Understanding Ecological Heterogeneity

Ahmedabad University

Science Writer
Shreya Venkatesh
Integrated MS Life Sciences
Class of 2028

Illustrator
Vidhi Narvekar
BA (Hons) Psychology
Class of 2026

Science Mentors
Jitesh Jhawar
Assistant Professor
School of Arts and Sciences

Ratna Ghosal
Associate Professor
School of Arts and Sciences

Shomen Mukherjee
Associate Professor
School of Arts and Sciences

Art Direction
Project Concept and Execution
Bhumi Shah
Fellow, Digital Curve
Centre for Learning Futures

Cover art
Vidhi Narvekar

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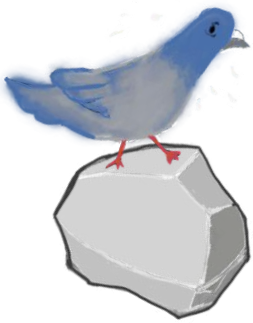
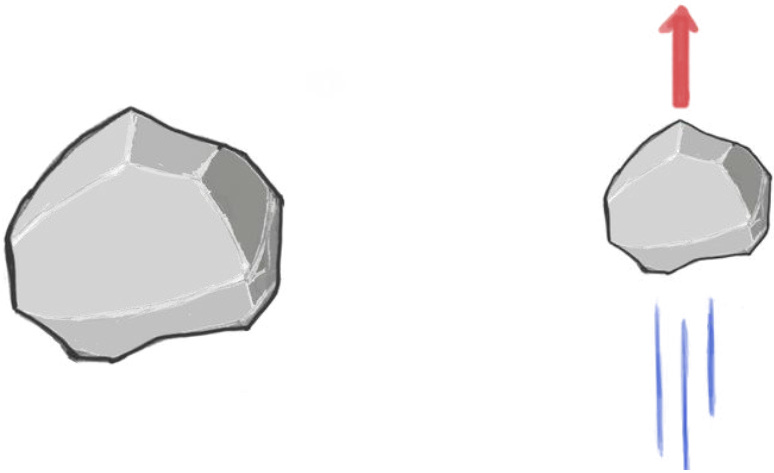
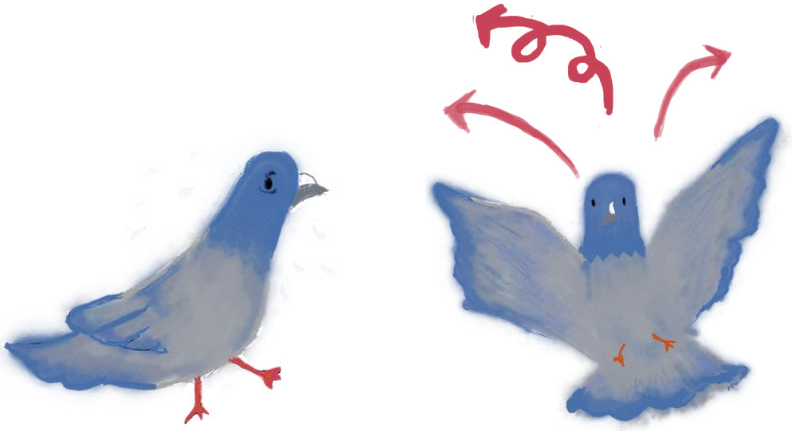


