The Ecology of Vernal Pools

We thank the Of Pools and People team for contributing the science, photography, and figures for this presentation.....

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A brief ecology of vernal pools based on research over the decades in Maine.

Below each slide you will find information pertaining to each of the images included in this presentation.

This slide presentation is an introduction to key concepts in vernal pool ecology that will help individuals and communities make wise planning decisions when trying to conserve vernal pool resources. It is also appropriate for anyone who is interested in learning more about the ecology of the wet places that likely occur in the woods near where you live.

This presentation is intended to introduce you to vernal pools and the animals that use them for breeding, feeding, and resting. It provides key concepts in vernal pool ecology that will help individuals and communities make informed planning decisions when trying to conserve vernal pool resources. It is also appropriate for anyone interested in learning more about the ecology of the wet places that likely occur in the woods near where you live.

Vernal pools are the only wetland in Maine defined primarily by what breeds in them rather than by vegetation type (e.g., marshes, swamps, etc.). By definition, vernal pools are ephemeral, so this excludes permanent ponds, streams, and beaver flowages.

Vernal Pools

Naturally occurring, temporary to semi-permanent hydrology pools occurring in shallow depressions in *forested landscapes*. Vernal pools provide the primary breeding habitat for **wood frogs, blue-spotted** and **spotted salamanders**, and **fairy shrimp** and provide habitat for other wildlife including several endangered and threatened species.

This is the general vernal pool definition used by regulatory agencies in Maine. Pools were defined as "naturally occurring" so that skidder ruts, farm ponds, recent gravel pits, and roadside ditches would not be considered vernal pools. Amphibians will lay their eggs in some of these human-made wetlands, but they are not the primary breeding habitat.

Vernal pools do not have permanent inlets or outlets—water features that would allow passage of fish. Many have seasonal inlets or outlets, but these are not suitable for regular fish passage. This is important because amphibians that breed in vernal pools lay eggs with no chemical or physical defenses against depredation by fish or other amphibians.

Vernal pools typically fill with snow melt and rising water tables in the spring and dry completely, or at least partially, by summer's end or at least in drought years.. This wet-dry cycle limits potential predators of wood frogs and salamanders by eliminating permanent fish populations and limiting the abundance of predatory invertebrates. It also prevents pools from filling in with organic matter because any accumulating material is oxidized during the dry period (unlike in peatlands). This regular drying may also limit mortality events from amphibian diseases.

In Maine, vernal pools occur in a variety of settings. This classic vernal pool, typical in southern Maine and southern New England, is a shallow depression in an upland setting. Often these pools have little or no vegetation but have plenty of woody material that has fallen into the pool from the surrounding trees. This woody material is used for amphibian egg-attachment sites.

Vernal pools may also be shallow depressions in river or lake floodplains. These pools provide important feeding and resting habitat for animals using the rivers, including wood, snapping, and painted turtles and ribbon snakes (especially in southern Maine).

Vernal pools may be vegetated with sedges, rushes, or grasses (small marshes or wet meadows with deep depressions) or…

part of forested wetlands (swamps). In southern Maine, vernal pools are often associated with red maple swamps; in central and northern Maine they commonly occur in northern white cedar swamps or spruce-fir flats. In these settings, the pool boundary may be hard to distinguish. It may be a series of small pools linked together (part of the so-called mound-and-pool or hummock-and-hollow microtopography typical of swamps).

Vernal pools derive their nutrients from leaf litter and other organic matter (detrital-based) unlike sunny open ponds where photosynthesis (primary production) is the base of the food chain. The breakdown of organic matter by micro-organisms releases nutrients to the pool. Many invertebrates shred the leaves, invertebrates graze on the fungi and microorganisms, and wood frog larvae graze on algae and slime that accumulates on the leaf litter. Leaves and organic matter fuel the growth in pools….leaves hop away as frogs, fly away as various aquatic insects, or walk away (slowly! as salamanders).

For more information, see Capps K.A., R. Rancatti, N. Tomczyk, T. Parr, A.J.K. Calhoun, and M.L. Hunter, Jr. 2014. Biogeochemical hotspots in forested landscapes: Quantifying the functional role of vernal pools in denitrification and organic matter processing. *Ecosystems* 17:1455-1468.

Vernal pools, like all ephemeral waters, are ecologically challenging for species that are dependent upon them. During a winter thaw, animals may move prematurely from their burrows and freeze as temperatures drop.

At the other extreme, if a pool dries too soon owing to a dry spring or summer…..

Egg masses may be left high and dry and will not hatch….or…

larvae may not have time to develop. All is not lost---egg masses and larvae provide food for other animals and nutrients for the pool. One need not try to "save" eggs or animals from a drying pool. It is part of the cycle and may help to keep predators and diseases in check. Moving animals may spread diseases or introduce maladaptive genes to a new location.

Given the small time frame pool animals have for laying eggs and for their larvae to develop (2-3.5 months), most start to move towards their breeding sites before the ice is starting to melt.

There are 4 vernal pool indicator species in Maine: fairy shrimp, blue spotted and spotted salamanders, and wood frogs. The amphibian species are considered indicator species because vernal pools are their PREFERRED breeding habitat where reproductive success is the greatest. One may also see them breeding in roadside ditches, skidder ruts, or permanent pond. Often, they so not successfully produce young in these situations.

Fairy shrimp are obligate vernal pool breeders. They overwinter as eggs which have been deposited on the pool bottom. They must dry and freeze before they are viable. As soon as the pool fills in the spring, fairy shrimp, (related to brine shrimp or sea monkeys) often before the ice is off the pond. Some animals hatch later in the summer. They may be up to an inch long and tend to congregate in sunny patches of the pool where they swim upside down while filter feeding. Their color varies with the color of the zooplankton they eat. They have a short life cycle, as short as 6 weeks. The female dies, deposits eggs, and the cycle is completed for the season. The Maine Department of Inland Fisheries and Wildlife is asking for data on fairy shrimp occurrence. If you have a pool with fairy shrimp, a data form with instructions is available on our website.

Note: lots of invertebrates breed and feed in pools. See Kenney and Burne's *A Field Guide to the animals of Vernal Pools* for a wonderful introduction to vernal pool invertebrates.

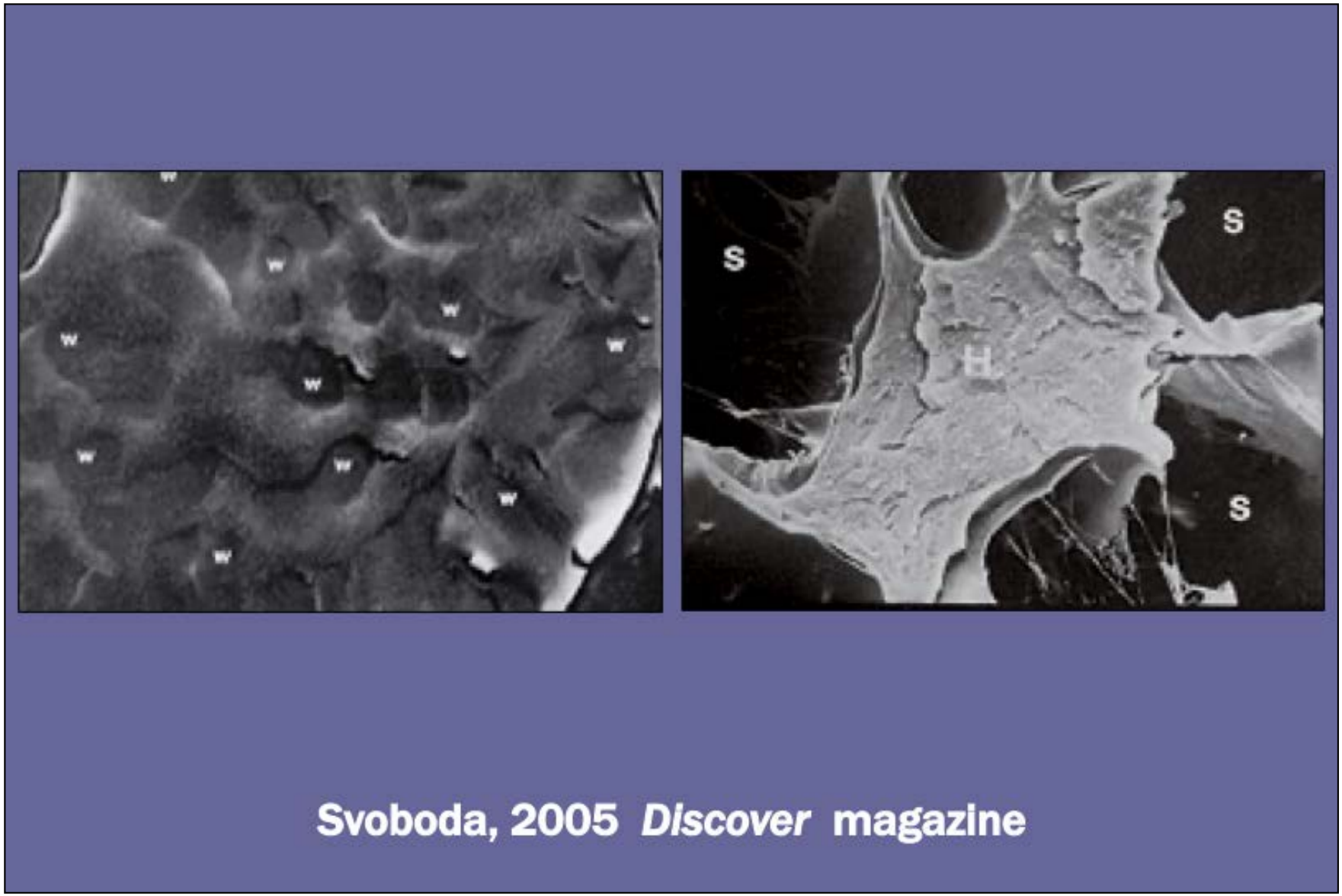
Science fiction under the snow!

