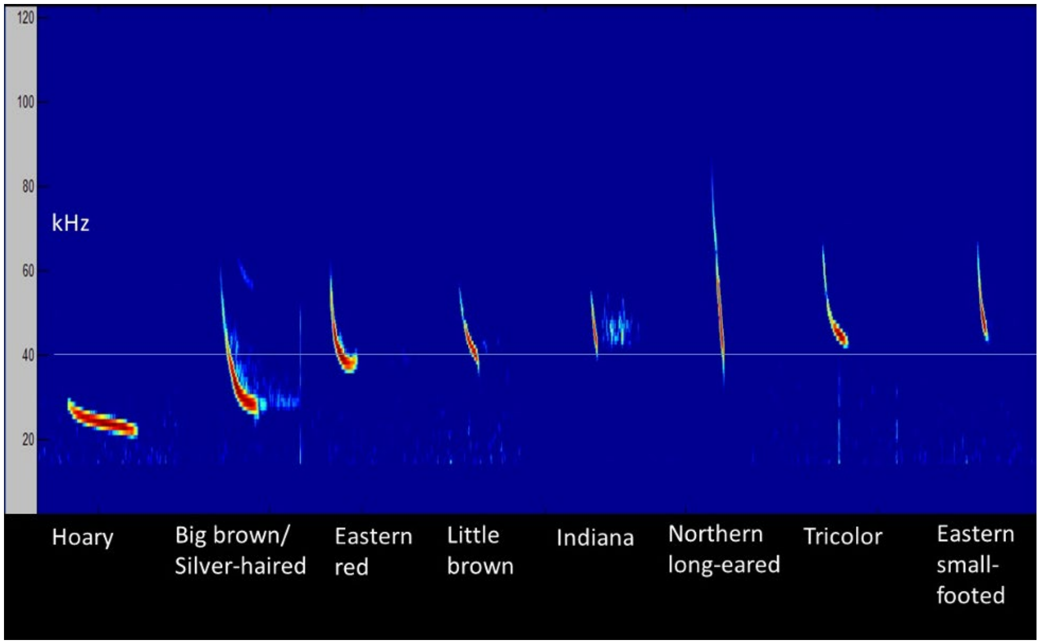


Figure 2. Spectrogram showing a typical ultrasonic navigational pulse for the nine bat species found in New York State. Image credit: Kathleen McDaniel of ERM, an environmental consulting firm.

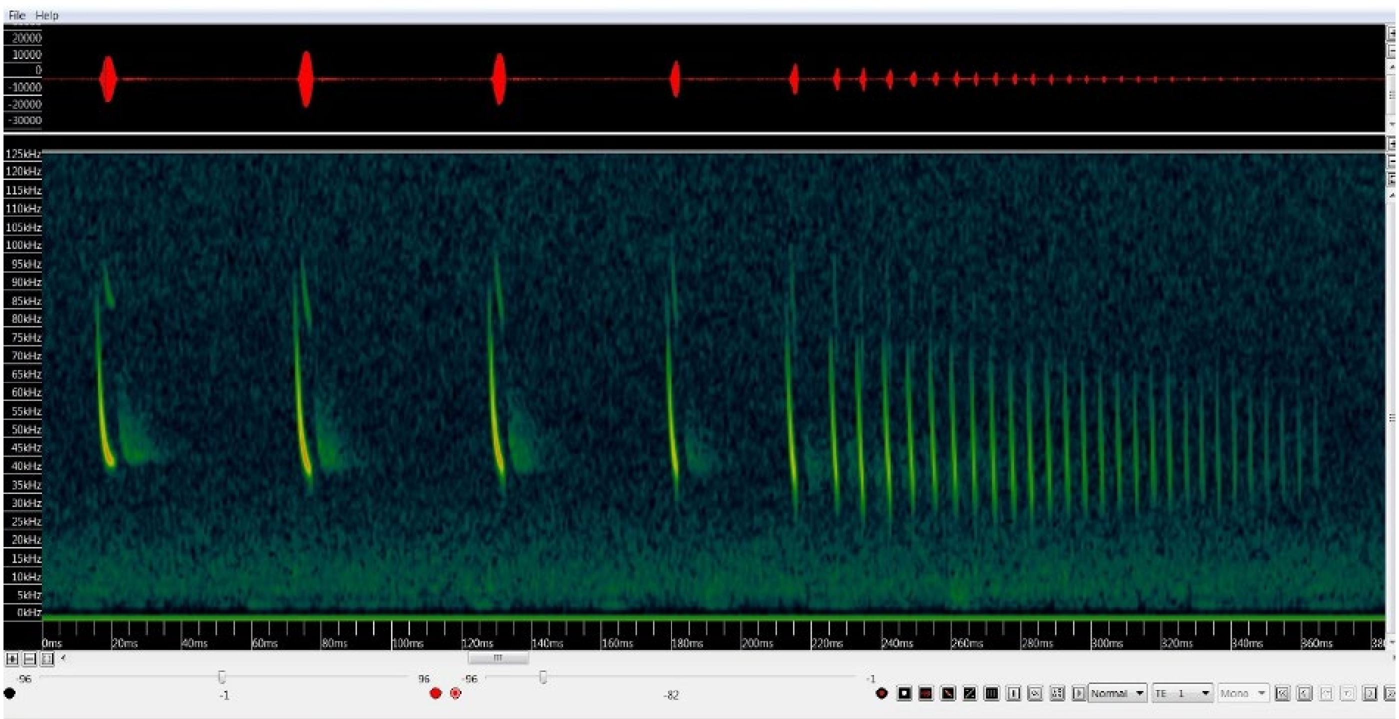


Figure 4. Spectogram of a feeding buzz. Feeding buzzes allow bats to "see" a variety of prey while in flight. When searching for food, such as moths and mosquitos, bats produce ultrasonic pulses that (1) cover a wider frequency range than their navigation pulses (2) are individually steeper, that is, are quicker, and (3) have a faster cadence, i.e., they are produced more rapidly. When the echoes suggest the location of potential prey, the pulses become even more rapid, but the frequency range narrows to that of the potential prey. When the bat is close enough, it grabs the prey with its wings, tail membrane, or feet and then eats the prey while continuing to fly.

however, are useful indicators that bats are using the area for feeding and can provide information on the relative quality of an area as bat foraging habitat. Interestingly, some prey can sense feeding buzzes (pulses) and have evolved to respond to them. Read Box 1 for more information on this evolutionary phenomenon.

Echolocating bats also produce a set of vocalizations termed "social calls," which bats use to interact with each other, usually at their roost. Social calls are usually within the range of human hearing, and people fortunate (or misfortunate) to have bats roosting in their home's attic can often hear these calls. Similar to bat feeding buzzes, social calls are not generally used to identify bats to the species level.

Bat Ecology Research

Because humans do not see well at night, gaining insight into the ecology of bats is challenging. Even determining whether a particular species is present in a given location can be difficult! One tool bat biologists often use to determine which bat species are present is a mist net. These nets are made with fine filaments that are often undetected by flying bats until it's too late and their flight momentum has carried them into the net, where their wings and feet become entangled. Researchers can then extract the bats from the net for study. When a bat is "in the hand," knowledgeable researchers can readily identify its species. Catching a bat of a particular species in a mist net is proof that the species is, in fact, found at that location. However, some bats are not easily captured in mist nets, particularly species that tend to forage higher in the sky—i.e., above the top of standard bat mist nets. Consequently, you can't conclude that a particular species doesn't occur in an area just because you haven't captured that species in your mist nets. While mist nets are important tools that many researchers use to survey local bat species, their limitations often require the use of additional survey methods.

