Biodiversity and Peace

An Inquiry-Based Rainforest Curriculum

RESOURCE BOOK

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Montessori Rainforest Curriculum for the Classroom

Dear Teachers, what follows is a collection of organizing principles, concepts, information, and lesson and activity ideas that you can incorporate into your classroom before or after you and your students visit Costa Rica. By no means is this an exhaustive text, nor should it be followed like a cookbook recipe. The Children's Eternal Rainforest in Costa Rica is a marvelous and very special ecosystem whose mysteries and wonders are more easily unlocked with a deeper appreciation and understanding of the information that unfolds before you in the following pages.

Bolded words are vocabulary that may be new to your students. Give these words to your students in the context of an activity and ask them to develop a glossary of terms they will need as they pursue their investigations in the forest.

For maximum effectiveness, please read the entire **Overview** before diving into this collection with your students. You will find suggestions regarding prerequisites, sequencing, and outside resources that will help you structure your unit to best suit your educational objectives. The bibliography that follows includes the works cited throughout this document.

For the forest!

Rainforest Organizing Principles or Key Concepts

In order from biggest overarching concepts going down:

Vertical organization – A tropical rainforest is essentially three **habitats** stacked, due to differing conditions of light, temperature, humidity, and wind at each level. Consequently, levels have different inhabitants (for example there are worms and ants and birds and **epiphytes** in the **canopy** that are NEVER found lower down, NONE of the rainforest products that we use come from the canopy, and 66% of rainforest plant and animal species are rarely if ever found below the canopy.) Different conditions result in **adaptations** in plants and animals at each level. This has enormous significance as it provides a mechanism by which new species are formed and therefore impacts the **biodiversity** of the forest.

Mosaic structure – Any given parcel will have patches that are **primary** forest, patches that are **light gaps** due to a tree fall or landslide, and patches that represent some stage of **succession** between those two. In addition, the edges of the forest and edges along riversides, trails, or clearings for field stations represent different **communities**, mostly **pioneer** and light tolerant **species**, and these communities differ from those found deeper in the forest. Some plant species prefer edge conditions; others are adapted to deep forest (interior species). Birds and monkeys may also avoid edges. Edges and gaps have drier conditions and warmer temperatures due to greater exposure to wind and light.

Life zones – These vary by **altitude** with temperature and precipitation differences. Seven of Costa Rica's **Life Zones** are found in the Monteverde area. The area around Pocosol has yet another and Bajo del Tigre is a ninth. A transect through the Tilarán mountains from the Pacific slope to the Atlantic slope through the Monteverde area, would cross areas of tropical moist forest, premontane moist forest, premontane wet forest, lower montane rain forest, premontane rain forest, and tropical wet forest. (A chart giving the elevation, mean annual rainfall, mean annual temperature, duration of dry season, and canopy height is found on p. 42 of *Monteverde*, Nadkarni and Wheelwright, eds.) All the features of the mosaic structure occur in every Life Zone, increasing the diversity within each Life Zone, and **ecotones**, or transitions between habitats, further diversify the living conditions and the communities of local inhabitants.

Those are the big three. The additional concepts below should also be examined and addressed:

Nutrient/water cycling – 60% of the rain that falls in a lowland rainforest has entered the air through **evapotranspiration** from the trees themselves.

Ninety percent of the nutrients in a primary rainforest are tied up in the **biomass**, not the soil. Rapid **decomposition** and shallow root systems quickly return nutrients back to plants, keeping the soil depleted.

Specifically cover the **carbon cycle**, the **nitrogen cycle** including nitrogen-fixing fungus and bacteria, the **oxygen cycle**, and the **phosphorus cycle**, in addition to the **water cycle**. A special feature of the cloud forest is that for part of the year much of the water enters the system via **condensation** from fog passing through the canopy, rather than as precipitation that could reach the ground. Emphasize how the closed canopy and the heavy moss mats on branches, along with epiphytes that trap water, bulbous pseudoroots of epiphytic orchids and even many tree trunks that hold water in their tissues slow the movement of water through the system, gradually releasing it to the environment, and maintaining **watersheds** through drier periods. When the vegetation is removed, streams which previously flowed all year round may dry up during the dry season. Therefore, deforestation in the Lake Arenal watershed could reduce water levels in the lake, depriving many people of power from the hydroelectric plant. (Arenal is a manmade lake; water from the reservoir provides Costa Rica with approximately 40% of its electricity and a large proportion of the water originates from streams and rivers that start in the CER).

Niches/symbiotic relationships/specialization – These have great stories: the strangler fig/fig wasp/bat connection; the avocados and the bellbird or quetzal; leafcutter ant colonies and all the **castes**; all the ways that tropical bats make a living and divide the habitat into specific **niches**; flowers and their pollinators (e.g. hummingbirds, bats, and insects); interactions among oropendula birds, cowbirds, botflies, and wasps; and trees with ant guardians are all good examples.

With interspecific relationships, you can use +, -, and 0 to indicate the effects two species have on each other. **Competition** is a negative for each of the two but a positive if the competition is absent. **Mutualism** is a positive for each, but a negative when they try to go it alone. **Protocooperation** is when two species that normally do fine on their own do better when interacting, so they are positive in a relationship but zero when not associated with each other. In **commensalism**, one species does better when interacting and worse when not, but no effect is observed on the other partner either way. **Amensalism** describes the situation when two species which do fine on their own interact to the detriment of one with no effect on the other. In **parasitism**, the parasite gains from the interaction and the other partner is likely to suffer somewhat, but without the interaction the parasite is negatively affected. In **predation**, obviously the predator suffers without prey and has a positive response with prey, while the prey suffers from the predation. It might be best to create a table to show these various relationships. Collecting examples of each as you pursue your studies is also valuable.

	Interacting		Not interacting	
Relationship	Species 1	Species 2	Species 1	Species 2
Competition	-	-	+	+
Mutualism	+	+	-	-
Protocooperation	+	+	0	0
Commensalism	+	0	-	0
Amensalism	+	0	-	0
Parasitism	-	+	+	-
Predation	-	+	+	-

Creating a web of connections is a fun activity that can involve building a model or drawing a complex illustration as a large poster. You can even do it with picture cards and yarn. Cards depicting various plants and animals are distributed to students arranged in a circle. This animal is connected to that tree because it eats the fruit so those two students each hold the end of a piece of yarn. Another student is connected because his caterpillar eats the leaves of the tree so they have a length of yarn between them. Another student is the pollinator of the tree so they get connected. A bird that eats that caterpillar is connected across the circle. A monkey that sleeps in the tree gets connected. An animal that poops under the tree gets connected, and an epiphyte that grows on the tree, and a termite nest, and birds that nest in the tree, and ants and woodcreepers that eat the ants. Many students may find themselves connected to quite a few other species. You can really get carried away and are only limited in the connections you demonstrate by the number of people you have in your circle. When you are finished you have a chaotic web of yarn. Remove one species from the circle and all other species attached to it will be affected, and then all secondarily attached species are affected, and so on until the whole web has collapsed. An extension of this is to introduce the concept of a **keystone** species. Removal of this species in any web has a greater impact on the rest of the web than removing other species would have because so many species depend on it in one way or another.

Classification – Try various formats besides **binomial nomenclature**. Distinguish between **lianas**, vines, and aerial roots – what are the differences, advantages, trade-offs? Epiphytes – what are the benefits and disadvantages for the epiphyte and the species it grows on? Classify species as to inhabitants of the canopy vs. forest floor, flying vs. walking, interior vs. edge, primary vs. **secondary**, flowering vs. nonflowering, in addition to the standard **vascular** vs. **nonvascular**, and all the traditional **taxa**. The really fascinating ones are those that defy easy classification, like *Balonophora*, an organism that looks like a pinkish strawberry on top of a mushroom stem that you could easily believe to be a fungus; however it is actually a parasitic plant that has no chlorophyll and lives by stealing nutrients from tree roots. Or deciding if *Monstera deliciosa* is a vine or an epiphyte, since once they reach the canopy the connection with the ground is severed and the plant grows through the canopy, dying off at the back end as it extends at the leading end. If you could observe this in time-lapse photography, it would look like a 10-meter long snake surfing across the crowns of the trees. Classification is an appropriate context for investigating **liverworts**, **club mosses**, **mosses**, **lichens**, and **ferns**, and discussing their reproduction strategies and characteristic structures.

Microhabitats – These are fun to explore: looking at all the species on a nurse tree; considering all the species that use the tank of a bromeliad as a home, hunting grounds, and water source; the inside of a hollow fig or a hole in a tree; and the depression left at the base of the trunk when a tree falls are a few examples. Create a food web or consider the adaptations involved for each.

The role of color – This is a very rich topic and includes:

- **Aposematic** coloration
- **Batesian** and **Mullerian mimicry**
- **Cryptic** coloration
- **UV** markings on flowers that guide a **pollinator**
- specific colors that attract hummingbirds
- the almost glowing white of night-blooming flowers that attracts bats or beetles
- **bioluminescent** fungus or the glowing spots on click beetles
- the way that red can look black in the shade and blaze in the sun (because of the wavelength of red light)
- butterflies with bright patterns on their upper wing surfaces folding them when they alight to camouflage themselves with the dark undersides
- fruit using color change to indicate ripeness to the **seed disperser**
- spots on the jaguar's coat (and the coats of some baby mammals) making them harder to see in the mottled light on the forest floor
- vibrantly colored **bracts** surrounding a small flower that attract a pollinator; the brack is retained by the plant and allows the **carotene** that produces the color to be recycled. Carotene formation is an energy expensive process
- bright stems to hold the fruit that attract a seed disperser (again the carotene is retained by the plant)
- the pink, red, white, or silver spots or stripes on leaves, or the purple undersides providing a surface that can absorb the green light being reflected by the other leaves around them, allowing them to make maximum use of the low light reaching the forest floor
- new leaves are often pink or tan (There are various theories as to why -

one is that not being green allows them to absorb light of wavelengths not absorbed by green leaves, another is that not being green allows them to avoid recognition as edible by leaf chewers, and the third is that they actually have higher levels of **alkaloids** or toxic substances to deter leaf chewers and the color is a warning coloration. Much research remains to be done.). You could use this concept to review the nature of the **visible light spectrum** and how color is perceived because all the other wavelengths are absorbed by the surface while that one is reflected to the eye. Also review which animals can see color and which are **color blind**! For example, female spider monkeys can see color and the males cannot, so they wait to see which fruit the females feed on to know what is ripe.

Adaptations – Features favored by **natural selection** because they increase an organism's success. This topic can be used as the jumping off point for many discussions:

- differences in species through the layers of the forest
- differences in species across Life Zones
- classification
- **specialization**
- **symbiotic** relationships
- birds bills and feet adapted for their specific feeding strategy and habitat
- exactly how each flower is adapted for its pollinator
- how tropical plants have different adaptations from those of temperate zones because of the **abiotic** conditions of the environment – especially since many environmental factors vary little throughout the year, except for the forests with a distinct dry season.

There are freshwater crabs that live in the canopy going from **bromeliad** to bromeliad! There are canopy worms that are blue and never come to the ground! The margay's back feet, rats that live in trees, **extrafloral nectaries** on plants – so many features of the living things you encounter is an adaptation to something!

Rainforests and the Montessori Time Line of Life

The Montessori Time Line of Life is a graphic representation of the evolution of life on earth. While the Earth is 4.6 billion years old, the very first **protocells** appeared before 3.5 billion years ago and by that date, the split between **Archaea** and bacteria occurred. These early life forms were evolving in the seas that covered most of the planet. **Eukaryotes** developed less than 2 billion years ago. Most current animal **phyla** and the earliest plants had already appeared in the sea before life began moving onto the land. Oxygenation of the atmosphere by means of **photosynthesis**, mostly by **cyanobacteria**, was a significant global change. The oxygen also led to the formation of the **ozone layer** in the stratosphere that blocks UV radiation, a necessary prerequisite for life to exist on land.

The earliest plants to colonize dry land evolved from the green **algae** growing in the shallows along the edges of bodies of water. These were nonvascular plants, and they moved onshore about 434 million years ago. [The dates are not as important as the sequence of events and some researchers argue that plants may have been on land as early as 1 billion years ago. However, there was an ice age with massive global glaciation about 500 million years ago, so it seems likely that land plants would have had to start over then anyway.] **Bryophytes** appeared next, in the form of liverworts, **hornworts**, and mosses, still nonvascular plants that share water and nutrients throughout their tissues from cell to cell, through the walls and membranes.

These were followed by the evolution of vascular plants that still had very simple reproductive strategies – plants like club mosses and **horsetails** and then ferns, which reproduce by means of **spores**. These plants were vascular, with tubes that transported water and nutrients throughout by **capillary action** and **pressure gradients**. Such tubes also gave the plants more structure and support to grow tall.

The next major advancement was the **gymnosperms**, such as conifers, cycads, and ginkos. These plants produced actual seeds, as opposed to spores, but the seeds did not carry their own initial food supply and were formed in structures like pine cones. Unfertilized seeds were exposed to the air and pollinated by the wind.

At the time these plants were evolving, the continents were assembled into one supercontinent, **Pangaea**, the climate was warm, and amphibians, reptiles, and beetles were greatly diversified.

