INTRODUCTION

A Sense of Self

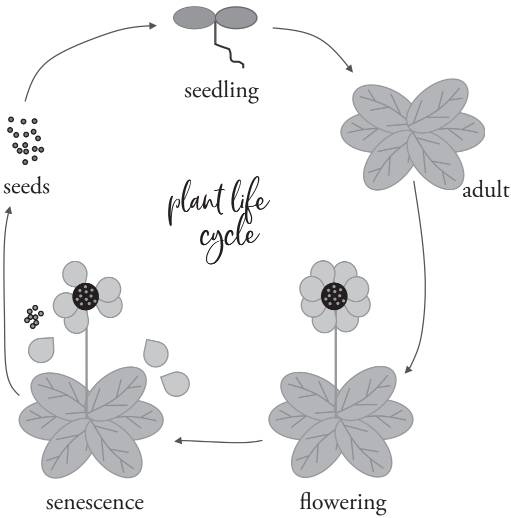
Imagine a life in which one's entire existence must be tuned and tailored to the changing, and at times harsh, environment. A life in which there is no potential for escape. This is the life of a plant. It is difficult for us, as humans, to comprehend this kind of existence. Although we usually stay put in the face of short-term adversity because we have physiological mechanisms to deal with minor annoyances, like being too hot (sweating) or too cold (shivering), if such conditions persist or become more extreme, we can choose to uproot ourselves and physically move to a different, hopefully better, location.

Plants don't have that option.

Because plants are largely immobile throughout their life cycle, if they are to survive and thrive in dynamic environments, they must have a keen sense of what is going on around them and the ability to respond appropriately. From the very outset of life, sensing the environment is crucial. Where a seed lands and germinates determines the surroundings in which the resulting plant will spend its entire life.

Germination is the start of the life cycle for seed-bearing plants. The seedling emerges from the seed, and the plant then matures to adult stage. Following a period of vegetative growth, the plant enters the reproductive stage, when it produces flowers. The next stage progresses from flowering to developing seeds. After the mature seeds are released, the aging plant enters senescence, during which petals and leaves may be shed. In some species, individuals die after reproducing, while in others, they go through recurrent reproductive cycles.[1]

Although plants are all around us, most of us have little understanding of their exquisite abilities to anticipate, defend against, and adapt to constantly changing conditions. The failure to adequately recognize plants and their roles in the ecosystems we inhabit is sometimes referred to as "plant blindness."[2] This term has become increasingly controversial because it is based on a disability metaphor; that is, it reflects deficit-based thinking around blindness.[3] We might instead refer to the tendency to overlook plants as "plant bias." Indeed, experimental research and surveys



A seed-bearing plant starts life when a seed germinates, making the transition to become a seedling. The plant matures to adult stage and undergoes a second transition, to the flowering stage. The plant then progresses from flowering to developing seeds. After the mature seeds are released the aging plant enters senescence, during which petals and leaves may be shed.

have demonstrated that humans prefer animals to plants and are more likely to notice and remember them.[4] We also need a companion term that encourages a deepening awareness and appreciation of the plants around us: some refer to "flora appreciation," but I prefer "plant awareness."[5] Reducing plant bias and increasing plant awareness are important not only for plants, but for humans—for our physical, mental, and intellectual health.

The aim of this book is to increase your plant awareness, mitigate potential biases against plants, and introduce you to the wisdom of plants and what they can teach us.

One of the themes we will explore is how plants sense and respond to the environment. If you pay closer attention to plants around you, you will see many examples. You have probably noticed a houseplant stretching toward the light from a window. This plant is showing an active adaptation behavior—sensing and seeking out light. Because plants use light to produce their food (in the form of sugars) through the process of photosynthesis, they will bend themselves to get it.[6]

Another example is the dropping of a maple tree's leaves in autumn. This is a seasonal, energy-saving behavior; it would be expensive for the tree to maintain its leaves during the winter. Shedding its leaves allows the tree to persist in a quieter metabolic state. The brilliant, intensely hued burst of color that appears before the leaves fall (a result of the breakdown of the green pigment chlorophyll) is an illustration of the kind of complex behaviors that plants undertake in response to environmental cues.[7]