Acoustic surveys are the most common additional method researchers use to document the presence of different bat species. Because bat echolocation traveling pulses can provide species-specific information, researchers can deploy automated ultrasonic recorders to undertake an acoustic survey for bat species. These ultrasonic recorders can often document bat species that are difficult to capture in mist nets. In addition, unlike mist nets, acoustic surveys have no physical impact on bats or on their behavior.

Box 1. Bats vs. Moths: A Co-evolutionary Arms Race

What is a co-evolutionary arms race? A frequently discussed example is the evolution of cheetahs and one of their preferred prey: the gazelle. Both run fast. Cheetahs that run faster are more likely to be successful in chasing down a gazelle and, therefore, more likely to live longer and leave more offspring. The trait of being faster would then be more common throughout the population. However, the fastest gazelles are more likely to escape from cheetahs; again, likely living longer and leaving more offspring with the trait of being faster. But if cheetahs then evolve that are even faster, only even faster gazelles could escape. This back and forth would continue in what is termed a co-evolutionary arms race.

How does this co-evolutionary arms race apply to moths and bats? Moths—many bats' preferred prey—are mostly nocturnal. Bats use their ability to echolocate to locate moths. However, moths would prefer not be become bat food. In response to bats' ability to echolocate, some moth species have evolved behavioral traits that reduce the bats' chance of hunting success. For example, several moth species have developed a tympanum, which is a sound sensitive structure that gives them the ability to hear in the ultrasonic range of pulses produced by bats. When "pinged" with an ultrasonic pulse (i.e., when they sense an ultrasonic pulse), some moths cease flying and fall to the ground while other moths undertake erratic flight patterns. Other moth species have a different response when pinged with an ultrasonic pulse: they produce their own ultrasonic sounds, effectively jamming the echolocation signals of the bat—making it difficult for the bat to pinpoint the moths' location. All of these behaviors can increase a moth's chance of survival and reproductive success.

In response, some bats have evolved countermeasures that include pulsing at frequencies outside the hearing range of most moths; changing the pattern and frequency of echolocation pulses during prey pursuit; and quiet, or "stealth," echolocation pulses that the moths cannot detect. Thus you have an ongoing co-evolutionary arms race between bats and moths. If you'd like to learn more and see scientists in the field studying this race for survival and success, check out "Moth Mimicry: Using Ultrasound to Avoid Bats" a video by HHMI Biointeractive found at www.biointeractive.org/classroom-resources/moth-mimicry-using-ultrasound-avoid-bats.

While acoustic surveys are a valuable research tool, they also have limitations that are important for researchers to understand. Some similarly sized bat species produce highly similar echolocation travel pulses. For example, it is exceptionally difficult to tell the difference between a Little Brown Bat (*Myotis lucifugus*) and the closely related Indiana Bat (*Myotis sodalis*), particularly because their geographic ranges overlap (they can live in the same area). Because the Indiana Bat is an endangered species, researchers need certainty in determining where they still remain so that efforts to improve their conservation status can be most effective. Some bats species also produce pulses that are relatively quiet and difficult to pick up, even by sensitive microphones. Some other bat species fly relatively high and are less likely to be recorded than lower flying species.

Another major limitation of bat acoustic surveys is that they are not appropriate for determining population estimates. Acoustic recordings cannot tell a researcher how many bats are present at a particular location. For example, if a recording contains 100 audio files that contain bat echolocation traveling pulses, the researcher has an irresolvable conundrum: Are these 100 files evidence of 100 individual bats that passed by the microphone, or could they represent one single bat that flew by the microphone 100 times? Perhaps those 100 files represent 20 bats that flew by 5 times each. Or 10 bats that flew by 10 times each. Given this uncertainty, bat acoustic surveys are more often used to simply document the presence of a particular species.

Although bat acoustic surveys are not useful for population counts, they can, nonetheless provide a very useful measure of how bat activity compares between two locations or between species. Researchers can use these measures of relative bat activity to explore which types of habitat a particular species of bat prefers. Acoustic surveys can also tell researchers how bat activity changes throughout the night and across the seasons.

Now that Maya has a better understanding of how bats use sound and how acoustic monitoring works, she would like to know more about the bats flying near her high school. Maya meets with Dr. Clark and Kaitlyn to discuss the possibilities. As a team, they decide that Maya will investigate the following questions: what bat species are present near her high school? Which bat species are most active? How does bat activity change through the night?

DISCUSSION QUESTIONS

1. Why didn't Maya ask how many bats are near her school, or how many individuals of each species are present?
2. List other types of questions about bats that are not easily answered with acoustic monitoring. How might you study bats to answer these questions?

2.2 GETTING STARTED ON A BIOACOUSTICS MONITORING PROJECT

Right before school's summer break, Maya is ready to get started. Dr. Clark has an extra acoustic monitor that is not currently being used (Figure 4) and Maya works with her teacher and school to get permission to put it on her school's roof. The research team gets together on May 1st to set up the recorder and train her on how to check the batteries and download the digitally recorded sound data (Figure 5).

Maya checks on the unit with her teacher the day after installing it, to make sure it is working and recording bat calls. Once Maya and her teacher are confident that the unit is working, Maya will visit the unit each week to download the recording data. In addition, Maya charges the batteries every two weeks. By July 24th, Maya has all the data for her project downloaded. In August, she meets up with Dr. Clark and they work together to analyze the data. Recall that bat calls are not within the normal hearing range of people, so they can't just play back the recordings and listen for bats. They have to use a software to help them identify what is a bat call and also what species it likely is coming from. In this case, Dr. Clark teaches Maya how to use an acoustic software program called Kaleidoscope, made by a company called Wildlife Acoustics, which specializes in analyzing bat acoustic data. Another widely used acoustic software program used to identify North American bat vocalizations is Sonabat (sonobat.com/).

Figure 4. The SM4Bat recorder and microphone made by Wildlife Acoustics. The recorder can be programmed to record at specific times. Bat researchers typically record from 30 minutes before sunset to 30 minutes after sunrise, when most bat species will forage for food.

Figure 5. A typical set up for the SM4 Bat recorder and microphone—here, on a high school in the Bronx, NY. The further the microphone is away from other structures, the better. Ideally, microphones should be set at least 3 meters above the ground or (seen here) above the roof to minimize clutter in recordings. Clutter is the reflection of pulses off nearby hard surfaces that can obfuscate, or "clutter" recordings—making them more difficult to interpret.

2.2.1 How to Run Bat Recording Auto ID Analysis in Kaleidoscope

Note: You do not need to follow these Kaleidoscope instructions to complete this exercise. Instructions and details are here for you to understand how the software works and to learn more about bioacoustic analysis. Additionally, these instructions will be helpful if you will be working with Kaleidoscope in the future. In Part 2.2.2, you are provided instructions on visualizing the results of the analysis completed for you in Part 2.2.1.

To help prepare Maya for their meeting, Dr. Clark recommended that Maya watch the video tutorial on how to use Kaleidoscope to auto-ID bats provided by Wildlife Acoustics. To watch this video, Maya went online to the Wildlife Acoustics website: www.wildlifeacoustics.com/ and clicked on "Video Tutorials" under the "Resources" tab and then clicked on "Kaleidoscope Pro Software." She then clicked on "Auto-ID For Bats" under "Kaleidoscope Pro Features" and watched the "Auto-ID For Bats Quickstart Tutorial." (Maya could have gone directly to this web page to start watching the video tutorial: www.wildlifeacoustics.com/resources/video-tutorials/kaleidoscope-pro-software/en/kaleidoscope-pro-software-auto-id-for-bats-quickstart-tutorial-english.) Sample bat recordings used in the tutorial and a PDF of the video transcript are also available in conjunction with this video tutorial.