Following the Permian-Triassic **extinction**, dinosaurs flourished, soon to be joined by mammals, flowering plants, birds, and many more kinds of insects. Continents moved around, splitting from each other, and mountain ranges rose, wore away, and others rose. New **ecosystems** developed in places that were colder, drier, or higher than anything found during the late Permian, but the lush green habitat that is now our tropical rainforest persisted throughout, in a belt around the Earth's equator and bordered by the Tropics of Cancer and Capricorn.

Ice Ages came and went, bringing **glaciation** as much as several miles thick over much of the land at higher **latitudes**, but the rainforests remained near the equator. The times when the glaciers approached most closely probably resulted in the drying of some areas of the rainforest, reducing the habitat to isolated pockets, or **refugia**, where the primitive life forms persisted and evolved independently of each other until the Ice Age ended. Then the rainforest patches merged again and the species that had appeared in the various refugia were able to disperse and interbreed, creating even greater biodiversity of species.

North America and South America were separated from each other in the Jurassic, when Pangaea broke into **Laurasia** and **Gondwana**, which later broke into the individual continents. Costa Rica itself was underwater until about 4 million years ago, when the **isthmus** of Panama was raised from the ocean floor as a result of the **plate** containing the Galapagos Islands pushing to the northeast. As it was lifted, it was populated by plants and animals moving north from South America or south from North America, a great melting pot or mixing bowl of species that had been evolving separately ever since those two continents had split, some 180 million years earlier.

On most parts of the planet, life has changed considerably since it first appeared, for many reasons. The climate may have changed when the land mass moved farther from the equator. Great areas of the land surface have been covered, sometimes more than once, by lava flows or glaciers. As mountains rose, **rain shadows** behind them created desert conditions. The climate of the planet in general has become cooler than it was during the Mesozoic. Plant and animal communities have had to adapt and evolve with these drastic changes.

When you walk through a rainforest, however, you might feel like you have stepped into the Time Line of Life. Algae coat the rocks in streams and around thermal vents in volcanic areas. Liverworts are plastered over the banks of streams and along trails. Tree trunks and limbs are thickly populated with a multitude of moss species, each a slightly different shade of green. Club mosses are common and ferns are amazingly diverse, growing as epiphytes, ground plants, climbers, and even as trees, although these tree ferns might only reach 60 feet tall instead of the giants of the dinosaur times! You might even get the impression that everything that ever evolved in the rainforest is still here, although actually the current species are not identical to the originals, just descendants. You may feel that nature has experimented wildly with all sorts of solutions to the question of how to make a living on earth and the results of these experiments are all around you, each filling its own small niche. Instead of competition wiping out the least successful, everything seems to have found a way to be successful enough to persist, in however small numbers, or maybe in only one ravine on the entire planet.

This is the meaning, and the development, of the amazingly high biodiversity and high **endemism** of the rainforest, and the reason that it is so very precious and worthy of protection.

Poem: Bosque Eterno de los Niños ***(The Children's Eternal Rainforest)***

by Luissiana Naranjo, Monteverde *(translated by Allison Deines)*

Me alivia saber que el silencio
Se encuentra en cada hoja de árbol
Como ese pedazo de aire con el que soñamos,
Siempre luminoso.

Saber que hoy
Tantas manos
Son semillas aprendices,
Y más tarde,
Serán troncos desafiantes de la luna,
Con sus ramajes de niños traviesos,
Impetuosos contra la sierra.

Porque ningún árbol quiere morir
Con su sombra desnuda,
Talada en su vientre
Como esa última hoguera
Que dió calor a algún hombre.

Y es que este suelo es testigo fertile
de su osadía,
Ser árbol entre tanto plomo y cemento,
Perder su identidad de bosque
Porque las raíces a veces resbalan
Y las nubes se alejan cansadas de sus ideales.

Este bosque es eterno
No solo porque preserva tibiamente
Al ave o planta,
Al insecto o rana,
Sino también al poeta,
Sí, a lo poéticamente verde,
A esa vida que se resume en esencia,
A este juego del tiempo que nunca nace, crece y muere,
A ese brote de infancia que todo lo supone,
A ese viento pionero que todo lo derrumba,
A esa lluvia insinuosa que todo lo multiplica
Y a este silencio… que se vuelve más
Poesía en su silencio.

Me alivia saber,
Que este bosque es eterno
Simplemente Porque
ustedes y yo,
Tiramos la moneda para ganarle a la memoria su existencia.

I am relieved to know that
silence is found in every leaf on the trees
like that breath of air that we dream of,
always luminous.

To know that today
so many hands
are apprentice seeds,
and later,
they will be trunks to defy the moon
with their branches like mischievous children,
impetuous against the saw.

Because no tree wants to die
with its shadow naked,
cut down in its womb
like that last hearth
that gave warmth to some man.

And that this land is fertile witness
of his audacity,
to be a tree amongst so much lead and
cement,
to lose its wild identity
because roots sometimes slip
and clouds tiredly move away from their
ideals.

This forest is eternal
not only because it warmly preserves the bird
or the plant,
the insect or the frog,
but also because it preserves the POET,
yes, it preserves that poetically green,
that life that is summed up in its essence,
that game of time that never is born, never
grows, and never dies,
that innocent sprout for which everything is
possible,
that pioneer wind that topples all,
that sensuous rain that multiplies all,
and the silence…that becomes more poetic in
its silence.

I am relieved to know,
that this forest is eternal
just
because you and I
tossed a coin
to win its existence from our imagination.

Taken from the 2001 book *Tertulia en el Bosque*

The Tropical Rainforest Outlined

In this section many important rainforest concepts are outlined (i.e., letters), which are followed by some activities and/or demonstrations (i.e., numbers) that communicate each concept.

I. *Placing the tropical rainforest in time, latitude, altitude, and climate profiles*

A. Rainforest is the oldest ecosystem on the planet, having persisted in refuges even during the Ice Ages. [This can be explored by looking at maps of the extent of various ice ages and is important in explaining the high biodiversity later on.]

B. Tropical rainforests are located between the Tropics of Cancer and of Capricorn in a band around the equator and up to 23.5 degrees latitude to the north and south of it.

1. Find the **Tropics** on a map or globe. Shade in the land areas.
2. Calculate the percent of the Earth's surface in the Tropics (40%). [At the time of Christopher Columbus, 14% of the earth's land surface was covered in tropical rainforest. By the 1980's when interest in rainforests peaked, it was down to 7%. It is now closer to 6%.]

C. Tropical rainforests are found from sea level to the tops of mountains in the tropics, although at each elevation the forest has a different name, or Life Zone, with different species and specific climate conditions.

1. Referring back to the map or globe, locate mountain ranges within the Tropics. Notice that deserts are mostly in the **Temperate Zone**, not in the Tropics, which surprises many because we think of the Tropics as being the hottest region.
2. Look at a chart of **Holdridge Life Zones** and compare this to a list of the Life Zones contained within the CER. http://www.cieer.org/geirs/holdridge_model.html What climate ranges differentiate the life zones within the CER? See http://costa-rica-guide.com/photo/3984/holdridge-life-zones-map.html to see the 19 Life Zones of Costa Rica. In the Monteverde area, the life zones that occur are Tropical moist forest, Premontane moist forest, Premontane wet forest, Lower montane wet forest, Lower montane rain forest, Premontane rain forest, and Tropical wet forest, following a transect across the mountains from the Pacific slope to the Atlantic slope.
3. Make a **climatogram** for your school's location and compare it to climatograms for tropical rainforests you find online. Instructions on creating a climatogram can be found at

http://www.pbs.org/americanfieldguide/teachers/prairie/studinst.pdf and students can find climate data for the place where they live and for the Monteverde area. Data for monthly rainfall and temperature for the Monteverde Cloud Forest Reserve can be found at http://www.science.smith.edu/~aguswa/papers/MetReport_2004.pdf and can be used to construct a climatogram, or you can find it in Nadkarni and Wheelwright's (2000) book on Monteverde.

D. A rainforest climate is characterized by rainfall measuring at least 100 mm per month and consistently warm temperatures that vary little from day to night, day to day, or month to month. In some Life Zones the rain is more concentrated in part of the year with a short dry season having less or even no rainfall. [The wettest rainforest is in Hawaii with 1168 cm (460 inches) annual rainfall.] Seasonal variability increases with distance from the equator but also differs between west and east coasts of Central American countries. Days at the equator have 12 hours of daylight and 12 hours of darkness and this also changes gradually with distance from the equator.
    1. Measure your shadow 4-6 times a day at regular intervals in your home state and again in Costa Rica. Calculate the percent of change over the course of one hour in each place. Explain the difference.
    2. Demonstrate how high 4000 mm (a ballpark estimate of rainfall for an Atlantic slope premontane rainforest) is. [Mark on the side of a building, inside a stairwell, or on the trunk of a tree. Measure and mark that distance on a length of thread tied to a bundle of helium balloons and let them rise until the mark is at ground level and the balloons are straight overhead. Other ideas?] Imagine water this deep!
    3. Shine a bright narrow flashlight beam on the surface of a globe. Have one student walk the globe around in an orbit around the second student with the light, with its axis tipped, to show how the light is angled and spread out over a greater area on the portions of the globe tipped away from the equator but the angle of light remains the same over the equator.
    4. Shine a flashlight at the floor straight down and measure the area illuminated by the bright center circle. Tip the flashlight 38 degrees, or the latitude at your home school, and measure the area illuminated. What is the percent difference? Look up the latitude for Monteverde.

5. Look up the monthly average high and low temperatures for San Jose, Costa Rica, in an almanac and graph in two colors, say red for high and blue for low. Look up the same information for your home town (try the local newspaper if your town is not in an almanac) and add to the graph in different colors, say orange for high and green for low. Explain the difference.
   a. Calculate the difference between the monthly average high and low temperatures for each location and graph that.

   b. Calculate the percent change between monthly average high and low temperatures for each location and graph that.
6. List the ways that plants and animals adapt to seasons in the Temperate Zone and think about a forest where plants and animals don't have to adapt to seasons. How does that free them up to function differently? [Animals – winter coats of different color, denser fur/shedding; timing of reproduction; **estivation/hibernation**; **migration**. Plants – dropping leaves/winter **dormancy**; blooming/pollen production; fruit maturation; complete winter dieback/resprouting from roots; growing as annuals, dying in winter after dropping seeds; coordination of timing between plants and their pollinators, or plants and their seed dispersers. Without the constraints of seasons, do plants still have to all bloom at the same time, produce ripe fruit once a year? If an animal doesn't hibernate or migrate during winter, how does it have a year round food supply? For pollinators to survive, do they need to service different plants year round, or do the plants they prefer flower year round? Encourage kids to really think it through.]

II. Structure of the forest

A. Forest floor and herb layer

1. Conditions – extremely low light, mild temperature, gradual delivery of precipitation, shallow soil covered with minimal **leaf litter**, little or no breeze
2. Observe which plant families are found here – ferns, *Heliconia*, *Zingiberaceae*, *Melastomataceae*, *Piperaceae*, small palms, nonvascular plants like liverworts and club moss, *Marantaceae*, *Violaceae*, *Myrtaceae*, *Araceae*, *Acanthaceae*, *Gesneriaceae*, and *Costaceae*
3. Adaptations – Ask yourself what plants and animals live here and how do they make a living? [Trees have to have very shallow roots, no **tap root** but rather a dense net of shallow fine roots that absorb water and nutrients before they can penetrate an inch into the soil. Larger roots are often above ground, snaking across the trails. **Leaf litter turnover** is very rapid, taking about six weeks to

completely decompose, which means there are lots of decomposers (beetles, millipedes, fungi, bacteria) but no worms! Leaf litter protects soil from **erosion** that might be caused by heavy rain, which is also blocked by the canopy. Ground level plants don't grow densely because of the low light. Leaves are usually arranged to maximize light gain, like in a circle, or a spiral, or staggered. Leaves often have waxy surfaces and/or **drip tips** to shed water easily, avoiding buildup of mold or **epiphylls**. Leaves are often not green to absorb light rays that bounce off other leaves which *are* green [[review wavelengths of various colors of the visible spectrum]] or else they might have dots or stripes of another color or undersides that are purple or another color. Because of the lack of breezes, these plants are never wind-pollinated and don't produce seeds that are wind-dispersed. That means pollination must be done by hummingbirds, butterflies, moths, flies, midges, wasps, bees, beetles, or bats. Seeds are dispersed when an animal eats the fruit or by hitching a ride on fur, as burs do. Seeds of **climax** trees don't stay viable very long but seeds of pioneer species can persist in the **seed bank** for years waiting for a light gap to give them the impetus to germinate. Most seeds that germinate on the forest floor grow in the direction of the light, but when vines germinate they do the opposite, growing in the direction of the deepest shade, because that will be the shadow of the biggest tree nearby. Once the vine reaches that trunk, it switches to seeking light and climbs the tree. Plant defenses are also fascinating adaptations to discuss. Animals (including birds) that walk the forest floor feed on leaves, fallen fruits and seeds, insects, and each other. Leafcutter ant colonies are major players in **aerating** and enriching soil, like worms are in the US.]

a. Do classroom experiments on the effects of low light on **germination** and growth rates of plants; wrap jars of water in various colors of paper and place them in the sun or under a bright light and after several hours take the temperature of the water to see which colors absorb the most energy; grow plants under lights that are covered with various colors of plastic to see if filtering out different wave lengths has differing effects on growth rates
b. Use a stream table to demonstrate the protection against erosion provided by leaf litter.

c. In the classroom or in the forest, mark specific fallen leaves and document the progress of decomposition over 7 days.
d. Demonstrate **phototropism** by planting a tray of grass seed and placing it on a windowsill to watch the grass bend toward the light, then turn the tray 180 degrees and watch the grass bend in the opposite direction to reorient toward the light.
e. Another demonstration is to create a sort of simple maze inside a tall (20"±) cardboard box by taping short pieces of cardboard perpendicular to the walls at staggered intervals up the sides, with a 4" hole on the side near the top to admit light. Place a germinated bean seed in a small pot of dirt at the bottom of the box. As it grows, the bean plant will navigate the maze to reach the lighted hole.

