AUTUMN

(Opening Music)
(Narrator) Coming up on Quest, Fall foliage happens at the same time every year

(Sandy Wilmot) I think trees are pretty amazing in their clockwork of being able to know when it's time to change from energy production to shutting down in preparation for winter – and they do it every year.

(Narrator) And the wild mushroom. It gets very little respect but plays a major role in the Northern New England autumn.

(Van de Poll) Mushrooms I think first and foremost are known as recyclers of biomass and I don't think you can over-emphasize that. In turns of cellulose among them and wood products, wow!

(Narrator) And can birds smell their way south to their wintering grounds?

(Wilson) There are some birds that use their nose; they're able to smell their way to particular places.

(Underwriters)

(Opening Music)

(Linda Greenlaw, Segment Host) Hi, I'm Linda Greenlaw. Here in northern New England, autumn is the season that always lives up to its hype. Although incredibly beautiful, it's a bittersweet time of the year. It's hard to shake that nagging feeling that the boom's about to be lowered and we should be doing more to get ready for winter. Come to think of it, that sense of urgency to get things done may be something we share with the natural world.

(Narrator) There's a reason why northern New England is known the world over for its fall foliage. Because most of our hardwoods, or deciduous trees, change colors at the same time, we get to enjoy an intensity that other regions cannot compete with. But you'd have to be an extremely astute observer to notice all the other changes going on in the natural world at this time of year. The behavior of birds, mammals, even insects, begins to change in mid-summer. And subtle adjustments are happening in plants long before the first "official" day of autumn.

(Charles Johnson, Naturalist) The preparation for autumn dormancy…in a lot of organisms starts at the solstice. The summer solstice…If animals weren't ready for winter and it suddenly arrived, they wouldn't make it.

(Narrator) So there must be some kind of internal calendar that plants and animals use to keep track of time so they don't get caught off-guard. Scientists now think there must be a biological clock ticking away in virtually every single organism. Finding it has become one of the biggest scientific challenges of our time.

(Bernd Heinrich, Biologist) There's an awful lot of work being done on you know, what the clock is…. Exactly how it works, it's still up in air.

(Narrator) What is clear is that organisms can set their biological clocks to the cooler nights and shorter days of autumn. But how they communicate that message and how they react to the information is what makes autumn as interesting as it is breathtaking.

Karen Bennett is a New Hampshire forester who is frequently asked about the timing of fall foliage.

(Karen Bennett, NH Forester) Sometimes people think it's weather-related, the cold weather causes them to, well that's part of it. But it's primarily the length of the day that triggers the tree to change the hormones that it sends out and cause the tree to stop growing. So it really is day length. That's the one thing that doesn't change over time.

(Reeser Manley, Professor of Plant Physiologist-University of Maine) Plants do a lot of things because they can't move around that I think are very fascinating. And they compensate for their immobility by these other mechanisms .

(Narrator) In plants, it's the job of a single pigment to pick up on changes in daylight and communicate that information.

(Charles Johnson, Naturalist) Phytochrome, which is one of the pigments in plants, is the instrument of both the calendar, tracking the calendar, the seasonal calendar, and triggering plant responses to the season. It's a timekeeper and it's a messenger. That's sort of the plant's way of telling itself it's time to start shutting down and get ready for fall.

(Sandy Wilmot, Vermont Monitoring Cooperative) I think trees are pretty amazing in their clockwork of being able to know when it's time to change from energy production to shutting down and preparing for winter. And they do it every year.

(Narrator) Sandy Wilmot oversees a group of Vermont scientists that cooperate on a number of projects, including forest surveys.

(Sandy Wilmot, Vermont Monitoring Cooperative) First I look for all those forest health signs in fall colors. And every once in awhile I have to sort of catch myself and say, "wait a minute, this is gorgeous. This is fantastic." And every year it happens at the same time.