A maple tree's shedding of its leaves in the fall is different in one important way from a houseplant's bending toward the light. All plant species show some inherited adaptations, such as a distinctive leaf shape or a deciduous versus evergreen life cycle, that have evolved over time and are genetically fixed, being passed from one generation to the next. But plants also exhibit environmental adaptations that are not genetically fixed—rather, they occur within a single generation or lifetime and are usually not heritable. These environmentally determined changes are driven by which genes are expressed, or actively used. They include changes in a plant's phenotype (observable characteristics) such as leaf size, thickness, color, or orientation, or stem length or thickness, based on changing environmental cues. This kind of change of form and function in response to dynamic environmental conditions, such as light or nutrient availability, is known as phenotypic plasticity.[8]

Plants sense and respond to more than environmental conditions; their awareness extends to the plants and other organisms that surround them.

We could call them “nosy neighbors.” Plants know “where” they are through environmental sensing, and they also know “who” is around them. That knowledge helps them make decisions about whether to collaborate or compete. They will compete with a neighboring plant for access to sunlight only if it makes sense to do so; if the neighbor is already significantly taller and the competition is unlikely to be successful, they will avoid competing. In some cases, as we will see, they may actually collaborate on gaining access to sunlight. Plants can also detect the behavioral responses of their neighbors, allowing them to extend their awareness of environmental cues and changes. And they sometimes even change their behavior depending on whether their neighbors are relatives.

Plants receive and respond to both internal and external cues and appear to have a recognition of ecosystem diversity, that is, they can perceive the range of individuals around them and the responses these neighbors exhibit to environmental cues. They monitor external changes and initiate internal communications pathways to coordinate their response to dynamic conditions.[9] The cues they respond to can be abiotic, or nonliving, cues, such as information about the temperature or the availability of light, water, or nutrients. Biotic signals, those originating from other living organisms, also serve as potent cues that can, for example, enable a plant to mount a defense against predation, herbivory, or bacterial or viral infection. Some plants, when attacked by insects, produce compounds that inhibit the digestion of the attacking insect, thereby limiting further damage.[10]

Plants may even have a form of memory. In some cases, it is mediated by epigenetic changes. Epigenetic changes modify how genes are expressed or activated; they do not alter the genetic code itself. An environmental stimulus may cause a molecular "flag" of sorts to regulate whether or not a gene is used to produce a protein. The change in protein regulation then modifies the plant's phenotype. Such epigenetic changes are sometimes transmitted to subsequent generations. The definitive mechanisms and specific roles of the environment in transgenerational epigenetic control in plants are still under study.[11]

One of the best known examples of plant memory is vernalization: certain plants will not flower until they have been exposed to a lengthy cold period. The winter cold is "remembered" as a sign that the plants should flower in the spring. Sun-tracking plants, such as sunflowers and Cornish mallow, also display memory, turning toward the direction of the sunrise before dawn.[12]

Plants use internal and external cues alongside adaptive behaviors and energy budgeting to make the most of the environment in which they grow. Photosynthesis requires light, inorganic carbon (in the form of carbon dioxide), and water, and plants also need nutrients like phosphorus and nitrogen. Therefore, it is not surprising that they are extremely sensitive to the availability of these resources and manage their energy budgets carefully. To make their food, plants allot energy to grow the leaves needed for harvesting sunlight. Then they convert the gathered light energy to chemical energy (sugars), using carbon dioxide and water. At the same time, they limit nonproductive uses of energy. In favorable light conditions, for example, they contribute energy to leaf building while diverting energy away from stem elongation.

Plants also show finely tuned adaptive responses when nutrients are limiting. Gardeners may recognize yellow leaves as a sign of nutrient deficiency and the need for fertilizer. But if a plant does not have a caretaker to provide supplemental minerals, it can proliferate or elongate its roots and develop root hairs to allow foraging in more distant soil patches. Plants can also use their memory to respond to histories of temporal or spatial variation in nutrient or resource availability.[13] Research in this area has shown that plants are constantly aware of their position in the environment, in terms of both space and time. Plants that have experienced variable nutrient availability in the past tend to exhibit risk-taking behaviors, such as allocating energy to root elongation instead of leaf production. In contrast, plants with a history of nutrient abundance are risk averse and conserve energy. At all developmental stages, plants respond to environmental fluctuations or unevenness so as to be able to use their energy for growth, survival, and reproduction, while limiting damage and nonproductive uses of their valuable energy.[14]

Altogether, these types of responses suggest that plants are able to learn and remember, if we understand learning as a change in behavior based on active recall, and memory as cellular communication about prior experiences.[15]

Because they exhibit a kind of awareness and memory, one could consider that plants know "who" and "what" they are. They proceed from this knowledge of self to go about *being*. And it is in the process of being that plants discern, respond to, *and* influence patterns in the environment. In other words, plants give survival their very best effort, while fully assessing the potential for success based upon the specific environment in which they exist.