Wood frogs have special adaptations that allow 2/3 or more of their body water to freeze. They have a natural antifreeze---glucose from the liver---that acts just like the alcohol in antifreeze…to lower the freezing point of the tissue.

They can tolerate a body temperature from 21-30 F. This adaptation may have evolved 15,000 years ago during the ice age. Wood frogs are the only frogs to live as far north as the Arctic circle.

Svoboda, 2005 *Discover* magazine

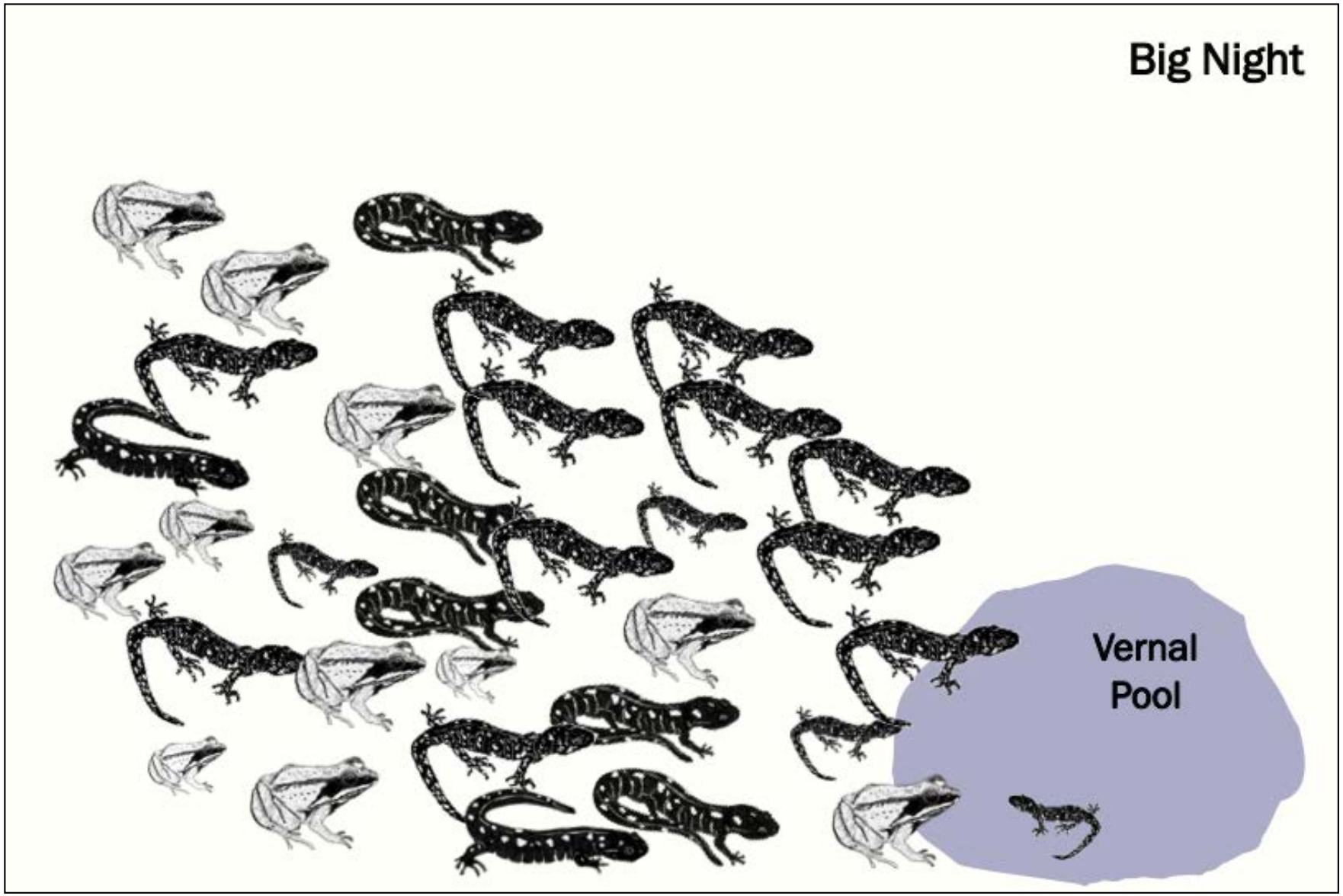
Notice the wood frog tucks its limbs close to its body and its fingers are curled under its arms to reduce the likelihood of drying out. Google: wood frog freezing to see YouTube videos or scientific papers on this topic.



Notice wood frog liver cells on the left are still intact; ones on the right have frozen below the freeze tolerance and their cells walls have broken and dehydrated.

Cryopreserving organs could one day revolutionize transplantation, but some scientists have their eyes on an even larger prize: freezing entire human bodies.

First warm spring rains awaken hibernating frogs and salamanders from their long, winter slumber.



The Great Migration, fondly called Big Night, involves 100,000s of animals coming out of a long hibernation to travel to breeding pools, often the same one they hatched from.

Dr. Rob Baldwin suggests that they travel distances comparable to those in the Great African wildebeest migration when one corrects for body size.

Wood frogs are explosive breeders usually arriving at a breeding pool within the same week. Males arrive at pools first and their quacking calls are contagious; first arrivals attract other males with females soon to respond to the breeding alert as well. If you have heard them before, you will likely agree that they sound like a flock of mallards “quacking” in the woods

A breeding frenzy occurs with the arrival of females. Often tan, or salmon colored, the females are typically about 25% larger than males. In addition to being smaller, males tend to be darker in color. Breeding can be stressful to females; plagued with the weight of multiple competing males, some females drown. Wood frogs live 3-5 years so they are unlikely to skip a breeding year. They have been documented to move to breeding pools when it is dry and 32 degrees. If the spring is cold and dry, but not rainy they most likely will still breed.

For more information, see: Vasconcelos, D. and A.J.K. Calhoun. 2006. Monitoring created seasonal pools for functional success: A six-year case study of amphibian responses, Sears Island, Maine, USA. *Wetlands* 26:992-1003.

Once a female has attracted a mate, they enter amplexus and the male fertilizes the eggs as they are laid. It is possible to estimate the population of breeding females in a given pool by counting the number of egg masses. Each female wood frog will only deposit one egg mass each year. It is possible to estimate the population of breeding females in a given pool by counting the number of egg masses.

Newly laid egg masses are only about the size of a quarter; they soon absorb water and become softball size.

Consisting of up to 1000 individual eggs, the exterior of a wood frog egg mass is quite lumpy. Sometimes described as having the appearance of tapioca pudding, or a pile of marbles, wood frog egg masses lack the thick outer jelly coating characteristic of spotted salamander egg masses. They are dark on the top and light below. Dark eggs attract warmth and can hatch more quickly; the coloration also reduces predation as dark blends in for predators looking down on the water and white matches the sky for below-egg predators. This pied pattern (black and white) is common in aquatic systems from water boatmen insects to orca whales.

Wood frogs are colonial breeders. They often deposit eggs in large "rafts." This strategy provides greater protection from predators (especially for the eggs in the middle) and may provide greater warmth.

Wood frog egg mass numbers may vary considerably from year to year depending on winter conditions. Wood frog mortality may be high in an extremely cold winter with minimal snow cover.