B. Understory
1. Conditions – only somewhat lighter and warmer than the floor
2. Plants found here – some are simply small sized trees, like *Psychotria*, tree ferns, various palms, sangre de cristo, *Bauhinia* – and few are immature canopy trees. Generally, immature canopy trees will only be found where the light is greater, like along riverbanks and trails or in a gap caused by a tree fall or landslide. Immature canopy trees exhibit a **monopodial** crown, rather like a closed umbrella, during their climb through the understory, but once they reach canopy height the umbrella opens into the characteristic **sympodial** shape of canopy crowns. Canopy trees do not develop side branches until they are quite tall (as high as 50 feet to the first branch in the lowland rainforests) so the understory is relatively open and can give the impression of a field of telephone poles in mature lowland rainforest. Trunks in **perhumid** forests are often so covered with moss, lichens, epiphytes, and vines that you can't see the bark. Secondary forest patches are notable for the low incidence of epiphytes, vines, and lianas.
   a. Epiphytes – are not parasites and do not root in soil but derive water and nutrients from the air and mist, from water running down the trunk they attach to, and from organic debris that accumulates around their "roots." They can be of many families, including orchids, bromeliads, and ferns [43 families identified – 29% of total flora in the area]. Tank bromeliads hold the most water in the base and can host 4-5 dozen species in this microhabitat!

b. Vines – have various ways of attaching as they climb (tendrils, claws, clinging roots, or twining) and remain green and flexible. Some like *Monstera* become epiphytic after reaching the canopy, severing their attachment to the ground and moving through the canopy by growing at the leading end while dying off at the trailing end. Leaves vary from a couple millimeters to nearly 2 meters. Other vines germinate in the canopy and after some time of development send down **aerial roots** to the ground. Vines that germinate on the ground demonstrate **skototropism** in growing away from light into shade while seeking a tree to climb. *Mucuna*, a common Costa Rican rainforest vine, is the host plant for butterflies of the genus *Morpho*.

c. Lianas – adopt the same strategy as vines, sacrificing rigidity and stoutness for length. Rattan, an Asian liana, can grow 300-500 meters long, but a tree could never grow that tall. Many families are represented among lianas, as this is a growth habit, not a **taxon**. They can germinate on the ground or in the canopy, as vines do. Lianas are not green like vines but woody and covered with bark. This allows them to become highways through the canopy for animals from ants to monkeys. Lianas and vines tie canopy trees together, helping weaker trees withstand wind but also competing for sunlight and soil resources. When a tree does fall, the fact that it is connected to others by vines and lianas can result in bringing other trees down with it.

C. Canopy – the height of the canopy varies with altitude. In the Amazon lowland, it can be well over 60 m feet high, but on mountains where it is windier the canopy is lower, and on the top of the continental divide it is called an elfin forest. Canopy height crowns have the open umbrella or sympodial shape but **canopy shyness** means that they don't overlap each other but rather leave a small gap between each crown. Viewed from the sky, the crowns can look like pieces of mosaic or stained glass with lines of grout surrounding each piece. The canopy experiences strong winds, bright direct sunlight, and the highest temperatures. Consequently, leaves exhibit different adaptations. They may be small, gray or silvery, with fine hairs, and turn sideways to the sun rather than tracking the sun, all ways to minimize water loss and reduce sun damage to tissue. There are even cacti growing as epiphytes in the canopy. This is where two-thirds of rainforest animals live.

D. **Emergent** – A few species of trees emerge from the canopy by becoming much taller than the rest, like kapok and mahogany. They are virtually the only species that produce wind-dispersed seeds - cottony in the case of kapok and winged for mahogany. Flowers of emergents are often bat-pollinated.

III. ***Classification of life*** – you can't look at every family of plants and phylum of animals but choose several to consider and make sure the kids know how to fit them into a tree of life, taxonomically.

A. Plants

1. Non-vascular – discuss reproduction and how nutrients are shared with the cells in the absence of a vascular system; identify common examples the students can see, at home and in the rainforest.
2. Vascular – Review parts of the plant, flower, root, leaf, seed, stem; leaf types (shape, **venation**, margins); types of roots and stems
   a. Non-flowering – discuss reproduction; identify examples.
   b. Flowering – give most common families and quick tips for distinguishing

B. Animals – Know the chief characteristics of the common phyla

1. Arthropoda – consider the most commonly encountered orders
2. Mollusca – mostly the snails encountered
3. Chordata – find genus and species in guide books

C. Fungus – reproduction and nutrition, including role as a decomposer and as a **nitrogen fixer**

IV. ***Biodiversit*y** - applies on several scales even within a single rainforest, from diversity of habitats and niches, to species level, to genetic level within species (**allelic** diversity) and causes include:

A. Interspecific and intraspecific competition, symbiosis, specialization, **co-evolution**

B. Structural complexity (mosaic of successional stages and patches, history of **stochastic disturbance** and human disturbance) vertical stratification, microhabitats, niche availability (including **guilds**, **allochronic** feeding and reproduction, synchronous blooming)

C. Abiotic and biotic factors (see above; can students generate any more?)

D. **Evolution**, adaptation, **allopatric** and **sympatric** speciation

E. Climate refuge hypothesis

F. Physiological "freedom" due to abundant resources

Rainforest *Significa*

- Rank of the Amazon among the largest and longest rivers of the world: **1**
- Rank of the Amazon basin among the Earth's largest contiguous rainforests: **1**
- Proportion of the area of the Amazon to all rainforests on Earth: **1:3**
- Ratio of the size of the Amazon basin to the continental US: **1:1**
- Total length in kilometers of the Amazon basin: **6,720**
- Kilometers of navigable rivers in the Amazon basin: **80,000**
- Percentage of Earth's fresh water flowing through the Amazon: **20**
- Ratio of the Amazon's flow to that of the Mississippi: **11:1**
- Cubic meters of water flowing through the Amazon's mouth per second: **198,000**
- Hours required for the Amazon's flow to fill a hypothetically drained Lake Ontario: **3**
- Rank of the Rio Negro among the world's rivers in diversity of fish species: **1**
- Rank of Colombia among the nations of the world in diversity of bird species: **1**
- Estimated number of insect species living in the Amazon: **30 million**
- Total number of all animal species known to science: **1.4 million**
- Species of butterflies found in Peru: **1,450**
- In all of North America: **730**
- Number of ant species found in 1 Bolivian tree stump: **43**
- Ant species in all the British Isles: **43**
- Percentage of the world's freshwater fish species found in the Amazon: **50**
- Species of animals found in one Jamaican bromeliad: **68**
- In one Asian pitcher plant: **55**
- Proportion of rainforest bird and mammal species to temperate zone species: **2:1**
- Arthropods on one Amazon tree: **1,700**
- Average rainfall in centimeters in the Amazon each year: **254**
- Percentage of rainforest rain that comes from the trees: **50**
- Number of gallons of water per minute returned to the air by one tree through transpiration: **60**
- Percentage of decrease in annual rainfall since 1900 in South America: **10**
- Historical plant and animal extinction rate: **1 per 1,000 years**
- Current rate: **50,000 per year**
- Rate of endemism in vascular plants in Ecuador: **up to 25%**

- Number of species that may be found in 2.5 hectares of Amazon rainforest: **23,000**
- Percentage of all known plant and animal species found in the Amazon: **30**
- Percentage of Amazonian trees whose roots extend less than 10 cm below the surface: **90**
- Number of plant species in all of New England: **1,200**
- In the Amazon: **80,000**
- Number of species of trees that can be found in one hectare of Amazon rainforest: **300**
- In one hectare of California forest: **5 to 10**
- On one hectare in Peru: **283**
- On 20 hectares in Malaysia: **830**
- In all the US and Canada: **700**
- In all of continental Europe: **50**
- Number of fires in Brazil visible from space each summer: **8,000**
- Percentage of calories and protein for the world's population that come from only 30 plants, most of them which originated in the tropics: **95**
- Percent of birds breeding in North American that migrate to tropical forests: **66**
- Percent of rainforest plant and animal species seldom found near the forest floor: **66**
- Percent of rainforest products we use that come from the canopy: **0**
- Percent of rainforest nutrients tied up in the biomass: **90**
- Percent of nutrients that filter deeper than 5 centimeters beneath the soil surface: **0.1** (note decimal)
- Percent of CO2 emissions from burning of rainforest: **20** (1 billion tons per year)
- Percent decrease of native New World population between 1492 and 1600: **90**
- Indian groups in Brazil wiped out in the twentieth century: **87**
- Number of indigenous tribes close to extinction: **1000+**
- Ratio of income from a managed extractive reserve to that cleared for cattle ranching: **2+ :1**

Give this to your students as is or delete selected information and ask them to complete the blanks you create.

	World	US and Canada	Costa Rica	% of the World	CER	% of the World
Land surface in sq km	148,300,000	18,246,100	51,100		225	
Known species	1,700,000		500,000		92,000	
Bird species	9998	914	943		440	
Mammal species	5490	474	251		100	
Reptiles	9084	385	225		101	
Amphibians	6433	208	142		60	
Butterflies	17,500	725	1,251		700	
Vascular plants	352,000	19,473	12,119		3,021	
Orchids	20,000	200	1300		878	
Trees	25,000	1,000	2,000		800	

Additional Online Resources

http://www.biologycorner.com/worksheets/environmentalaction.html - A role play about a funding organization considering several proposals from organizations for their environmental projects and the decision-making process in choosing the recipients of grant money.

http://sustainability.publicradio.org/consumerconsequences/ - Consumer Consequences, an interactive game designed to illustrate the impact of our lifestyles on the Earth and whether it is sustainable in the long run.

Elementary school animations
http://kerala.skoool.in/content/KS3%20LOs/biology/interdependence/index.html – shows a cartoony slide show on interdependence within a community

http://kerala.skoool.in/content/KS3%20LOs/biology/plant_mineral_req/index.html - cartoony slide show on plant mineral requirements

Intro to classification
http://www.pbs.org/wgbh/nova/nature/classifying-life.html - learn about taxonomy and practice classifying three life forms

Carbon footprint
http://www.teachersdomain.org/resource/tdc02.sci.life.eco.warmingweb/ - tour a drawing of a house and find out where energy is going, to see how to lower your carbon footprint

Carbon cycle
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/foodchains/foodchainact.shtml - The carbon cycle and food chains

http://www.windows2universe.org/earth/climate/carbon_cycle.html - A carbon cycle game that shows where carbon gets stored and asks questions about carbon along the way

Fun food web interactive
http://www.vtaide.com/png/foodchains.htm - Explains food chains and food webs and has a link to an activity that allows you to create a food web that is a little confusing as the pictures are too tiny to be able to easily identify what they are and animals I wanted to use weren't shown, plus there were a limited number of arrows and in fixed directions that made it harder to arrange the web

http://www.gould.edu.au/foodwebs/kids_web.htm - really good interactive for assigning trophic levels and then seeing the completed food web charted out, but habitats are limited

Great videos: Life after people. Thinking ahead when the ecosystems take back over
http://www.history.com/shows/life-after-people/videos/playlists/what-will-happen-after-people#history-life-after-people-american-pastime-sf

If you have other favorite online sites that you like to use for particular lessons regarding rainforests or other ecological concepts, feel free to e-mail Maggie at maggie.eisenberger@friendsoftherainforest.org and we will add these to this list to share with others.

Activity and Lesson Ideas

PHOTOS

Exercises to Explore Biodiversity

How Big Is a Hectare?

Background

Read the Rainforest Significa sheet, which contains lots of statistics on the biodiversity of the rainforest, many referencing a hectare as the size of a study plot. Students are not often sensorially familiar with the size of an acre, much less a hectare. All science uses metric measurement so the students need to be introduced to this unit.

Materials

Trundle wheel

Compass

Surveyor’s flagging tape (optional, for classes of less than 16)

Wooden stakes or tent pegs (optional, as above)

Procedure

Take the students to an area that is a large open field or meadow. Decide where to place one corner and leave a student or two standing there (alternately, drive a post with flagging at the corner). Choose a direction on the compass that will allow you to work in your space and count off 100 meters, using the compass to make sure you go straight in one direction. Depending on the size of the class, you can station students or drive more posts every 25 meters. At the next corner, use the compass to make a 90 degree turn and measure the next 100 meters, continuing until you have described a square 100 meters on each side. If you have stationed students around the edges, they can look across the space at each other and experience the size of the hectare.