After watching the video tutorial, Maya met with Dr. Clark who explained how software programs such as Kaleidoscope analyze bat echolocation pulses to make species identifications (IDs). Maya was surprised to learn that no software program can be 100% accurate in ascribing bat echolocation pulses to a particular species. Maya remembered that closely related bat species and bat species of similar sizes can produce highly similar vocalizations that even bat acoustic experts may not be able to accurately identify. While bat vocalization auto-ID software programs continue to improve in their accuracy, these programs remain imperfect. Because of these limitations, Dr. Clark noted that he prefers to take a conservative approach to bat vocalization analysis. For any tricky or difficult to determine recordings, he would rather not assign a species ID to a particular vocalization than to risk misidentifying that vocalization.

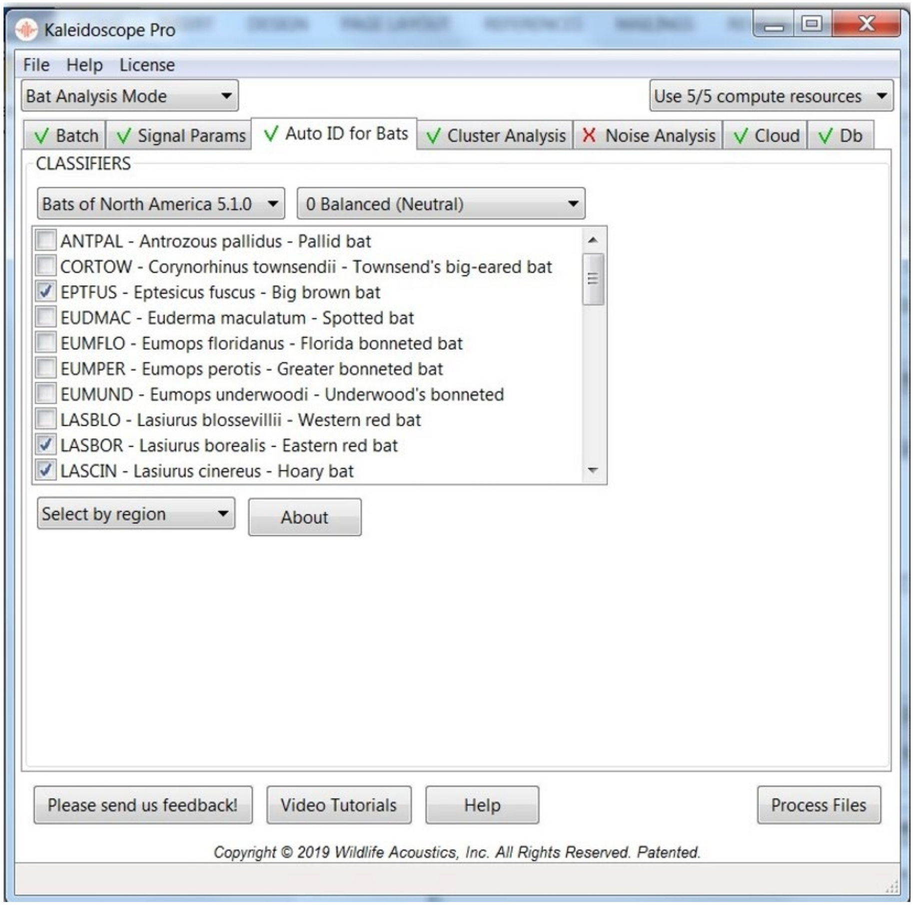
Maya then followed the steps provided by Dr. Clark:

1. Open Kaleidoscope (see screenshot of software below to follow along with where these below selection are made).
    a. At the upper left corner of screen, make sure that "Bat Analysis Mode" tab is selected and not "Non-bat Analysis Mode."
    b. At the upper right corner of screen, make sure that "Use 5/5 computer resources" tab is selected. **Note**: This option uses the maximum amount of available computer resources to analyze the bat recordings. If the computer was also running other programs that required substantial computer resources, fewer resources could be selected, but then the analysis requires more time.

2. Go to "Signal Params" tab.
    a. Change the "Minimum number of pulses" to "3". This option requires that a file must have a minimum of 3 bat pulses before Kaleidoscope will try to identify which species produced a pulse. **Note**: This option is more conservative than leaving the minimum number of pulses at "2".
    b. Leave all other default settings.

3. Go to "Auto ID for Bats" tab.
    a. Select "Bats of North America 5.1.0" (or more recent version if one is available).
    b. Select "+1 More Accurate (Conservative)." (Not shown in screenshot.) **Note**: Because auto-ID of bat pulses is not an exact science, Dr. Clark prefers that Kaleidoscope run in its Conservative mode. As a result, Kaleidoscope will positively ID fewer bat pulses, but the program will also make fewer misidentifications.
    c. Select by Region (State): e.g., "New York." (Not shown in screenshot.) **Note**: Kaleidoscope compares

your recordings to recordings of local bat species it keeps in libraries for each species. If you don't limit the potential bat species to only those found in your state (or region), Kaleidoscope is almost certain to misidentify many of your calls.



4. Confirm these tabs are disabled: "Cluster Analysis," "Cloud," and "Db." We will not be using these software capabilities.

5. Go to "Batch" tab.

6. For "INPUTS":
   a. Set input directory (use "Browse" to find the file where your recordings are located).
   b. Check "Wav (and W4V) files" (Wav and W4V flies are different types of audio files that the unit recorded).

7. For "OUTPUTS":
   a. First, you will need to create an output folder—this is the folder where the results of the auto-ID process will go. **Caveat**: this folder can't be within the input folder. You may wish to give the output folder the same name as the input folder, but with additional text that separates from the input folder (e.g., input folder: "Bronx Zoo – July 2018," and output folder: "Bronx Zoo – July 2018 – output").
   b. Set output directory (use "Browse" to find the output file you created).
   c. Select "None" for "Create subdirectories."
   d. Change "Split to max duration, seconds" to "8". (Not shown in screenshot.) **Note**: Individuals bat recording files can be as long as 15 seconds. To help standardize data analysis, Dr. Clark recommends using this function to keep maximum file length to 8 seconds, which is also the maximum duration other bat analysis software programs can analyze.

e. Check "Wav (and W4V) files." "Wav files are a full-spectrum recording format. You may be more familiar with MP3 or MP4 recording formats, which only include some components of a sound and are often used for digital music to reduce the amount of data space a full-spectrum recording would require.

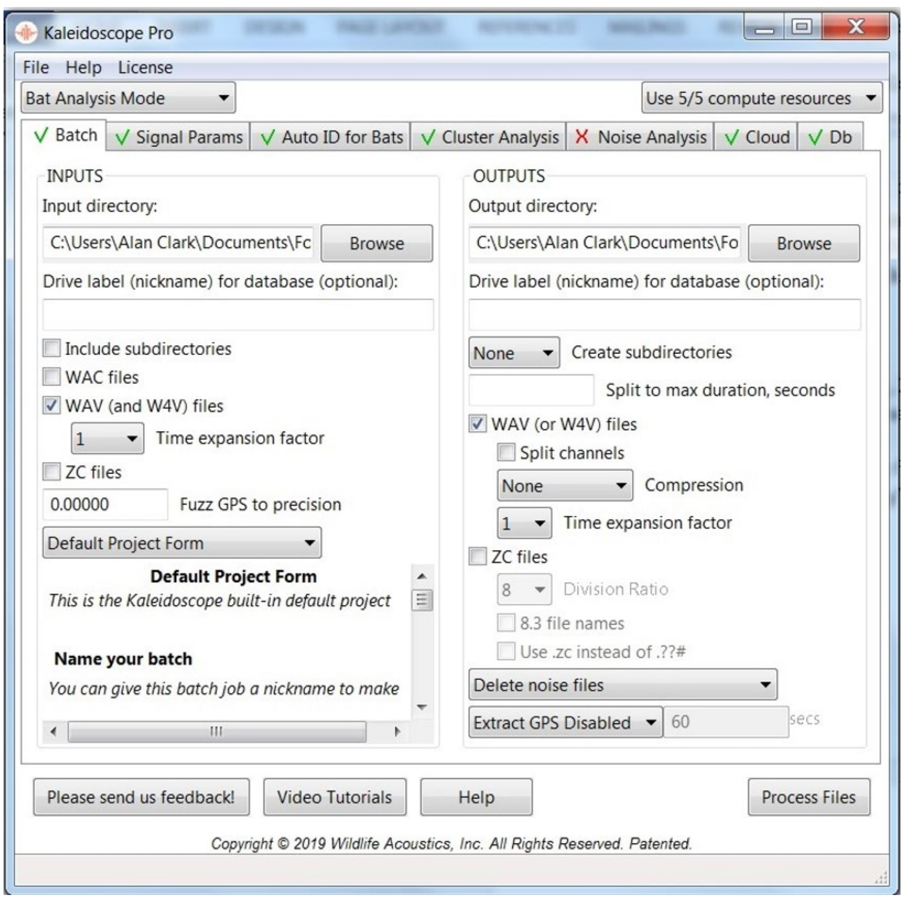
f. Select "None" for "Compression." Sound recordings can be compressed. But here, we want the uncompressed recording to facilitate data analysis.

