Title: Investigating the Evolutionary Adaptations that have Enabled Plants to Survive in a Diversity of Habitats

Author(s):

Allison R. Rober
Michigan State University
roberall@msu.edu

Colin Phillippo
Michigan State University
phill394@msu.edu

Sara A. Wyse
Michigan State University
kelzersa@msu.edu

Charles Elzinga
Michigan State University
elzingac@msu.edu

Sonya M. Lawrence
Michigan State University
lawren48@msu.edu

Tammy Long
Michigan State University
longta@msu.edu

Abstract:

Our planet's biodiversity is being lost at an alarming rate. In order to preserve biodiversity, we must understand how ecosystems function, and how the loss of diversity may affect the services provided to us by a fully functioning ecosystem. It is our responsibility as educators to build an appreciation for biodiversity and ecosystem function in our students through scientific exploration. During this exercise students will investigate the evolutionary adaptations that have allowed plants to survive in a diversity of habitats in a teaching greenhouse. Students will be introduced to the biotic and abiotic constraints organisms must overcome in order to survive in a desert and rainforest ecosystem. Students will observe and describe the similarities and differences in adaptations that have allowed populations of organisms to overcome environmental challenges. Throughout this exercise students will observe and reflect upon the different scales of diversity (i.e., genetic, species, habitat, and ecosystem). This exercise will also introduce the concept of ecosystem services and reinforce the importance of biodiversity to economic and aesthetic values.

Learning objectives:

During this lab activity, you will:

1. Examine a diversity of plants in a variety of aquatic and terrestrial ecosystems.
2. Identify plant adaptations required for living in a particular environment.
3. Describe the evolutionary mechanisms responsible for the variety of adaptations and subsequent biodiversity of the plants we see today.
4. Apply your knowledge of adaptations to design an organism suitable for a particular environment.

Timeframe:

Instructors should allow adequate time to:

Become acquainted with the greenhouse facility or other natural ecosystem prior to class (60 minutes).

Familiarize yourself with the evolution of plant life (60 minutes).

Identify examples within the greenhouse or other ecosystem that illustrate major events in plant evolution (i.e. algae, bryophytes, seedless vascular plants, gymnosperms, and angiosperms) (~30 minutes).

Be prepared to discuss several examples of benefits derived from biodiversity (e.g. ecosystem services) as well as consequences of biodiversity loss (60 minutes).

Class time:

This exercise is designed for a 2 hour and 50 minute introductory undergraduate biology laboratory. Students prepare a pre-lab prior to class to ensure that they have read and understand the material provided. Students complete a post-lab following the lab. Both pre and post-lab guidelines can be found at the following web address: http://www.msu.edu/course/bs/110/lab/prelabs_postlabs.html

List of materials:

1. Access to a greenhouse facility or a diversity of plant types from a variety of ecosystems (rainforest, desert, and aquatic). Please visit the Michigan State University Botany Greenhouse website (https://www.msu.edu/~muggjohn/botany/index.html) for a virtual tour of the facility used in this exercise.

2. Signs to indicate stations in the greenhouse facility. Appendix E provides a table with the plants and their adaptations that we used in creating this activity. Other plants can be used based on the instructor's goals for the class. For instance an instructor may choose to use urban plant life, temperate rainforest plants rather than tropical or cold desert plants rather than arid.

3. Several representatives from each evolutionary line of plants:

   a. algae

   b. bryophytes (mosses, hornworts, liverworts)

   c. seedless vascular plants (ferns, *Equisetum*)

   d. gymnosperms (conifers, ginkgos, cycads)

   e. angiosperms (flowering plants)

      i. monocots (optional)

      ii. dicots (optional)

Procedure and general instructions (for instructor). REQUIRED.

Lesson Plan

Biodiversity and Ecosystems

This active learning exercise uses a *learning cycle* approach, which is an instructional design used to engage students with a question or problem, explore the problem interactively, and then explain the ecological significance of the results (Brandsford et al. 1999). This design allows students to construct their own understanding during the investigation while participating in scientific inquiry.