(Narrator) If we could see inside the flaming red maple or any other deciduous tree in autumn, we'd be amazed at how much is going on. There are shuttles that take water, sugars, minerals and other nutrients out of leaves and into storage compartments in stems and roots. Growth hormones are locked away in storage. And chlorophyll production comes to a halt. And then the magical happens. Other pigments undergo a biochemical transformation and burst into the vivid colors we look forward to every year.

Reeser Manley teaches plant physiology at the University of Maine.

(Reeser Manley, Professor of Plant Physiology-University of Maine)
As we get more and more sophisticated in our ability to measure these chemicals, I think we're going to discover there are these kinds of root-shoot discussions going on all the time.

(Narrator) Carotenoids, the same pigments that create the yellows and oranges in fruits and vegetables - like bananas and carrots – help keep chlorophyll from breaking down during the growing season. They only become visible after the tree tells the green chlorophyll that it's no longer needed. At the same time, sugars begin to assemble in the leaf. The colorless flavenoid pigments, that also help keep chlorophyll intact in the summer, then bond with the sugars to create some brilliantly colored anthocyanin pigments. These are the same reds and purples that color the brightest fruits – such as strawberries and grapes. Even as these pigments start masking the green in leaves, it's vividly clear that chlorophyll does not disappear all at once.

(Charles Johnson, Naturalist) The sort of rule of thumb in seeing the best colors for tourists is…the bright sunny days and cold nights. And the theory there is the bright sunny days increases the production of sugar in the leaves, which again latch on to these flavenoids and become the anthocyanins and give you the brilliant colors. And the cold nights shut down the transportation of the sugars so they stay in the leaf. So the next morning when the sun comes up again, you get this brilliant brilliance.

(Narrator) Charles Johnson and Nona Estrin recently co-wrote a book on the seasons of New England.

(Nona Estrin, Naturalist) That was right here from this window, and we sort of look how it had changed over a few days. October 6th to October 9th. People always want to be there on the brightest day. The day when the bright reds are the most prominent. I like to think of fall in which there's an early peak, a mid-peak and a late peak.

(Nona&Charles walking on road)
Nona: The maples are still showing a little tinge of green.
Charles: The sugars will be caught in those leaves and they'll latch onto those anthocyanins.
Nona: Those anthocyanins. (Laughs)
Charles: And turn a beautiful red and it will be the perfect opportunity for leaf peeping tomorrow.

(Nona Estrin, Naturalist) the color spectrum is actually the broadest when the first red maples turn. The flowers are usually still blooming; a lot of asters. There's a lot of green. The color spectrum is the widest. And then that spectrum starts to narrow down as we get the brighter reds. And it narrows even further when we come to the yellow. What I call the "yellow explosion" at the very end. When you think it's all over and suddenly, there's a lot of yellow.

(Narrator) Some trees and shrubs, like red maples and sumac, actually pump up the production of anthocyanins in autumn. Why these plants need so many bright red and purple pigments has triggered new speculation and research among scientists. We have much more to learn about our natural world - even with something as familiar as fall foliage.

(Karen Bennett, NH Forester)
When people ask why do leaves change color, we have some knowledge. But we don't have complete knowledge. The biology of trees is still not fully known. So that's why scientists are asking; they've been asking for hundreds of years, why do things happen? Because we don't fully understand everything that's going on in those trees or the leaves, they're still asking those questions.

(Sandy Wilmot, Vermont Monitoring Cooperative) Forests go through this process of changing colors and it's a part of their life. So you could say that the death of the leaves is part of the life of the tree.

(Narrator) But every year, the show has to end. The leaves' striking colors and all other signs of life seemingly drain out. Their relationship with a tree is about to be severed. This is the other half of autumn in northern New England. As the dry, curled up brown leaves begin accumulating on the ground, many of our trees and shrubs are left with the barest of essentials to face winter's rigors. It makes you wonder why the leaves had to fall in the first place?