g. Select "1" for "Time expansion factor." Wav files can be recorded in a "time expansion" format that allows data to be added to a recording. Here, Kaleidoscope is simply asking if the recordings were recorded with a time expansion factor. Wildlife Acoustic bat recorders do not use time expansion factors, so the setting here is simply "1".

h. Select "Delete noise files." So, what are these noise files? Many sounds contain ultrasonic elements. For example, if you snap your fingers, you will be producing sounds in both our hearing range and the ultrasonic range. Sirens, HVAC equipment, even some insects all produce sounds with ultrasonic components. Kaleidoscope is programmed to recognize sounds that, while in the ultrasonic range, are not bat calls. Those files are labelled "noise." If you selected the "Delete noise files" option, those files will be automatically deleted and not considered when the bat recording data are analyzed.

i. Select "Extract GPS Disabled." If you were conducted an active survey, moving between locations while recording bats, you could enable the GPS function which automatically puts GPS location data on each recording so that you know both when and where the bat was recorded.

8. Click the "Process Files" button at the bottom right.



Note 1: When Kaleidoscope finishes processing files, two new windows will pop up: a "viewer" file that shows a spectrogram of the first call in the output folder and a "results" file. These windows are used to manually review each call and its ID after Kaleidoscope runs. Dr. Clark noted that Maya would not be using those windows, so she should simply close them.

Note 2: Dr. Clark also mentioned that 2 gigabytes (GB) of recorded data usually takes about 2 minutes to process on his computer, but that the speed at which Kaleidoscope auto-IDs files run will vary greatly, depending on the capability of the computer on which Kaleidoscope is run. Kaleidoscope can also be run while in the "Cloud." Instructions on how to run Kaleidoscope in the Cloud were provided to your teacher/supervisor, should they prefer that approach to identifying bat calls.

After Kaleidoscope finishes processing the files, the analyzed calls are placed in the folder you created for output. At the very bottom of that file are three CSV files: "id," "id summary," and "meta." The primary file of interest is the "id" file.

Things for Further Consideration from Dr. Clark

Bat researchers using acoustic recorders to survey bats usually receive specialized training in how to identify bat species using acoustic recordings. Developing such expertise can take a considerable amount of time and effort. Such researchers usually use bat auto-ID software as a starting point for their analyses. After running a program such as Kaleidoscope, researchers carefully review many, if not all, individual recordings to confirm, correct, or supplement the program's auto-ID selection. For example, a limitation of bat auto-ID programs is that they can only assign one ID to a recording file. However, a recording file can sometimes contain more than one bat species or more than one individual of the same species. A knowledgeable researcher can look at a recording, determine if it contains pulses of two or more bat species, and update to file's information to reflect that situation using the windows described above in "Note 1."

However, Dr. Clark doesn't expect his high school student researchers to become bat vocalization ID experts! Rather, he recommends that, since most student researchers do not have the expertise required to evaluate the accuracy of a software program's auto-ID selections, students set the program's parameters to its most conservative settings. Dr. Clark also notes that if Kaleidoscope auto-IDed a few pulses in one or more of your recordings as coming from an unlikely or rare bat species, you should be highly skeptical of that ID. If possible, you might want to find a local bat vocalization expert and share those unlikely IDs for their expert opinion.

Just because pulses cannot always be identified confidently to the species level doesn't mean that those bat recordings don't have important value. Unidentified ultrasonic bat pulses are evidence of bat activity. So, for instance, if a researcher wants to compare when at night bats are most active overall, their research can include both identified and unidentified pulses. Also, if a researcher is comparing overall bat activity between two sites, unidentified bat pulses can be included in the analyses.

2.2.2 Interpreting the Data and Visualizing the Results

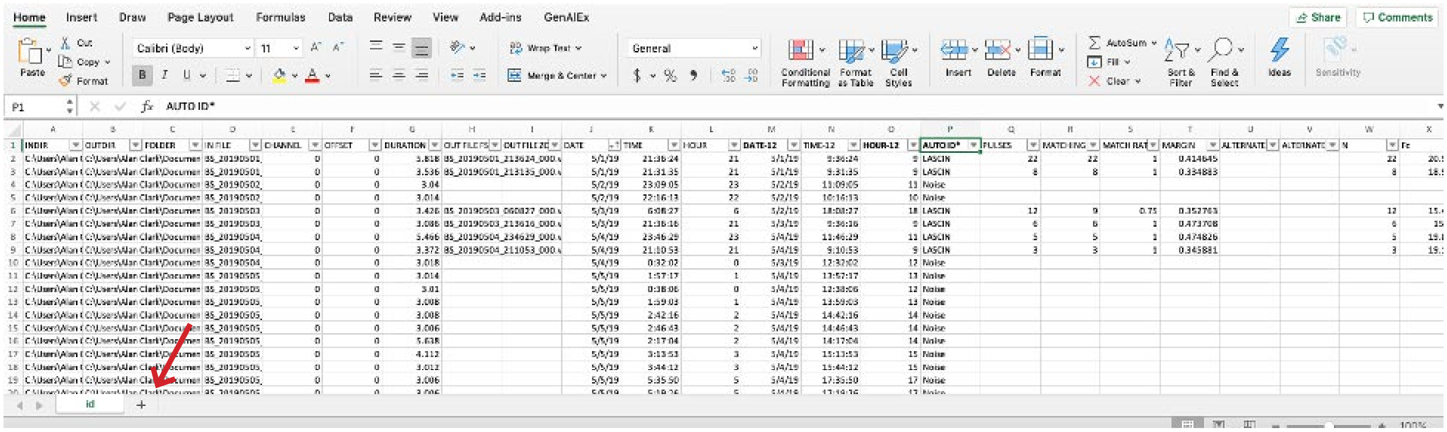
Maya is now ready to start exploring the data found in Kaleidoscope's "id" file, but when she opens it, it is very hard to interpret. Here you'll help Maya summarize and visualize the results from the "id" file and answer these five questions.

During June and July...
Question 1: What bat species are present near Maya's high school?
Question 2: Which bat species is the most active?
Question 3: What is the average activity for the most active bat species?
Question 4: How does hourly average bat activity change throughout the night?
Question 5: Do the two most active bat species have different patterns of activity through the night?