Goal:

The goal of this week's lab is to engage students in the study of plant characteristics as a way to teach and learn about plant adaptations and plant and ecosystem diversity.

Objectives:
During this lab activity, you will:

1. Examine a diversity of plants in a variety of aquatic and terrestrial ecosystems.

2. Identify plant adaptations required for living in a particular environment.

3. Describe the evolutionary mechanisms responsible for the variety of adaptations and subsequent biodiversity of the plants we see today.

4. Apply your knowledge of adaptations to design an organism suitable for a particular environment.

Lab Safety: Proper lab attire is required.

Lesson Plan:

Common Student Preconceptions with Evolutionary Plant Ecology:

1. Plants are perfectly adapted to their niches.
2. Plant anatomical structures are optimally designed and utilized for some purpose.
3. Plants "need" to adapt in order to survive.

1. **Engage** – Set the stage for the lab activity (about 30 minutes)

    A. Discussion: Ecology Background
        1. Ask students what they know about the two ecosystems they will be touring today (rainforest/desert):
            a. What are some similarities and differences between the abiotic constraints in these environments?
                1. Make sure students know the difference between abiotic and biotic factors.
            b. What functions are necessary for organisms to survive in a given environment?
                1. Students discuss in groups and generate a list of functions:
                    1. Obtain water and nutrients
                    2. Transport water and nutrients
                    3. Obtaining energy
                    4. Structural support
                    5. Reproducing and dispersing

        2. Discuss scales of ecosystems and biodiversity
            a. They can be very large (rainforest/desert).
            b. They can be very small (microbial communities in the soil).
            c. Scales of biodiversity:
                1. Ecosystem diversity

2. Habitat diversity
3. Species diversity
4. Genetic diversity

3. How does diversity arise? (link back to previous activities that illustrate the origin of variation and how it is acted upon by selection).
   a. Connections among genes, alleles, mutations and phenotypic variation observed in many different populations of organisms.
   b. Different selective agents act on phenotypes in different environments. This explains why we see such a diversity of structures to achieve similar functions in different populations.

4. Discuss the effects of biodiversity loss
   a. What is so important about biodiversity? Why do we care that we are losing biodiversity?
      1. Students discuss in groups and generate a list of responses:
         1. Aesthetic value
         2. Ethical Issues
         3. Economic value
            a. Food items
            b. Eco tourism
            c. Loss of ecosystem functioning and goods and services. Insert your favorite example here (e.g., Wetlands)
               1. Draining and filling wetlands for agricultural and urban land-use leave us without the nutrient storage, flood control, water quality control, and animal habitat which are goods and services that wetlands provide.

2. **Explore** – Students work independently to complete the exercise in the greenhouse (about 2 hours)

   A. Overview Greenhouse layout and expectations
      1. Stop at pre-determined stations in both the rainforest and desert rooms.

      2. Observe, sketch and record structures and their functions. Hypothesize what biotic and abiotic factor(s) may have acted as a selecting agent.

      3. In the evolution room, plants are arranged from most primitive (algae) to most advanced (angiosperms).
         a. Construct an evolutionary tree illustrating the major evolutionary events in plant history (i.e., movement to land, vascular system, seeds, and flowers).
         b. Draw examples of the types of plants in each group.
         c. Add to the evolutionary tree what key features/structures separate groups of plants from one another (see Appendix D for example).

3. **Extend** – Students apply their knowledge in a new context (Homework assignment)
   A. Students choose their own ecosystem and design a plant to live there.

B. Students define which biotic and abiotic constraints exist in their chosen environment and the features their plant must exhibit in order to survive there.
    1. Students may draw pictures/illustrations to display their plant and its adaptations.

Procedure and general instructions (for students).

Biodiversity and Ecosystems

What is the influence of environment on ecosystem biodiversity?

An ecosystem is a community of organisms living and interacting in their physical environment. The biotic components of an ecosystem include all the living organisms, such as plants, animals, bacteria, and fungi. The abiotic components of an ecosystem comprise the physical features, such as the soil type, water conditions, topography, temperature, and rainfall.

