Biogeography, Biodiversity, and the Hawaiian Islands

The study of the distribution of plants and animals across the space of the globe is known as biogeography. This science has been instrumental in the foundation of evolutionary theory and the discovery and monitoring of climate change. Spatial patterns of species distribution are especially striking in remote island groups such as Hawai‘i, although these patterns can also be seen in other virtual islands of habitat, such as mountaintops or isolated remnants of old-growth forest.

In this lab we’re going to think about the forces that shape the distribution and characteristics of species. We’ll investigate one of the central methodologies that botanists use — the collection of botanical voucher specimens and their maintenance in herbaria — and we’ll visit the UH herbarium to look at some of the differences between cosmopolitan and endemic species.

Islands and Natural Selection

Islands are a good place to look at biogeographical patterns, because they often contain a restricted set of species, and we can compare and think about the differences between them. Observing species distributions in the Pacific led Charles Darwin and Alfred Russell Wallace to articulate the theory of natural selection in the mid-19th century. Most famously, Darwin noted variation among the finches on the Galapagos Islands — though some people argue that if Darwin had come to Hawai‘i he would have chosen the Hawaiian honeycreepers as the exemplar of variation!

Figure 1: Honeycreeper phylogeny. Courtesy of the National Center for Science Education.
The theory of natural selection offers an explanation of the processes by which all forms of life have slowly come into being, that is, evolution. Natural selection is based on four principals:

1. That characteristics (or "traits") are variable within populations (i.e. "variation");
2. That these variable characteristics can be inherited by offspring (i.e. "heritability");
3. That more offspring are produced than can survive (i.e. "superfecundity");
4. That any variable characteristics which increase the chance of reproductive success will increase in frequency within populations (i.e. "fitness" — but we should be careful about what this means!)

Note that #1–#3 are simply observations while #4 is a conclusion drawn from them. One of Darwin & Wallace’s contemporaries, Thomas Huxley, was apparently furious when he read this theory because he said he was so simple he should have thought of it himself! It is important to understand that the characteristics which confer reproductive advantage are always changing in response to ever-changing environmental conditions — especially if a species moves to a new environment or encounters a new species — so the process of evolution is not a directional progress towards superiority, but a constant subtle readjustment of fitting into a complex and changing world. Often several variants may be advantageous in different ways, which can lead to the evolution of new species. We can see this process in the endemic Hawaiian honeycreepers.

To start with, think about how species would get to a remote group of islands, a process called colonization. Terrestrial species would have to cross huge ocean distances to arrive, which seriously limits the number and kind of colonizers. Before human settlement the only mammals in these islands were bats and monkseals, and the only reptiles were sea turtles. While many species of seabirds got to Hawai‘i, only a few kinds of inland birds did, possibly as small flocks were blown off migratory paths and carried here in a storm.

We can imagine the first finches arrived to find unoccupied habitats — though this is an oversimplification for reasons we can discuss. As a flock became established, it naturally had a certain amount of variation in characteristics such as bill shape. Some birds may have had slightly thinner and longer bills, while others had shorter, sturdier ones. While this variation may have been insignificant before, on a settled continent already occupied by hummingbirds and grosbeaks, in these new habitats it allowed some birds to better draw nectar from flowers, while others were more adept at cracking seeds. If the birds who had bills with these characteristics were able to obtain more food, i.e. energy, they may have had more success reproducing, while at the same time their use of certain kinds of food may have isolated them from birds pursuing other feeding strategies. This isolation, whether geographical or behavioral, would lead subpopulations of the flock to diverge in characteristics until there were two or more distinct species, a process called speciation, or, in cases where one species evolves to occupy many different ecological niches, adaptive radiation. In fact, all of the diverse Hawaiian honeycreepers probably evolved in this way from one colonizing species.

At the same time, characteristics that formerly conferred fitness — i.e. reproductive success — might no longer matter. Elaborate nest-building behaviors that formerly offered protection from predators would be a costly use of energy in an environment that lacked land mammals and reptiles. The members of the flock that spent the most time doing this might have the least time for gathering food, and so their relative reproductive success would drop, decreasing the frequency of this trait within the overall population. It turns out that most species that evolve on isolated islands lack many developed defensive traits. Birds often build nests on the ground and don’t run from other animals; plants often lack thorns or toxins. These characteristics are selected by the environments of isolated islands. If these islands are later colonized by species
which evolved in the more aggressive and competitive environments of large continents, the island species are at a disadvantage. Many species endemic to islands have become extinct in the last several hundred years of global exchange, and many of those that remain are among the most vulnerable and endangered in the world.