Dark colored wood frog tadpoles show up nicely as they feed on the algae coating the outer surface of spotted salamander egg masses.

Soon after hatching, thousands of wood frog tadpoles may be seen feeding on phytoplankton and algae in swarms near the water's surface. Wood frog tadpoles are generally surface feeders commonly seen throughout the day. Wood frog tadpoles have been seen feeding on blue-spotted salamander embryos and occasionally spotted salamander embryos as well. So much for being vegetarian grazers…..

For more information, see: Baldwin, R.F., P.G. deMaynadier, and A.J.K. Calhoun. 2007. *Rana sylvatica* predation. *Herpetological Review* 38:194-195.

Thousands of wood frog metamorphs, or newly emerged frogs, may be produced in a small pool each year. These metamorphs were trapped in this pitfall bucket (a bucket sunken into the ground near a pool) in just one night. Each metamorph is roughly the size of an adult's thumbnail.

The majority of newly emerged wood frogs may spend the first winter within 100 feet of the pool they hatch from although it is hard to track them.. They are small and vulnerable to drying and predation so if habitat is suitable, they will winter close to the pool.

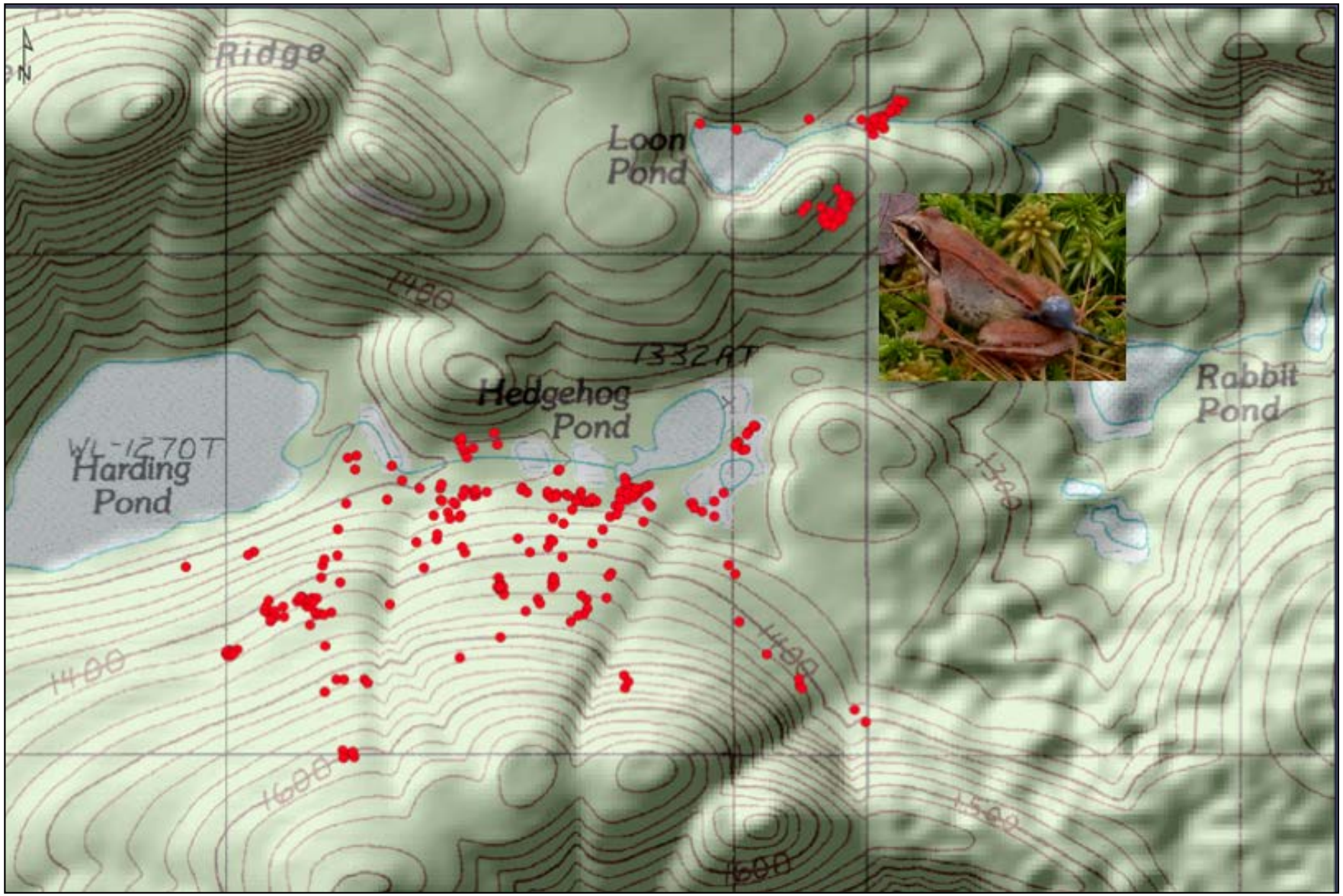
By following adult wood frogs through the forest, studies in Maine have shown that adults summer in different habitats depending on what region of Maine they come from. For example, in the lowlands, wood frogs summer in forested wetlands. In higher elevations, one study found them to travel uphill to summer in damp areas around large boulders or glacial erratics. The bottom line is context is everything and one needs to take that into account when trying to conserve ideal habitat for them.

See these studies for more information on their post breeding habitat needs:

Groff LA, AJK Calhoun, CS Loftin. 2017. Amphibian terrestrial habitat selection and movement patterns vary with annual life history period. *Canadian Journal of Zoology*.

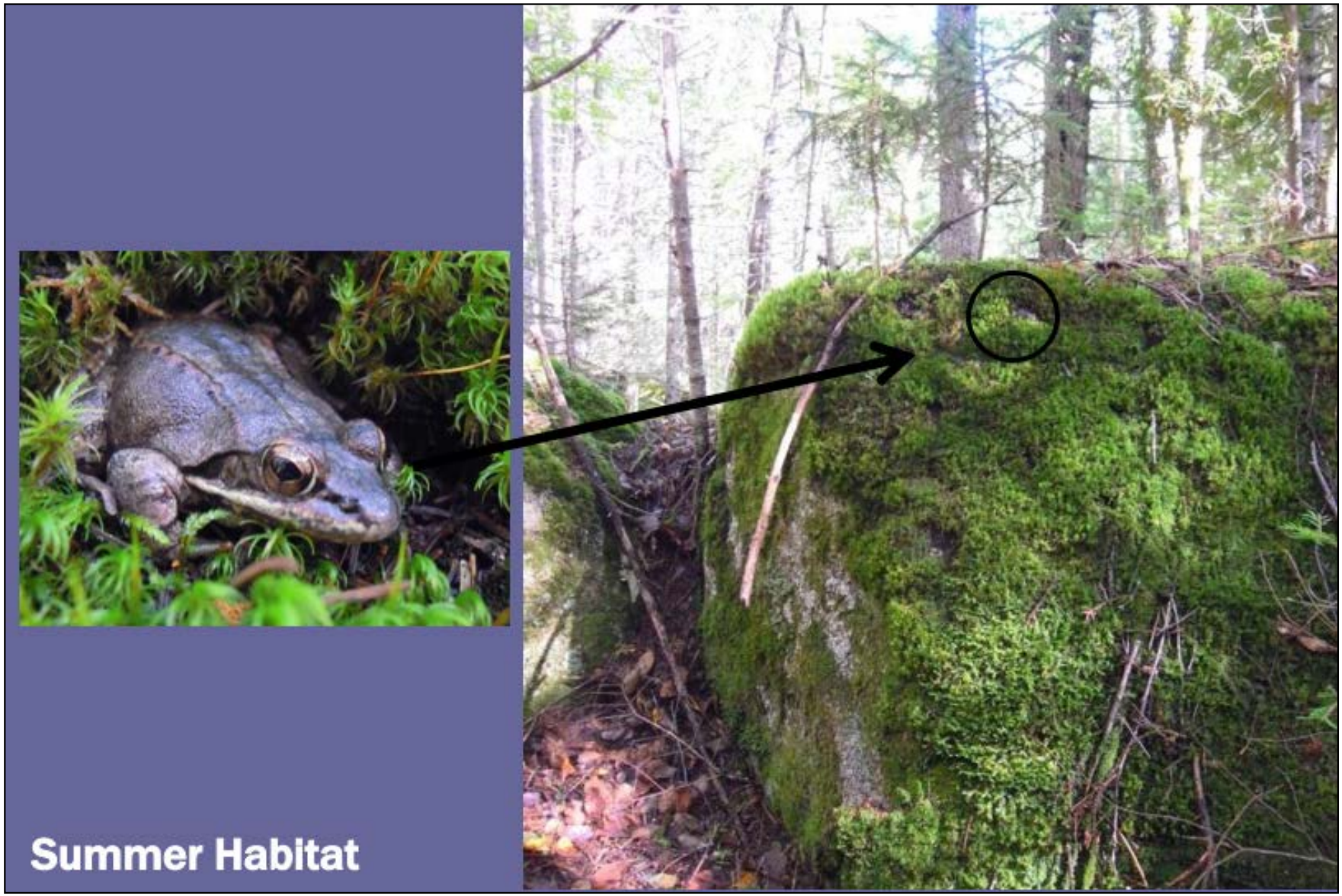
Groff L., C.S. Loftin, and A.J.K. Calhoun. 2017. Predictors of Breeding Site Occupancy by Pool-Breeding Amphibians in Maine's Wetland-limited, Montane Landscapes. *Journal of wildlife management.* 81: 269–278.