When you study an ecosystem, you have an opportunity to observe how organisms are affected by the physical environment and other organisms, and how the physical environment is influenced by the organisms it supports. The abiotic components are often easier to catalog because there are many tools available (e.g., rain gauges, thermometers, soil chemistry measuring kits, etc.) that help us to quantify non-living aspects of the environment. The biotic components are often more complex, and require careful consideration of not only the individual organism of interest, but populations, communities of species, and inter-specific interactions within communities. Furthermore, exploring biotic components of an ecosystem often requires a solid understanding of the abiotic components that exist within the ecosystem.

The variation observed in nature is a direct result of evolution in plant and animal populations. As you learned in previous labs, random mutations arise in a population simply by chance. These random mutations give rise to traits that are selected for or against depending on its favorability in a given environment. If mutations were not random, we might expect all organisms in an environment to evolve similar structures and functions to cope with environmental stresses, and there would be very little diversity within ecosystems. However, we see a great diversity of life-forms within and between ecosystems.

What do all organisms need to survive?

There are certain things that organisms need to survive. For example, organisms must have a way to locate and acquire nourishment, transport nutrients, water, energy and gases, successfully reproduce, avoid predation, and most require structural support. Years of evolutionary history have lead organisms in particular ecosystems to have unique adaptations that enable them to survive and reproduce in their habitat.

The Constraints of a Terrestrial Environment

Consider the vast diversity of plants that carpet the land and inhabit the water. From moss growing out of cracks in the sidewalk, to ferns in shady forests, to pine trees high on mountain peaks, to flowers in cultivated gardens; all plants share some fundamental characteristics. Yet they also represent a variety of success stories in solving the many different problems presented by their environment.

Think about what you know about plants that make them the same; they are eukaryotic, multicellular, autotrophic (produce their own food through photosynthesis by using water, light and carbon dioxide to produce glucose and oxygen), possess chlorophyll, contain cellulose in their cell walls, and are virtually immobile. These are the characteristics that define plants.

Aquatic filamentous green algae are the likely ancestors of plants. A number of biochemical similarities between plants and green algae support this theory. They have the same chlorophyll, the cell walls of both are made of cellulose and both store carbohydrates in the form of starch. Furthermore, certain aspects of cell division and mitosis are similar in plants and algae.

Prior to the Precambrian period, aquatic algae were the only photosynthetic organisms. Individuals of the earliest land plants best able to cope with the drying and wetting cycles associated with terrestrial habitats survived and reproduced more than individuals who did not. Since that time, plants have become adapted to living on land. Over a very long period of time, their descendents covered the land with a tremendous diversity of species. The move to land was not without its complications. The algal precursors of terrestrial plants lived in an aquatic habitat under very different conditions, and simply could not have survived on land in their present form. What are the challenges that are associated with the move to a terrestrial environment?

Challenge 1. Obtaining and transporting water

An obvious difference between terrestrial and aquatic habitats is the lack of abundant water in the terrestrial habitat. Algal cells obtain water through diffusion across its cell wall and membranes. However, land plants must develop means to obtain water (rhizoids or roots), ways to transport water to the rest of the plant (xylem), and methods to prevent desiccation (waxy cuticles). Unlike many animals, plants have the constraint of immobility. Animals can move to water when they need it, but for all practical purposes, plants cannot. Plants have solved the water problem in a variety of ways, some which allow for a wide distribution of species into even the driest climates, and others which restrict plant growth to limited habitats under very specialized conditions.

Challenge 2. Acquiring and transporting nutrients

Plants require a relatively short list of nutrients for survival. Carbon dioxide (CO_2), essential for photosynthesis, is readily available in the air, but when plants take it in, they often let water out. The balance between CO_2 gain and water loss can sometimes limit plant growth. Other essential nutrients include nitrogen, phosphorous, and potassium (N, P, and K) which are all found in limited supply in the soil. Terrestrial plants cannot move themselves to another nutrient rich site when all the nutrients have been used up. Water currents solve this problem in an aquatic environment, but terrestrial plants must use alternative strategies. On land, the plant must be able to obtain nutrients (usually through the soil) and transport them to the rest of the plant (phloem). Plants must also be able to transport sugars made in the leaves back to the rest of the plant where they can be incorporated into the stem and root tissue.