So, while it may indeed look to the uninformed eye as though plants are just "sitting there," they exhibit awareness and intelligent behaviors from the very earliest stages of development until senescence or death. They have developed extraordinary abilities to sense what is going on around them and tune their growth and development to environmental cues to maximize productivity and survival. Because of this constant exploring and monitoring, plants should not be viewed as immobile and passive, argues the philosopher Michael Marder; the place occupied by a plant "dynamically emerges from the plant's living interpretation of and interaction with its environment."[16]

Whether one understands plants as aware or as intelligent, behind either concept lies a general appreciation of plant behavior. The idea that plants "behave," rather than passively existing or growing, has only recently become more widely accepted among biologists. Behavior in plants often manifests itself in the way they grow—growing at a different rate, or in a certain direction. Because plants grow slowly, their activity occurs on a different time scale from the kind of movement we call "behavior" in animals.

Another obstacle to accepting the idea of plant behavior came from the long-standing belief that behavior is only possible in organisms with a central nervous system, which plants lack. But scientists began to understand behavior more broadly, as describing the ability to gather and integrate information about the condition of the external and internal environment and then using that information to alter internal signaling or communications pathways (neural networks in animals and signal transduction pathways in organisms such as plants), resulting in changes to growth or allocation of nutrients and other resources. With this understanding, the idea that plants can "behave" became more acceptable.

Once we acknowledge that plants exhibit behavior, does that mean they are also able to "choose," "make decisions," and have "intention"? Most plant scientists agree that the ability to distinguish between multiple signals and to selectively alter behavior based on one signal over another is evidence of decision-making. Plants also have intention, contends Michael Marder, though it differs from intention in animals: "When animals intend something, they enact their directedness-toward by moving their muscles; when plants intend something, their intentionality is expressed in modular growth and phenotypic plasticity. Plant and animal behaviors are the accomplishments of the goals set in their respective intentional comportments."[17]

The next question, whether these abilities demonstrate that plants possess intelligence or consciousness, is a topic that garners both avid supporters and a larger group, perhaps, of detractors. And others still remain agnostic, noting that plants need not have consciousness or intelligence to be viewed as worthy of study and awe.[18] Regardless of whether plants possess awareness—the ability to perceive what is going on around them and respond accordingly—and consciousness—the ability to actively perceive, contemplate, and assign meaning to a decision about a particular response—the complexity of plants and their abilities to sense, integrate, and respond to environmental stimuli has been increasingly accepted. Further, whereas there are still controversies about, and in some instances resistance to, seeing plants as intelligent, there is increasing consensus that plants, and other organisms such as ants and bees that lack highly developed brains, can exhibit intelligent behaviors that allow them to respond as individuals or in community to a dynamic environment.

