**The Teal Spruce Sampling Game: Teacher Instructions**

**Materials**

1. Activity map (one per group)
2. Activity instruction sheet (one per student)
3. Data entry sheet (one per group)
4. Ten cups, labeled A-J
5. Sixty markers of designated colors (12 blue, 30 red, 6 orange, 11 green)

**Setup**

1. Place activity map in accessible area
2. Place labeled cups in order next to map
3. Fill cups with designated markers:
   1. 2 blue, 2 orange, 2 red
   2. 2 blue, 2 orange, 2 red
   3. 3 blue, 1 orange, 2 red
   4. 2 blue, 1 orange, 3 red
   5. 2 blue, 4 red
   6. 1 blue, 5 red
   7. 6 red
   8. 4 red, 2 green
   9. 3 red, 3 green
   10. 6 green
4. Separate class into groups (at least three groups recommended)
5. Provide each group with a data entry sheet

**Instructions**

Collecting samples in the field costs money! Each team has a limited budget they can use to try and answer their research question. Here are the rules for spending their budget:

1. Their collection trip must start and end in Huville
2. They cannot spend more than their budget
3. Visiting sites on a section of road costs $1 (They may visit any number of sites on that road)
4. Going to and from a sampling site costs the amount listed next to the trail
5. To collect samples from a site they visit (Listed as sites **A-J**) they must spend $1 for each sample they collect (***Example****: 3 samples = $3*)

Each group’s budget will be determined by the instructor and fall into one of three categories:

Underfunded: $54

Minimum funding: $74

Well-funded: $94

**Core concepts for discussion:**

***Lesson Goal #1****: Explain how climate change relates to changes in species distribution.*

In part, this game illustrates that regional climate is not static but has instead changed drastically over time. This has had the effect of altering the vegetation types that exist in a given region at a given point in time. For instance, a tree species we see growing in an area today may not have been able to grow there during the last ice-age. The expanding glaciers of the last ice-age brought about a cold and dry climate that was difficult for many species to tolerate, forcing them to migrate southwards towards regions with a more suitable climate. This would have resulted in a displacement of the species’ old ranges until the end of the ice-age, whereupon the warming climate made the former species ranges accessible again. However, besides migration, there has been evidence that populations of some species managed to survive within their old range despite the difficult ice-age climate. They persisted in what are called “climate refugia”, which are sites where various factors allowed for a sufficiently favorable habitat to persist such that species could remain despite the otherwise unsuitable regional climate. For example, a river canyon might retain enough moisture and a warmer temperature to harbor a tree species that could not survive the surrounding cold and dry landscape. This means that when the climate warmed after the last ice-age, the populations that survived within those small pockets of favorable habitat were able to expand and repopulate their old range along with those populations migrating back northward again. This concept is essential for understanding the results from the sampling activity, which illustrates both of these species responses (migration and refugial persistence) to drastic climate change.

***Lesson Goal #2****: Understand how basic probability concepts are necessary for real world inferences.*

This game will introduce or refresh the utility of basic probability in interpreting collected data. In many scientific endeavors, observations of counts and occurrence are used to generate probabilities that help explain natural phenomenon. In the “Teal Spruce” game, we used probability to understand past population patterns by observing how many individuals from a given population contain informative genetic markers. Although actual DNA markers are not used, it is important to understand that the simple probability calculations associated with the game are a reasonable representation of the actual process biogeographers use to interpret population responses to past climate change. Specifically, the frequencies of the occurrence of rare or unique genetic markers can be interpreted to indicate whether a species remained within a geographic area during a past period of climate change or if it instead migrated there after conditions improved. These concepts are fundamental for not only understanding this activity but also understanding how scientist translate observations into useful interpretations.

***Lesson Goal #3****: Demonstrate how scientists must create sampling strategies to maximize the amount of useful information despite being limited by budget and time constraints.*

In the real world there is limited time and money available to collect data and answer a research question. Scientists must carefully consider what key information they need to know to be able to answer their question and how they should manage their data collection to successfully gather that information given the constraints. In the “Teal Spruce” activity, each student is a member of a research group tasked with collecting samples of a plant species distributed across a theoretical landscape. They must use the genetic patterns in these samples to understand how this species responded to a major climate shift. To represent budget constraints each group is given a set number of research dollars with which to perform actions. They will not have enough dollars to fully sample every site, so they will need to decide the optimal allocation of their funds. Therefore, the goal of the activity is for each group to come up with its own idea of the best sampling approach, collect the data, and draw conclusions on what happened to Teal Spruce. At the end of the scenario the groups will be able to compare their methods and results and see what conclusions each group was able to draw based on their approach.