Discussion

Gather the students together in the middle and discuss the statistics below. If you don’t have room to do a hectare, measure an acre and tell the students that a hectare is approximately 2.5 (2.47 to be exact) acres (or do both!). How do they convert the statistics? Consider that in a North American forest, the maximum number of tree species per acre is 25 and the average is 5, while in a rainforest, as many as 700 species have been counted in an acre, with an average of about 250. Convert those figures to hectares. In Costa Rica a plot of only 100 square meters was surveyed and found to contain 233 species of vascular plants (including 73 tree species). One hectare in Peru was found to contain 580 trees (245 species), and about 66% of the species were represented by a single specimen. Another 19% of the species were represented by only two trees each, and the rest were more common. (The most common trees would be pioneer or light gap species that grow along river banks, roads, trails, and in gaps from tree falls.)

Biodiversity of Animal Life in the Rainforest

Background

This is a sensorial demonstration of the distribution of species on Earth. Over 50% of known species of plants and animals occur in rainforests. Seventy-five percent of the earth's surface is covered by water. About 6% of the land surface is tropical rainforest. Since rainforest covers a relatively small area, this means that relatively few of any one species can live there, with the result that nearly every species found in a rainforest can be considered rare on a global scale, if not threatened.

Materials

Do this exercise in a large space with a linoleum tile floor with easy to see squares. The best floor is one with 12 inch squares, so each square is a square foot, but any large squares will do. If you don't have access to such a floor, use a blacktop and mark off 100 squares.

Procedure

Explain to the students that these 100 squares represent 100 percent of the earth's surface. Ask the students to evenly distribute themselves in the space, each student representing a species. There are plants and animals living all over the world, even in the water. Since 50% of species live in rainforest, though, they are going to have to redistribute themselves. Choose 25 squares to represent land only. Six to seven percent of the 25 squares that are rainforest means half of the students live on only two squares. Obviously, half of your students won't be able to stand on just two squares, but it's fun to try!

Discussion

Remind your students (or get them to brainstorm and come up with these) that there are a couple of reasons why so many species can live on such a small portion of the earth's surface. One is that there are almost no large animals in rainforest ecosystems. Those that are (forest elephants in Africa, subspecies of rhinos on Indonesian islands), are critically endangered. Of the 500,000 species of plants and animals in Costa Rica, about 300,000 are insects! Another reason is that the rainforest is a very complex ecosystem, both in terms of the vertical layering and the mosaic patchiness, providing many more niches than a more homogeneous environment like the taiga. Finally the number of species may be large but the number of individuals of most species, especially the more massive ones, is relatively small.

How Does a Predator/Prey Relationship Affect Populations?

Background

Predation is easiest to study in a community that has only one species of predator and one species of prey in a closed system with no immigration or emigration to influence the population size of each. In the lab, these studies are done with two species of invertebrates competing for resources in petri dishes but there is a real world situation that provides an example most students find more appealing.

Materials

http://www.isleroyalewolf.org/population_dynamics is a website that describes a population study of predators (wolves) and prey (moose) on an island, which is essentially a closed system.

Procedure

The site includes graphs of the various relationships, as well as a PowerPoint for you to download and present. You may prefer to download the data on which the graphs are based and ask students to produce the graphs themselves. The information not only demonstrates how the populations respond to each other but also includes other influences for students to consider, like inbreeding, effects of climate change or tick-borne disease, genetic rescue by an immigrant, and forest succession changing the habitat.

Discussion

Translating these dynamics to the rainforest is an exercise students can now tackle. The top predator is the jaguar, which is a solitary territorial hunter, not a social pack animal. What effect does that have on the extent of land necessary to maintain a healthy population? A study of jaguars in Belize found that a single male required at least 50 sq km of territory, although that would be smaller in the Amazon where there is more prey. A major threat to jaguars is loss of habitat, through logging or clearing for ranching or agriculture. The jaguar has a broader diet of prey, including ground birds, river turtles, small to medium size mammals, and even fish. How does that change the dynamic of the various populations? Additional outside influences are also more important, like people killing the jaguar out of fear for their livestock or family members, or poachers competing with the jaguar for their prey (sometimes killing dozens of peccary at a time with machine guns to sell to meat markets, not just for subsistence!)

How Is Biodiversity Related to Population Sizes?

Background

In the US and other temperate regions, it is common to find tree stands with only a few species. When a disease or insect attacks a particular species of tree, it is easy for the disease to spread as neighboring trees are likely to be of the same species. It was easy for the Dutch elm disease to eradicate Dutch elm trees from the US because they were planted close enough together that the disease spread readily. Pines also grow in virtual monocultural stands and are similarly vulnerable to attack from pine borers and bark beetles. Because of the high biodiversity in the rainforest, distances between trees of the same species are often great and diseases spread very slowly.

Chicleros, who tap trees for chicle, or the rubber tappers of the Amazon, typically developed circuits. A circuit was a trail that went from one tree to another throughout an area of the forest, taking several months to complete, during which the tapper would collect sap and carry it with him to the end. To protect the health of the trees, no tree should be tapped more often than every four years and seven years was an optimal time span, which meant the tapper had to have four to seven different circuits established. This required knowledge of and access to a vast area of the forest. Likewise, a scientist studying a particular tree in the tropical rainforest may have to walk more than a mile to find a second individual of his target species!

Materials

Two containers of assorted beans. One, representing the Temperate Forest, holds a mixture of only three kinds of beans, like lima, navy, and pinto beans. The second container, representing the Tropical Rainforest, should be as diverse an assortment as possible. A bag of *15 Bean Soup Mix* is a good starts, as it includes the beans mentioned above, plus great northerns, green and yellow peas, lentils, black beans, kidney beans, and more. Add to that just a few each of chick peas, coffee beans, whole black peppercorns, pearl tapioca, barley, sunflower kernels, yellow and blue popcorn, apple and citrus seeds, whole cloves, whole nutmegs, pine nuts, pumpkin and watermelon seeds, fennel and caraway seeds, or even acorns and other seeds collected outdoors.

Procedure

Students work in pairs. Each pair needs two trays or box lids, one labeled Temperate Forest and one labeled Tropical Rainforest. Each team receives a scoop from each bag of beans, one in each tray. Students sort the beans on the first tray into like piles, then count and record the number in each pile; for example, A = 67, B = 74, C = 45. Letters are assigned arbitrarily and students don't have to know the name of the seed or bean they are looking at.

Then sort the beans/seeds in the second tray into like piles and record the number of each. I control my mixture so that many items in the tray will be represented by only one or two individuals and it is virtually impossible to get more than 20 of any one item. The students' lists will look more like A = 1, B = 3, C = 7 and so on, often through Z and beyond to AA, BB, CC until all piles are labeled and counted.

Discussion

Ask which forest requires more species to act as pollinators or seed dispersers, especially given that in the tropical rainforest many more of such species are specialists rather than generalists, as is often the case in a temperate forest. What obstacles does this present? If a butterfly only has a single species for a host plant or a hummingbird is specialized for one species of flower, how far is it traveling to find what it needs? Which forest is more vulnerable to a disease or insect species that attacks only one kind of tree? What benefits or obstacles does this biodiversity pattern present to someone trying to live by sustainably harvesting forest products? Does this suggest another reason why wind pollination would not be an efficient strategy in rainforest? Remember, each individual tree of a species could be as far as a mile from the previous one!

What Affect Does Logging or Deforestation Have on Biodiversity?

Background

Five hundred years ago, when the Age of Exploration began, 14% of the earth's land area was covered in rainforest. Now only about 6% remains. Deforestation occurs for many reasons. Natives clear land for their **milpa**, or small farm. They cut trees for firewood and building materials. They clear tracks for moving through the forest to extract resources they need. On a larger scale, governments build roads or clear a wide swath for high tension electrical power lines or an even wider swath for pipelines that carry natural gas or oil. Entire river valleys are inundated for a reservoir when a dam is built. Huge agricultural corporations destroy vast tracts in order to establish palm oil plantations, fields of soy for diesel fuel, or corn for ethanol fuel. Enormous parcels are destroyed when companies move in to drill for oil or mine for bauxite (aluminum ore), copper, or other minerals. Once a town is developed adjacent to rainforest, it serves as a nucleus for forest clearance. A crystal clear example of this is the Brazilian Atlantic rainforest, where now only small isolated areas along the Pacific coast remain of what used to be continuous forest contiguous with the Amazon basin to the north. Whenever the forest is cleared, squatters usually follow and the clearing is extended, spreading like a disease. This loss not only diminishes the total extent of rainforest cover but also the number of species, driving many rare or endemic species into extinction.

Materials

You can use the Tropical Rainforest bean mixture but this is more fun to do with Jelly Bellies, M&Ms, and Skittles – Montessorians love to eat their work! Again, control the mix so the numbers of each color and type of candy is not even, no one item dominates, and quite a few are rare. Not every student needs even one of every type of candy. Jelly Belly mixtures are good for this!

Students also need a gridded sheet of paper, 10 squares by 10 squares, although you could do 6 x 6 to make the work go faster.

Procedure

Give each student about 1/3 cup of the candy mixture.

First, they sort the candy into like piles and record the total number of "species" of candy. Then mix the piles thoroughly together again and pat out evenly onto the grid paper. Each piece of candy is a tree.

Students can now imagine scenarios. Maybe the government builds a road across their "forest" so they would be clearing in a straight line in some direction. Or the government builds a dam across a river, so they would clear an area that would graduallybe flooded by the dam on their grid. If they are making a road, after the road is in, settlers would come in and clear land along either side of the road. Or maybe there is a town at one edge of their grid that is expanding outwards, so that they would be clearing from one edge of the paper across. Students should each have a scenario in mind so they aren't all doing the same thing.

Once they know their scenarios, they begin to clear, one square at a time. After removing the candy from one square, they should look at what they removed and see if there are more of each kind still on the board somewhere. If any "species" has gone extinct, they write down the new number of species remaining. They will be keeping a table of this count as they go through the squares. Then, following their scenario, they will clear another square and record the number of species remaining. Continue clearing spaces one at a time and subtract for each extinction. They can continue to clear until the last square is empty, as any of these scenarios will result in clearing a large area of forest.

Now they graph the pattern of extinction they recorded, with number of squares cleared across the x-axis and number of species remaining along the y-axis. They should know which is the dependent variable and which is the independent variable and not need to be told how to graph this!

Discussion

Invariably, in clearing the first half of the squares, one fourth to one third of the species are lost. The extinction rate increases rapidly as the second half is cleared, describing a J-shaped curve on the graph. Point out that since we have already destroyed a little over half of the rainforest that existed just 500 years ago when the Age of Exploration began, we have reached that point where the extinction rate has become quite rapid. This pattern is only typical of an ecosystem of high biodiversity, where you have a large number of species but only a few of those species occurs in large numbers. Only 4% of Europe's original forest cover remains, and yet *not one* species of tree has been lost. Would that be possible in the rainforest? Clearly not!

Extension

Use the same grid paper and scenario chosen by the student to explore the issue of edge effects. If the entire paper is a rainforest and each side of each square is assigned a length, say 100 meters, how much edge does the forest have? What is the proportion of edge to interior if you count edge squares versus squares with no edge? Carry out one of the scenarios such as clearing a road across the forest. Now how much edge is there? What is the new proportion of edge to interior? Suppose you are a legislator proposing some forest be set aside as a reserve? The same amount of area (number of squares) could be protected in a variety of shapes. Does a square, a circle, or a rectangle make a difference in the proportions of edge to interior? Since the smallest possible proportion will give you the healthiest forest, what shape should you choose?

[This exercise is adapted from *You Can't Grow Home Again.*]

How Does Specialization Affect Biodiversity?

Background

For this exercise, we are using bats to demonstrate specialization of niches. Bat species comprise about a fourth of all mammal species in the world. In the rainforest, however, they can be as many as half or more of the mammal species. This is possible because each species occupies a particular niche, so there is food and space for all of them. In terms of biomass, bats can account for more than all other mammal species combined.

Where we live, bats commonly live by catching insects in flight, but in the rainforest they have partitioned their niches very finely. For one thing, species specialize in eating fish, frogs, birds, lizards, small mammals, spiders, fruit, pollen, nectar, and blood – not just insects. Further diversity is revealed in their habits. One species of vampire bat feeds on mammal blood but the other two specialize in bird blood. Some insect eaters catch insects in flight, others glean them from leaves of the forest floor. Some fly high over the canopy, others specialize in the understory, and still others forage low over water. One species snatches water beetles out of the water. Some feed on pollen and nectar, others supplement a diet of fruit or insects with either pollen or nectar but rarely both. Some capture frogs, homing in on their mating calls and snatching them with their feet, while others capture fish the same way an eagle does. Some are entirely nocturnal, hunting all night; others are crepuscular, satisfying their appetites in an hour or two at dusk and again just before dawn. Some are highly specialized, while the ones that eat baby birds might also be happy with a little lizard or a large tarantula. Competition is further reduced by their relative sizes. Big bats go for larger fruits or insects while smaller bats are limited to smaller fruits or insects. The diversity of bat species reflects the diversity of niches available in the lush environment of a tropical rainforest and reduces competition for any particular food source.

Materials

A good material to use for this activity is the Montessori material that consists of triangles of various attributes. There are equilateral, isosceles, and scalene triangles, each in three sizes and each in three colors – red, yellow, and blue. The word triangle applies to the entire box, but scalene triangles would limit the pile to a third of the box. Specifying the color and size reduces your choices to only one triangle. If you don't have this material, you can make cards with different shapes in different colors from a set of blank playing cards. Each student is a different species of bat. You should not have more students play than you have specific triangles, 27 if you are using the Montessori triangles.