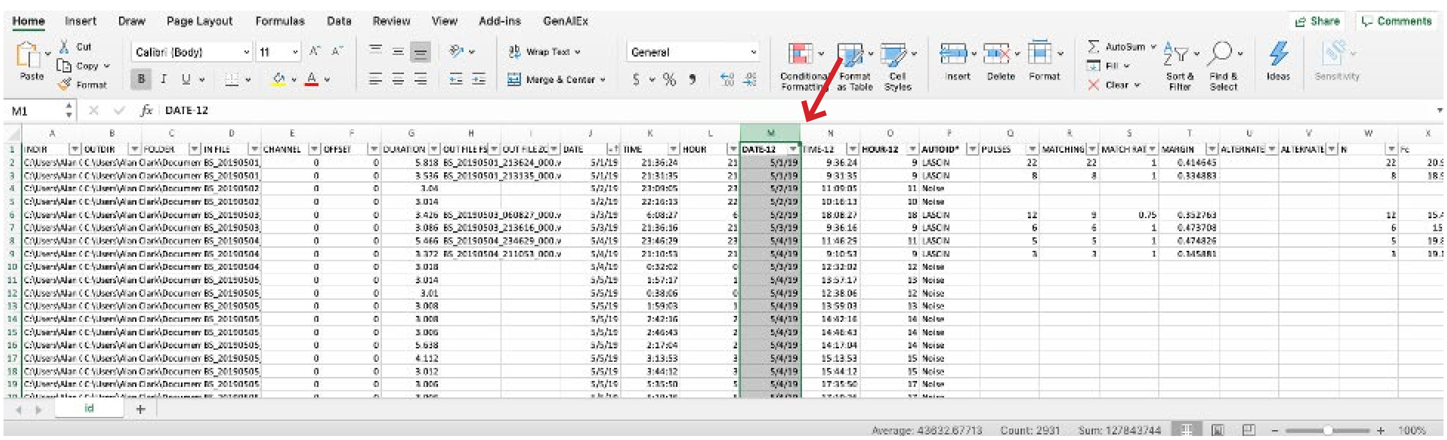
Instructions:

1. Open the "id" file produced by Kaleidoscope as a CSV file. CSV files are comma delimited files and can be opened in spreadsheet software, such as Microsoft Excel or Google Sheets. The instructions below are explained using Microsoft Excel for Mac (Office 365 Version 16.30), but similar capabilities are possible with other software. You may need to adjust the instructions to the needs of the spreadsheet software you are using.

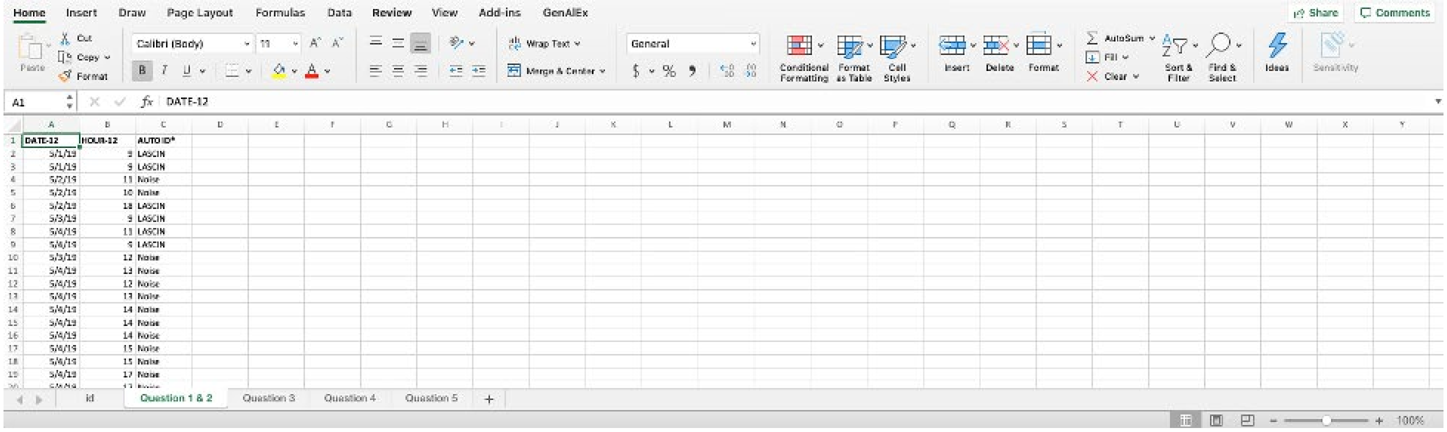
2. Once you have opened the spreadsheet, familiarize yourself with the data. Many of the columns will not be relevant for your analyses. In this case, we will only need the following columns: “Date-12,” “Hour-12,” and “AUTO ID." **Note**: most North American bats are nocturnal, so we tend to describe bat activity per night. However, because a “night” covers two different calendar days and because we use the same numbers to describe two different times of day (e.g., 1:00 am versus 1:00 pm) tracking and describing bat recording data can be very confusing. Therefore, we use “Date-12” and “Hour-12” to convert these data to formats that are easier to track and understand when thinking of “nights." To create a new worksheet in your spreadsheet with only these data:
    a. Click the “+” tab at the bottom of the worksheet, next to the tab titled “id.”



    b. In the original data sheet tab, highlight the column you are interested in by clicking on the letter above it (in this case, columns M, O, and P).



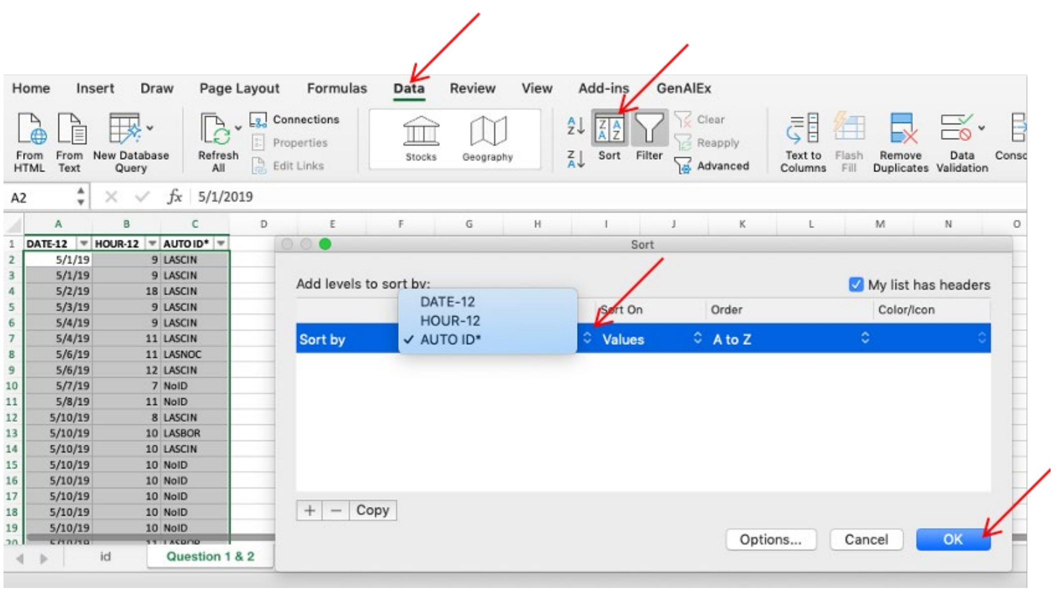
    c. Once it is highlighted, right-click on the column and select “Copy,” or press “command-c.” (**Note**: on a Windows computer, press “ctrl” instead of “command.”)
    d. In your new worksheet, select the first open cell, right-click and select “Paste,” or press “command-v.”
    e. Repeat b-d for the additional two columns.
        - **Tip**: Alternatively, you can copy all three columns at once by holding the “command” key down while selecting each column and then selecting “Copy” or pressing “command-c.”
    f. Your new worksheet should look like the screenshot below. You can also rename the new worksheet “Question 1 & 2” by right-clicking on the tab at the bottom and selecting “Rename.”
    g. Then make three more blank worksheets (by clicking on “+” button) and rename them “Question 3,” “Question 4,” and “Question 5” for use in future steps.



h. Save your workbook with a new file name that includes your name or group name in it.

