# The Broken Cycle

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ABOVE: Both frogs shown were from the same breeding pair, but the frog in the top photo was raised in a vivarium without a naturally-occurring nutrient cycle and the other frog was raised in a vivarium where arthropods were supported by the soil and leaf litter.

Can soil make red frogs redder, tadpoles healthier, and froggers happier? The answers may surprise you. The potential roles of substrates used in vivaria are often overlooked. Given enough light, water, and humidity, plants will grow in just about anything, and for most vivarists, this is all they ask. Hydroponic substrates like expanded clay pellets are appealing because they are clean, lightweight, and work extremely well for supporting healthy growth for a wide variety of plant species. In contrast, soil is heavy, messy, potentially harbors insects and disease, and tends to get soggy when wet. An alternative to mineral soils are potting mixes that are sterile but suffer from the other disadvantages of soil plus the organic matter contained within them breaking down over time, changing their texture and reducing the substrate's ability to drain. But there may be hidden advantages to soils that may surprise you.

Studying nature provides lessons about what might be missing in our vivaria. Let's compare the way nutrients cycle in a vivarium versus the way they cycle in a tropical rainforest. In nature, rocks and minerals in the earth weather and break down over time to form soil. The texture of soil allows it to retain moisture and create an environment where microbes like bacteria, fungi, and algae can grow, forming the basis for the soil ecosystem. These microbes extract minerals from the soil and fix nitrogen from the air, which forms the beginning of the nutrient cycle. Tiny invertebrates feed on the microbes and, in turn, become food for larger invertebrates. Plants send roots into the soil to extract the nutrients made available by the activities of the microbes. These nutrients get stored in stems, bark, and leaves. Eventually the leaves drop or the plants die and fall back to the surface of the soil. Invertebrates chew up the wood and leaves into small pieces and convert them into frass or invertebrate tissues. Microbes then digest the frass and dead invertebrates, once again releasing the nutrients back into the soil and completing the cycle (Fig 1). Throughout this process arthropods are everywhere, consuming nutrients at every stage. Some feed on microbes or other invertebrates in the soil, others feed on living plants, and still others feed on the dead and decaying leaves and wood on the forest floor or suspended in the forest canopy. Of course the frogs are there consuming arthropods of many different kinds and using compounds from throughout the nutrient cycle for their own use. In a vivarium a similar cycle occurs but with some important differences.

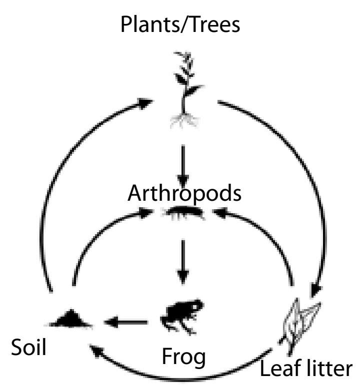


Figure 1: Natural Nutrient Cycle

The substrate in a vivarium supports microbes, just as in a natural forest, and those microbes free up nutrients for plants to consume. Plant tissues die and fall back to the substrate where they are decomposed by microbes to renew the cycle (Fig 2).

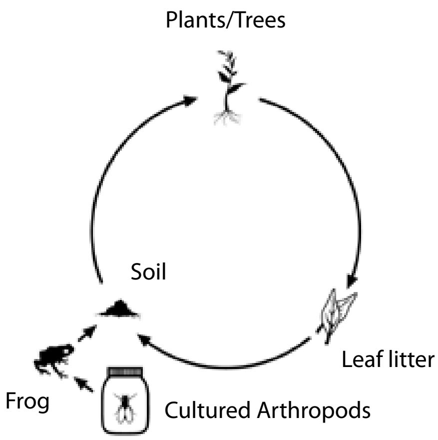


Figure 2: Vivarium Nutrient Cycle

However, in a vivarium the arthropods are often all but missing. Instead, insects are cultured on a prepared medium outside the vivarium and introduced as food for the frogs. The medium used to culture the insects contains the basic nutritional requirements of the feeder insect and may contain supplements to enhance the nutritional value of the insects to the frogs. In addition, vitamin and mineral supplements are routinely added to the feeder insects to ensure the frogs obtain all of their nutritional requirements. If the frogs are receiving a nutritious diet, why does it matter that the nutrient cycles are different in a vivarium from those in natural forests?