Baldwin, R., A.J.K. Calhoun, and P.G. deMaynadier. 2006. Conservation planning for amphibian species with complex habitat requirements: A case study using movements and habitat selection of the wood frog (*Rana sylvatica)*. *Journal of Herpetology* 40:443-454.



On this map each dot represents a frog location, from this example in northern Maine, you can see that wood frogs often travel hundreds of meters to summer habitat.

For more information, see: Luke A. Groff, Aram J. K. Calhoun, and Cynthia S. Loftin "Hibernal Habitat Selection by Wood Frogs (*Lithobates sylvaticus*) in a Northern New England Montane Landscape," Journal of Herpetology 50(4), 559-569, (1 December 2016).



Luke Groff found that some frogs in the higher elevations in the mountainous region of Maine may summer in upland forests around large glacial erratics, either in cool mosses on top of boulders or in damp, often wet soil at the base of the rocks.

Wood frogs in Downeast, central and mid-coast Maine, on the other hand, often summer in forested wetlands. Clearly, context matters when deciding what the best post-breeding habitat to conserve near pools would be.

For more information, see: Baldwin, R., A.J.K. Calhoun, and P.G. deMaynadier. 2006. *Conservation planning for amphibian species with complex habitat requirements: A case study using movements and habitat selection of the wood frog (Rana sylvatica).* Journal of Herpetology 40:443-454.

Wood frog adults use a different habitat for hibernation and may return close to the same site every year. This adult female frog was tracked to her hibernaculum—or hibernating depression—in a well drained upland forest. They burrow just below the leaf litter in shallow depressions where, during the winter, up to 2/3 of their body will freeze solid.

Again, if we don't have good snowpack and we have a very cold winter, wood frog mortality may be high.

For more information, see: Groff, L.A., A.J.K. Calhoun, and C. Loftin. 2016. Hibernal ecology and habitat selection of wood frogs (*Lithobates sylvaticus*) in a northern New England montane landscape. *Journal of herpetology.*

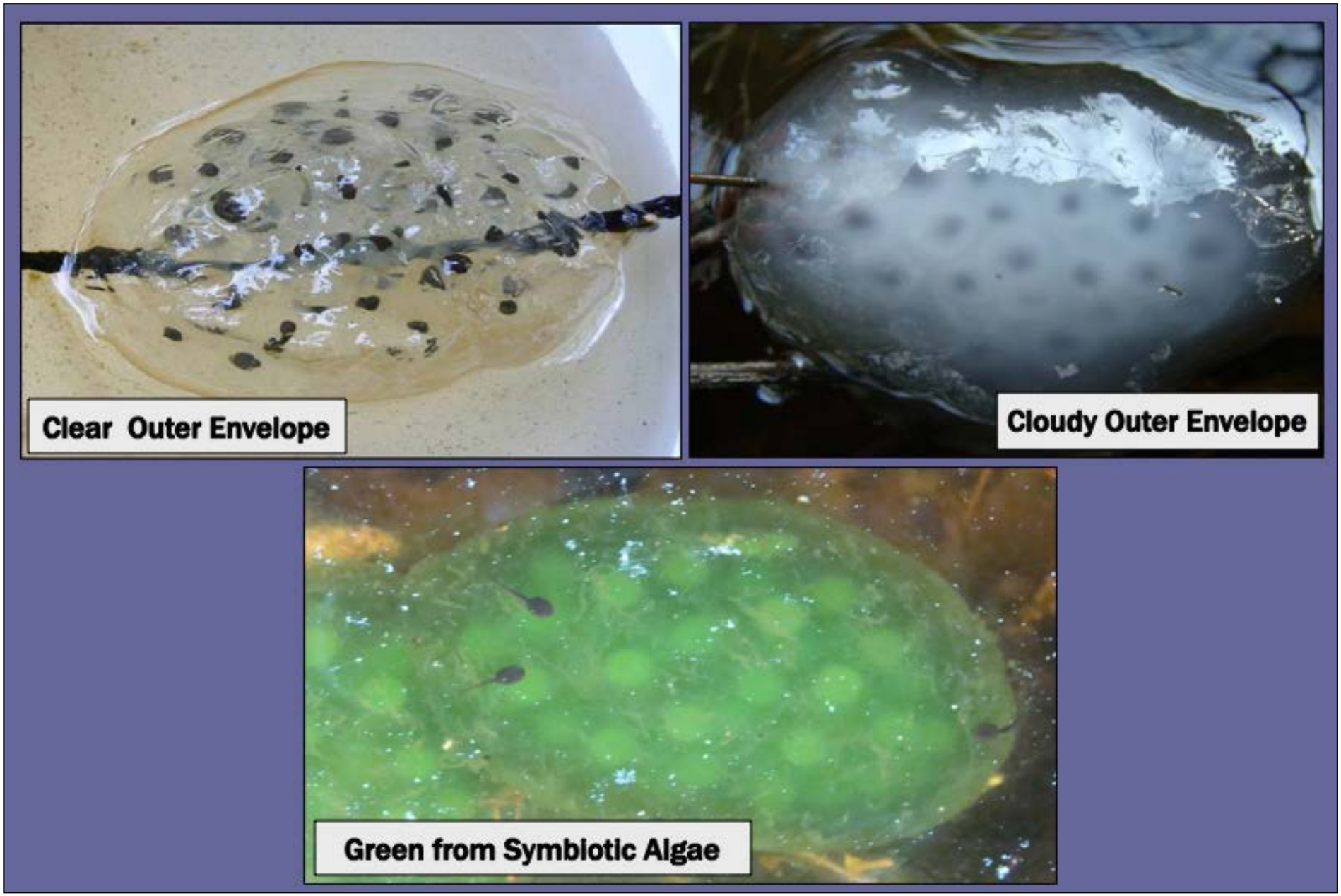
Spotted salamanders, also known as mole salamanders (because they live in burrows below ground) have lungs and can live up to 20 years. They are related to the blue-spotted salamander that is also found in Maine vernal pools. Spotted salamanders range in size from 5-8 inches long. They occur east of the Mississippi.

On the first warm rainy nights of spring when the temperature reaches at least 40 degrees, spotted salamanders migrate from their upland wintering habitat to vernal pools to breed. This gathering is referred to as a salamander congress. If weather conditions are not perfect---warm and rainy---some salamanders may not breed. That is why egg mass counts can vary a lot from year to year.

Male salamanders deposit sperm packets, known as spermatophores, that are eventually “picked up” by the female through her cloaca (a multi-purpose orifice). From a distance, spermatophores look like specks of white paint on the leaf litter. Egg masses will be deposited soon after spermataphores are deposited in a pool.

Here a female spotted salamander is in the process of laying her eggs. They generally attach egg masses to vegetation and may breed in water much deeper than is used by wood frogs. Each female may lay 1-3 masses with 15-100 eggs per mass. If multiple egg masses are deposited by the same adult, usually one egg mass is larger with 1 or 2 smaller satellite egg masses near by.

The pool in this photo lacked adequate vegetation for egg laying attachment sites and all masses were deposited in one area where submerged sticks were abundant. However, unlike wood frogs, spotted salamanders do not typically deposit their eggs communally in large rafts. It is common to see individual masses and small clusters of masses widely dispersed within a pool. Because of the potential for this extensive distribution, it will require careful searching to locate all masses present. Polarized sunglasses reduce glare and allow for easier viewing.