Challenge 3. Exploiting an energy source

In an aquatic habitat, the sun's rays cannot penetrate to great water depths, so plants float on or near the water surface. Thus, energy is often a limiting factor to the growth of autotrophic organisms in water. On land, however, the sun is readily available and plants are in competition for this energy. Some terrestrial plants cannot get enough energy for survival. Taller plants with bigger leaves can shade shorter plants and prevent them from receiving light. Competition for light encourages growth of tall trees in some terrestrial plant species and growth of large shade leaves in others. Plants in some habitats receive excess sunlight and must avoid water loss while still photosynthesizing.

Challenge 4. Providing structural support for the plant body
Under water, plants are buoyant, which counteracts the downward pull of gravity, and have no need for support systems. On land, however, any structure that is raised above the ground must have some supportive tissue in it or the plant will collapse under its own weight. Support tissues are usually internal in plants that possess them.

Challenge 5. Reproduction
Sexual reproduction in all organisms requires the uniting of gametes in the process of fertilization. Algae release great quantities of gametes (many of which have tails for swimming) into the water. Some sperm will likely swim or float to an egg, and fertilization will take place. Many terrestrial animals can move to find their mates and carry their gametes with them. Terrestrial plants, however, cannot simply uproot themselves and go seeking mates. Neither can they depend upon a constant aqueous medium for the transport of their gametes to one another. Plants (bryophytes, ferns, gymnosperms, and angiosperms) have evolved different strategies to transport the gametes from one plant to the next, facilitating sexual reproduction in the absence of individual plant mobility.

Once fertilization takes place, the zygote and developing embryo are quite vulnerable to desiccation. This is not a problem for algae but it is a problem for terrestrial plants. Protective tissues encase and nourish the developing embryo in all groups of terrestrial plants, but the degree of protection and nourishment varies considerably. Because the embryo cannot yet make its own food through photosynthesis, it is dependent upon another energy source until it can produce chlorophyll.

Challenge 6. Dispersal
Water currents move algal propagules (offspring) to new habitats. How can terrestrial plants avoid competing with their offspring for space and other resources? They must disperse their propagules to new locations, far enough from themselves to allow for exploitation of another resource base. The variability in terrestrial plant dispersal structures and mechanisms is astounding. Wings to catch the wind, fruit to attract animals, and barbs which stick to passers-by are only a few of the dispersal structures and mechanisms found in the plant kingdom.

What you will do

Today we will be touring the greenhouse to observe biodiversity and plant adaptations in different environments. You will explore the adaptations that have allowed plants to evolve and adapt to life on land by observing structures and linking those structures to functions that help plants overcome the challenges of life in their ecosystem.

Proper lab attire is required for participation in this activity.

Project Objectives

During this lab activity, you will:

1. Examine a diversity of plants in a variety of aquatic and terrestrial ecosystems.
2. Describe a variety of evolutionary features that gave rise to such a diversity of plants.
3. Identify plant adaptations required for living in a particular environment.
4. Apply your knowledge of plant adaptations to design an organism suitable for a particular environment.

Methods

Engagement

Part 1: Observing Plant Diversity in the Desert

Familiarize yourself with the diversity of plants in the desert room of the greenhouse (use appendix A for additional information). Stop at each specified station (described below) and draw/describe the plant structures that you see there. Then, determine which environmental variable(s) might have acted as a selective pressure in the evolution of these structures. Construct a table for your data and sketches for stations 1-5. Each row in your table should correspond with a single station.