In Hawai‘i this extinction crisis is most dramatically noticeable among the forest songbirds. On most of O‘ahu the only songbirds you will see are non-native, continental species introduced in the last hundred years. Because it is difficult to see native birds, we will focus our observational activity in this class on plants, because we can find examples of both natives and non-natives growing on campus, and we can see additional examples in the collection of plants at the UH herbarium, which have been gathered over the years by researchers using the technique which we will learn today.

II Botanical methodology: collecting vouchers

In order to get a sense of the observational work that underlies biogeography, we are going to practice one of the fundamental techniques of botany, the collection and preparation of a botanical voucher. However, because the collection of specimens can itself have environmental impact, we will need to be careful to select plants that are plentiful and robust enough not to be affected by our work! We might collect either small representative parts of a large plant, or small plants growing in abundance — ideally “weeds,” a cultural category of plants which are often quite interesting!

Because the reproductive parts of plants — flowers and fruits — are often their most distinctive features, we want to collect plants that have flowers or fruits or both, though many times the plants we’re interested in will be in a non-reproductive stage of their cycle. We also want to include leaves attached to the stem, which can offer additional identifying information. Look for a representative part of the plant that will fit within the standard size of the plant presses, 30 cm x 40 cm.

When you collect a plant, you always want to record metadata, information about the plant and the collection. If we’re collecting only part of a plant, we want to describe the whole plant in our metadata. For example, how tall is the tree? Is it tall and thin or sprawling and branching? Is it growing in full sun or in shade? Metadata should always include the date, time, and location of the collection, described as accurately as possible. And metadata should always include the collectors’ name, and a collection number. If you’ve collected 171 plant specimens before, you would give your next plant the number 172. If this is the first plant you’ve collected, you can call it #1, or 2010-1, a system that sometimes works better for the only-occasional botanist.

Because the documentation of plant distributions is a vital part of understanding and conserving natural resources, Lyndon Wester, a biogeographer in our department, prepared a video about the process which was presented to the National University of Laos, a country in which he does much of his work. This video, Protecting Biological Heritage: Making and Preserving Plant Specimens, is available on youtube at <http://www.youtube.com/watch?v=YTfGLwWOlo>.

After collecting specimens and preparing them in plant presses, we’re going to take them to the drying rack in the Botany Department, and then visit the Herbarium to look at plant vouchers that have been collected in the past. In your field notebooks, please record the metadata for some of the plants we look at, along with your descriptions and notes. By referring to the plants using their Herbarium record number, your notes become a reference which can be consulted later, allowing you to go back to the same specimens to check any new insights or theories you may have in the future.
**Plant collection exercise**

For this exercise each student will collect plant material to make a plant voucher. Since a critical part of preparing vouchers is attaching detailed information about the collection (i.e. metadata), make sure to record in your field notebooks the following:

**Collection information**
- Scientific name of plant and plant family:
- Collector’s name:
- Collection number:
- Date and time:

**Locality**
- Regional location:
- Distance/direction from landmark:
- Latitude/Longitude/Elevation:

**Habitat**
- Soil:
- Topography:
- Slope/Aspect:
- Associated species:

**Characteristics**
- Height:
- Form (tree/shrub/vine/herb):
- Fragrance & color of flowers (/leaves):
- Abundance (rare/common):
- Any features of the plant which are not observable in the part which you’ve collected (e.g. appearance of bark, presence of birds or bugs, etc.)

Label your voucher specimen with your name and collection number. After viewing examples in the herbarium, you’ll be able to prepare a label for your voucher containing full metadata. We may use a new online tool for this at <http://www.herbarium.hawaii.edu/taxonomic_core/data/>.

You may also take photographs of the plant as additional documentation — but make sure that you’re photographing the very same plant you’re collecting, and not another one nearby or another like it.

If we were collecting plants in a cultural context, we would also want to record information about the ethnobotanical knowledge associated with the plants, such as the local identifying characteristics, name(s), use(s), preferred stages of collection, and cultural significance.
III Herbarium collections

The Joseph F. Rock Herbarium is located in the Harold St. John building on the UH Mānoa campus (both Rock and St. John worked at UH and collected many vouchers which are stored in the collection as well as planting many of the trees found on campus). All herbaria have code letters which are used when referring to vouchers from their collections, and the code for our herbarium is HAW, which you should include when recording the voucher metadata. We will examine a number of plant vouchers from the collection, and do the following:

1. Copy the complete metadata from at least one herbarium voucher.

2. Look at variation in several plants of the same species. Again, list species and collection locations, and note morphological variation.