(Sandy Wilmot, Vermont Monitoring Cooperative) The fall is an important part of the life of trees. They know winter is coming. They've adapted to these mechanisms to draw back the nutrients from the leaves into the tree and store it in the twigs and roots of the trees. So that they can survive the cold temperatures, energy is needed then. If the leaves stayed out all winter, that surface area of the leaves would capture snow, draw the branches down, and there would be a lot of branch breakage, which we see happens sometimes when early snows come. The cells in a tree don't die during the winter. There's a certain amount of energy that's needed to maintain them above a temperature that they can be sustained. So all winter long trees are using some of the energy they've stored up during the summer.

(Narrator) Losing leaves would be very traumatic to trees if they weren't ready for it to happen. The leaf is actually part of a vascular sytem that runs uninterrupted through twigs, branches, down the trunk and out to the smallest root hairs underground. The job of severing the leaf has been compared to self-amputation, and trees have a surgically precise way of doing it. Where a leaf meets the twig is a layer of microscopic cells – specially designed to break.

(Manley): It's a very specific zone within the pedial(?) …only a few cell layers wide or thick. Very distinctly different anatomically. When you look at it in cross-section or in longitudinal section through the pedial(?), you notice that the cells are much, much smaller, neatly arranged in tight rows. You can almost visualize before it happens, the line of abscission that will occur.

(Narrator:) In autumn, the cells of this layer begin to swell and form a cork-like material that slowly cuts off the flow of nutrients between leaf and tree. Once another layer of cells containing scar tissue and wound gum is in place, the seal is complete. A similar process goes on in evergreens, although on a much smaller scale. Evergreens shed their leaves, or needles, too, but except for the tamarack, they don't shed all of them at once. And only older needles, ones that have functioned for several years, are "retired." Like all plants, evergreens will slow their growth in winter. So what happens to all those leaves that fall from our trees?

For every acre of northern New England forest, there's usually about 1 ½ tons of dry foliage – leaves or needles on the ground by season's end.

(Bennett): When leaves hit the ground, they're really not done. They may be severed from the tree, and they may be dead. But there's still loads of good food in there for micro-organisms in the ground that feed on them, that extract the nutrients, extract the carbon, extract the nitrogen. And these organisms basically eat them, and excrete them, and break them down into smaller components that are used in essence by the tree again or the other plants. So when the leaves fall, they're not done. They may not be part of the tree, but they still have a lot of life in them, so to speak.

When the first leaf or needle falls to the ground, there's a whole cast of organisms waiting down below. If ever arthropod, snail, earthworm, nematode, slime mold, fungus, and bacterium found in just one acre of soil could be piled on a scale, their combined mass would likely weigh in at five tons. It takes this diversity of organisms to cut, grind, and digest all this material and keep leaf litter from accumulating year after year.
This process actually begins before the leaves fall with fungi spores in the air.

(Manley): Tissues are breaking down, defenses are breaking down. And so you would expect the normal processes would include more infection. In fact, many of the saprophytic fungi that actually help in decomposing the fallen leaf, are on the leaf before it leaves the tree.

(Narrator): It's an odd partnership. Initially acting as an insecticide to keep pests away from the tree, saprophytic fungi later then aid with the demise of the leaf. Once on the ground, other fungi join in.

Rick Van de Poll is one of New Hampshire's leading mushrooms experts.

(Van de Poll): In a cubic inch of soil, regular old duff, they say there's something on the order of a mile or a mile-point-two of hyphal threads and those are the individual cell structures of the mushroom, end on end. Tease it out, it's a mile or so in a cubic inch of soil.

(Narrator): Most of the action takes place in the layer of soil right under the leaf litter. But much of the leaf litter is composed of compounds notoriously difficult to break down.

(Van de Poll): Mushrooms, I think, first and foremost are known as recyclers of biomass. I think that is the biggest single well-known contributing role. And I don't think you can over-emphasize that. In terms of cellulose and lignin and wood products, wow!

This organism has in part evolved into the perfect mechanism to provide and recycle those nutrients. A leaf hits the ground, gets compressed, mycelial growth, or the mushrooms long hyphal threads start to proliferate upwards towards new nutrient sources, and these leaves are fresh with lignins and cellulose and all kinds of stuff. And sugars that the mushrooms will utilize in their own growth. They may not have chlorophyll left, but nonetheless they do have other compounds the mushrooms can use. So eventually these leaves just compress, compress, compress and the mycelium begin to infiltrate.