Procedure

Place the triangles around the room at different levels but all in plain sight, even if somewhat camouflaged. Tell the students they are bats and the triangles are their food, then let them go find food. Many students will not get anything because others will take everything they see first. Then pass out a set of cards that have the same figures on them as the ones you are using to represent the food. Now each student has a shape of a particular color and size, too, if you are using that material. Redistribute the food cards and this time tell them they can eat anything the same shape as what is shown on their card, regardless of other attributes. This time when they go find food, more will get something to eat because they will all be a little more discerning in their search. Redistribute the food cards and this time tell them they can only eat something that is the same shape and color as shown on the card they were given. Even more of them will be able to find food this time, since they have to be even more discriminating about what they can eat. When you finally specify that they can only eat what has all the same attributes as shown on their own cards, everyone will get food.

Discussion

Explain that bats do not generally live in enormous colonies in the rainforest the way they do in the US, in caves, for example. Rather a small number will roost in a hollow tree or under a large leaf. The number of bats occupying a given niche within a given geographical area is not more than can be sustained by the food resources available, so populations of most species will be relatively small, even while the number of species is so high. Even though the students may have felt crowded space-wise and may have bumped into one another in looking for their food cards, they were not competing for the same card. Food is a **limiting factor** for how big the population of any species can grow within a given community. If your students have not encountered that term, this is a good discussion for introducing it.

Bats and Frogs

Background – See information about bat niches and variety of diets in previous material.

Materials

Bandanas for every person playing
Spoons, sticks, combs covered with wax paper for kazoos, any small noisemakers

Procedure

Begin by pairing up students to be pairs of frogs and keeping one person in reserve to play the bat. The bat leaves the room. Frog pairs each must figure out what their mating call will be. It could be some simple vocalization, snapping fingers, tapping spoons or wooden sticks together, or whatever else they can think of that is easy and practical. A moderator goes around to each pair to confirm that each pair's call is distinct from all others.

All players don blindfolds, probably bandanas. Someone who is not playing – the moderator or teachers – leads the frogs around the room, dropping off members of pairs at good distances from each other and distributing all the frogs fairly evenly in the space. The moderator can twirl them around so they are disoriented as to which way the wall is or where they are in the space.

The bat is blindfolded before being brought back into the room. Frogs begin calling to each other and listening for their mates, gradually working closer together. The bat moves toward the closest calling frog to tag it. If the bat tags a frog, the frog has been eaten and can remove his blindfold and move out of the way. He no longer calls. His mate will probably keep calling until he realizes his partner is no longer responding, and then he may call louder or may decide to keep quiet to avoid being eaten himself.

Continue the game until all the frogs have either found mates (at which time they would no longer call and are safe), been eaten, or stopped calling because they got no response. Now they can all remove their blindfolds and see how successful the frogs and bats have been.

Discussion

Why do different frogs have different calls? How important was the sense of hearing both to the frogs and to the bats? Mating is apparently a risky business for frogs, so why is it worth it? How would population density for a particular species of frog affect the success of frog mating? How does biodiversity in the community of frogs benefit every species engaging in synchronized mating?

Rainforest Stories: Leafcutter Ants

Leafcutter ants are not one species of ant, or even one genus of ant, but a tribe that contains two genera and all their species. Some specialize on grass and are commonly found in pastures of Monteverde, constructing enormous bare earth mounds with trails leading off in all directions. Others specialize in leaves of trees and smaller plants and are frequently encountered while walking in the forest. Some species are active at night and must be observed with flashlights, while others are active in the day.

Leafcutter ants live in colonies underground. About five million ants inhabit a colony that can get as big as 15 m across and 5 m deep. Someone observing a leafcutter ant nest could easily assume there were several species of ant sharing the nest, but these very different appearing individuals are actually different morphs of the same species, with the same DNA. Within a nest, you can find the queen of the colony, nurses who tend the eggs and larvae, farmers, leaf-gatherers, scouts, minima to protect the gatherers, and soldiers. Each has a different body size and often body parts adapted as special tools for their role.

The queen lays all the eggs. Nurses bring food to the queen and to the larvae. The farmers are growing this food, and surprisingly, leafcutters' food is not leaves. They masticate cuttings of leaves and flowers into a pulpy mass and pat it onto the walls and roofs of the many underground chambers, small caverns in which the food grows. The farmers take cuttings of the fungal mycelia from established areas and plant it onto the newly spread pulp, adding a bit of their own fecal material and saliva for fertilization. Repeated application of fecal droplets provides the nitrogen this fungus needs to thrive. As it grows, it produces hyphae, the swollen tips of which are then harvested for feeding the colony's inhabitants.

The scouts go out every day and select the plants which the leaf-gatherers will be working on. They clear a pathway of all leaves and other obstacles and lay down a pheromone trail from the nest to the selected plants. They can be seen running back and forth beside these trails all day, removing any leaves that might fall on the trail and replenishing the pheromones if they get disturbed by a hiker's boot. Scouts are very discriminating in choosing plants. It's not so much that they avoid leaves with natural alkaloids that repel most leaf-eating insects, but rather that they avoid leaves that produce natural antifungal compounds, as this would be toxic to their food fungus!

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Leafcutter Ants *(continued from previous page)*

Leaf-gatherers march out in a line in the morning, in the hundreds, and when they reach the target plants they cut rounded pieces out of the leaves. Slow motion video reveals they do not scissor their jaws. Instead, they open their jaws and move them into place. The jaws then vibrate as much as a thousand times a second, cutting through the leaf tissue in the same way that an electric knife works. After cutting a piece of a leaf, or sometimes flower petals, the ant lifts it overhead with the front pair of legs and starts back to the nest. If you look closely, you will often notice a very tiny morph of these ants riding on the surface of the leaf fragment. These minima have two functions. One is to clean the surface of the leaf of any competing fungus or other growth. The other is to act as a sort of anti-aircraft fighter. There is a parasitic wasp that uses its long ovipositor to insert an egg into the back of the head of a leafcutter ant. This egg will hatch and feed on the ant's inner tissues, eventually killing it. When such a wasp approaches a leafcutter carrying a leaf with a minima riding shotgun, the minima is able to drive off the wasp and prevent the egg being laid.

Soldiers defend the nest from invaders of all sorts. If you stamp your feet on the ground above the nest, soldiers will swarm out and you can see the enormous heads and powerful jaws of this morph. You will want to move away, as they are strong enough to cut through leather to deliver a powerful bite to your feet. A nest is easy to spot, even if you don't follow a trail to get to it. No vegetation grows across its surface, which resembles very finely ground crumbs, almost like coffee grounds. There is a main entrance, where workers and soldiers depart and return, and a sort of back door, through which trash is carried out. Below this second opening will be a great spill of crumbs of dead fungus, dead ants, used up leaf pulp, and all the other detritus that would otherwise accumulate and poison the nest. If you plunge your hands into this area, you will be surprised at how warm it is, as this material is decomposing and generating heat. If you hold a handful of it for a minute, you will have the sensation that the crumbs are alive and moving, but what you are feeling is the thousands of tiny decomposers feeding on this matter.

The leafcutter ant nest is commonly visited by another insect, the tarantula hawk wasp. This large wasp has a brilliant metallic blue body and orange wings and preys on tarantulas. Stinging a tarantula paralyzes it. Then the wasp inserts eggs into the tarantula's body and drags it to the ant hill, as it is easy to dig in. The wasp opens a pit and drags the tarantula in, then buries it. The wasp eggs will hatch and the larvae will feed on the tissues of the paralyzed tarantula, in effect their supply of fresh meat, enough to last until the larvae are ready to pupate. Harassing these wasps is not recommended, as they can deliver a very painful sting.

Leafcutters perform an essential service to the forest. Nearly 20% of the annual vegetation growth in the forest is harvested by the ants for their subterranean gardens. Over the lifetime of a colony, these ants can move as much as 20 tons of soil, aerating roots of surrounding plants and improving drainage through the poor soils. Their decomposing litter recycles nutrients into the soil and their own manure recycles nitrogen for plants. Very wet forests do not successfully harbor earthworms, so in some places these ants are the main soil engineers. Species that significantly affect the environment and, consequently, the community of organisms that share that environment (like beavers and termites) are called landscape engineers and are a sort of keystone species in their own right.

The drones of the colony are all male, but occasionally, the colony produces a generation of virgin females and males with wings. These fly out all together and mate with winged adults from other colonies, after which the males die and the females go in search of a place to start their own new colonies as queens. A colony can last as long as 20 years.

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Understanding the Components of Sustainability

Sustainable Use and Nutrient Cycling in the Rainforest

Leafcutter Ants *(continued from previous page)*

The relationship of the leafcutter ant and its fungus is a remarkable example of mutualism. Each leafcutter species cultivates its own particular species of fungus. These fungi have become just as dependent on the ants as the ants are on the fungi. The fungus cannot break down leaf tissue in the absence of the ants, as in a lab setting, because it needs the enzymes in the ants' fecal material to accomplish this, with the result that the fungus cannot feed without the presence of the ants. Normally, fungi reproduce by growing a fruiting body that releases spores, but leafcutter ant fungi have lost the ability to reproduce on their own. When a new leafcutter queen flies from a nest to establish a new colony, she carries in her buccal pouch enough fungus to inoculate the new nest. Without the ants to propagate the fungus, the fungus would disappear from the earth.

Background Before beginning this simulation, review the trophic levels. A plant is a producer, making its own food from sunshine and carbon dioxide and water. First level consumers are the next level – all the organisms that feed on plants. This includes herbivores and omnivores. Second level consumers feed on first level consumers. These can be carnivores or omnivores. When any organism dies, it decomposes. Trophic levels are usually represented in the shape of a pyramid, because a functioning system has to have many more organisms at the bottom level, as producers, and fewer and fewer as you go up trophic levels. This is because the energy from one level is diminished as you go up the pyramid.

Students play the part of the nutrients cycling through the rainforest. Since a cycle is a circle, it doesn't matter where you start to describe the cycle, but let's say the nutrient starts in the soil. It gets taken up by a plant, or producer, and is part of the plant's tissues. When the plant is eaten by an herbivore or omnivore, the nutrient becomes part of the consumer's tissues. If that animal is eaten by another, the nutrient gets passed along too. When the last consumer dies, the nutrient is released by decomposition back into the soil.

This game is best played if the teacher posts the rules but does not give out copies of these instructions. Simply explain the background and the process of playing. Brainstorming suggestions are more for the teacher's use and don't need to be shared with students. If you don't have enough students, borrow from another class. They won't mind!

Procedure

Set-up - Arrange 30 chairs in a circle (for 30 players – adjust the number if you have more or fewer, but it doesn't work very well with fewer than 25). Prepare 30 index cards, or larger sheets of paper, marked with the initial of the trophic level. Make 10 S cards for soil, 10 P cards for plants, 5 H cards for herbivores, 3 O cards for omnivores, and 2 C cards for carnivores. Tape a card on the top of the back of each chair, facing in to the circle. The middle of the circle is the compost pile on the floor, where decomposition takes place. You can make another card to tape there, or just tell them where it is.

Rules for Moving

SOIL nutrients can move to **PLANT** chairs.
PLANT nutrients can move to **HERBIVORE** or **OMNIVORE** chairs.
HERBIVORE nutrients can more to **OMNIVORE** or **CARNIVORE** chairs.
OMNIVORE nutrients can go to **CARNIVORE** chairs.
ALL nutrients can go to **SOIL** chairs. (Any idea why?)
Any nutrient that can't find an open chair without breaking the rules goes to the **COMPOST PILE**.
Any nutrient in the **COMPOST PILE** can move to **SOIL** chair.

Playing the Game

1. Make a chart to record the number of nutrients in each location at the end of each round. Make room for at least forty rounds.
2. Make sure all students know what chair they are in and what the rules say they can move to next.
3. Announce "Cycle!" All nutrients must move, following the rules.
4. Record how many nutrients are in the soil, how many in plants, how many in herbivores, omnivores, carnivores, and the compost pile for round 1.
5. Repeat steps 3 and 4 four more times. How stable is the forest? What if you did it ten more times?

People Come and Change the Game **-** People who live in rainforests tend to move around every few years, living in one place until it gets harder to find food nearby and then moving a good distance away, allowing the place to recover for many years before they might settle in that area again. When people arrive, they become part of the cycle, as they eat plants and herbivores. They also use plants for building their shelter and for medicines and baskets. Past rules still apply but there are a couple of new rules.

- Nutrients on one of the sideways chairs wait until the round ends and then move to the **VILLAGE** on the next round.
- Nutrients in the **VILLAGE** stand in line.
- Before each round, the nutrient at the front of the line moves to the **COMPOST PILE**.

1. Turn the last PLANT chair and the first HERBIVORE sideways, facing each other, and locate the VILLAGE outside the circle near those two chairs.
2. Everyone takes a seat. If you are in a sideways chair, immediately move into the VILLAGE.
3. Announce "Cycle!" and everyone moves, following the new rules.
4. Record the number of nutrients in each location on your table.
5. Repeat steps 3 and 4 six more times. How stable is the forest? Is there a difference in the level of nutrients in the SOIL? In the number of living plants and animals?

The People Move on and the Game Changes Back **-** The people have depleted the nearby food supply and abandon their shelters, allowing them to decompose and return to the soil. In fact, they leave behind everything they don't want to carry and all of it is compostable because it was made from the forest in the first place. Go back to using the original rules.