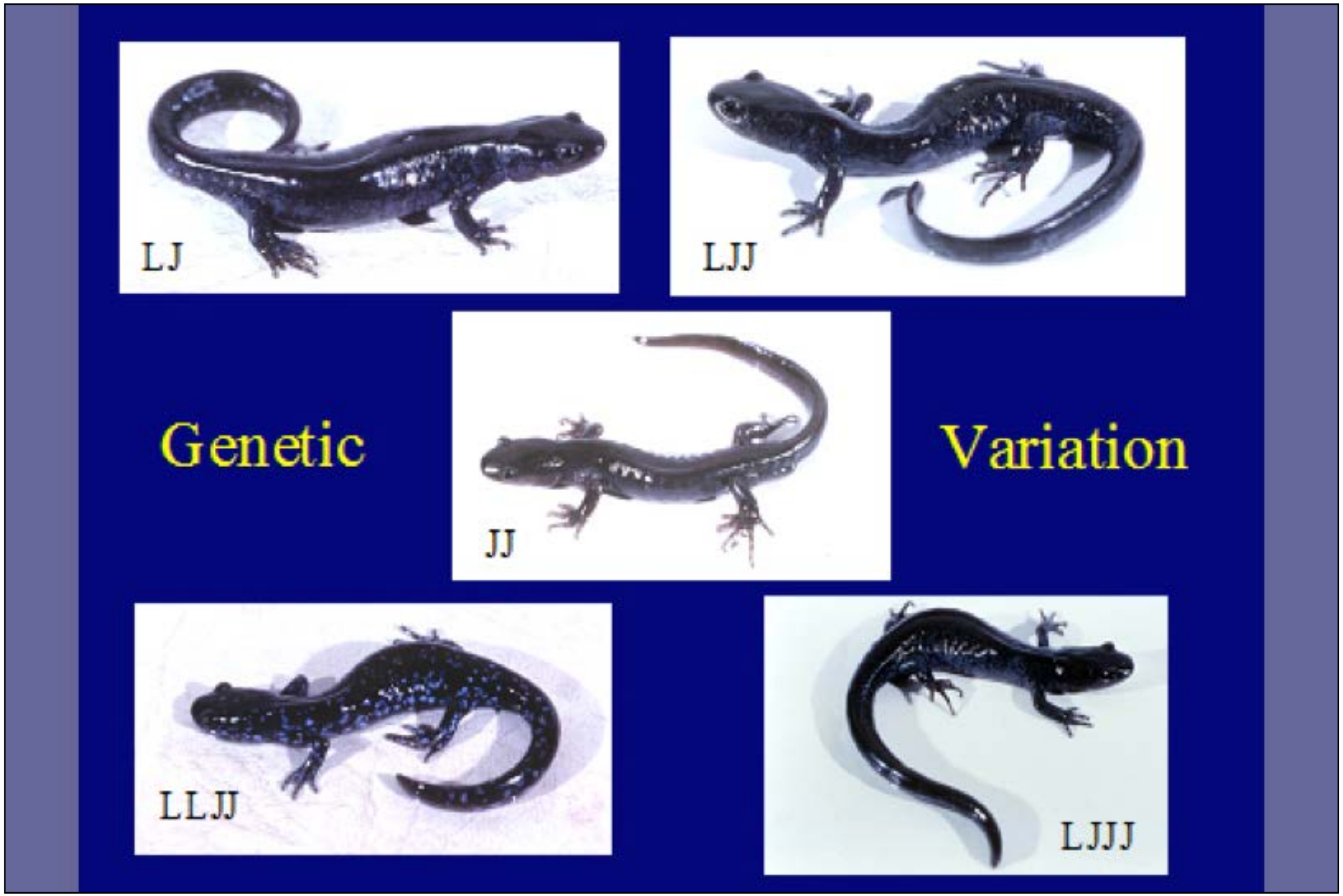
Genetic variation determines whether the outer gelatinous membrane of a spotted salamander egg mass is clear or cloudy. Green egg masses contain a symbiotic algae (*Oophilia amblystomatis*) that provides oxygen to the egg mass and in turn gains nitrogen and phosphorous from the developing embryos.

Salamander larvae are not easy to identify to species. However, both blue spotted and spotted salamander larvae have these external feather gills that aid them in absorbing oxygen in a low-oxygen environment. Salamander larvae are extremely fragile in the first few weeks after hatching: do not handle them. If you wish to photograph them, fill a cup with water and collect the animal in a cup or pan without touching the animal.

Salamander larvae tend to spend the day camouflaged on pool bottoms on leaf litter, downed woody material, or rocks.

Bryan Windmiller and Steve Faccio, researchers from Massachusetts and Vermont respectively, have radio-tracked spotted salamanders and found that they prefer well-drained uplands (largely small mammal burrows) as both summer and winter habitat. (Faccio has also documented movements of Jefferson salamanders)..see under Publications on this website.

Blue-spotted salamanders, the second type of mole salamander, also may live up to 20 years, and like spotted salamanders, they may opt not to breed every year, depending upon weather conditions.



Blue-spotted salamanders in Maine are variable in size and color as they are the result of hybridization between Jefferson Salamanders (J genes) and pure - blue spotted salamanders (L genes). This means that hybrid individuals, which are mostly female, may be LJJ (1 part blue, 2 parts Jefferson) or any of the other combinations listed above. Pure blue spotted are diploid, smaller, and have brighter blue speckles on dark background than the hybrids which tend to be larger and more brown-colored (as in previous slide). We have representatives of all variations in Maine except for pure breed Jefferson salamanders. Blue-spotted and hybrids may all occur in the same pool.

You can see here that pure blue spotted (LL) are much smaller than spotted salamanders; they are darkly colored with bright blue spots (note the first slide of a blue-spotted hybrid is one with a lot of Jefferson genes, it is larger and browner).

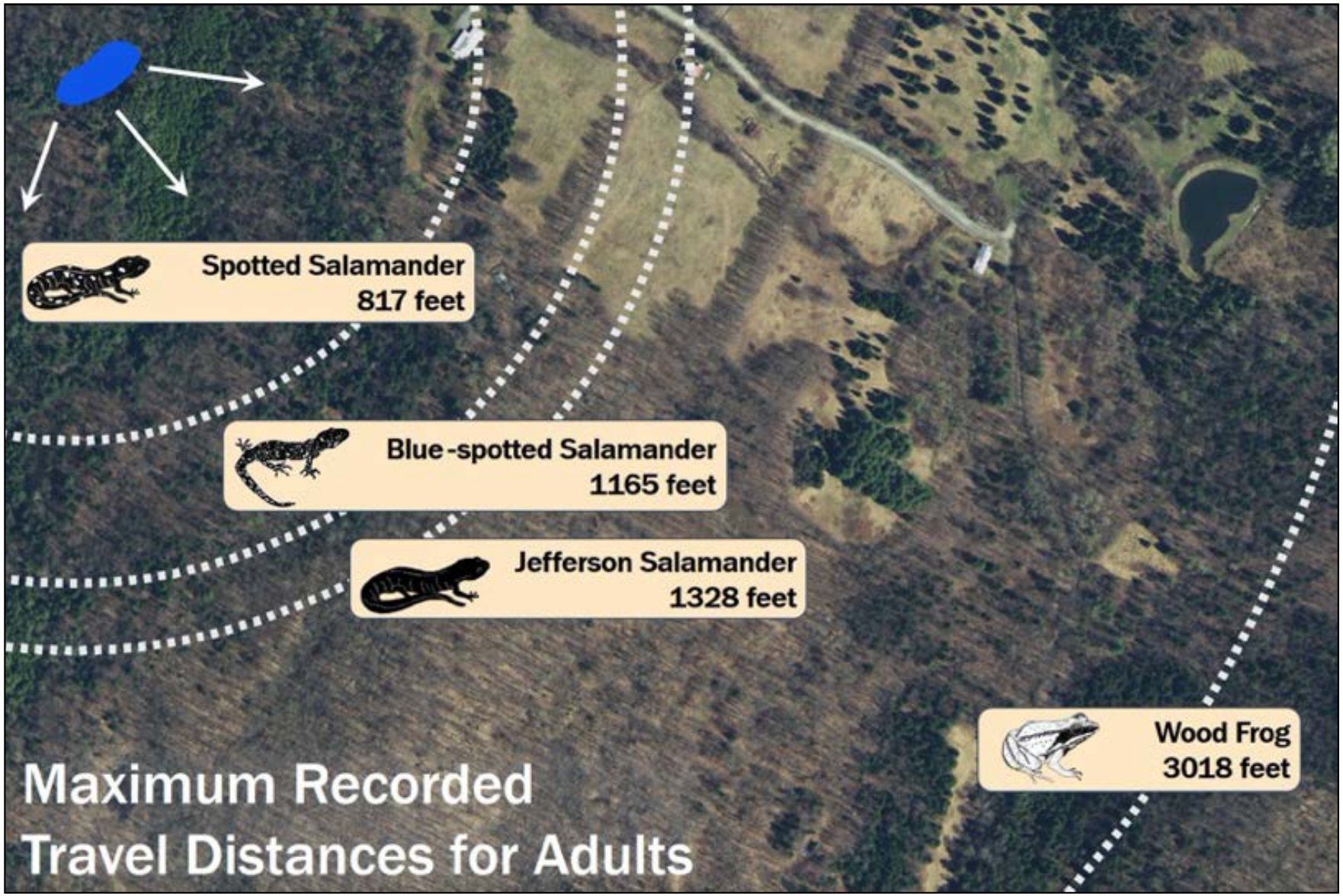
Eggs masses of pure blue spotted salamanders and the hybrids vary. Pure blue spotted salamanders have single to a few eggs per mass and are surrounded by an extremely runny, loose jelly coating that drips off attachment sites.