For every acre of forest like this, more than 100 pounds of nitrogen, phosphorus, potassium, calcium, and magnesium are returned to the soil each year. Trees then utilize or "borrow" these nutrients for their growth. Leaf litter is the "payback" and is by far the single largest source of nutrients for the forest. Much of the work of fungi goes on in the deeper and wetter leaf litter layers. For the most part we're unaware of their work until their fruiting parts, some brightly colored, suddenly sprout up through the moist soil.

Many wild animals take notice. Squirrels savor mushrooms and toad stools and often store them out on tree limbs to dry so they can enjoy eating them later all winter long. And moose and white-tailed deer also love them. Mushrooms and lichens comprise 40 percent of their diet of in the fall.

(Van de Poll)**:** Certainly they need more of the oilier materials, the beechnuts, the acorns and so forth. And yet they relish these things. I've see groups of 40-50 pounds of mushrooms completely consumed by how many deer, I don't know. But there's just little nubbins left. So they obviously love certain ones and you don't find any of those in the fall or very many of them because they're consumed first.

But I don't think the mushrooms serve as an accessory. I think they also provide the vitamins and minerals that are essential.

(Van de Poll): Oh, beautiful. See it's nice network on type, the nice reticulating venation on the top of the stalk. There's no time like autumn for mushroom connoisseurs of the two-legged kind.

(Van de Poll): Look at the difference. When we think about mushrooms. Dampness right. What else?

(Student): Darkness!

(Van de Poll): Darkness. True enough, a lot grow in the dark.

(Student): Poisonous!

(Van de Poll:) Poisonous! There we go. Let's get down and dirty with the mushrooms. Mushrooms!, oh my God! You are a mushroom collector? You can lose some of your best friends and relatives, I might suggest, having some experience there, if you tell them you're into mushrooms. Because it's a kind of weird, dirty, dank, dark, moldy, mildewy kind of subject. Right? So you gotta to be a little bit twisted to like mushrooms. So I honor you for all joining the forces of twisted minds here.

And as I warn my students, you take one bite of a wild mushroom and you will never be the same. You can't exactly figure it out, but put it this way, my experience is if people start consuming wild mushrooms it becomes an addictive habit very, very quickly and they'll want to know more.

(Narrator): Van de Poll is understandably a popular guide for those wanting to learn more about wild mushrooms.

(Van de Poll): Oh man, look at that! That is absolutely exquisite. We've got to stop the crew. Everybody's got to take a look at that one. Wicked common. That's not the common name for it, but it is. That's the wicked common mushroom. (laughter).

Amenida muscaria, the fly agaric. Sometimes called the stupefying fly agaric because it stupefies flies. Musca. Fly in Latin. Musca. Muscaria. They use this by cutting up pieces of the cap, putting it in a bowl of milk, typically goat's milk, and the flies would be attracted to it, drink the milk, and die. Or at least get stupified. This is one of the most well-known mushrooms in the world. And for many good reasons. One, it's quite toxic. Alright? And it's not that it's just poisonous, it won't kill you per se. But as they say in the trade, you may wish that you died.

Chicken of the woods. Chicken of the woods. Where's the rest of it? That's exactly what I asked. See? I couldn't believe it. That's exactly what I said. Where's the rest? This is the smalles chicken of the woods I have ever seen. And you know what? I think they really know what it is and they have a basket hidden in the woods. Fifty pounds of it. This is remarkably good tasting; one of my favorite edible mushrooms in the entire world.

In terms of the natural world itself, the kingdom of fungi has always surprised me, and will continue to surprise me as to how important it is. And how not only would plants not be here, but certainly we would not be here without fungi. And certainly the

relationships between the different kingdoms, between the different organisms, and between the different communities of organisms, how important that role of fungi is.