Nature is a chemical factory that reaches its peak in the moist, tropical forests where dendrobatids live. As mentioned earlier, the arthropods in natural forests are consuming almost every kind of living tissue. Microbes, plants, and arthropods don't particularly like to get eaten, so many of them produce toxic chemicals to help protect themselves against predators. These defenses are almost never 100% effective because there is almost always some species that has evolved a way to get around those defenses. But the defenses are good enough to ensure species survival, so the chemicals continue to get manufactured and passed along through the food web. In addition, disease is ever present in the warm, humid environment of the tropical rainforest and the organisms that live there produce many other chemicals to defend themselves against infection and disease. The end result is that the plants and microbes of the forest collectively produce a chemical soup that gets passed along through arthropods and ends up in frogs. Even if the chemicals have no nutritional value, the frogs use many of these chemicals to defend themselves against predators and disease and to produce brilliant colors. Cultured insects do not supply the frogs with a chemical soup to exploit. At best they only supply a weak broth. It's likely that many of the chemicals our frogs would utilize in the wild are already present in the vivarium within the rich variety of plants we grow in order to provide a comfortable home for the frogs and a pleasing display for ourselves. But in the case of most vivaria, the frogs can't access those chemicals because the cycle has been broken.

In a typical vivarium few arthropod species survive, either because they do not have suitable habitat or because they are eaten by frogs faster than they can reproduce. In the confined space of a vivarium, the arthropods most likely to succeed will be those that are small enough to hide in tiny cracks, crevices, and pores, allowing a high enough proportion of them to escape predation by the frogs and sustain the population. Providing at least a thin layer of soil or potting mix with an ample layer of decaying leaves will increase the chances that the vivarium will be able to sustain a thriving population of small arthropods that can supplement the frogs' diets and complete the natural cycle, thus reconnecting the frogs to the chemical soup stored within the plants. Increasing the diversity of arthropods will also increase the number and amount of stored chemicals that become available to the frogs because different arthropod species will have different potentials for consuming, storing, and transporting chemicals to a frog. A white springtail is much less likely to transfer red pigments to a frog than is a red soil mite.

Currently, the best way to maximize the diversity of arthropods in a vivarium is to seed it with living compost or natural forest humus. However, seeding with wild materials presents the risk of introducing undesirable insects or disease, so it is not for the timid. In particular, the seed material should never be collected where pesticides have been used or chytrid fungus is potentially present. But it is worth considering carefully what is deemed as undesirable. Snails, slugs, and millipedes are typically considered undesirable in a vivarium. But many plants produce defensive chemicals only in response to damage by a predator, so low levels of herbivory by invertebrates may actually benefit the vivarium by increasing the production of chemicals that our frogs are able to exploit.

Reconnecting our frogs to the natural nutrient cycle may solve some of the lingering problems associated with dendrobatid husbandry. The probability of successfully creating a small but sustainable population of soil arthropods in a vivarium depends on several factors. Foremost is the ratio of frog biomass to soil volume. The fewer grams of frog per unit of soil in a vivarium, the lower the predation pressure on the arthropod population will be and the higher the chances that the population will persist. Secondary is the availability of refugia. Refugia are places where organisms can escape (i.e., take refuge) and predators cannot reach them. For soil arthropods, refugia can be found under leaves, in crevices of wood, and within the soil itself. The greater the variety of pore space sizes between substrate particles, the greater the variety of arthropods the soil will support. And the more pores of suitable sizes that are available, the greater the population of arthropods the vivarium as a whole can support. Finally, the potential population of soil arthropods will depend on the productivity of the soil ecosystem. Productivity is measured by the amount of biomass that can grow in a given time. There are two things that primarily determine soil productivity. One is the amount of nutrient availability. In a vivarium this is supplied by frog waste, dead insects, and decomposing plant material, so maintaining a generous layer of leaf litter will ensure that there are plenty of nutrients available to support a thriving arthropod population. The second factor is soil capacity. This is the amount of nutrients that can be stored in the soil. The soil acts like a rechargeable battery: it stores nutrients and then releases them slowly to the organisms within the soil. A soil's nutrient capacity is largely determined by its clay content. Clay particles, being negatively charged, bind to positively charged nutrient molecules. So soils that contain some clay have a greater capacity to store nutrients than soils lacking clay. However, too much clay will drain poorly and eliminate larger pore spaces where arthropods can live, so there is a trade-off.