Ideally a scientist would deeply sample every site, but given a tight budget two different strategies could be considered: a broad approach or a narrow approach. A broad approach would collect a few samples from many sites, whereas a narrow approach would deeply sample from a select few sites. A broad, but shallow, sampling strategy would readily show major patterns of genetic variation across the study area but might miss finer details. Keep in mind that there is an element of chance for which individuals are sampled at a site. With shallow sampling, the scientist will most likely collect the more common genetic patterns. This approach is best when the goal is to understand the entire study area or when there isn’t a clear idea where to sample. A narrow, but deep, sampling strategy would catch those fine details the broad approach misses, but limits the number of sites the group can visit. It would be harder to catch the major patterns across the range and the group could still miss important details from the sites that weren’t sampled. It is best used when there is an area-specific question or there is prior knowledge on where it would be best to sample. Of course, it is also possible to take an in-between approach and broadly sample most sites, but deeply sample a very select few sites of interest.

In the case of the “Teal Spruce” activity, a student’s thought process might proceed something along the following: “Our hypotheses specifically address the possibility that an eastern population might have survived the ice age. Based on the background reading, we can infer two areas of interest: a western population refugium and an eastern population refugium. Given the maximum extent of the ice sheets (dotted blue line on map), we can infer that these two refugia were likely in the southern ends of these two ranges. A sound sampling strategy might therefore be deep sampling of several sites in the presumed refugia, and a few from the rest of the range.”

***Lesson Goal #4****: Exhibit the methodology scientists use to interpret collected data and, subsequently, use this evidence to make an informed conclusion about their research question.*

As the teacher, you have access to the full dataset. This is effectively what having deep sampling from every site would look like. This data can be interpreted as evidence of an eastern refugium, but that migrants from the western refugium also reached the eastern range. The eastern range is therefore a mix of long-term persistence and recent migrants. There is an increased amount of genetic diversity found in both refugial areas (southern edge of both ranges). The eastern refugium did not expand, but the western refugium expanded northward and eastward and shows a corresponding pattern of decreasing genetic diversity. The decrease in genetic diversity is due to the fact that not every tree participates in migration. If only a certain percentage of trees reach each stage of a migration, then some genetic variants get left behind purely based on probability. In the “Teal Spruce” scenario, only a single genetic variant (red) from the western refugium ultimately crosses the mountains over into the eastern range. The other variants found in the western refugium are progressively left behind during the expansion across the western range. Over the course of its long-term isolation from the western range, the eastern refugium became genetically distinct from the western refugium (represented here by the unique green genetic variant). The only indication we have of an eastern refugium is therefore the sudden emergence of the green genetic variant in the eastern range, where we might have otherwise only expected more of the red genetic variant.

Your students, however, will have a variety of limited datasets depending on the sampling strategies employed. If they carefully considered the question they were trying to answer, they were likely able to collect a suitable dataset and could correctly interpret this system. However, bad luck or improper sampling might result in different interpretations. These “incorrect” approaches should be considered part of the activity and a learning experience. The student’s will have an opportunity to compare and contrast their methods as part of the activity (see lesson goal #5). When interpreting data your students should consider the original question of the activity. Here are several leading questions you can pose to get them thinking: Without any data, where would they expect to find evidence of refugia? What do they think a refugium would look like in their data? Do any of their patterns strike them as evidence of a refugium? Without any data, where would they expect to find evidence of migration? What would migration look like in their data? Do any of their patterns strike them as evidence of a refugium?

***Lesson Goal #5****: Demonstrate the importance of contextualizing scientific study results with other studies.*

While deep sampling of every site would be ideal, the realities of research generally prevent an ideal scenario. The cost associated with visiting all possible research sites combined with the funds needed to sample/sequence multiple individuals presents a researcher with a series of important choices. In this exercise, there is a continuum of the number of sites visited versus how well each site is sampled. Sample too few sites, and the group could miss the signal for the interior refugium by skipping over key populations. Sample each site shallowly, and it is possible the group misses important markers that indicate a refugium or gradients in diversity that indicate migration. Groups that balance site number with sample depth will likely come close to deciphering the full pattern. It is important that the groups come together at the end of the exercise to present their study design and their interpretation of the evidence they collected with it. Ideally, there are a variety of interpretations among the groups and a discussion can be had on why they think these differences exist and what, based on the accumulated evidence, the students think the true answer to the study scenario must be. The teacher can then conclude by highlighting the impact that study design has on research findings and how crucial the broader scientific discussion is in properly interpreting those findings.