This group of mushrooms are tough generally, somewhat woody sometimes fleshy like this one. It's one of those things that whereas they are a lot of books that are available, you really need to go out with somebody who knows a little something about mushrooms in order to be sure, especially if you're going to eat them.

(Narrator): In the autumnal woods of northern New England, it's not just the trees and shrubs that get a new look. Virtually every resident bird and mammal end up with more feathers or fur in the fall - usually 50 percent more.

Dave Erler is a naturalist at the Squam Lakes Natural Science Center.

(Dave Erler, Squam Lakes Natural Science Center): there's not only what appears to be a thicker coat, but there's actually more fur there, considerably more fur. Even little animals, like the black-capped chickadee have considerable more feathers on them in the winter than they do in the summer to help with their insulation.

(Narrator): The underfur that mammals grow in the fall is often crimped as well, allowing for more air pockets and better insulation. Mammals' comfort zone for cold temperatures can drop by 40 degrees or more with these denser winter coats. But why do some animals' autumn molt come in white and others not? Sure, it's a good way to camouflage them in the snow to fool predators. And we now know that it also helps keep the animals warm.

Melanin is the pigment that gives color to an animal's coat. But it also takes up space in the shafts of fur and feathers alike.

(Johnson): If the feather is white, it lacks that pigment, but the space is still there. Which provides extra insulating value to the white feather or fur.

(Narrator): As with plants, it is the shortening of the days that triggers the changes in animals. A sensor, sometimes called the third eye, also helps detect changes in light. This is the pineal gland. It's the size of a pea and is located in the middle of the brain of mammals.

(Dave Erler): Amazingly to me, the nerves of the eyes help to stimulate, send the signal to that gland to secrete the chemicals in to the blood which affects the melatonin or hormone levels in their body and controls so many of the developmental or reproductive processes that are going on. Tremendous importance, but not as full understood as I think we'll hopefully will get to someday.

(Narrator): Biologists are just now discovering that there may be a variety of internal clocks keeping time in nature – even in single-cell organisms. But much more research still needs to be done.

(Heinrich): They've found that many cells can even measure time. On a rhythmic basis have certain behaviors, such as cell division. Genes have now been identified as are involved in the clock. If you knock them out, they can't tell time anymore, and everything is, activity is at random times. So what the clock actually is a lot of contention for different kinds of clocks.

(Narrator): For a few northern New England mammals, autumn is the time of year to look for mates. For large ungulates – those wild animals with hoofs – the rutting season takes place in the fall.

(Erler): The deer, moose, of course they're larger animals, their gestation period is longer. Their breeding period, or the rut, occurs for moose most typically in October, and for white-tailed deer, more in November. But they need to mate then so their young can develop and be born in the time of the year where they can grow sufficiently and build up fat reserves of their own to get through the next winter that's coming along.

(Narrator) Since the males tend to put on such a dramatic show while in rut, the female's role can get overlooked.

(Erler): The female is the one that chooses. We often think of the male being the chooser, but he's the one that's proving to the females that he's the most verile, the one that's best able to produce off-spring that are going to be able to survive for her. So she's actually the one that's selecting.

(Narrator): Females encourage as much competition as possible so that only the fittest males are allowed to pass their genes on to the next generation. Compared to some of their more demonstrative cousins out West, the white-tailed deer and moose of northern New England are mild-mannered during the rutting season. Males often will try to be an inconspicuous as possible while "tending to" females, even hiding with them to escape the notice of other male suitors.

(Erler): It's a stressful period for animals. We often think of the males being the big strongest males. But they're often the ones in poorest shape going into winter. Whether you're a bull moose or a large buck deer, because they've spent so much energy, not necessarily fighting, but just trying to keep that little corral or herd of deer or moose, trying to keep that group together, so he has exclusive breeding rights. And so at the same time, he's spending so much energy in that area, and not eating much, there isn't much food consumption during that time, that he goes into winter in pretty poor shape.

(Narrator): For many northern New England animals, being ready for winter means having plenty of food stockpiled. Birds, mammals, even insects, are known to cache food so that it can be found and used at a later time.