The eggs of the hybrid individuals tend to be deposited in long strings along sticks or vegetation and have a high percentage of infertile eggs (note all the white circles that represent inviable embryos).

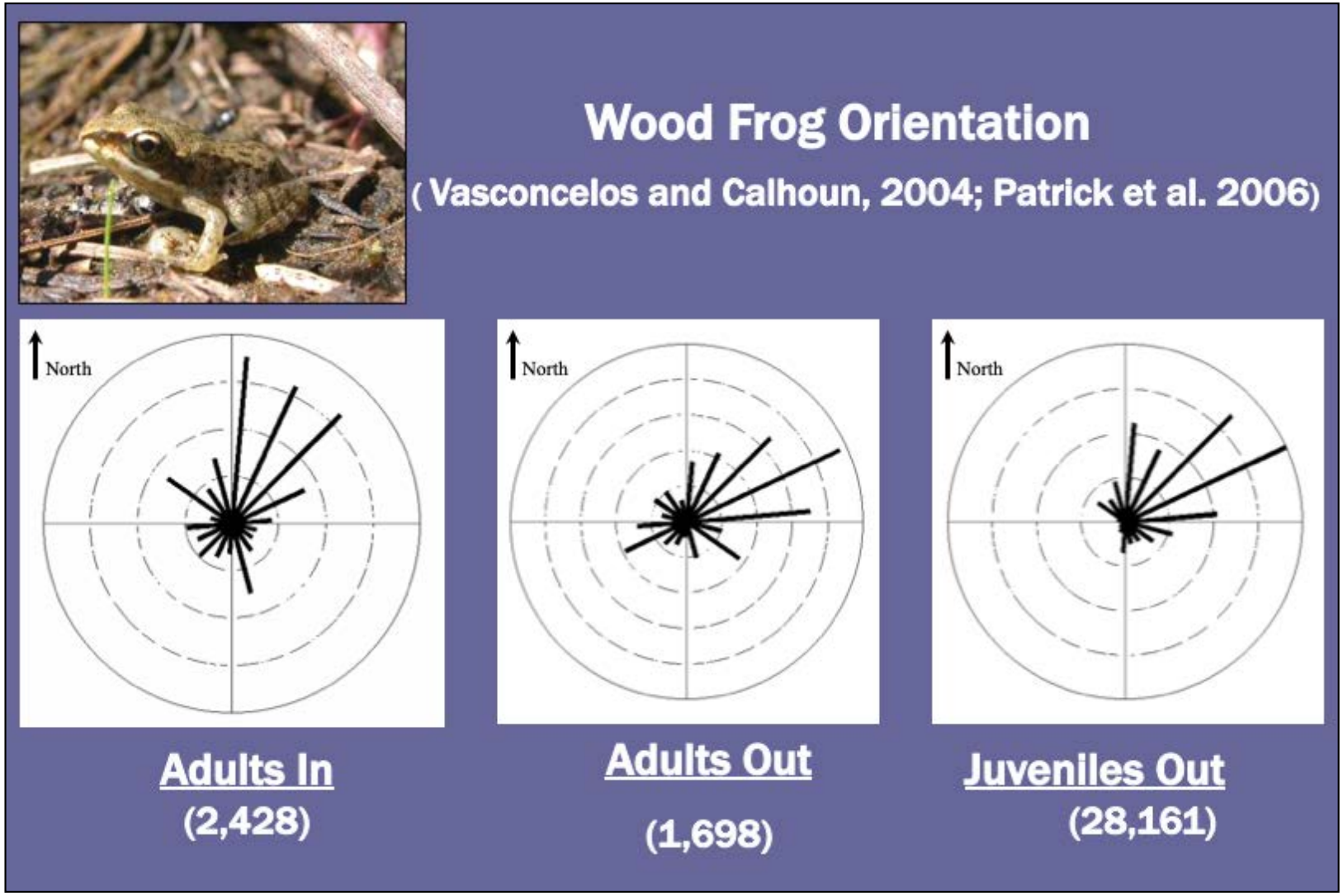
For more information, see: Hoffmann, K., M. Hunter, Jr., A.J.K. Calhoun, and J. Bogart 2018. Post-breeding migration and habitat of unisexual salamanders in Maine, USA. Journal of Herpetology 52:273-281

This next section highlights some recent research findings that may help us to craft creative solutions to amphibian conservation.

Researchers use drift fence arrays with pitfall traps (buckets) to track animals traveling to and leaving vernal pools. Buckets are sunk into the ground on each side of the fence and they collect animals headed to and from the pool. Researchers can identify, sex, age, and mark animals in order to keep track of breeding populations or just keep track of animals feeding or resting in vernal pools. Drift fence arrays may also be used to determine which direction animals are traveling on their way to and from their breeding pools. When animals are caught, they are taken out of the bucket and placed on the opposite side of the fence in the direction they were headed before they were captured.



Research studies from the eastern US looking at amphibian movements from breeding pools to post-breeding habitats have given us information on travel distances for adult salamanders and wood frogs. In the next slide, you can see that, different species have different average travel distances with wood frogs being the widest ranging. The key is that animals move hundreds of feet from pools, and young animals dispersing may travel even farther than has been documented.