1. Turn all the chairs back to face into the circle.
2. All nutrients stay where they were when the **VILLAGE** was abandoned. Any nutrients that were in the **VILLAGE** move to the **COMPOST PILE**.
3. Announce "*Cycle!*" All nutrients must move, following the rules.
4. Record the number of nutrients that are in each location.
5. Repeat steps 3 and 4 six more times. How stable is the forest? Is it back to its original condition? The people won't return for 50 rounds. What would happen if the population of the region increased greatly?

Settlers Arrive and the Game Changes Again - Settlers arrive. They come from a more distant TOWN where food and shelter are harder to obtain. They were living in a slum and unemployed but the government offered to grant them deed to a parcel of land if they would clear it and raise crops and livestock. These people don't know how to use the forest for their food, medicine, and shelter. They need to make money to buy these things so they raise cattle, maybe a few pigs and horses, and grow soybeans, corn, or sugar cane. They will sell these things to the people in the city for cash, which they will use to buy their food and tools and clothing, everything they need. The original rules apply, and there are some new rules.

- Nutrients on one of the sideways chairs wait until the round ends and then move to the **TOWN** on the next round.
- The first four Nutrients to leave the circle stay in the **TOWN**. These are the nutrients the Settlers consume themselves.
- All other Nutrients that leave the circle take the road to the **OUTSIDE WORLD**. These are the crops and livestock the Settlers raise and sell to get the cash they need. These Nutrients can never return.

1. Turn chairs sideways again, this time 5 PLANT chairs, 4 HERBIVORE chairs, and 2 OMNIVORE chairs. These are the plants and animals that the Settlers raise to sell. Locate the TOWN outside the circle near the chairs that are sideways. Across the room there is now the OUTSIDE WORLD where the Settlers send their livestock and crops to sell. You can imagine a road from the TOWN to the OUTSIDE WORLD.
2. Everyone takes a seat. If you are in a sideways chair, immediately move into the TOWN.
3. Announce "Cycle!" and everyone moves, following the new rules.
4. Record the number of nutrients in each location on your table.
5. Repeat steps 3 and 4 six more times. What happens to the nutrient levels in the SOIL? What happens to the number of plants and animals? Can the Settlers still make enough money here to survive?

Can You Change the Game? - The Settlers have ruined their soil but they really want to stay in their town because they still liked their life here better than when they were in the city and unemployed. Brainstorm some ways they can put nutrients back in the SOIL.

You can put the Settlers' garbage in the compost or add nutrients by applying fertilizer, but if you buy fertilizer you need more cash and have to turn another chair sideways to raise more crops to sell. Or could you replant the trees on part of the land you have? Maybe that would attract birds and other wildlife to return and you could invite tourists to come visit? If you run a tourist lodge, would most of the food you raise on your land actually be used on your land, feeding your customers, so fewer nutrients are lost? Could you get money by harvesting fruits, either from the trees you plant or from the forest itself, like Brazil nuts? Does that still remove nutrients from the cycle but at a different rate? Could you apply for a grant to do a scientific study? Is it possible to earn enough money from other activities that you can turn more chairs back into the circle? Any changes the students make will require an adjustment to the set-up and/or the rules. See if they can come up with a scenario that allows the soil to gradually recover lost nutrients over a few cycles.

Rewind - It's pretty hard to completely restore the soil, even if you abandon your farm, since so many of the nutrients have left the area. If you chose to add fertilizer, you have to make more money to pay for it which means selling more crops and sending more nutrients away. If you could turn back the clock to just before the Settlers arrived, could you design a lifestyle for them that would have the result of not ruining the soil in the first place?

Discussion

Have a class discussion or write a reflection. - If the Settlers are forced to move away by the depletion of nutrients, can the rainforest recover again, and if so, how long do you think it might take? Students should realize that in most cases, loss of forest cover also results in erosion of the thin layer of top soil because of the heavy rains in the rain forest. What is left is usually hard-baked clay or even stone. You can also explain that most of the seed-dispersers of the forest will not cross open land, as it exposes them to predators. This means that seeds of pioneer tree species will not be brought in to begin regenerating the forest. Bats are the only seed dispersers that will cross a clearing but they won't go long distances so they are only good at helping a forest regenerate if the clearing is small, like the one made by the indigenous people. It's possible that the forest can gradually creep back over the cleared land from the edges, but it is just as likely that the drying effect at the edge of the forest will cause it to gradually retreat and enlarge the cleared area.

Is it realistic to think that the indigenous people could continue to use the forest sustainably, and indefinitely, or what other problems can you imagine? As they gain access to Western medicine, will their population grow and have a greater effect on their environment? Might the young people choose to move to town to go to school and get used to having hot water and television and not want to return?

In what ways does this simulation oversimplify the way nutrients cycle through organisms and the soil? What has been left out?

The Tragedy of the Commons

Background

This exercise was inspired by an essay written in the late 19^{th} century on the topic of sustainable harvesting of resources. It is based on a traditional English practice of having a commons, or pastureland that belonged to the town itself, open to use by the townspeople for grazing their livestock together. Often, the homes were built in a square or ring around the commons, to protect the livestock from marauding predators as well as rustlers, and to make it convenient for all the homeowners to access the space and care for their animals. A small pond or watering trough could serve all the animals. Townspeople could even cooperatively engage a single shepherd to watch their flock and share that expense. Cattle and sheep were raised like this and the individual animals still belonged to individual families. Problems arose, as you can imagine, if one family increased their herd to graze as many animals as possible. This gave that family greater profit in the short term, but destroyed the pasture in the long term and caused all others families to suffer. Prolonged overuse resulted in the resource becoming useless to anyone.

Materials

A container of 16 beans for each group of 4 students

Procedure and Discussion

Simulation Activity

1. Divide students into groups of 4. Give each group a container of 16 beans.
2. Tell the students that these beans represent the resources that can be harvested from a section of the rainforest. The object is to harvest as many beans as possible without destroying the forest. Each bean is worth a dollar, so the more the students harvest, the more money they make. No conversation is allowed within the group.
3. Explain that each student will have four 20-second harvests to obtain his income for the year. Tell them that for each bean remaining in the container at the end of a harvest, a new bean will be added, so if four beans are left, four will be added, but the total number of beans in the container can never exceed 16. If no beans are left, none will be added. Tell each group to write down how many beans each person harvests in each period.
4. Explain that at the starting signal, each student in each group has 20 seconds to harvest all, some, or none of the 16 beans. Tell them there will be a total of four harvests, during which each student in the group will secure his income for the year. Since they cannot discuss strategy, there may be a student who will take most, or even all, of the beans each round.
5. At the end of the harvests, find out which individual and which group has the most beans. In discussion, get students to explain why beans are added only if beans remain, and in proportion to the number that remains.

This models natural reproduction. What do they think would be the best strategy for harvesting from this common resource in a sustainable way? *Only 8 beans should be removed per harvest*. Continue to expand the discussion. What if one family has been unable to have children and another family has more than the average? What if a new family wanted to move in? Or some children grow up and start their own family? Is it better to have money, or crops? *Crops provide food directly. Money can offer the ability to invest, diversify, develop another resource farther away, purchase products from other towns or commons, but food will be more expensive if you have to buy it from someone else who grew it than if you grow your own.* What would be the fair thing to do if one family's father is injured and becomes crippled and cannot help tend the livestock or whatever the commons is being used for? What if someone gets too old to help? Should they still get a share of the resource?

6. Finally, ask students to brainstorm what shared resources we still have, since we don't use the commons model any more. *Clean air, clean water, parks, tropical rainforests, the open ocean, the climate. Often rivers, like the Missouri River, or rivers in Europe, are depended on by people in many states or countries with conflicting ideas of how to manage the flow.*

Before moving on to the next essay on sustainability, you may want to explore this and related concepts in a bit more detail with your students by looking at what some calculate as 'the annual sustainable resource overshoot day', which gets earlier every year. See http://www.footprintnetwork.org/en/index.php/GFN/page/earth_overshoot_day/ to get the students discussing how ecological sustainability is tightly linked to social justice and environmental issues.

Moral Implications of Cultural Carrying Capacity

An essay by Garrett Hardin

For many years, Angel Island in San Francisco Bay was plagued with too many deer. A few animals transplanted there in the early 1900s lacked predators and rapidly increased to nearly 300 deer—far beyond the carrying capacity of the island. Scrawny, underfed animals tugged at the heartstrings of Californians, who carried extra food for them from the mainland to the island.

Such well-meaning charity worsened the plight of the deer. Excess animals trampled the soil, stripped the bark from small trees, and destroyed seedlings of all kinds. The net effect was to lower the island's carrying capacity, year by year, as the deer continued to multiply in a deteriorating habitat.

State game managers proposed that skilled hunters shoot the excess deer. "How cruel!" some people protested. Then the managers proposed that coyotes be introduced onto the island. Though not big enough to kill adult deer, coyotes can kill fawns, thereby reducing the size of the herd. However, the Society for the Prevention of Cruelty to Animals was adamantly opposed to this proposal.

In the end, it was agreed that some deer would be transported to other areas suitable for deer. A total of 203 animals were caught and trucked many miles away. From the fate of a sample of animals fitted with radio collars, it was estimated that 85% of the transported deer died within a year (most of them within 2 months) from various causes: predation by coyotes, bobcats, and domestic dogs, shooting by poachers and legal hunters, and being hit by cars.

The net cost (in 1982 dollars) for relocating each animal surviving for a year was $2,876. The state refused to continue financing the program, and no volunteers stepped forward to pay future bills.

Angel Island is a microcosm of the planet as a whole. Organisms reproduce exponentially, but the environment does not increase at all. The moral is a simple ecological commandment: Thou shalt not transgress the carrying capacity.

Now let's examine the situation for humans. A competent physicist has placed global human carrying capacity at 50 billion, about eight times the current world population. Before you give in to the temptation to urge women to have more babies, consider what Robert Malthus said nearly 200 years ago: "There should be no more people in a country than could enjoy daily a glass of wine and piece of beef for dinner."

A diet of grain or bread and water is symbolic of minimum living standards; wine and beef are symbolic of higher living standards that make greater demands on the environment. When land that could produce plants for direct human consumption is used to grow grapes for wine or corn for cattle, more energy is expended to feed the human population. Because carrying capacity is defined as the maximum number of animals (humans) an area can *support, using part of the area to support such cultural luxuries as wine and beef reduces the carrying capacity. This reduced capacity is called the cultural carrying capacity, and it is always smaller than simple carrying capacity.*

Energy is the common coin of the realm for all competing demands on the environment. Energy saved by giving up a luxury can be used to produce more food staples and support more people. We could increase the simple carrying capacity of the earth by giving up any (or all) of the following "luxuries": street lighting, vacations, private cars, air conditioning, and artistic performances of all sorts. But what we consider luxuries depends on our values as individuals and societies, and values are largely matters of choice. At one extreme, we could maximize the number of human beings living at the lowest possible level of comfort. Or we could try to optimize the quality of life for a much smaller human population.

The carrying capacity of the earth is a scientific question. It may be possible to support 50 billion people at a bread-and-water level. Is that what we choose? The question, "What is the cultural carrying capacity?" requires that we debate questions of value, about which opinions differ.

An even greater difficulty must be faced. So far, we have been treating carrying capacity as a global issue, as if there were some global sovereignty capable of enforcing a solution on all people. But there is no global sovereignty ("one world"), nor is there any prospect of one in the foreseeable future. Thus, we must ask how some 200 nations are to coexist in a finite global environment if different sovereignties adopt different standards of living.

Consider a protected redwood forest that produces neither food for humans nor lumber for houses. Because people must travel many kilometers to visit it, the forest is a net loss in the national energy budget. However, for those fortunate enough to wander through the cathedral-like aisles beneath an evergreen vault, a redwood forest does something precious for the human spirit. But then intrudes an appeal from a distant land, where millions are starving because their population has overshot the carrying capacity; we are asked to save lives by sending food. As long as we have surpluses, we may safely indulge in the pleasures of philanthropy. But after we have run out of our surpluses, then what?

A spokesperson for the needy from that land makes a proposal: "If you would only cut down your redwood forests, you could use the lumber to build houses and then grow potatoes on the land, shipping the food to us. Since we are all passengers together on Spaceship Earth, are you not duty bound to do so? Which is more precious, trees or human beings?"

This last question may sound ethically compelling, but let's look at the consequences of assigning a preemptive and supreme value to human lives. At least 3 billion people in the world are poorer than the 36 million "legally poor" in America, and their numbers are increasing by about 1 million per year. Unless *this increase is halted, sharing food and energy on the basis of need would require the sacrifice of one amenity after another in rich countries. The ultimate result of sharing would be complete poverty everywhere on the earth to maintain the earth's simple carrying capacity. Is that the best humanity can do?*

To date, there has been overwhelmingly negative reaction to all proposals to make international philanthropy conditional on the cessation of population growth by overpopulated recipient nations. Foreign aid is governed by two apparently inflexible assumptions:

- *The right to produce children is a universal, irrevocable right of every nation, no matter how hard it presses against the carrying capacity of its territory.*
- *When lives are in danger, the moral obligation of rich countries to save human lives is absolute and undeniable.*

Considered separately, each of these two well-meaning doctrines might be defensible; taken together, they constitute a fatal recipe. If humanity gives maximum carrying capacity precedence over problems of cultural carrying capacity, the result will be universal poverty and environmental ruin.
Or do you see an escape from this harsh dilemma?