3. Question 1: What bat species are present near Maya's High School?
For Question 1, look at your third column, "AUTO ID." **Tip**: You might want to use the "Filter" function under the "Data" menu to easily determine what the species/categories are in the AUTO ID column.
What are the different IDs that appear?
What species names do they correspond to?
Tip: Do an Internet search for the bats of New York State and compare the list of scientific names to the abbreviation IDs. There is a pattern to the abbreviations, see if you can figure it out!

4. Question 2: Which bat species is most active?
For Question 2, we recommend that you create a pie chart to compare the relative activity of each bat species. **Note**: data can be presented graphically in several formats (e.g., line graphs, bar graphs, pie charts, etc.), but a pie chart is a good way to look at this data set. To create a pie chart:
a. First, delete all rows that list "Noise" in the Auto-ID column.
   - **Tip**: Select the first 3 columns (the data columns) on the worksheet ("DATE-12," "HOUR-12," and "AUTO-ID") by holding shift while clicking the column letter headers. In the toolbar on the top, click the Data menu and then "Sort." Under "Column," select "AUTO ID" and press "OK."
   - **CAUTION**: Make sure that you don't sort only the "AUTO ID" column; all columns must be sorted together to make sure that the data in each row refers to the same data file.



b. Your data should now be sorted by ID. Scroll down through your data to the entries with "Noise" as the "AUTO ID" category. Then select all rows with "Noise" as their ID and delete (click on the first row number and last that has "Noise" as the ID and then scroll to the last that has "Noise" and hold the Shift button while you select the last row that has "Noise" and then hit the delete button).

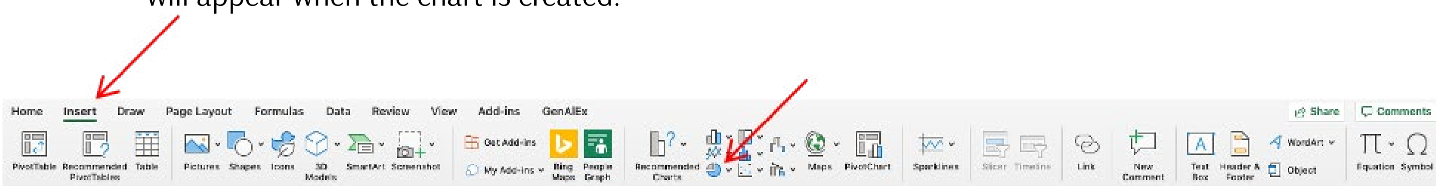
c. Next to the data columns, make a new column heading in your Questions 1 & 2 worksheet called "Total Passes."

d. Then, make a column heading for each variable (ID code) in the "AUTO ID" column (excluding the variable "Noise").
   - **Tip**: You should have a total of 8 new columns.

e. Determine the total amount of activity by counting the total number of passes completed by all bats. This will be the total number of rows in your data set, including those identified as "No ID." Put this number under "Total Passes."
   - **Tip**: You can use the row number on the left side of the screen, but don't forget to exclude the title row in your count!

f. Next, determine the amount of activity for each bat species by counting the total number of rows recorded for each species. Put this number under the column you've just made for the species IDs.
   - **Tip**: You can use the row number on the left side of the screen and do math to figure out how many rows for each ID, or use the Excel formula "COUNTIF" which counts a cell within a range of cells if it meets a criteria that you set. To use "COUNTIF", enter "=COUNTIF("under the species column you are working on, select the entire "AUTO ID" column and then type a comma and the species ID code of interest in " " and end the formula with an end parentheses. For example: =COUNTIF(C:C, "NoID") would get you a count of all of the instances of "NoID" in the "AUTO ID" column.
   - **Tip**: Check your work! Enter "=SUM(" into a blank cell, and select all your totals for each AUTO ID category. Press enter. This number should match the number under "Total Passes."

g. To create a pie chart, highlight the column title and count number for each of your species, including "NoID." Do not include "Total Passes." In the toolbar on the top, select the "Insert" menu, then click on the image of a pie chart, and select the type of pie chart you want to create.
   - **Tip**: you can edit your final pie chart's colors, text, and layout using the "Chart Design" options that will appear when the chart is created.



h. Save your workbook.

What is the total number of passes?

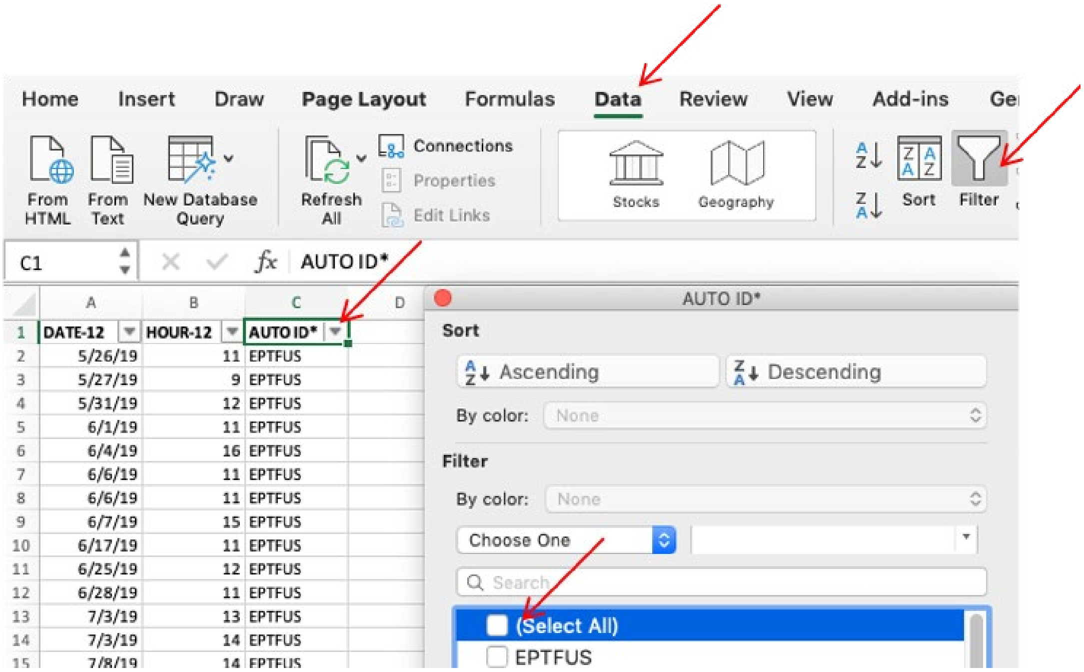
Why can we include "No ID" passes in this calculation for total bat activity?

Which bat species was the most active? (You will use this species to answer the next two questions.)

5. Question 3: What is the average activity for the most active bat species? For Question 3, we want to determine the average number of passes per night for the species that is most active. **Tip**: we recommend using a new tab (worksheet) for this analysis—copy and paste the three data columns from your Question 1 & 2 sheet into the worksheet you named Question 3.

   a. First, we want to sort the data by date.
      - **Tip**: See step 4a for a reminder on how to sort your data.

b. Next, we want to only look at our most active species. Select the column “AUTO ID,” and in the “Data” menu, select “Filter.” A small black arrow should now appear next to the “AUTO ID” column. Click the arrow, and a box will pop up. Deselect “Select all” and then select only the species you are interested in. Click outside of the pop up box to exit the box.