(Johnson): Birds will stash seeds, acorns particularly. Bluejays will do that where you have oaks obviously or even beech seeds. But they will either scatter them around almost plant them in different places where as the chipmunks and squirrels will go to specific larders and stockpile them there. Which some people discover in their basements or their mattresses, closets. Huge larders that have been brought inside.

(Narrator): All these animals know that timing is of the essence.

(Heinrich):
The beavers here they have to start in the fall. They to start cutting trees and brush and dragging it out, to make a food pile. They store food instead of laying up fat. They can't cut too early because then the stuff will rot. So they have to bring the branches in there when the water is cold so that the food value gets preserved in the twigs and the bark that they eat. So they have to do it at a certain time.

(Narrator): The red squirrel begins harvesting in late summer - as soon as the cones of spruce, fir, and pine mature. Some squirrels will cache as many as 16,000 cones, yet may only be able to find half of those when they really need them in the winter. And it's no coincidence that the animals' autumn harvest comes when many plants are sowing their seeds. It's another one of nature's interesting dependencies.

(Johnson): This is I think a good example of how the animals and plants and have evolved together. People often think that the tree does this and the animal does this. But it's actually a good example of how they work together. If you take, let's say, oaks and bluejays, or some birds that eats the acorns, the acorn normally has no mechanism for getting away from the tree. So when it ripens, it just drops. And that's not good for dispersal. That's not good for new oaks in a future. So it depends on squirrels or turkeys, or bluejays, to actually take the acorn and move it some distance away. Gray squirrels will actually plant acorns. This is of obvious benefit to the tree because it gets dispersed, it gets new territory and it grows anew.

(Narrator): Yet every two to five years there seems to be a glut of cones and nuts in autumn. Many more than the hoarders can handle. Why is that?

(Johnson): This is a mechanism for the tree to flood the environment with seeds so that they will not be eaten all at once by the animals or birds.

This means there's more seeds in the cones and nuts left to germinate. And for most plants, just a few seedlings taking root per decade is enough to ensure a species' survival. Of course hoarding of seeds and nuts by animals are just one way for plants to find promising new ground. Some plants float their seeds in the wind. Others throw seeds from shattering pods to areas just beyond the shadow of a parent. And some are designed to hitch a ride on unsuspecting passers by with their hooks or sticky secretions. There seems to be no best answer to the challenge of successfully dispersing seeds, each species has evolved its own unique solution. What's remarkable is how the plant world has come up with so much variety and originality.

(Narrator): For some animals, autumn means leaving northern New England to avoid winter altogether. Across North American, five billion birds migrate each fall. This includes 200 species from northern New England. Some do not even wait for fall. It's July and August when the first wave; the warblers and sandpipers, begin heading south. The greatest number of birds are passing through northern New England during the first few weeks of September. They're followed by sparrows, thrushes, robins and hawks which wait until October to start their journies. Again, it's biochemicals and hormones that tell birds when to start preparing for migration.

(Strong): As the day length starts to decrease hormonal changes begin to occur. They go into a period of hyperphagia. Where these birds are basically feeding pretty much through the entire daylight hours. One of the things they are trying to do is to put on enough body fat to enable them to make these long migratory flights. A classic example, the blackpoll warbler actually puts on about 40% of its normal body weight in fat before it starts to migrate. The only way it can do this is through some hormonal mechanism that actually, basically tells it to eat, eat, eat, eat, eat. Under normal situations, normal circumstances, it couldn't eat enough to put on that kind of body mass.

(Charles Johnson): A lot of birds over the summer will increase the actual physical length of their gut in order to process the berries

and sugars and get more energy out of them. So there is something that we don't see but scientists who have dissected them know there is actual physiological and physical changes that happen that allows the bird to start processing more food and putting on the fat and getting ready well ahead of time.