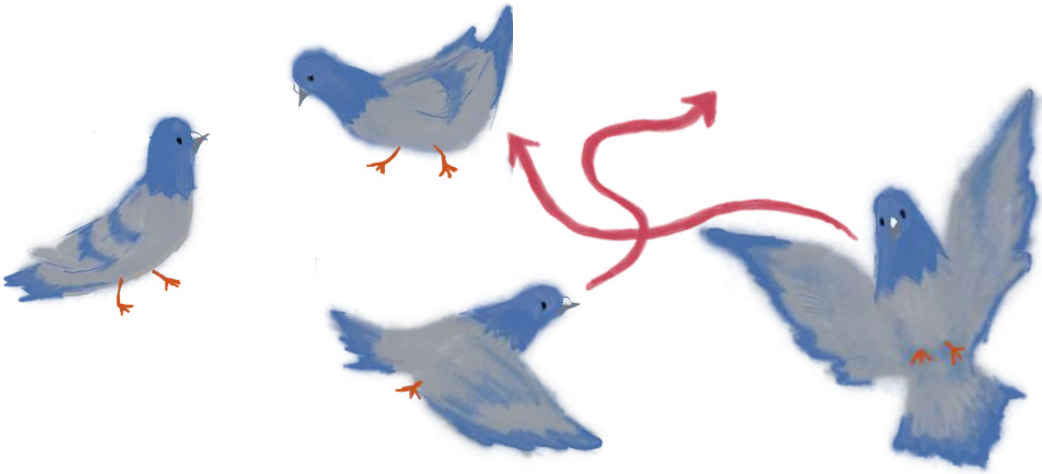
Imagine you are in a physics class to learn about the freefall motion of an object. The teacher walks in with a box of stones of different sizes. She throws a stone upward in the air. At a particular moment, it starts to move back downward, causing it to fall to the ground. Throughout this journey, the stone's motion is governed by the laws of physics, and it applies universally to all objects. The teacher further explains how, by understanding gravity and the laws of motion, we can predict that the stone will inevitably fall back down after being thrown into the air.



You now come to a biology class to learn about birds and the mechanics of living organisms. What would happen if the teacher released a pigeon into the air? It is natural to think that the pigeon would fly away instead of immediately falling to the ground, unlike the stone you saw earlier in physics class. This is because a pigeon's ability to fly counteracts the effects of gravity, allowing it to remain airborne.



What if the teacher releases two pigeons simultaneously? What would they do? Would they fly in the same direction? Would they move in opposite directions? Would they be disoriented? Would they collide with each other? Would they hover in the air and move randomly? Would they descend slowly on the ground? This is a result of the combination of flight behaviours and flight adaptations. Pigeons' movements, like those of any living organism, are unpredictable. Now, add an eagle into the mix. Would the eagle attack the pigeons? Would the eagle fly away? Would the pigeons flock around the eagle? The unpredictability of each individual's behaviour would lead to a more complex social environment.



This simple exercise in your class highlights the principle of individuality, which not only distinguishes physical systems from biological ones but highlights a diverse range of behaviours and responses exhibited by different organisms. The stones, being non-living objects, follow the laws of physics and fall due to gravity. The pigeons, on the other hand, are living organisms that have complex biological functions and behaviours. They demonstrate flight adaptations and can move in various directions based on their individual instincts and environmental cues. The eagle's presence adds another layer of complexity as its actions and interactions with the pigeons are influenced by its instincts and predatory nature.

Heterogeneity refers to the diversity and variability in the behaviour of individuals within a system or a group. Heterogeneity makes it challenging to derive general laws or predictions in ecology, as the behaviour and responses of organisms can vary significantly due to their individual characteristics, genetic makeup, and environmental factors. This very complexity brings forth innumerable scientific puzzles for ecologists. Let’s delve into how heterogeneity plays a crucial role in ecology, a field that studies dynamically interacting systems of organisms.

What is Ecological Heterogeneity

Heterogeneity in ecology is defined as the 'variety' of something, be it an object or a phenomenon within the environment. This concept manifests in different forms and can be visualised throughout every aspect of the environment. It is classified based on two parameters: space and time. The book ‘Ecological Heterogeneity’ defines an environment as spatially heterogeneous if ‘the rate of a process varies over space with structural variations of the environment or if a chosen qualitative/quantitative descriptor such as vegetation cover or air temperature assumes different values at different locations’. Another type of heterogeneity is 'Temporal', which refers to one point in space and many points in time. [1]

The variety or ‘discontinuities’ as the book states it; that contribute to heterogeneity across space and time are classified under a triad of behaviours. These behaviours, namely chaotic (irregular but predictable discontinuities), random (unpredictable discontinuities) and deterministic (even, intended discontinuities), remain interconnected and often overlap with each other. To make it simpler, let’s take patterns found on fur or skin. If the spots or stripes on the fur of an animal are evenly spaced and equally sized, this ‘design’ can be considered deterministic. If the pattern is ‘patchy’ on the animal’s fur, this can be considered random. Lastly, population dynamics of certain species are found to show chaotic behaviours. This proves that identifying heterogeneous phenomena is very difficult, especially when such discontinuities, both spatial and temporal, keep transitioning from chaotic to random to deterministic. [1]

Interestingly, heterogeneity arises on various levels within nature. Heterogeneity can be found within individuals, within and between different populations, and even in different habitats. Different animals in a group or a population are different because of their anatomy, age and experience, how much they eat, how healthy they are and many other factors. This is heterogeneity in individuals within a population. Conversely, a group will be different from another group of the same species living in a different place, and their behaviour will be heterogeneous.