   Probably we’ll look at species of *Metrosideros polymorpha* (‘ōhi’a lehua), *Colocasia esculenta* (taro, kalo), and/or *Saccharum officinarum* (sugarcane, kō).

3. Compare endemic and cosmopolitan species. List both species and where they were collected, and then comment on any morphological differences (i.e. differences in form) that you can distinguish.

   Probably we’ll look at species of *Rubus, Acacia*, and/or *Chenopodium*.

Herbaria with important collections of Hawaiian plants

University of Hawai‘i (Joseph F. Rock) Herbarium <http://www.herbarium.hawaii.edu/>

U.S. National Herbarium (USNM) Flora of the Hawaiian Islands collection
   <http://botany.si.edu/pacificislandbiodiversity/hawaiianflora/specs.cfm>

Bishop Museum Herbarium (BISH) searchable at the National Biological Information Infrastructure (NBII)
   Pacific Basin Information Node (PBIN)
   http://www2.bishopmuseum.org/natscidb/?w=PBIN&pt=t&list=o&srch=b&cols=8&rpp=500&pge=1


Geographic categorizations of species

**Endemic:** Occurred originally only within a particular area (in which it probably evolved).

**Indigenous:** Occurs originally in an area, and also in other areas.

**Native:** Similar to indigenous, less often used because of the confusion between species that originally occurred in the islands and species brought by native Hawaiians.

**Polynesian introductions:** the “canoe plants” and animals introduced over 1000 years ago.

**Non-native:** Originates outside an area. Usually refers particularly to species introduced from other parts of the world within the last 250 years.

**Naturalized** (or feral): Non-native species which have established self-sustaining populations.

**Adventive:** Introduced species which may be in the process of becoming naturalized.

**Invasive:** Naturalized species which spread rapidly or threaten the viability of native species.
Making herbarium voucher labels

After examining herbarium vouchers, we can prepare labels for the plants we collected. To use the online tool, start by setting up an account (under purpose, choose "Geog 101L") at: <http://www.herbarium.hawaii.edu/taxonomic_core/data/> Once you log in, a page will come up asking you to enter the metadata for your voucher. Fill in any of the fields for which you have data. Here are a few notes on how to do this:

- **Plant names**: You will need to enter the scientific name for your plant, and its family. Scientific (or Linnean) names are called binomials because they have two basic parts, the genus (think of generic or general) and the species (think of specific or special). As a rule, the genus is always capitalized and the species isn’t. These names are sometimes followed by the name of the author who described them, and there is an optional field for this on the record sheet; you can either look up the author on the ITIS database, or you can ignore that for now. In cases where you can identify the genus of a plant but not its species, you can enter “sp.”, which means an undetermined species (e.g. *Bougainvillea sp.*).

- Plants are hierarchically classified, so more than one species belongs to a genus, more than one genera (the plural of genus) belongs to a family, more than one family belongs to an order, and so on up. All we need here is the family, and the "division" to which it belongs. Under Division select "Angiospermae (Flowering plants)" — unless you collected a fern, in which case select "Pteridophyta."

- **Reproduction**: If your voucher has flowers or fruit, select "Fertile"; otherwise "Sterile."

- **Georeferencing**: The herbarium uses latitude and longitude to provide a link to a map of the plant’s location. However, it needs lat/long in decimal degrees, rather than degrees minutes seconds (DDMMSS), so you may need to do a conversion. Remember, since a minute is 1/60 of a degree, and a second is 1/60 of a minute, and therefore 1/3600 of a degree, you can get decimal degrees as DD + MM/60 + SS/3600. Then remember that West longitude (& South latitude for that matter, although it doesn’t concern us here) are counted as negative, so need a "-" minus sign stuck in front of them. So, for example, 157°48’54"W would be - (157 + 48/60 + 54/3600)° or -157.815°.

- **Description**: Enter the information you’ve observed about the characteristics and habitat of the plant. Only describe features which you could observe (e.g. fragrance and color of flowers, presence of spines on trunk), and don’t enter the conclusions you might draw (e.g. plant is non-native) — these belong in your notebook but not in the herbarium record.

- **City/Township** should be "Honolulu." Under Location put "University of Hawai’i at Mānoa campus" followed by any more detailed description you have.