Station 1: Herbivory Defense Mechanisms
Station 2: Light Tolerance
Station 3: Water Loss
Station 4: Convergent Evolution
Station 5: Mutualism

Part 2: Observing Plant Diversity in the Rainforest

Familiarize yourself with the diversity of plants in the rainforest room in the greenhouse (use appendix B for additional information). Stop at each specified station (described below) and draw/describe the plant structures that you see there. Then, determine which environmental variable(s) might have acted as a selective pressure in the evolution of these structures. Construct a table for your data and sketches for stations 6-9. Each row in your table should correspond with a single station.

Station 6: Allelochemical Defense Mechanisms
Station 7: Commercial Importance
Station 8: Accessing Light
Station 9: Water Tolerance

Exploration

Part 3: Exploring Evolutionary Trends in Plant Diversity Using the Evolution Room

Familiarize yourself with the diversity of plants in the evolution room in the greenhouse (use appendix C for additional information).

1. Construct an evolutionary tree illustrating the sequence of the major evolutionary events in plant history. An evolutionary tree is a branching diagram showing the evolutionary relationships between organisms based on similarities and differences in their physical and/or genetic characteristics.
2. Draw examples of the types of plants in each group.
3. Add to the branches of the evolutionary tree which key features/structures separate groups of plants from one another.

Expand

Part 4: Final Assessment

Choose an ecosystem (this **cannot** be the desert or rainforest) and identify its key biotic and abiotic constraints. Design a plant with adaptations to deal with those constraints. Sketch and describe your plant, labeling relevant features.

Post Lab: Arrange your data using the following headers and respective items under each heading:

Raw Data, Field Notes, and Observations (3pts)

1. Diversity of plants in the Desert
    a. Construct a table for your data and sketches for stations 1-5. Each row in your table should correspond with a single station.

2. Diversity of plants in the Rainforest
    a. Construct a table for your data and sketches for stations 6-9. Each row in your table should correspond with a single station.

Data Analysis and Results (3 pts)

1. Diversity of plants in the evolution room:
    a. Construct an evolutionary tree illustrating the sequence of major evolutionary events in plant history.
    b. Draw examples of the types of plants in each group.
    c. Add to the branches of the evolutionary tree which key features/structures separate groups of plants from one another.

Conclusions (3pts)

1. Choose an ecosystem (**NOT the desert or rainforest**) and identify its key biotic and abiotic constraints.
2. Design a plant with adaptations to deal with those constraints, and able to meet the challenges of living organisms.
3. Sketch and describe your plant, labeling relevant features.

Reflections (3 pts)

1. What did you learn in this exercise? How does this exercise contribute to your awareness and understanding of biodiversity and how evolution by natural selection influences the phenotypic characteristics of plants?

Appendix A. Desert Ecosystem Information

1. Environmental Conditions

Deserts are located at about 30° north and south of the equator. Due to global air circulation, rain is forced to fall before it enters the desert biomes, therefore deserts receive less than 25 cm of rain per year. Rainfall occurs in short time periods and often in enormous downpours. Deserts are characterized by high pressure zones (e.g., clear weather) and high temperatures, but nighttime temperatures are often much lower. Because of sparse vegetative cover, there is little water vapor in the atmosphere to prevent radiation of heat at night.

2. Plant Strategies

There are a variety of plant adaptations that have evolved to allow plants to live in the desert:

Water

Plants have adapted to the desert pattern of rainfall by being succulent (having water-storing stems or leaves). Most ephemeral plants have shallow roots to catch surface water. Perennials have very deep roots to reach the extremely low water table. Some perennials have massive, water-storing roots. Many plants have a spherical shape, reducing the surface-area to volume ratio and therefore evaporation. Desert plants must also deal with high concentrations of salt which accumulate at the soil surface due to the high rate of water evaporation.

Sunlight

Some desert plants have evolved CAM (crassulacean acid metabolism) photosynthesis to avoid excessive water loss during the day. Stomata open at night when the transpirational stress is low and carbon dioxide is fixed into a 4-carbon compound which is stored in vacuoles. During the day stomata are closed and the 4-carbon compounds are broken down to provide CO_2 for photosynthesis. In other words, there is a temporal separation between CO_2 fixation and the Calvin cycle. Note that many, but not all CAM plants are succulents and that not all succulents are CAM. CAM is present in at least 18 families of plants including the Crassulaceae, Euphorbiaceae, Cactaceae, Asteraceae, Asclepiadaceae, Vitaceae, Orchidaceae and Bromeliaceae. It has evolved independently many times and is an excellent example of convergent evolution.