As a longtime professor of human ecology at the University of California at Santa Barbara, the late Garrett Hardin (1915–2003) made important contributions in relating ethics to biology. He has raised hard ethical questions, sometimes taken unpopular stands, and forced people to think deeply about environmental problems and their possible solutions. He is best known for his 1968 essay "The Tragedy of the Commons," which has had a significant impact on the disciplines of economics and political science and on the management of potentially renewable resources. His 17 books include *Filters Against Folly: How to Survive Despite Economists, Ecologists, and the Merely Eloquent*, *Living Within Limits*, and *The Ostrich Factor: Our Population Myopia*.

Critical Thinking, Discussion Questions

1. What population size would allow the world's people to have a good quality of life? What do you believe is the cultural carrying capacity of the United States? Should the United States have a national policy to establish this population size as soon as possible? Explain.

2. Do you support the two principles this essay lists as the basis of foreign aid to needy countries? If not, what changes would you make in the requirements for receiving such aid?

The Price of a Hamburger

Background – Much of the ground beef used for fast food hamburgers and tacos comes from ranches in Central and South America on land that used to be rainforest.

Materials – Open space, and string, cord, rope, or ribbon that has been fastened together at the ends so that the diameter of the circle it makes measures 26.3 feet or 7.9 meters

Procedure – Invite students to distribute themselves evenly in a circular shape, each holding the ribbon inside a hooked index finger. When they have formed the best circle they can, have one person measure the diameter of the circle. Look around at each other, and look at the space enclosed. Imagine it with trees, understory and forest floor plants. Imagine the height of the trees, over 100 feet above. Imagine the number of epiphytes that would find perches on those trees. Imagine the terrestrial mammals and birds that would feed on the fruits and seeds of those trees. Imagine the monkeys and birds that would make their homes in those trees. Imagine the vines and lianas that would climb those trees and bind them to each other. Imagine the water the roots of those plants would draw up and how their presence would shade the forest floor and help the soil retain moisture and not wash away in the rain, buried in the litter of leaves. Imagine all the mosses and ferns on the ground and trees, and all the fungus thriving in the dead leaves and everywhere all the way up to the canopy. Imagine all the millions of insects and arachnids and Myriopoda – decomposers, herbivores, pollinators, predators, and parasites – that are able to make their homes and their living in this space. Imagine the coolness of the shade of those trees, maybe even the mist of the clouds on your skin. Imagine the faint sound of dripping, the rich smell of overripe fruit.

Now picture the land cleared, nothing but dry baked clay, the dirt having been washed away by heavy rains after the trees were logged and the lower plants burned off or killed by the intense and unaccustomed light of the sun. There is no “above” anymore. Only an invasive grass might grow here, and even then a dry season and the trampling of grazing cows could kill that off as well.

Discussion – This is the amount of land required to be cleared to graze cattle that is needed to provide one quarter-pound hamburger. Either tell the students that this is approximately 55 square feet, or let them do the math, based on their measurement of the diameter of the circle. Brainstorm ways to avoid consuming beef from rainforests.

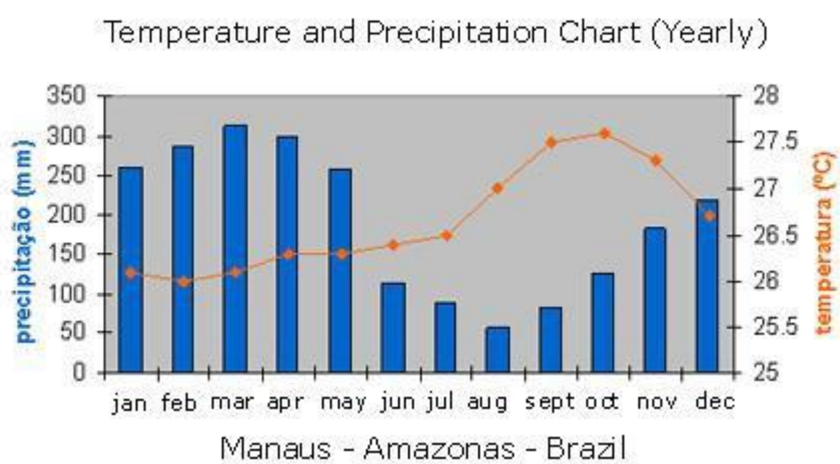
Using Excel to Create a Climatogram

Background – A climatogram is a chart commonly used to graph both annual average temperature (highs, lows, and averages) and precipitation information for a city or region. Generally, it is based on 30 or more years of data. It has both bars and lines plotted on two vertical axes (*y axes*) using annual temperature and precipitation data with a single horizontal axis (*x axis*) displaying time labeled with each month of the year. Both axes, typically precipitation on the left and temperature on the right, have numerical values in degrees Fahrenheit or Celsius and inches or millimeters of precipitation that generally do not match.

For scientific purposes, metric measurements should always be used. For this exercise, you will download real climate data for your location using the internet and use Microsoft Excel or a similar spreadsheet program to create a climatogram. Once completed, you can draw conclusions on the best or worst time of year to visit your city, which of course depends on the type of activities you prefer.

Procedure and Discussion

Practice Using a Climatogram: Manaus - Climatograms are frequently included in travel books and tourism brochures so interested visitors can select the best time of year to visit a certain location. Look at the climatogram for Manaus, Brazil.



The bar graph corresponds to the average monthly precipitation in inches and is plotted along the left *y*-axis. The line graphs correspond to the average monthly high, low, and mean temperatures, as shown in the key, in degrees Fahrenheit, along the right *y*-axis. Based on the graph, which months would be your choice for visiting Manaus? Why? Which months do you think would be the worst time to visit? Why?

Create a Climatogram for Your City

1. Open a new Excel spreadsheet.
2. Label columns A through E Month, Avg. High, Avg. Low, Mean, Avg. Precip. Indicate the units of measurement, whether degrees Fahrenheit or Celsius, inches or millimeters. Enter the names of the months of the year in lines of the first column under Month.
3. Go to the website for the Weather Channel (www.weather.com). Enter your zip code in the search bar. On the left, scroll down under Forecasts to Monthly. Beneath the Monthly Planner, click on the Averages button. You can choose Graph Display or Table Display of the data for your city. At the top of the Table you can click to choose metric or English units, and of course you should use metric.
4. Transfer the data from the table to the corresponding fields of your Excel spreadsheet. Use the data to create the graph. If you have not used Excel for graphing, you can follow the directions on this website http://www.marquemywords.co.uk/stories/academic-articles/creating-a-climate-graph-in-microsoft-excel.html?start=1 or in this youtube video http://www.youtube.com/watch?v=WLc_trZW_D4

Look at a Climatogram for San Jose, Costa Rica and Compare - Return to the Weather Channel and follow the directions above to find the Averages for San Jose, Costa Rica. This time choose Graph Display for the data. Compare the range of variation throughout the year in monthly precipitation for your city and San Jose. Compare the range of variation throughout the year in monthly temperatures for your city and San Jose. Pay special attention to the difference between high and low averages for each month. Which location shows less variation from day to night? What's the difference between the greatest and least reading for high temperature over the year in San Jose? In your city?

Rainforest Stories: Strangler Figs

Strangler fig trees are at the center of a complex web of life in the rainforest. These trees start life in the canopy, from a seed that sprouts in the fork of a mature tree and sends an aerial root down toward the ground. During this time, it lives as an epiphyte, but once the root reaches the ground, it anchors the tree and allows it to draw nutrients and water from the soil as it grows taller. Plants that are epiphytes only in the beginnings of their lives are called hemi-epiphytes. This is a very effective adaptation for competing for light in the dark of the rainforest understory.

But how did that seed get into the fork of the tree? Birds or monkeys might defecate it there, but one of the most important animals that feeds on figs is the bat. Seeds that pass through an animal's digestive system are often destroyed by stomach acid, but not in this case. The fig contains a chemical that acts as a laxative, causing the seed to pass quickly through the bat and be excreted in only about twenty minutes. The seed, however, doesn't drop on the ground from the bat in flight. It has a sticky coating on it that causes it to adhere to the fur on the bat's rear end. This is uncomfortable to the bat, so it lands in the fork of a tree and rubs its rump on the bark until the seed is dislodged, exactly where the seed needs to be to begin its life as a new strangler fig tree.

As this new tree grows, its roots branch and spread against the trunk of the host tree. Another fig, or maybe several more, may start on other limbs of the same host tree. Wherever these branching roots encounter each other, even if they are from different species of strangler figs, the roots anastomose, or fuse, forming a woven basket appearance around the trunk of the host tree.

In one hundred years, the strangler has overtopped the host tree and kills it, mostly by shading it from the sun and outcompeting it for nutrients and water in the soil. It doesn't strangle, exactly, as the name suggests, but it does prevent the host tree from expanding in girth. After four hundred years, the host tree has completely rotted away, leaving the open basket-weave style trunk of the strangler fig standing on its own. Of course, by this time, the limbs are festooned with vines, lianas, mosses, termite nests, ant nests, bird nests, and epiphytic orchids, bromeliads, and ferns.

There are actually 900 species of figs (but only a few grow as stranglers). And there are 900 species of wasps that pollinate them! The flowers on figs are actually located inside the fruit, a very unusual arrangement. The tiny wasp enters the fig through a natural hole covered with overlapping scales, tearing off her wings as she enters. She carries pollen from her natal fig, packed into pouches in her thorax. Inside, she lays her eggs and dies. Inside the fig are very many flowers, some male, some short female (also called gall flowers), and some long female. Only a female flower can develop a seed in its ovule. The wasp can only reach the ovules of the short female flowers, so that's where she lays her eggs, pollinating the other flowers as she moves around. The eggs hatch into larvae. The larvae feed on the flowers until they are ready to pupate. While the larvae are growing, they secrete a chemical that prevents the fig from ripening. If the fig were to ripen, a monkey or bird would eat the fig and all the larvae would die, so this is an important adaptation!

Obviously, if the wasp laid an egg on every flower, the fig couldn't produce any seeds at all, but a parasite plays a role in keeping that from happening. This parasitic wasp lays its eggs, individually, into ovules closest to the outside of the fruit, inserting its ovipositor right through the skin of the fruit. If this egg is laid in a flower containing the egg of the pollinator wasp, the larva of the parasite will kill the pollinator larva. Because of this danger, the pollinator wasp only lays eggs on the interior flowers, away from the reach of the parasitic wasp. Interior flowers become food for the larvae while the outer ovules develop the seeds for the fig. This is a stable mutualism that is at least 100 million years old.

(continued on following page)

Strangler figs *(continued from previous page)*

Finally, the adult wasps emerge from their pupal cases and crawl around inside the fig, hundreds of them, mating with their own siblings. The males do not even have wings. After mating, they cooperatively chew a hold through to the outside of the fruit for the females to escape through, then fall on the ground or crawl back inside and die. Some of the males may not have gotten to mate, but they help anyway because their genetic material is still being passed on through their brothers and sisters. The fertilized females, who have collected plenty of pollen during the post-pupal activity, leave through the tunnel and fly off to find their own immature fig fruit in which to lay their eggs, unwittingly pollinating the fig flowers in their new home. Once the wasps have left the original fig fruit, it proceeds to ripen and produce seeds – the seeds the bat will leave in the fork of a tree!

Originally, it was thought that each wasp species was specialized for a specific fig species. Recently it was discovered that when different species of fig roots encounter each other and fuse on the trunk of a host tree, the flowers that form can be chimerae. This means that tissues in the flower can have the DNA of either one of the species that fused, and neighboring tissues can carry different DNA. As a result, sometimes different species of wasps visit the flowers of a single fig, since its chimerical nature results in some flowers attracting one species and other flowers attracting a different species of wasp.

Figs are an extremely important food source in the tropical rainforest. They don't all fruit at the same time. In a temperate forest, all the trees of a single species produce a crop of fruit all at once. In the tropical rainforest, there is no winter, when animals might migrate to a warmer climate or hibernate. Animals need food sources that are available year round. There always seems to be a fruiting fig somewhere close by. Some monkeys eat the fruit and howler monkeys eat the leaves. Toucans and other big birds eat the fruit, as do bats, kinkajous, and iguanas. A huge variety of insects also feed on the leaves, from caterpillars and crickets to leafcutter ants and leaf borers. In fact, more species of animals feed on the fig trees than on any other rainforest plant. The fact that so many other species depend either completely or partially on the fig makes the fig what is called a keystone species. Without that species, life for almost everything else, directly or indirectly, would be significantly altered if not impossible.

The one-to-one specialization of figs for their pollinators relieves the pressure of competition for pollinators for the trees but presents a problem for the pollinators. With sixty-five species of figs in Costa Rica, fig trees are the commonest type of tree in the forest. For a pollinator looking for only one species of fig, they suddenly seem rare. A normal distribution for one species might be one adult in a hectare, requiring long flights for a pollinator leaving the fig of one tree and looking for another where she will lay her eggs. Since fruiting is not synchronous within a species, there may actually be only one tree at the right phenological stage of development for her needs in a 365 hectare area!