To understand habitat level heterogeneity, consider the example of a lake covered in leaf litter. Leaf litter is distributed unevenly within the entire lake, showcasing the heterogeneity of space of leaf litter. Leaves in lakes slowly settle down into the lake bed and begin to decompose. Individual leaves could decompose at different speeds and settle in different levels in the lake. You could also imagine how the bacteria levels in the lake are influenced by the amount of litter in the lake. For example, lower levels in the lake can have lesser oxygen, and in turn, this influences the kinds of fish that thrive at different lake levels. The fish species then interact with each other and may compete for food within the lake at different levels. All of this builds up to the heterogeneity within the habitat and the species thriving in it.

1 A vital component of any ecosystem, sunlight is especially important in aquatic environments. Different plants exist because varying amounts of sunshine reach different levels of water.

2 Considering their diet, **Trout** thrive in shallower waters - feeding off of invertebrates, flies and zooplankton. But be careful. There's a lot of competition for this fish.

3 **Carps** are fish that move between different levels of water depending on the seasons, but they prefer levels where they can reach their main prey - flies. However, there is definitely competition!

4 Debris such as dried, decaying leaves are ideal for the **Perch**, hence it is no wonder they navigate deeper waters in hopes of finding clumps of leaves.

5 **Pikes** are relatively large fish and given their diet of other fish plus their own kind, they require waters with plentiful coverage for both attacking and hiding.

6 The level of bacteria, in turn, also influences the speed at which the leaf litter decomposes and can be affected by the amount of oxygen present.

One might ask, if individual heterogeneity is so vast and expansive, how can we possibly study it? Scientists and researchers tackle these questions one tiny piece at a time. They take into account various factors that they might think influence the individual heterogeneity of a single organism. Some of these factors have been illustrated here, namely Gender, Age, and size. Let's take gender first - a difference is easily seen in the colour of the plumage of the Fairywren, a species of birds. Spotted Deer is a good example of distinguishing age, the antlers helping one distinguish a fawn from a juvenile and an adult. Finally, owls come in various shapes and sizes, each unique and important in its own way. The owls illustrated are great greys, barn owls, jungle owls, great horned owls, and pygmy owls.


Great Horned Owl 5
4 Great Grey Owl
6 Jungle Owl
7 Spotted Deer

Do Habitats Contribute to Heterogeneity?

Heterogeneity is influenced by a variety of factors of the species itself. However, one would question whether the environment or the habitat influences individual heterogeneity. The answer is yes. The habitat or the environment of an animal greatly influences their behaviour. To explain this, take leopards that reside in India. Leopards occupy various habitats in India, ranging from grasslands to temperate deciduous forests. In fact, leopards are almost found in any type of forest habitat within India except mangroves and deserts. Leopards in different habitats therefore, have different behaviours and adaptations suited for each environment. A leopard in a grassland, for example, would face great difficulties in surviving in lush rainforests.

Alpine Forests

Alpine forests contain coniferous trees, and the landscape is dotted with plenty of rocky cliffs and steep slopes. High altitudes and low temperatures make this habitat one of the more challenging locations for leopards.

Grasslands

Grasslands are usually vast expanses of grass and shrubs. They definitely receive more rain than deserts, but much less rain than forests. There is a lot of tall grass present, which allows leopards living there to blend into the surroundings whilst hunting prey.

Temperate Forests

Temperate forests are abundant in India, and leopards thrive in these regions. These forests are characterized by wide, thin leaves that change colour and drop from the trees as the seasons change.