There is evidence that completing the cycle works. For the past nine years I have maintained a large (1m x 1m x 0.5m) vivarium containing *Dendrobates pumilio* "Blue Jeans." The substrate is pure clay kitty litter 7 – 14 cm thick and topped with a 0.5mm layer of humus that has built up over the years, along with a thick layer of

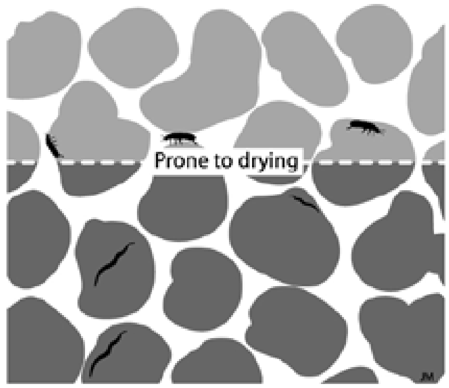


Figure 3:

decomposing leaves on the surface. The substrate supports a diversity of invertebrates including springtails, mites, centipedes, millipedes, slugs, isopods and an unidentified beetle (Fig. 3). For the first several years new froglets were removed from this vivarium when they attained a size of about 1 cm in length and placed in a traditional planted vivarium for rearing. Survival rate was about 50% and all froglets matured with faded color compared to the vividly colored adults, despite receiving carotenoid-rich supplements. Over the past two years I have left froglets in the larger vivarium until they reached maturity. During this period, survival rate has been slightly higher for froglets left in the larger vivarium, possibly due to the availability of small arthropods, which they continuously forage. The results have shown a dramatic improvement in adult coloration. Unlike their siblings that have been raised in a conventional vivarium, the froglets reared in the vivarium containing abundant soil arthropods are as brightly colored as the adults and indistinguishable from their wild-caught parents (Fig 4). It's impossible to know why the froglets reared in this larger vivarium develop better coloration than those reared elsewhere, but I believe it is because the abundance of soil arthropods unleashes the full nutrient potential of the vivarium by reconnecting the frogs to the natural nutrient cycle. Providing substrates that support a diverse population of soil arthropods may be an overlooked ingredient in dart frog husbandry.

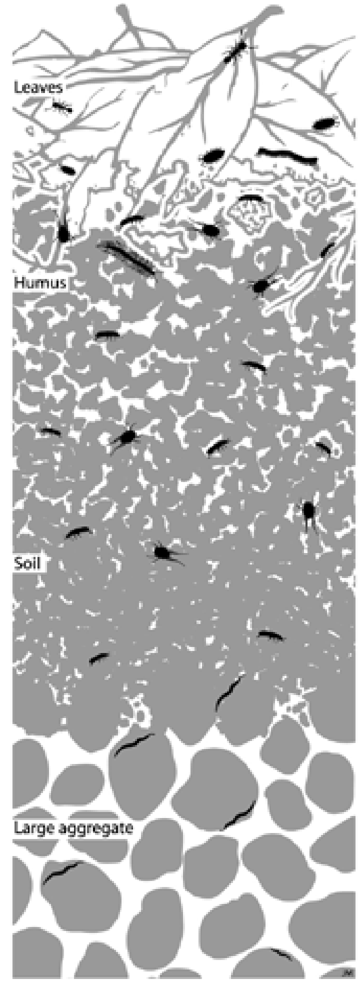


Figure 4:

## Definitions

***Invertebrate*** – animals lacking a backbone

***Frass*** – digestive waste products produced by arthropods

***Arthropod*** – animals lacking a backbone and containing an exoskeleton made of chiton (e.g. insects, spiders, crustaceans, centipedes, millipedes)

***Insect*** – a class of arthropod possessing three pairs of legs and a body divided into three segments (head, thorax, and abdomen).