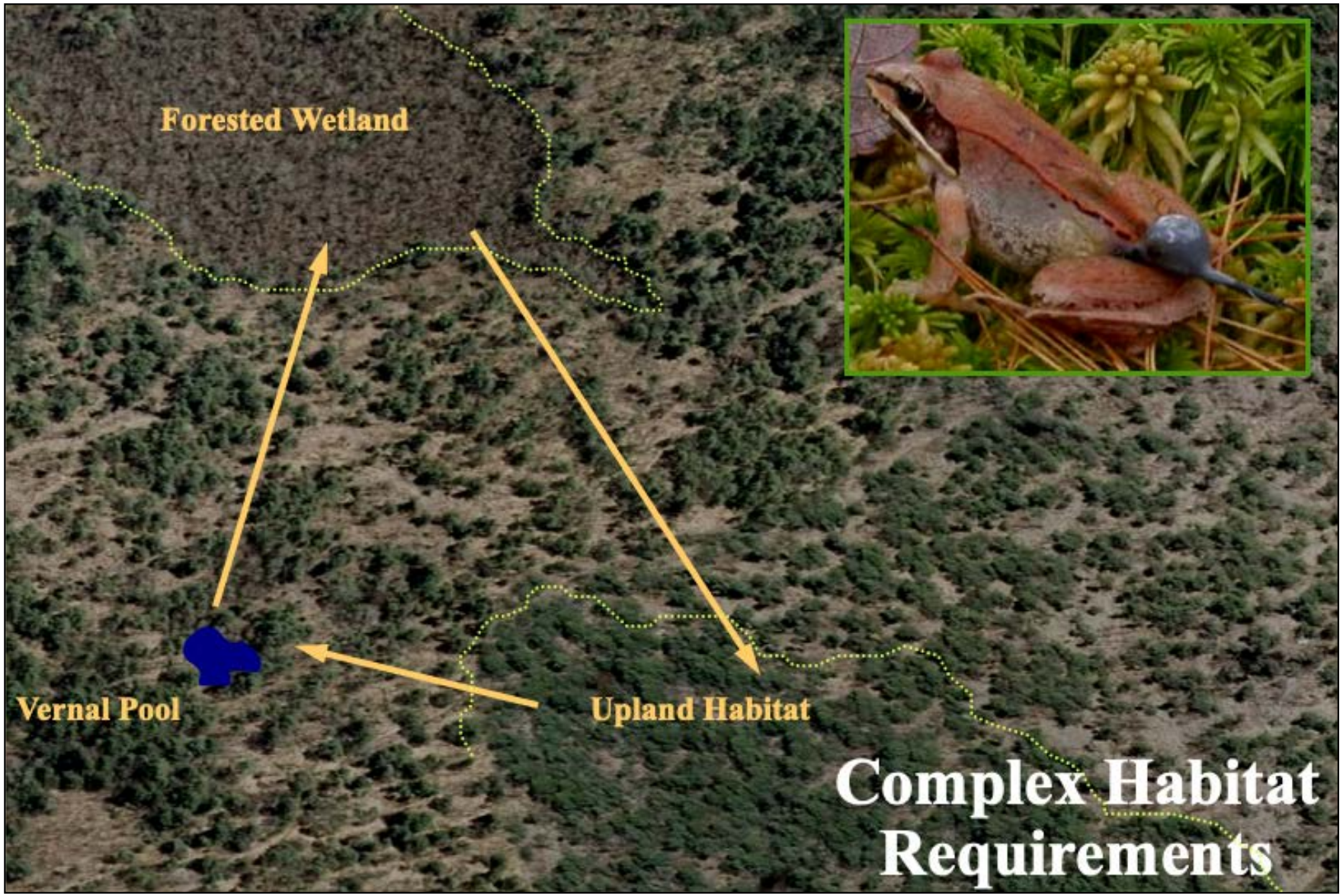


In these diagrams, the middle of each circle depicts the vernal pool. Each line leaving the pool represents numbers of animals traveling in that direction to the pool to breed (adults in) and away from the pool after breeding (adults out). The longer the line, the more animals traveled in that direction. We use circular statistics to show that the number of animals moving in the directions shown above is significant…not just random. In this slide, you can see that adults moving into breeding pools, leaving breeding pools, and juveniles leaving pools for the first time, traveled mainly in a northeasterly direction. We know that forested wetlands, the preferred summer habitat for wood frogs, were located in this direction. This research suggests that animals have directional movement and if we can figure out where key habitat elements, such as forested wetlands, are, we can predict where animals might be headed. It was only northeast in this study; it could be any direction depending on where the forested wetlands or other suitable habitats are located.

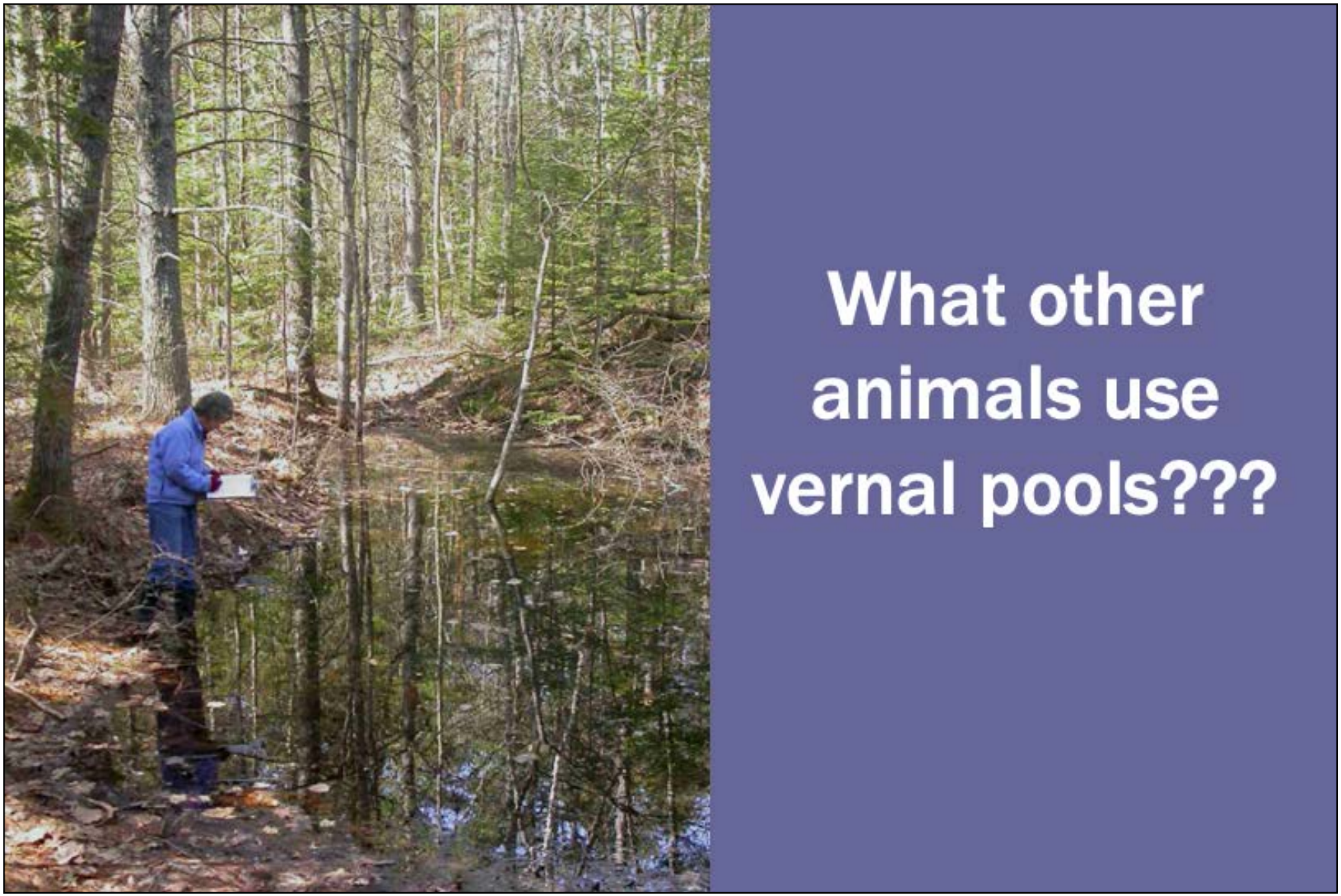
The fact that newly emerging individuals are headed in that direction suggests that there is some programming……either genetic or other cues……that aids in navigation from a breeding pool. This may be confounded if natural pools are disturbed and replaced with created pools, particularly if the created pool is not in

the same directional orientation to suitable summer habitat.

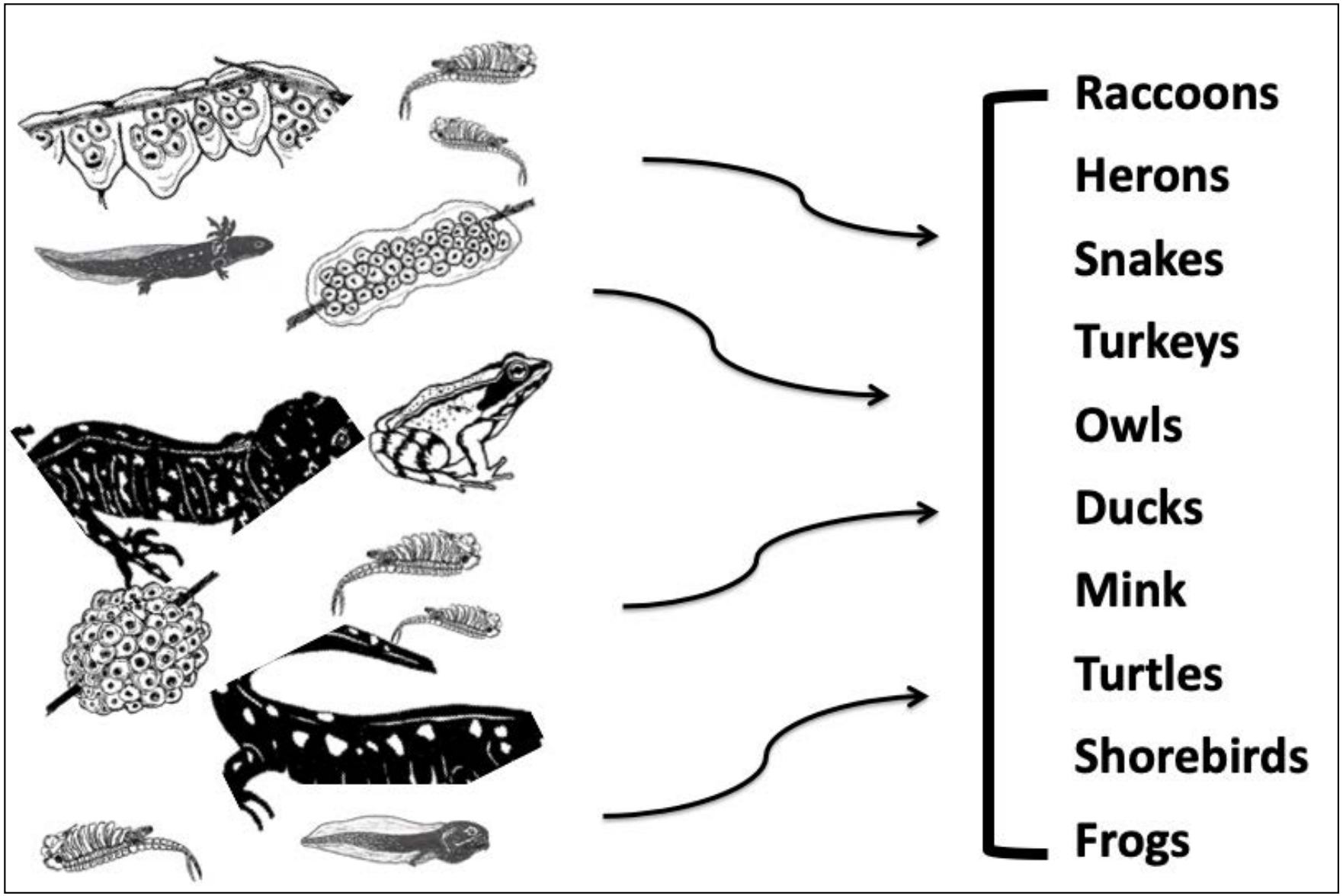
We know that both salamanders and wood frogs have a high rate (up to 95%) of natal fidelity. This means that they return to breed in the pool from which they hatched…..even if the pool is dry from drought or draining or if the pool has been paved. This is another good reason to try to protect naturally occurring pools. It makes sense for animals to return to a pool from which they hatched as it suggests the pool IS good breeding habitat.