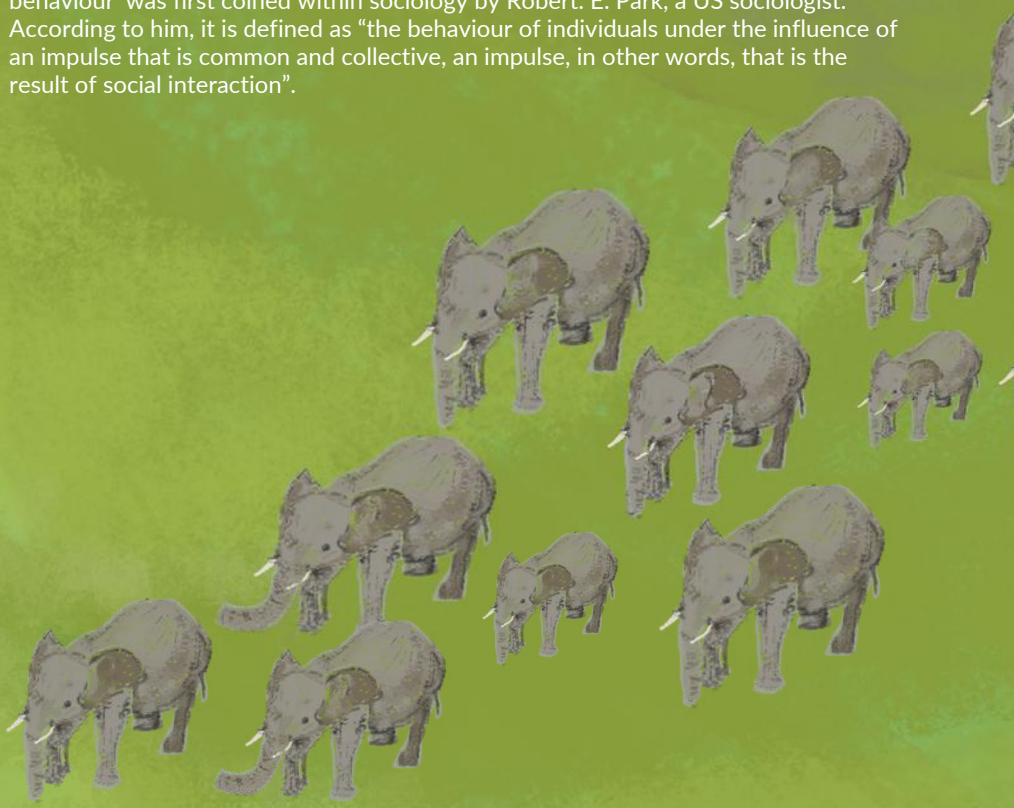
Tropical Rainforests

Tropical Rainforests are usually dense and warm, and experience heavy rainfall almost all year around. The canopies are heavy, casting deep shadows that allow the leopard to go unnoticed.

Hence, habitats are crucial for the survival of any animal, and the interaction between the environment and said animal is essential for both to thrive. Every animal is different, and sometimes the difference can be attributed to where the animal lives. This difference may even be apparent in the appearance and structure of the animal, as seen in the leopards that thrive in India's various environments. This difference in habitats hence, contributes to the heterogeneity.

Collective Dynamics

Just like humans, some animals usually do not wander alone. They form groups and interact with members of the group daily. Each group member regulates their behaviour to complement every other individual, allowing them to move as a group collectively. This behaviour of the entire group is known as 'collective behaviour' or 'collective dynamics', as said by many scientists. Interestingly, the term 'collective behaviour' was first coined within sociology by Robert. E. Park, a US sociologist. According to him, it is defined as "the behaviour of individuals under the influence of an impulse that is common and collective, an impulse, in other words, that is the result of social interaction".



Various studies and experiments have shown that differences in the physical makeup of every individual drive an animal group's structure, behaviour, and functioning. The structure of the group may include how each individual is organized and the roles of each individual; the function of the group may be its temporary or permanent goal, and the group's behaviour refers to its `collective behaviour.' These 'individual make-ups' consist of physiological, cognitive, and behavioural components - together, which build the facets of heterogeneity. Individual heterogeneity extends to more than collective dynamics, having social, ecological, and evolutionary significance in the environment.

To give an idea regarding the connection between collective behaviour and individual heterogeneity, let us look at a honey bee colony. A honey bee colony usually consists of a queen bee, female worker bees and male drones. Jitesh Jhawar, an Ecology Professor at Ahmedabad University, studied, along with other researchers, the behaviour of a colony of honeybees. In their study, every individual bee was studied in relation to rising temperatures in the external environment. In simpler words, for honeybees to regulate the temperature of the nest, some either moved out of the nest brought water to the colony or attempted to circulate air within the colony. It was found that older bees usually evacuated their nests, and it was not just age that influenced these behaviours. Bees depicted certain kinds of behaviour - such as fanning, depending on the behaviour of the other individual bees surrounding them, thereby showcasing how individual heterogeneity influenced the collective behaviour of the nest. [3]