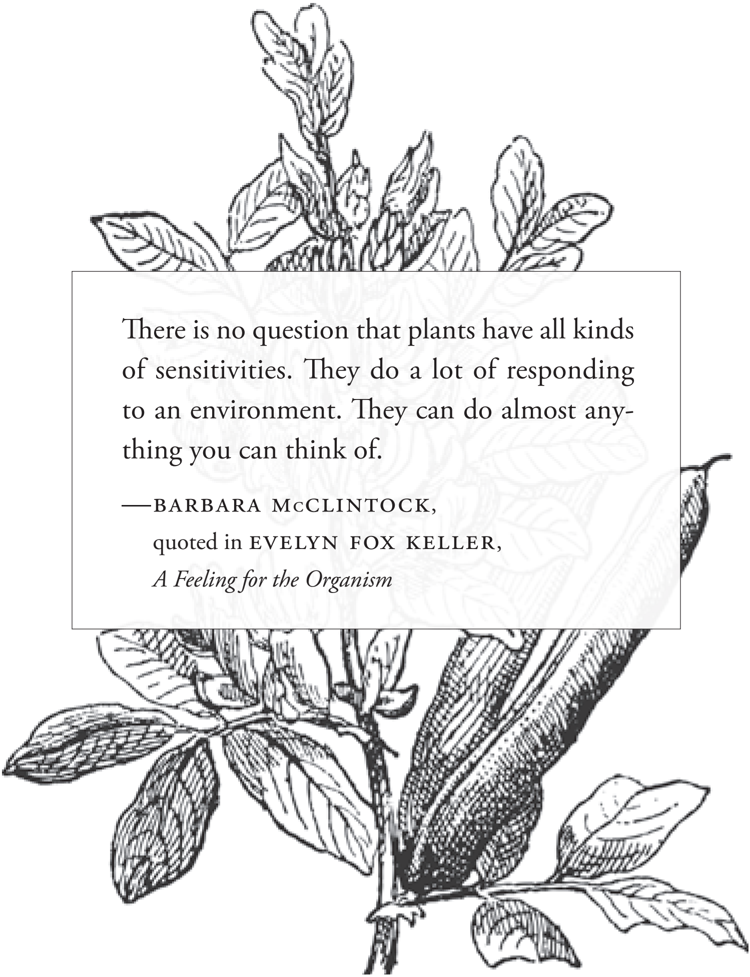
The evidence that plants make adaptable choices—behaviors that increase their success and persistence—

merits deep reflection and can provide valuable lessons for humans. Like all biological organisms, plants usually make choices that are clearly beneficial, yet they can also initiate behaviors that we might characterize as bad, either because maladaptive for the plant itself, or because harmful to others. Biologists believe that, with some exceptions, the choices a plant makes will usually benefit its own survival and reproduction because over evolutionary time, plants that make better choices will have more offspring than those that make worse choices. But sometimes what's good for one species is bad for another. For example, some plants can harm neighbors through release of chemical compounds or by taking over entire ecosystems. The latter strategy often characterizes plants deemed invasive, such as kudzu, which is a major ecosystem problem in the southeastern United States, as it has replaced native plants and impacted local insects and other animals.[19]

Despite the harm that plants can sometimes do, for the most part, their behaviors work to benefit their own flourishing and that of the communities in which they live. In the pages to come, we will explore many of those behaviors. We can learn a great deal from observing how plants live in their environment. Notably the knowledge of plants—lessons from these organisms on *being*—shows us that you thrive or languish based on your ability to know who you are, where you are, and what you are supposed to be doing. Then you must find a way to carry on from this "sense of self" to your surroundings and to pursuing your purpose, a task that may be challenging if you are in distress, compromised, or have mutated from your ingrained, encoded, or adapted purpose. Plants in distress have some means to improve their chance of recovering from stress and resuming growth. And if the plant has a caretaker with the ability to recognize signs of distress, that caretaker can provide the necessary assistance.

All of the activity that plants engage in—operating sophisticated light catching systems, foraging for nutrients, communicating warnings of danger to others within their community—is how plants sense and adapt to their environments. It is how they survive and thrive. And it is occurring all of the time, right in front of us.

As humans we must first pay attention. We must look beyond what is quickly observed to be fully aware of how plants support themselves and the other organisms with which they live, and how they transform their environment. Then, after careful, close observation, we must ask the right questions to learn from them about how to live with purpose, agency, and intention. And maybe we can take on some of these behaviors. Their lessons are ours for the learning.



There is no question that plants have all kinds of sensitivities. They do a lot of responding to an environment. They can do almost anything you can think of.

—BARBARA McCLINTOCK,
quoted in EVELYN FOX KELLER,
A Feeling for the Organism

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A Changing Environment

I vividly remember one of the first science experiments I ever performed, when I was in kindergarten. By watching a simple bean seedling grow, I learned about the remarkable ability of plants to adapt to their environment—and now, decades later, I am still in awe at that ability. The experiment was coordinated by my kindergarten teacher, who instructed each of us to grow a bean seedling on a windowsill at home. We were to put wet cotton balls or some wet soil in the bottom of a plastic cup, add a few beans, and observe them daily. One day when I looked at my beans, I made an exciting discovery. I noticed that a crack had appeared in one of them, and a tiny root was emerging from the crack. Then, in the days that followed, a stem began to emerge from the other end of the bean, and tiny leaves unfurled. Reaching toward the sun in our window, the bean plant continued to grow.