- Only attach a photo if it is one of the particular individual plant which you collected.

Once you’ve entered all this information, hit “Save” and the herbarium will have a record of your collection. From the next page you’ll be able to create an label by clicking on the pdf icon. Under quantify put 2, and you’ll see a page with two identical labels on it. Print these. One label will go to the herbarium along with the voucher. The other you should staple or glue into your fieldnotebook as a record of your collection.
IV Transported landscapes, cultural biogeography, & conservation biogeography

While evolutionary biogeography focuses on the distribution and characteristics of plants on a long chronological scale, some biogeographers also look at how these have changed in the more recent past, and continue to change today, as the result of human activities. The study of how human societies have reorganized species distributions is sometimes known as cultural biogeography.

In Hawai‘i, there are two important historical periods that reshaped the biotic landscape. The first starts with the original human settlement of the islands by Polynesians over a thousand years ago. The second starts with the arrival of English ships commanded by Captain James Cook in 1778, which initiated a period of global exchange.

When Polynesians settled Hawai‘i they brought with them about thirty species that ethnobotanists sometimes refer to as the “Polynesian toolkit” or “canoe plants.” (The introductions also included four animals: pigs, dogs, chickens and rats.) As Hawaiians cultivated these plants in fields and orchards and gardens and lo‘i, the environment grew to resemble settlements in southern Polynesia, forming an example of a “transported landscape.”

It’s worth thinking about the plants you would take with you if you were moving to a remote island for the next, say, thousand years, and assuming that there are no plants suitable for food or clothing on the island. Think too about other uses of plants, such as medicine or containers. Try picking 30 plants and see if that seems like an excessive or a small number, and then compare plant lists with other people in the class.

What characteristics do these plants have that make them attractive candidates for transportation? We often think about the ways that humans use plants, but we can also see this as a way that plants have made use of humans as dispersal agents in order to extend their ranges (for an extended argument along these lines, see Pollan 2001). One of the characteristics that shapes the distributions of species is their ability to find ways to disperse their offspring. How do you think has this affected the assemblage of plants now found in the Hawaiian Islands?
Cosmopolitan introductions and impacts

Plants and animals introduced in Hawai‘i since Cook’s arrival are often called “European introductions” but this is a bit of a misnomer, since most of the plants introduced are from Asia or Africa or the Americas (often in the tropics), and many times the people bringing them to the islands weren’t Europeans, but traders or sailors or immigrant workers from other parts of the world. Probably a better term is cosmopolitan introductions. So many species have been introduced from different parts of the world that by now most plants and animals you’ll see are non-native. While many species were introduced intentionally, for a number of reasons (agriculture, forestry, landscaping, etc.), others were unintentional “hitchhikers” on boats or introduced animals.

Often species interact in complex ecological ways. One of the biggest threats to native songbirds is disease (birdpox, avian malaria), spread by mosquitoes, because the endemic birds evolved without the presence of these diseases, and therefore never evolved resistance to them. While the diseases may have been present in the chickens introduced by Polynesians, there was no way for the endemic birds to get the diseases until mosquitoes were introduced unintentionally in 1826. To make matters worse, Europeans also brought larger pigs, which formed naturalized (feral) populations which root around for edible plants in the forest, making ruts which fill with water which creates more mosquito habitat. After native birds disappeared in the lowland settled areas (where habitat loss was probably also a contributing factor to population decline), people introduced cosmopolitan songbird species, which also compete for habitat and serve as vectors for avian diseases. Thus the threats facing native birds involve a whole array of species: viruses, mosquitoes, pigs, humans, songbirds, and the plants that have replaced native species.

Much of the work now being done in this area is called conservation biogeography, which combines the study of the evolutionary and ecological characteristics of species, and investigation into the ways they interact in a world in which many former geographic barriers have been broken. The goal is to maintain the diversity of species and of the variation within species; in this diversity is both a greater resilience and adaptability to the continually changing environment, and also a great beauty. This is certainly an important field and the work tends to be cross-disciplinary; anyone interested in further exploring it should look at the courses offered in the interdepartmental program in Ecology, Evolution, and Conservation Biology (EECB, <http://www.hawaii.edu/eecb/>), as well as those taught in our Geography department by Lyndon Wester or Stacy Jørgensen.

Internet resources

Canoe Plants of Ancient Hawai‘i <http://www.canoeplants.com/>
Hawaiian Native Plant Genera <http://www.botany.hawaii.edu/faculty/carr/natives.htm>

References and further reading