(Nona Estrin) For example, we have a plant here called the alternate leave dogwood. It's a little shrubby tree that nobody would ever notice. Eight feet high, hardly notice it. But, it has flowers in the spring, not highly significant, but create a berry which must be enormously useful in stoking calories. Because when that berry is just, just beginning to ripen, all the thrush family, every one of them in mixed groups descend upon these trees in the woods. Now that's going to happen in August, late August or early September. You are walking out and out of the corner of your eye there is a flurry, and you look over. And if you know how to look for these guys, all the thrushes, the little brown speckled birds that sing so beautifully to us all summer are silent now, but they are fluttering all around these bushes eating the berries.

(Charles Johnson) The insect-eating birds will often turn to the higher energy, sugar-rich foods, the fruits and berries and you will see that around here. As fall approaches, they will turn to the sugar sources for more of the energy which can actually be converted into fats. This is better for a migrant. Instead of lugging around carbohydrates which require water they can actually turn the sugar right into fat which is a better transportation mode – because it does not require water and it can be burned directly with much higher energy for the long-distance migration. With a lot of birds these change-overs will be evident. If you watch out your window you can see it happening.

(Nona Estrin, Naturalist) I love that time and that s just one of literally hundreds and hundreds and hundreds of little feeding episodes that are taking place in the woods at that time, in the fields and around the ponds.

(Narrator): Birds also pay attention to the weather when they're ready to leave. In the wake of all those low-pressure systems that regularly converge over northern New England, northerly air gets pulled out of Canada. This makes for ideal conditions for flights south - tail winds and clearing weather happening at the same time.

(Allan Strong, Ornithologist): What's really fascinating, and you can see this in the day in the Northeast, if you go, not so much with the songbirds, but if you go out to the coast of New Hampshire, the coast of Maine, or even here in Vermont on Lake Champlain, if you go out when there's a south wind, or it's a very nice day. It might be mid-November, but you're not going to see very many birds moving. If you go out when there's a northwest wind, or a northerly wind, and you go out there, you'll see streams of geese, and streams of ducks. Streams of loons flying down the lake, or flying along the ocean. They're basically using the nasty weather as a tailwind, and they're using that to help them, propel them along their way.

(Narrator): But there are many hazards to migration. There are hunters and predators waiting as the birds funnel into relatively narrow travel routes. And it's estimated that as many as 10 percent get disoriented, more and more so by the lights on tall structures. Herb Wilson is a Colby College ornithologist and keeps up on the latest studies on migrating birds colliding with towers.

(Herb Wilson, Ornithologist-Colby College) Most of the work that has been done on tower kills has been done south of us. If you think about it, the further and further south you go the more and more birds you pick up. And by the time you get down to Florida, there's a huge population of birds – some of which originated in Arkansas, some in Ohio, some in upper New Brunswick. There aren't typically as many migrants passing through northern New England as there would be in the coastal states of the Gulf of Mexico or Florida.

(Narrator): Estimates of birds killed in collisions with communication towers range from four million to 40 million birds annually, and some of those deaths occur in northern New England. Scientists wish they had more long-term studies of bird collisions to help them understand the full extent of the damage. And they'd like to know more about why birds don't see the towers or guy wires, and why tower lights seem to confuse them. With 5,000 towers being constructed each year in the United States, it's clear the problem is not going to go away.

One of the things that puzzled ornithologists for a long time is that many songbirds and waterfowl fly in the middle of the night. How do they know where they are going?

(Allan Strong, Ornithologist): It seems like the more that we learn about the cues that birds use the more we find that it really is the diversity of cues that birds use. One of the things that puzzled ornithologists for a long time is many songbirds fly in the middle of night. How do they know where they're going? Well it turns out birds use the stars, the stellar compass as a way to navigate through the night skies.

(Herb Wilson, Ornithologist): There's some real advantages to flying at night. One of which is the likelihood of being picked off by a falcon is less at night when these birds aren't active. Secondly, obviously you're won't be able to pick up the North Star in the daytime. And we know that flight is a tremendously energetically expensive undertaking and birds in fact generate a huge amount of

heat. More heat than they need. And they have to get rid of that heat. And some people think that having nighttime migration when the temperature is cooler, is in fact a good way to get rid of that excess heat.