Defense Against Herbivores

Since plants are the primary source of water in the desert, many animals eat them as a means of acquiring water. Some plants have responded by developing protective spines. Others produce toxic substances in their leaves to make them unpalatable. One group of plants, the stone plants, mimics rocks to avoid consumption by thirsty animals. Their flowers, however, are quite noticeable, helping pollinators in recognize the plant.

Appendix B: Tropical Rainforest Ecosystem Information

1. Environmental Conditions
Rainforests, located in the equatorial zone around the world, are characterized by warm temperatures and high rainfall (200–400 cm/yr). Temperatures remain fairly constant from season to season; night time temperatures are only a few degrees lower than the daytime temperatures. The soil in rainforests is generally poor in nutrients because the high rainfall flushes nutrients out of the soil that are not quickly absorbed by the living plants. Light intensity in the understory is very low; less than 1% of the light penetrates to the forest floor. In contrast, the canopy layer (where most of the diversity exists) is subject to intense sunlight and wind.

Many pharmaceutical companies have been collecting plant and soil samples from tropical forests to find new medicines. Tropical rainforests are being harvested at an alarming rate. Currently 27 million acres (an area roughly the size of Pennsylvania) are being cleared each year for diverse uses including subsistence farming, cattle grazing and commercial utilization (i.e. coffee, bananas).

The diversity of life forms in tropical rain forests is staggering. A few thousand acres of forest in Costa Rica contain half as many bird species as occur in all of the U.S. and Canada. In rainforests alone, we are currently losing 27,000 species of plants animals, bacteria, and fungi every year. The rampant destruction of the rain forests will soon affect everyone. In addition, global climate change may accelerate the loss of tropical rainforests and therefore biodiversity.

2. Plant Strategies
There are a variety of plant adaptations that have evolved to allow plants to be successful in the rain forest:

Water

Rainforests are characterized by heavy precipitation which is often in excess of what plants need for survival. Many rainforest plants have evolved mechanisms for dealing with excess water that can build-up on leaves, promoting fungal growth which could lead to the death of the plant from fungal infection. Many plants have leaves with structures which prevent the buildup of water, such as drip tips. Also, rainforest plants may have highly divided leaves so water is unable to pool on them.

Sunlight

Vines are common in the tropics as a way to "reach up" to the sun. Many plants have developed an epiphytic growth pattern; they live on tree branches in the upper canopy but do not derive nutrients from the tree. Epiphytes benefit from being high in the canopy where the light is, but have had to evolve ways to gather nutrients and water without having their roots in soil. Many plants in the understory, where light levels are low, have specialized cells that focus light into the interior of the leaf more efficiently. This increases the amount of light they can capture.

Defense Against Herbivores

Since plants are susceptible to herbivores and disease year-round, many plants have evolved toxins or other mechanisms to deter herbivores and pathogens. To ward off deadly fungal diseases, leaves are often thick and tough. Some tropical woods have fungicidal properties in addition to being extremely hard and dense. Some species are so hard they are used in place of cement. Their hard, dense wood makes it difficult for other organisms to bore into them.

Appendix C. Evolution Room Information

Prior to the Precambrian period, aquatic algae were the only photosynthetic organisms living totally immersed in water. Since that time, plant descendants have adapted to living on land. A land existence has two important advantages over an aquatic existence:

1. There is a greater availability of light on land. Even very clear water filters out a substantial amount of light. Light is the primary source of energy for photosynthesis, the process by which plants assimilate nutrients.

2. Both carbon dioxide and oxygen are in higher concentrations in the air and diffuse more readily through air than through water. Plants need carbon dioxide to photosynthesize (to produce glucose) and oxygen to generate energy through respiration.