We have also learned that some vernal pool species, like wood frogs and blue spotted salamanders, require more than one habitat to complete their life cycle. The wood frog needs a vernal pool for breeding, forested wetlands for summer habitat, and well-drained uplands for winter hibernation. We suspect that blue spotted salamanders require the same habitat elements.



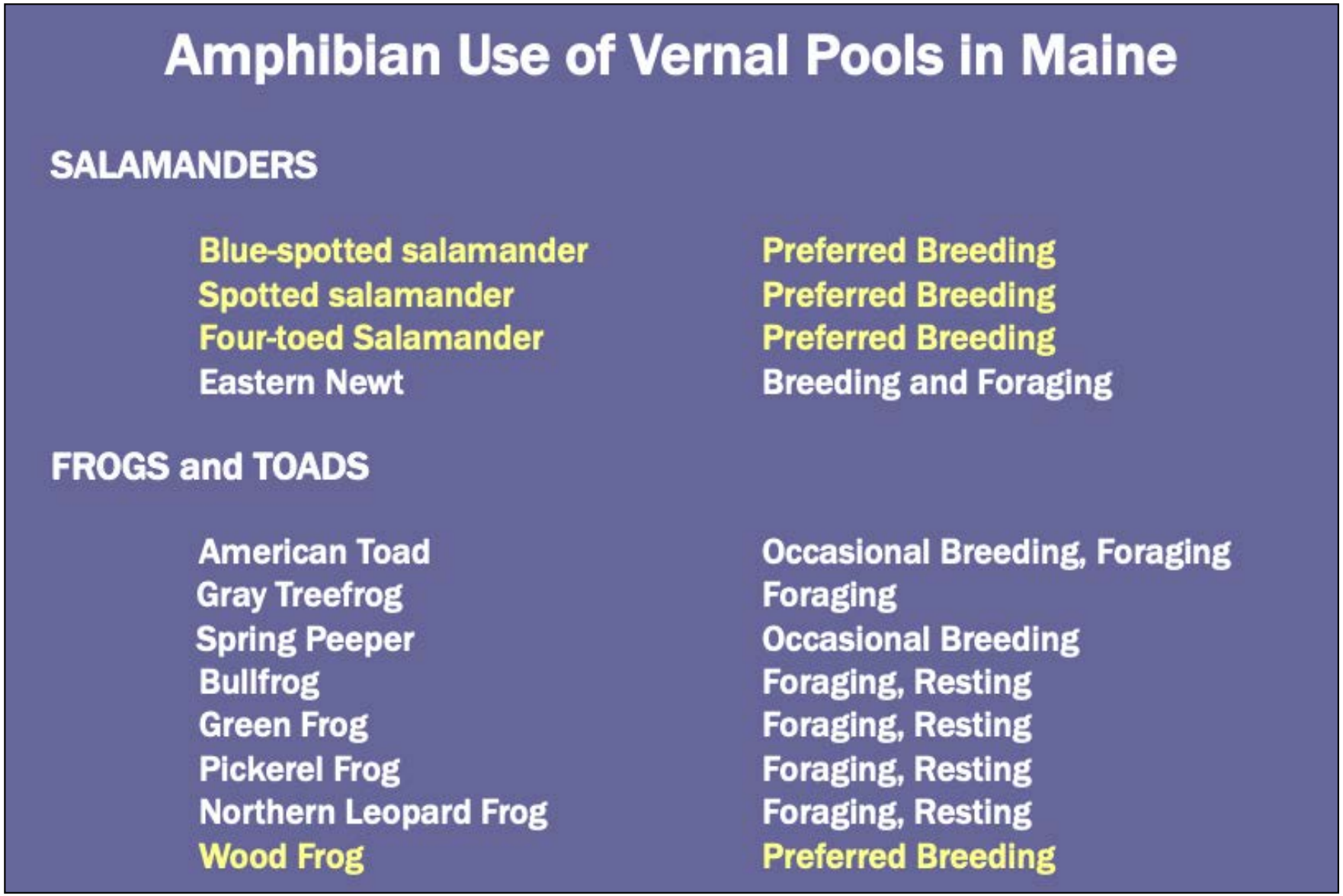
Vernal pools are important wetland habitat for a variety of species for feeding and resting.



Vernal pools provide a concentrated source of food for a large percentage of our wildlife. The next series of images are of many of our wildlife species that have been documented in or around vernal pools. Some of these photos were taken with use of remote game cameras.

Many very aquatic species, such as this snapping turtle, have been found visiting vernal pools in spring and throughout the summer. They come out of hibernation and head to pools to feed on amphibian eggs, and later in the summer, salamander larvae and tadpoles. Pools provide a valuable food resource for a number of aquatic species and in this way, provide support to animals that breed in permanent waters. Often we forget that animals that breed and hibernate in permanent ponds may travel overland to other aquatic habitats.

The bullfrog, another highly aquatic amphibian that breeds and hibernates in permanent ponds, was found to visit vernal pools during the spring, summer, and fall in order to take advantage of the rich food resources. Researchers in Acadia National Park put individualized beaded waist belts and radio-transmitters on bullfrogs to see how and when they used vernal pools. They found that bullfrogs visited pools at different times depending on the sex and age of the frog (Gahl et al. 2008). The key is that they all depended on pools for a ready food source.



Common amphibians associated with vernal pools in New England

Ribbon snakes and garter snakes commonly show up in our pitfall traps as they make their way to pools to feed.

Blanding's and spotted turtles (Maine-listed species), wood turtles and many others depend on vernal pools for resting and feeding throughout the summer months.

If visiting a vernal pool is not in your plan, dinner can be delivered to the upland. This collection from a bucket from ONE night illustrates the tremendous biomass (weight) of animals moving out of breeding pools back into the upland. In fact, amphibian biomass in our New England forests is greater than all the small mammals and birds combined on a per/area basis. This is a tremendous injection of nutrients made from leaf litter back into our forests. We can think of these animals as earthworms of the forest as they aerate soils and return nutrients to them AND provide food to a wide array of terrestrial animals including raccoon, mink, skunk, weasels, hawks, crows, ducks etc.

Pools deliver both salamanders….

And frogs to upland customers….

Follow moose or deer scat trails….

and you might end up at a vernal pool. We know that large mammals, including bear, make use of the early productivity of pools post hibernation and visit them also at summer's end when pools may still hold moisture when the rest of the upland forest is dry. Pool complexes provide feeding and resting habitat for birds including returning migrants looking for a meal, large and small mammals, and snakes and turtles …..by providing a rich soup of invertebrates (insects, spiders, clams, snails), frogs, and salamanders (in all their stages).

If you would like to learn more about vernal pools, look for these resources on planning developments around vernal pools, forestry practices, and more general texts on all-things-vernal-pool.

PDFs of the manuals and selected chapters of the Calhoun and deMaynadier book are available on our website

Every vernal pool enthusiast should have this compact, comprehensive field guide to vernal pool animals including invertebrates. Although it is based on Massachusetts fauna, it overlaps with northeastern and some mid-western states.

A MUST for vernal pool volunteers.