(Allan Strong): If you've flown this route before, you don't know if a new communication tower has been put up in between your wintering grounds, and your breeding grounds. There are nocturnal predators as well. Owls are obviously a species that will prey on songbirds during the night and so not just the hawks and falcons that we think about that are diernal, or daytime predators. But there are nocturnal predators out there as well.

(Herb Wilson, Ornithologist): But other birds use daytime cues. They follow ridgelines, coastlines, things like that. And this would be particularly useful for birds like large flying birds that need to use thermals to keep themselves aloft. Obviously, these thermals are only going to develop during the daytime. So these birds may use more visual landmarks, daytime landmarks, geographic landmarks.

(Narrator): And there are birds that may use yet other senses to help them navigate.

(Allan Strong, Ornithologist): Birds have been shown that they have some magnetic receptors in their brain. And they're able to use that to navigate and use the Earth's magnetic field as another cue.

(Herb Wilson, Ornithologist): The curious thing is that we don't have any idea where that sensor is in the brain of a bird. But we know that they can do it from various laboratory experiments.
We also know that there are some birds that use their nose; they are able to smell their way to particular places. Homing pigeons are good examples of that. They are able to have a ofactory map to find their way back to their roost. There are birds that nest along the Maine coast, the Leach's storm petrel and tube noses, albatross relatives; they're able to locate their particular burrow by smell. Birds certainly can't smell their way all across North America, but at least over small scales, they're able to use olfaction as a means of navigating.

(Narrator): It seems likely that birds rely on several different direction-finding systems. Some for long-range and others for short-range navigation.

(Herb Wilson, Ornithologist): There clearly are instances where birds are able to find their way to particular places with some internal clock that they have, internal compass that they have.

(Narrator): A less obvious fall migration occurs with some of our insects. Several species of moths, dragonflies and butterflies are among those that head south in September and October. For persistence, navigational skill and endurance, the North American monarch reigns supreme. Each fall a biological clock tells millions of monarch butterflies to start flying south and head for a tiny area in the mountains west of Mexico City, 2500 miles away.

(Bernd Heinrich, Zoologist): It's really spectacular in the fall to watch them. And they always head in the same direction, no matter what the wind is. They might wander around a bit and stop to feed, but they are all headed in the same southerly direction.

(Narrator): What's even more amazing is that these are not the same monarchs that migrated north the spring before! In fact, most are four or five generations removed from those butterflies. Yet somehow they know the flight plan or at least have some kind of internal compass to guide them south.

(Bernd Heinrich, Zoologist): In the last 20-30 years we found out that it's not only insects and birds. Mammals, fish, all kinds of different animals that migrate appear to have magnetic capability, sensing magnetic orientation.

(Nona Estrin): We have millions of years of expertise as a species in observing. And everyone is a keen observor of the world around them. Even if they don't know the facts, about the names of plants or even if they live in the city, they still are a very keen observor about the things that are going on around them.

(Rick Van de Poll): I would just point out that there are a lot of things that confront us every day as humans. Certainly there is a lot of reason to understand our natural world more. And I won't even begin to presume that I can provide a rationale for that.

(Charles Johnson, Naturalist): Depending on your interests there are all sorts of seasons, what we were saying I think is that there are an infinite number of seasons depending on if you are taking a wide look at nature, there are relationships that go on between plants and animals that have their seasons, and you can almost predict one event based on what's happening somewhere else. So it's a lot more complex and yet a lot more simple when you think of it that way.

(Nona Johnson): There's a lot going on before you tend to think of migration and you look up and see the geese or hawks going over, there is a lot going on.

(Linda Greenlaw, Segment Host): Through science we are beginning to understand the amazing changes that occur this time of year in northern New England. And our curiosity will lead us to new discoveries. It's clear that autumn plays a huge role in the continuation of life. And our perception of fall as a time of dying may need tweaking. I'm Linda Greenlaw. See you next time.