Many old hollow stranglers can be seen in the Monteverde area. Dairy farmers clearing land for pasture often left stranglers standing, even while cutting down everything else. This is because the sap is very thick and sticky and it would gum up their saws to where they couldn't work. The gum was nearly impossible to clean off the saw blades. The dairy farmers learned to avoid cutting the figs, perhaps telling themselves that maybe it wouldn't hurt the cows to have a bit of shade here and there, after all.



Ecology 101 - How To: Ideas, Tips, Suggestions for Students

While this is not intended to be an exhaustive course in ecological techniques, the pages below are designed to enhance the experience of each student while interacting with the flora and fauna of CER, and to improve the quality of data they collect. Furthermore, the section title “Ideas, Tips, and Suggestions” is an indicator that what follows below is not necessarily ecological law.

How to keep a field journal - A field journal may never be as important to someone else as it is to you. For this reason, there is no one singular way in which it needs to be completed. However, years from now the knowledge and information you collect today, or on a particular trip or visit, may be of extreme importance to someone else. *What did you see? What happened while you were there? What were the conditions like? When did …x…. event happen and where?* For these reasons, the value of your notebook to others will greatly increase the more information you include and if you follow a standardized format. Again this is your journal and you may find a style and format that works for you, but the following suggestions may help you increase the value of your journal for others.

Key guidelines to follow:

- Kind of journal (paper/ring-binder folder) … the gold standard of field journals are the Rite-in-the-Rain variety (bound, hardcover, special “acid-free” and water proof paper) but are expensive.. We will opt for more reasonably priced options and may be able to provide you with a field journal for the trip.

- Size should be about 5”x8” more or less.

- It helps if it is lined (or in some cases with a grid).

- You will need to write with water-proof ink, or pencil.

- Top line of each page should give the following: date (write out the month in full), exact location (GPS coordinates), reason of visit or observations.

- Time should be included along the left margin and should be done in military style: 6 am is 0600 h or 9 pm is 2100 h.

- When writing your observations think of answering Who, What, Where, When, How many (or much), Why (although you may never know this….state as much and indicate your reasoning).

- Actual quantities (even if they are estimates) are better than using descriptions like “many”. This includes size, again approximate sizes (30 m). See section on *How to take digital photos in the field*.

- Imagine that you are watching a one-act play. In addition to the principal event (actors and activity), don’t forget to describe the scenery around the stage. What are the weather, topography, and surrounding vegetation like?

- Sketches and drawings can not only provide additional key details, they may also save space (i.e. “a picture is worth a thousand words”)

- The camera in your pocket may provide you with better images than what you can draw. Take pictures, record sounds. BUT…make sure you keep track of picture and file numbers in your field journal, especially if any amount of time might take place before you complete your observation notes.

- You need to put page numbers on the bottom or top of each page

- The first 5-10 pages of your journal should be kept blank for you to create a table of contents.

- As you add multiple journals to your collection you should keep an index journal where you keep track of what observations or visits are in which journals. This requires that you number each journal.

- You should only write on the front of each page, or regularly skip some pages. This may seem wasteful, but it allows you extra space to add more information if you make a subsequent observation of the phenomena or event later; plus you can maybe fill in those gaps in your knowledge once you have consulted with other sources.

- For archival purposes it’s maybe a good idea to take advantage of technology and “back-up” your journal with digital photos on a daily or trip basis.

How to take digital pictures in the field - Digital photos can be a great asset (and arguably indispensable) to an ecologist working in the field. Good images, videos, and even sound recordings can greatly enhance any information collected in your field journal. However, it is important that your digital camera complement your journal, NOT try and replace it.

Key guidelines to follow:

- Multiple pictures from different angles are better than just one.

- Use some form of size reference if an actual measuring device (e.g. ruler) is unavailable. The pencil you use to write your notes is as good as anything else. You can even use people as a reference if you are estimating the size of large things like trees.

- If taking pictures of plants be sure to get pictures of whole plant (branching structure), root/base of trunk structures, close-up of the trunk (bark structure), a full or partial branch (leaf arrangement), and close up of three or more leaves from above and below (margin and venation patterns, hairs), flowers and fruits, if present, and from different angles (e.g. above and profile).

- If taking pictures of animals do not forget to capture an image of what it is doing, or where (specifically) it is found. Yet given the mobile nature of these creatures they may not always pose the way you want. Capture an image first (to archive its presence), then you can carefully and slowly move closer to capture more detail. If the creature in question is doing something particularly interesting then maybe you can capture a video of the behavior (in which case you can try and stabilize yourself or the camera against a tree…but look out for biting, stinging, prickly things first). Generally, you should avoid using a flash for animals.

- When taking pictures of a particular site, it is always a good idea to take one picture in each of the four cardinal directions. Hold your camera at the same level angle for each picture (an approximate 360 view).

- To take quality, in-focus pictures you should be familiar with the zoom (animals) and macro (plants and close-up stationary things) functions of the camera you are using.

- You may want to improve the quality of your photos by using a variety of editing software. Zooming, cropping, sharpening, and modifying the contrast or the background are probably all you might like to do to enhance the quality of your images. However, you'll want to be very careful not to modify any of the colors or patterns. .

- If you do modify your images it's a good idea to do so with a copy and preserve the original photo. Modified images should have the same file name as the original (see below), but end with a clue as to how it was modified.
  - Example……

- Naming your photos should probably include at a very minimum: the object of the image (common and/or scientific name to the nearest taxonomic level); location and specific site; your initials as the photographer; date; time.
  - Example……

Rainforest Biodiversity Studies and Reading a Landscape - To understand biodiversity of tropical rainforests, students must be exposed to a number of concepts and topics, whether through independent research, lecture, or hands-on activities. Before asking your students to read a landscape, confirm that they are familiar with all the necessary terms and techniques. Biodiversity is supported and explained by several factors and hypotheses:

- Abiotic factors (geography, including Paleogeography, Ice Ages, island biogeography, latitude, altitude; life zones; climate; soil; substrate; water cycle and hydrology; nutrient cycling; carbon cycling; light gaps, disturbances, and edges; topography)
- Biotic factors (vertical stratification of forest; diversity of niches; communities; co-evolution; symbiotic relationships – interspecific and intraspecific competition, mutualism, protocooperation, commensalism, amensalism, parasitism, and predation; plant and animal adaptations including mimicry, camouflage; pollination; co-evolution; specialization; seed dispersal; trophic levels – including decomposers; primary and secondary succession); indicator or keystone species; phenology
- Structural complexity (mosaic of successional stages and patches, history of stochastic disturbance and human disturbance, vertical stratification, microhabitats), niche availability (including allochronic feeding and reproduction, synchronous blooming, guilds)
- Evolution, adaptation, allopatric and sympatric speciation
- Climate refuge hypothesis
- Physiological “freedom” due to abundant resources

Biodiversity applies on several scales even within a single rainforest, from diversity of habitats and niches, to species level, to genetic level within species (allelic diversity).

Reading a landscape - On their first exposure to a rainforest environment, students could conduct a survey or snapshot of a 50 meter section, or transect, of a trail. Students can be divided into teams and assigned different trails, or different sections of the same trail, ideally at different types of places; for example, one higher up, one at the bottom, one on a steep section, one on a relatively flat section, one in a heavily forested area, and one in a relatively open area as from a recent slide or treefall. Each team will require the necessary equipment to take their measurements, as well as binoculars and notebooks for recording their observations and data. At least one person per team should also be good at sketching or cameras can be used for documentation. Below is a list of the questions students should attempt to answer about their particular section of forest. Some of these skills need to be learned and practiced beforehand. Other information can be taken from a local newspaper or almanac.

A. Abiotic factors

- GPS location
- Altitude
- Ambient temperature
- Wind speed
- Relative humidity
- Day length
- Annual precipitation
- Season
- Soil temperature
- Light at ground level
- Soil moisture content
- Soil pH
- Soil compaction
- What color is the soil? Is it hydric, mesic or xeric? How deep is the O-Soil horizon?

B. Forest structure

- Measure the depth of leaf litter at 10 points along the transect
- Measure the density of the understory at ground level (stems per square meter) in 10 places beside the trail
- Measure the density of the understory at the height of 2 meters (stems per square meter) in 10 places beside the trail
- Measure DBH of trunks over 10 cm in diameter (either sampling, or all of them)
- Estimate height of lowest branch on mature trees
- Sketch a vertical profile of the transect – is it visibly stratified into herbaceous, shrub, understory, and canopy?
- Is the forest dominated by deciduous trees, conifers, palms, or an equal number of each?
- Is there any evidence of fire damage, landslides, light gaps from tree falls, logging?
- Are trees, by species, clumped, random, or regularly distributed?
- Can you observe a transition in species as light or slope conditions change?
- Does your section include an ecotone, or transition between habitat types? Is it abrupt or gradual?
- Are canopy trees well-spaced or overcrowded? Can you observe signs of succession? Are the saplings the same species as the mature trees? Students don't need to be able to identify particular tree species to answer the questions in this section, simply to distinguish "same" from "other."

C. Diversity

- Quantify as much as possible, or estimate based on sample observations, information on leaf shapes, bark types, plant defenses (hairs, spines, thorns), root types (buttresses, stilt, aerial), flower shapes and colors, vines vs. lianas, epiphyte and epiphyll types, presence/absence of seeds and their types, general tree shapes (monopodial, sympodial), leaf arrangements of herbaceous plants (alternate, opposite, spiral, etc.)
- Looking at particular flowers, speculate on what might pollinate each type
- Looking at particular seeds, speculate on what might disperse each type
- Quantify number of RTU's (recognizable taxonomic units) for trees, palms, shrubs, ferns, mosses, liverworts, epiphytes, grasses, mammals, reptiles and amphibians, birds, and insects (or count separately for Arthropoda, Lepidoptera, Hymenoptera, Coleoptera, Odonata, Orthoptera, Diptera, Hemiptera, Mantoptera, Phasmatodea, Isoptera). To count RTU's you don't have to be able to name species, just recognize that this one is different from the others, so you have a total number of tree types, palm types, etc.
- Can you tell how old the forest is? Is it mostly primary or secondary (climax species or pioneer species)? What other evidence can you use to determine the age of the forest? (The density and thickness of lianas, density of epiphytic growth, density of vines, thickness of moss on trunks and branches, height of trees, diameter of trees, and light level at forest floor, which is inversely proportional to age)

Comparing these snapshots of the various transects studied could be useful in the future in choosing sites for additional investigation. It also offers the opportunity to compare tropical rainforest with the forest around the students' school in the States.

If time allows, two other surveys would be interesting to carry out.
One would involve water testing at various sites, on different sizes of streams and including the lake at Pocosol. Measurements can be taken of water temperature on the surface and at various depths, depth (on the lake, to make a topographic map of the bottom), turbidity, dissolved oxygen, CO_2, salinity, and pH. Another would be a close-up examination of the community living on a fallen log or trunk. This would include on the surface and underneath bark. I recommend extreme caution doing this, as you could disturb snakes or ants that can really deliver a painful bite.

Environmental Science
ECOLOGICAL SAMPLING METHODS

Contents – Introduction to some basic sampling techniques
(detailed methods can be found at the link below)

Excellent, clear and concise, illustrated instructions can be found for these topics and skills at: http://www.countrysideinfo.co.uk/howto.htm

Ecological Sampling ideas:

- Using either a quadrat or a transect, count the number of squirrel nests visible in the trees. These are large masses of leaves/twigs that stand out against the bare branches in winter very visibly. Can you ask a question and collect data to answer it? For example, are the squirrel nests denser on a south facing slope or a north facing slope? Are they denser in old growth forest or in secondary forest? Are they denser in close proximity to housing or in forest interiors? Consider possible explanations for any observed differences.
- Using a quadrat or transect, classify trees that are greater than 10 cm. dbh as coniferous or deciduous. Ask a question and collect data to answer it, similar to the questions above. Brainstorm explanations for differences observed.
- Use small quadrats of a meter square. Measure the depth of leaf litter down to the soil surface in a variety of locations – forest interior, forest edges, in deciduous forest, in coniferous forest. Consider reasons for any differences observed. Alternatively, collect all the leaf litter and organic material above the soil surface from a meter square in several places and take it back to the classroom, dry it, and weigh it. Try to avoid bringing insects or other wildlife back with you!
- For an urban school with limited opportunities to get out into undeveloped territory, students can survey for biodiversity of trash. Wearing latex (or other lab style) gloves for protection, students collect trash from different types of neighborhoods – residential, commercial, around a school or church, around a park – and set up a system for classification. For example, kingdoms are Beverages, Food, Tobacco, and Other (or find a more descriptive term for odds and ends like batteries, shoes, etc. – Manufactured Goods?). Phyla of Beverages could be Plain Water, Nonalcoholic, and Alcoholic. Under Classes of Nonalcoholic drinks could be Carbonated and Non-carbonated. Under Non-carbonated you could have Families called Flavored/Enhanced Waters and Fruit-Based. It's best to let the kids figure out their own classification system, so these are just examples. After students have classified the trash from the different areas, they should discuss what they can tell about the people who frequent those areas from the type of trash, as well as the amount, that they toss. They can also rate each area for the biodiversity exhibited by the trash and could even practice calculating the Simpson Diversity Index.

Glossary

Lots of acronyms and terms … to be student generated with a mix of ‘standard’ definitions as well as student explanations of the terms. Where relevant, these will be illustrated by the students themselves, either by drawing or photography.

ACM

BEN

CER

FCER

MCL

….etc.

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Monteverde Conservation League website: http://www.acmcr.org/home.htm