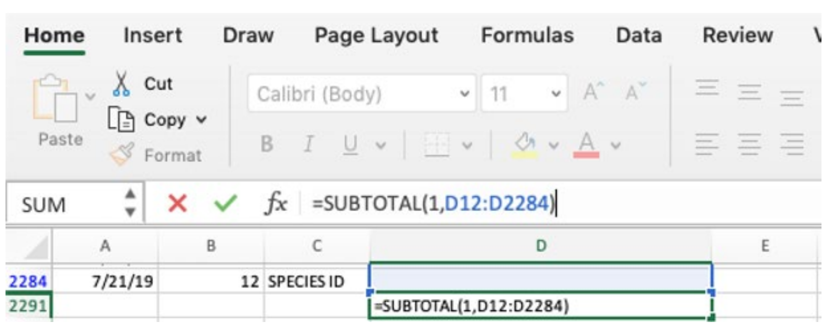


c. Insert a column next to “AUTO ID” titled “# Passes per Night." In this column, use the “Count” formula to determine the number of rows (or passes) that occurred for each date.

- **Tip**: To use “Count” formula, enter “=COUNT(” under “# Passes per Night” and next to your date of interest and select all the entries that are the same date in column A (“DATE-12”) and press enter (for example, highlight all of the 5/10/19 dates). Scroll to the next date and repeat this process (by using the “Count” formula in the # of Passes per Night column next to each new date for each of the dates with recordings).

d. At the bottom of the # Passes per Night” column, enter “=SUBTOTAL(1, ” and select all of your data in the “# Passes per Night” column (can include blank cells) to determine the average number of passes per night for this species. Press enter. (See screenshot below.)

- **Tip**: Because we have filtered the data, we cannot use the “Average” function here. Instead, we use “Subtotal,” and we indicate a “1” to tell the function to take an average. In this formula, you could also use “9” to take a sum, or “2” for count.



During your analysis, did you notice any dates that were missing? What do you think the reasoning for this is?

What do you think this will do to our average calculation?

e. Go back through the data and find any dates that are missing. If a date is missing, right-click (or two finger click on Mac touch pad) the row number below the missing date and click "Insert Row." A blank row should now appear in your data set. Fill in the missing date under "DATE-12," and indicate "0" for "# Passes per Night." Complete this for all missing dates in the data set. **Note**: This step would not be taken if the recording unit was malfunctioning for any particular night, but in this case, Maya did not have any issue with her recording unit not working.
f. Save your workbook.

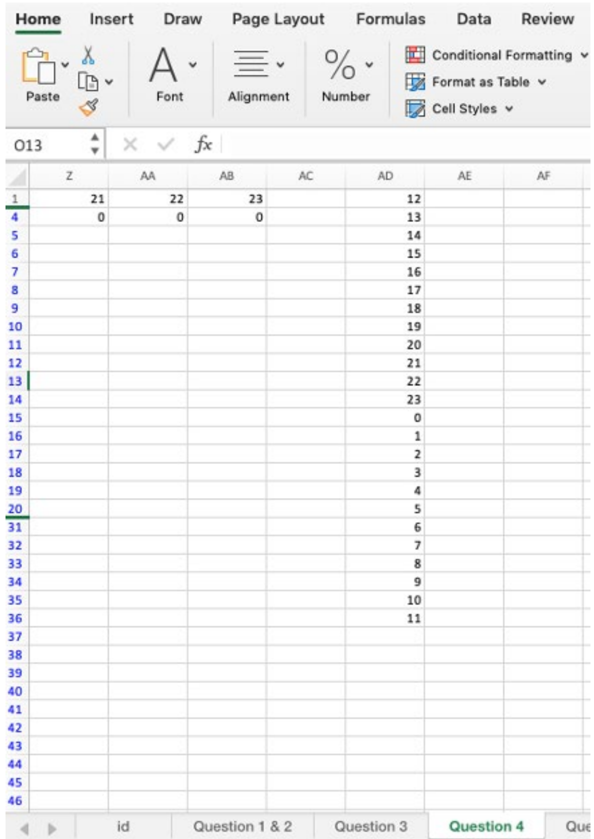
How did this change your average number of passes per night?

6. Question 4: How does hourly average bat activity change throughout the night?
For Question 4, we will create a line graph to show how bat activity changes over time.
   a. First, go to your Question 1 & 2 worksheet and copy three data columns and paste in your Question 4 worksheet.
   b. Sort the data by "HOUR-12" (see 4a above). Then, we will again filter "AUTO ID" for our most active species (see 5b above).
   c. For graphing purposes, make new column headings next to the data columns for each hour of the day. To the left of your new columns, label the top row "Hour-12." Label the next row "[Species] Count" with the abbreviation for the most active species in brackets.
      - **Tip**: you should have 24 new columns labeled from "0" to "23," plus an additional column with row labels.

E	F	G	H	I	J	K	L	M
HOUR - 12	0	1	2	3	4	5	6	7
[SPECIES] COUNT								

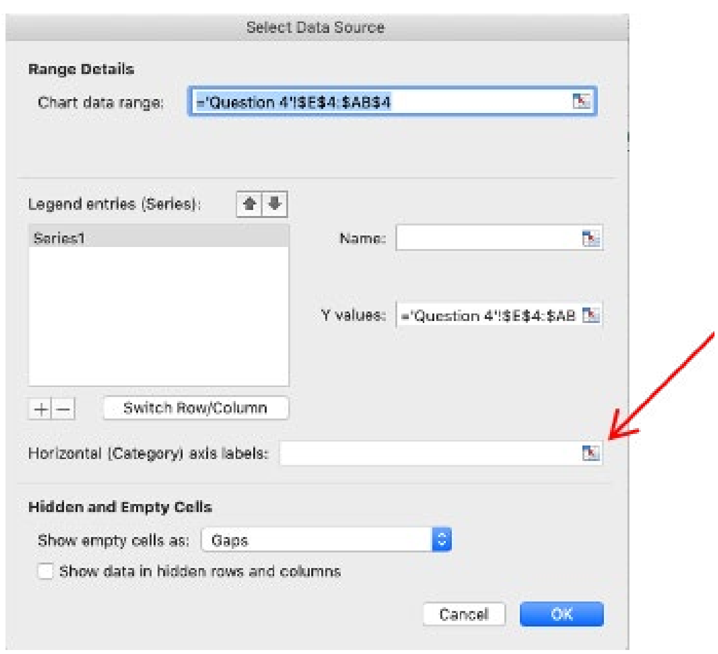
   d. Under each new column, use the "Count" formula to determine the number of rows that occurred for each hour (see 5c above). Be sure to indicate "0" below the column header if there are no passes recorded that hour.
   e. Next, check your work by adding up all your count data in this row and comparing it to the total you had in the Question 1 & 2 worksheet.
      - **Tip**: You can use the "Sum" formula to add across the row. Type "=SUM(" and highlight the row of count data and press Enter.
   f. To create your graph, select all the cells with the count calculations you have created (do not include the column headings). In the toolbar on the top, click the "Insert" tab and then select the line chart icon and then select "Line with Markers" option.

   g. Use the "Chart Design" tab (visible when chart is selected) to edit your graph, adding axis titles and a main title. You can also edit its color and layout.
   h. To make your graph more accessible, we suggest you edit the x-axis labels to reflect the 24-hour clock, rather than the HOUR-12 numbers. To do this you will first need to translate the HOUR-12 data to the corresponding hour on the 24-hour clock.
      - Scroll past your calculations and make a list of these numbers in an empty column (see screenshot). These numbers represent the 24-HOUR clock times that correspond to the HOUR-12 data. For example, hour 23 for the HOUR-12 data is equivalent to 11 am in the 24-hour clock and hour 12 for the HOUR-12 data is equivalent to 0 (or midnight) for the 24-hour clock.