Why stop there? Let's look at another example of a typical Asian elephant herd. An elephant herd primarily consists of adult females and young calves that are cared for within the group. In a journal article written by T.N.C Vidya and R. Sukumar, the reproductive behaviour of individual female elephants is theorised to influence the reproductive behaviour of other individuals in the herd. One way in which this is seen is by the age and maturity of female elephants. Older and more mature elephants that have already mated are theorised to drive away potential mating opportunities for younger, more submissive elephants, thereby maintaining the hierarchy of the herd and possibly deciding the future matriarch. [4]

How an ecologist study heterogeneity?

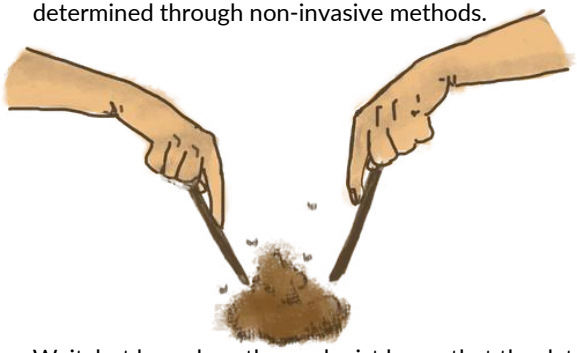
Given how immensely integrated the concept of heterogeneity is within ecology, how does one even study heterogeneity? How can we see the influence of individual heterogeneity on collective behaviour? Scientists and researchers tackle these questions one tiny piece at a time. They take into account various factors that they might think influence the heterogeneity of a single species.

Research conducted by Professor Ratna Ghosal, Brinky Desai, Tathagata Bhowmik and Rohith Srinivasan from the Division of Biological and Life Sciences at Ahmedabad University, in collaboration with Nikhil Whitaker from Madras Crocodile Bank Trust studied stress physiology of mugger crocodiles in Gujarat, India. Stress physiology, in simple terms, is essentially the body's reaction or response towards stressful conditions caused by the surrounding environment or within the body itself. This paper studies two different populations of mugger crocodiles, which were influenced by the stress present in their respective habitats. This is done by investigating the amount of stress hormones present in the 'scat' or poop of the crocodiles. Let us explore how heterogeneity plays a crucial role and creates various constraints in this particular context.

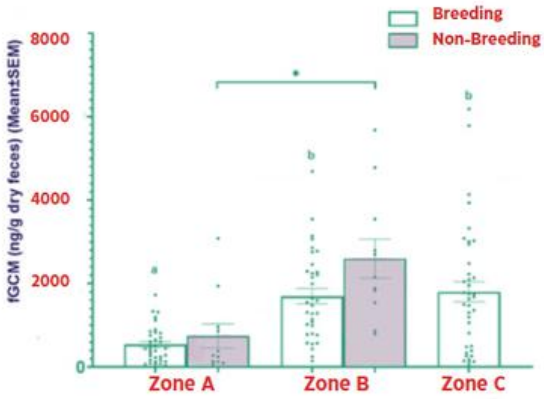
Do you know how an ecologist might study crocodile behaviour? Maybe there is something different about the two groups that they can study, but what is it? In this case, their habitats are different even though they are just 45 kilometres apart geographically! One group of crocodiles dwells in Charotar's clean, fresh lakes and have little to no conflict with people. Another group of crocodiles dwells in Vadodara city's nearly polluted Vishwamitri river and are known to have conflicts with people. Unfortunately, these conflicts often ended with either humans getting injured or with muggers getting killed.

Okay, the ecologist has figured out the differences in habitats, but is there something specific within the locations that influences the stress responses of the animals? Maybe the difference in quality of the water is the one that causes the most stress to the crocodiles, or maybe the type of food the crocodiles have in the waters. Maybe the conflict in Vadodara is the reason for the stress physiology of the crocodiles there, or maybe the male-to-female ratio in the populations.

To investigate possible factors influencing stress, ecologists must first gather data. There are two ways to collect data: Invasive methods, such as blood sampling, need physical contact and body penetration to collect data, whereas non-invasive approaches, such as faecal samples, do not cause direct harm or contact with the animal. In the case of these crocodiles, the concentration of stress hormones can be determined through non-invasive methods.