The algal ancestors of plants probably grew on the edges of streams and shores of lakes or salt marshes. As water levels fluctuated, areas along shores would have been occasionally above water level. Some shore-living algae may have developed an ability to survive periods when they were not submerged. Eventually, some forms developed **waxy cuticles** that prevented drying and allowed them to survive permanently on land.

Air, unlike water, does not give support to plant bodies, so land plants either have remained small or have evolved support structures. Large plants also had to transport nutrients obtained in the soil to sites of photosynthesis in stems and leaves. Hence, they developed **vascular tissue** (xylem and phloem) that facilitates the movement of water and nutrients, and in some cases provides additional structural support. Finally, sexual reproduction depends on flagellated sperm swimming through the water to the eggs. Land plants have evolved a variety of mechanisms for joining sperm and egg without the gametes drying out.

Several adaptations have allowed these plants varying degrees of success on land. These include:

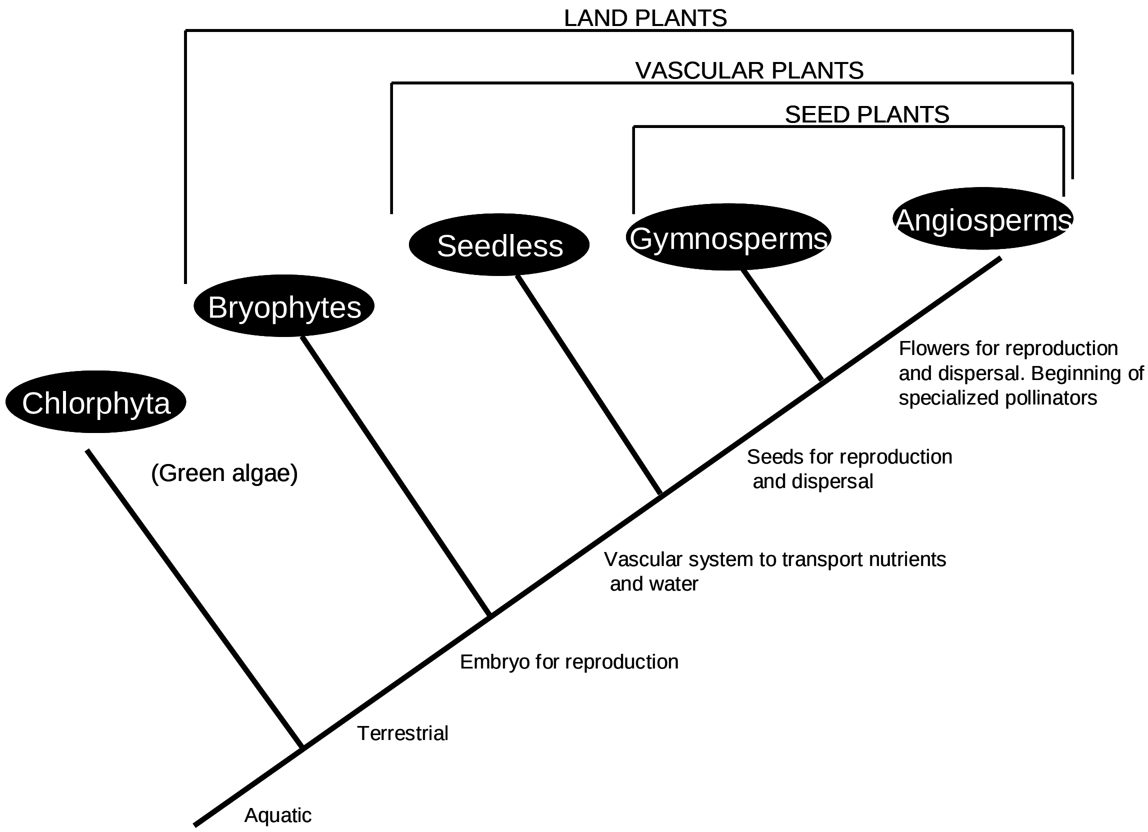
1. Reproductive structures with a sterile jacket of cells surrounding the gametes which help prevent desiccation. The reproductive structures of the algae, in contrast, are usually single cells.