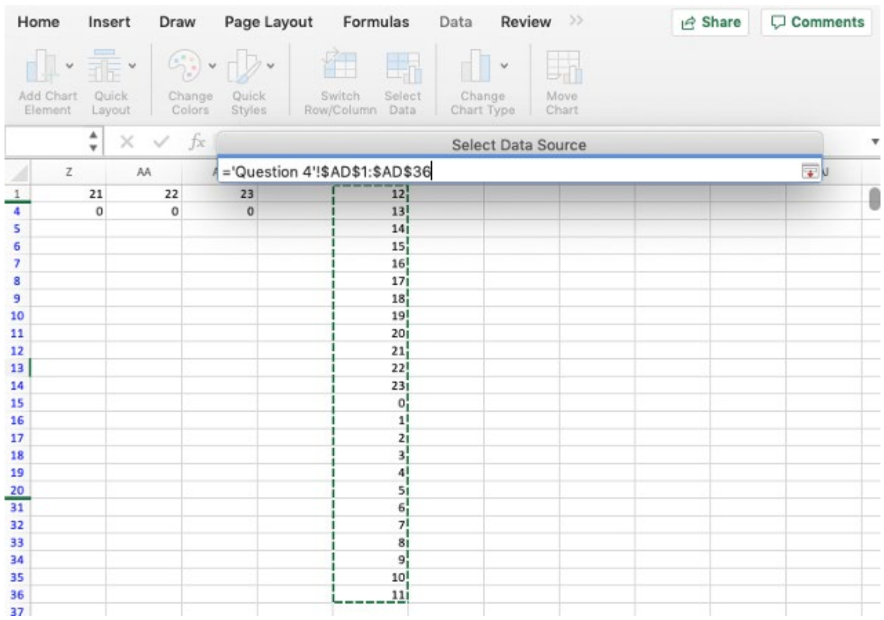


- Now click on your chart and the "Chart Design" tab will appear on the top tool bar. Select the "Select Data" button and a pop up box will appear.

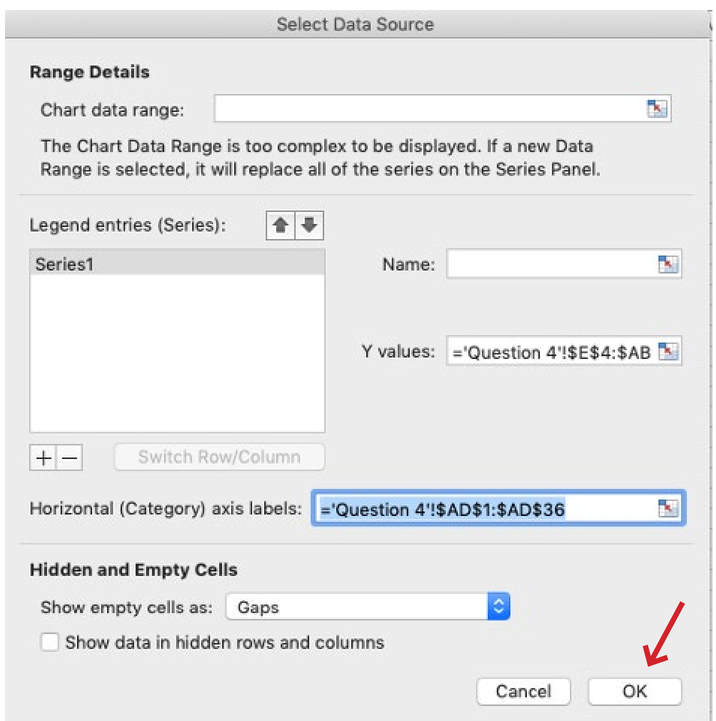
- Navigate to the "Horizontal (Category) axis labels:" field and click on the icon on the right.



- The window will minimize and then you use your cursor to select your newly listed times, and the formula will automatically appear in the "Select Data Source" box.



- Hit "Enter" and then the full "Select Data Source" box will return and then you hit "OK."



- You will now notice that the x-axis labels on your chart have changed to reflect the 24-hour clock times, with the first label starting with 12 (noon) and the last ending with 23 (11 pm). Following this procedure will ensure that the middle of your chart corresponds to the night-time hours (the hours the bats are active).
- Save your workbook.

How does average bat activity change throughout the night? (Describe this species' nightly activity trend shown in the graph.)

7. Question 5: Do the two most active bat species have different patterns of activity through the night?
    a. We recommend copying over the three columns of data from the Question 1 & 2 worksheet and pasting them your Question 5 worksheet for this analysis.
    b. For Question 5, repeat steps 6a-h (Question 4), but filter "AUTO-ID" with the second most active bat (see Question 2).

Compare this chart to the one completed in Question 4. How is average nightly bat activity different or the same for these two species?

c. Now we will copy over the count data from Question 4 because we'll be graphing the activity for both of the most active bats on the same chart.
d. Navigate to your Question 4 worksheet and select the count data from Question 4 and copy it.
e. Under the first cell for your count data for Question 5, right-click the cell and select "Paste Special." Under the section "Paste," click "Values," then hit "OK." Be sure to include the row label.
f. To create your graph, highlight both count calculations. In the toolbar on the top, click "Insert," then select the line chart icon, and select "Lines with Marks."
g. Change the x-axis labels by repeating the step 6.g above.
    - **Tip**: To get the "Select Data" pop up, you can also right-click the graph and select "Select Data." After selecting your "Horizontal (Category) axis labels," you can also edit your chart legend: Under "Series," select the series whose name you want to change, and type the appropriate species name under "Name." Repeat for the other series, then click "OK."

You'll notice that the shape of the second species activity looks different now that it's graphed with the activity of the first. Why is that?

h. To get a clearer picture of the patterns of activity between these two species, we can graph the percent of all passes that happen in each hour for each species. So if there were a total of 100 passes for species A and two of them happened in the 9 pm hour, then it'd be 2%. And if species B had a total of 1000 passes and 20 of them happened 9 pm hour, then it'd also be 2%. Looking at it this way, we can now say that relative to their total activity throughout the night, each species has a 2% of their activity in the 9pm hour. Let's now try it with our data.
i. Scroll over to the end of your count data and make a new column headed "Total Passes."
j. For your first row of count data, add up all of the passes for your second most active species. You can do the math in your head, or use the sum formula by typing in the cell under "Total Passes "=SUM(" and then highlighting the count data in the first row and hitting enter.
k. Repeat this for the next row (the count data copied over from Question 4, your first most active species). You will now have to the total number of passes for each species.
l. Below the copied over count data from Question 4, you will start a new row that will calculate the percentage of passes per hour for your second most active species. Label this row "[Species] %" with the abbreviation of the second most active species in the brackets. In the first hour column ("0"), type "=", and click the count data for that hour. Then type "/", and click the number in your "Total Passes" column. Hit enter. Repeat for each hour.
m. In the next row down, repeat step 7.l for your most active species.
n. You can check your work to and make sure that your total percentage for each species equals 100 by using the "Sum" formula for the percentage rows under the "Total Passes" column.

o. Repeat step 7.f-g to re-graph relative species activity but using the percentage data.

Looking at relative activity (comparing percentages), does the second most active species demonstrate similar nightly activity patterns, or does it behave differently? If differently, how does it differ?

8. Please save your Excel workbook (confirm your name is incorporated in the file name) and submit your results as instructed by your teacher.

REFLECTION AND THINKING FORWARD

1. Write up a brief summary of Maya's findings.
2. Were there any results that surprised you or you found particularly interesting? What did you expect and what did you find?
3. Maya thinks these results will make an exciting science fair project, but she still has some time before it's due. Help her brainstorm other questions she might be able to answer with her data set. If you were to expand the study, how would you do it? What would you need? What other questions might you ask?

ACKNOWLEDGMENTS

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