Wait, but how does the ecologist know that the data they are collecting is valid? What if studying the concentration of stress hormones isn't correct, and they need to study a different chemical? They collect data from another source, from crocodiles that exist in similar conditions. The ecologist, therefore, collects data regarding the stress levels of captive mugger crocodiles in the Madras Crocodile Bank.



Now, what should the ecologist do with the data? Is just averaging the numbers enough? Actually, ecologists focus also on information collected from each and every individual. Error bars can be added to accomplish this. There are several applications for error bars, and one of them is to show the average deviation of the data obtained from the typical value. The bar graph shown is an amazing example of this! The individual dots on the graph show the individual data points collected, and the bars show the averages of the amount of fGCM across the groups in both breeding and non-breeding seasons.

All of this forms stepping stones in the process of studying heterogeneity. Of course, this is but a drop in the ocean, and ecologists face many more challenges during research. For these crocodile populations, the ecologists have determined that the muggers from Vadodara do indeed experience higher stress levels than the muggers from Charotar during both breeding and non-breeding seasons. This indicates that the crocodiles may be experiencing a condition known as ‘chronic stress’, which basically means it is a prolonged feeling of stress that can negatively affect the quality of health.

Given this, the ecologist can conclude that mugger crocodiles in Vadodara are living in a much more troublesome environment than the crocodiles in Charotar. However, what may have caused this? As mentioned before, it is difficult to determine the exact cause for this difference in stress levels, but the research has proposed various ways through which possible factors can be studied. Remember, every small difference in the behaviour and environment of an animal can lead to huge consequences in the behaviour of an entire group.

And there it is! Heterogeneity does indeed play an important role in ecology - if not biology as a whole. It is the very foundation of biology and is seen in almost every process, mechanism, or structure in nature. Heterogeneity also arises at various levels of ecology, moving from just a single animal to a population of animals to an entire ecosystem. Sure enough, as the level at which heterogeneity is observed gets higher, studying it gets a lot harder. Despite this, ecologists have found multiple ways to make researching heterogeneity easier during their research, though, despite; heterogeneity still remains one of the most interesting and challenging subjects in the world of ecology.

Further Readings

[1] Ecological Heterogeneity. Ecological Studies, 1991. https://doi.org/10.1007/978-1-4612-3062-5.

[2] Jolles, Jolle W., Andrew J. King, and Shaun S. Killen. “The Role of Individual Heterogeneity in Collective Animal Behaviour.” Trends in Ecology & Evolution 35, no. 3 (March 1, 2020): 278–91. https://doi.org/10.1016/j.tree.2019.11.001.

[3] Jhawar, Jitesh, Jacob D. Davidson, Anja Weidenmüller, Benjamin Wild, David M. Dormagen, Tim Landgraf, Iain D. Couzin, and Michael L. Smith. “How Honeybees Respond to Heat Stress From the Individual to Colony Level.” Journal of the Royal Society Interface 20, no. 207 (October 1, 2023). https://doi.org/10.1098/rsif.2023.0290.

[4] Vidya, T. N. C., and R. Sukumar. “Social and Reproductive Behaviour in Elephants.” Current Science 89, no. 7 (2005): 1200–1207. http://www.jstor.org/stable/24110972.

[5] Desai, Brinky, Tathagata Bhowmik, Rohith Srinivasan, Nikhil Whitaker, and Ratna Ghosal. “Monitoring the Stress Physiology of Free-ranging Mugger Crocodiles (Crocodylus Palustris) Across Diverse Habitats Within Central Gujarat, India.” Conservation Physiology 12, no. 1 (January 1, 2024). https://doi.org/10.1093/conphys/coae035.

Shreya Venkatesh is a student of Integrated MS Life Sciences at Ahmedabad University. She has been studying biology in all of its forms and has always had a strong interest in ecology. She thinks that people from every sphere of life should have easy access to knowledge about topics related to the sphere of ecology. She hopes that this booklet would be a step in that direction, and help people comprehend basic concepts like heterogeneity whilst valuing it for its true complexity.

Vidhi Narvekar is a student of BA (Hons) majoring in Psychology at Ahmedabad University. She is keenly interested in environmental sciences. She is a visual storyteller, passionate about ecology and wishes to foster a deeper understanding of the environment through various depictions of complex yet simple phenomenon in nature, such as heterogeneity.

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