2. A zygote retained within the female tissues (archegonium). This offers protection to the embryo and prevents it from drying out. The zygotes in algae are exposed and are not protected by the female gametophyte.

3. A waxy cuticle covers the aerial parts of these plants, helping to prevent water loss through evaporation. Algae do not possess cuticles.

All of this diversity is divided into four general groups: **bryophytes** (mosses, liverworts, and hornworts which lack vascular tissue), **seedless vascular plants** (ferns, horsetails, and club mosses, which have vascular tissue, but lack seeds), **gymnosperms** (cycads, ginkgos and conifers which have naked seeds, but lack flowers and fruit), and **angiosperms** (flowering plants which have enclosed seeds, flowers, and fruit).

Appendix D. Evolutionary tree answer key



Appendix E: Examples of plants located at each station

Station	Plants	Adaptation
1. Herbivory Defense Mechanisms	African Milk Bush	Latex gum glues mouthparts of herbivores shut.
	Cacti/Euphorbs	Spines protect fleshy tissue from herbivory.
2. Light Tolerance	Cacti w/ white hairs Pleated cacti	White hairs reflect light. Pleats reduce surface area to volume ratio.
3. Water Loss	Cacti, C4 plants, succulent plants with waxy cuticle	Fleshy tissue holds water. Pleats expand in the wet season and contract during droughts. C4 plants use CAM photosynthesis to reduce water loss (see Appendix A). Waxy cuticle holds in water.
4. Convergent Evolution	Cacti and Euphorbs	Have evolved similar adaptations (succulence and spines) although they are unrelated organisms.
5. Mutualism	Bullhorn Acacia Tree	Ants protect the Acacia tree while the tree provides a home and food for the ants.
6. Allelochemical Defense Mechanisms	Citrus, Curry, Cardamom	All plants containing strong scents to ward off herbivores.
7. Commercial Importance	Coffee, Banana, Cocoa, Papaya, Pineapple, Vanilla	All plants which are very important commercially.
8. Accessing Light	Vines, Bromeliads	Vines reach up to the light while Bromeliads live on branches high in the canopy to access light.
9. Water Tolerance	Leaves with drip tips and/or grooves. Waxy covered leaves.	Drip tips funnel water off leaves to prohibit fungus build-up. Holes in leaves shed excess water. A waxy cuticle helps shed water from the leafs surface.

Appendix F. References

Bransford J.D., Brown A.L., and Cocking R.R. 2000. How People learn: Brain, Mind, Experience, and School. Washington DC: National Academies Press.

Elzinga, C., S. M. Lawrence, L. M. Leege, M. K. Heidemann and D. O. Straney. 2008. Biological Sciences 110 Laboratory Manual. 13th edition. pp. 145-160. Hayden-McNeil Publishing, Inc. Plymouth, Michigan.

Heidemann, M.K. 1985. Chapter 38. In: Exercises in biological science. pp. 227–230. Wadsworth Publishing Company. Belmont. California.

Jacobs, M. 1988. *The tropical forest: A first encounter*. pp. 146–147. Springer-Verlag. New York.

Jungles (video; 2006). Planet Earth Series, BBC Worldwide.

Morgan, J.G. and M.E.B. Carter. 1993. Investigating biology: A laboratory manual for biology. pp. 551–555. The Benjamin/Cummings Publishing Company, Inc. New York.

Purves, W.K., G.H. Orians and H.C. Heller. 1992. Chapters 45–48 In: Life: The science of biology. 3rd edition. W.H. Freeman. Salt Lake City.

Rain Forest (video; 1983). National Geographic Society.

Raven, P. H., R.F. Evert and S.E. Eichhorn. 2005. Biology of plants 7th edition. W.H. Freeman and Company, New York.

Deserts (video; 2006). Planet Earth Series, BBC Worldwide.

The desert (video; 1980). The Biology Media.