ECOSYSTEM DIVERSITY

One of the first issues to think about when considering a release of a GM plant is the environment it will be released into. Ecosystems are a complex balance of processes that are in constant flux. Some ecosystems are resilient, while others are more fragile. Some plants are highly adaptable and found in many different environments; others need specific conditions to survive. When beginning to assess the potential use of a GM plant, fundamental questions about the wild-type plant and the potential effects on ecosystem diversity need to be addressed. What is its range? What is the mode of reproduction? What environmental niche does it fill? While a GM plant may not be as fit as the wild type, pollination and outcrossing are issues that would still need to be considered.

The United States Department of Agriculture maintains an online database for plants growing in the U.S. This website is a good place to find information about the wild-type version of the GM plant of interest, which should form the basis of any environmental assessment. The database lists many basic details about each plant, including occurrence information, habitat information, federal/state status (i.e. invasive, weed, rare, endangered, etc.), and related species, as well as links to other websites for more information. While not exhaustive, this material will be a helpful starting point when looking at the following sections on how plants (GM or not) can disrupt ecosystems.

Native vs. non-native

Native plants may have more closely related plant species growing in similar environment, thus increasing the chances of hybridization. However, native plants tend to have established control mechanisms, such as competition from other plants and damage from herbivores, which prevent the species from overtaking an area. Non-native plants sometimes benefit from what is called ecological release, when a species enters a new area and is no longer constrained by previous control mechanisms and can flourish. When this happens, a species tends to be called invasive.

Both native and non-native species can be part of a balanced and functioning ecosystem. But sometimes, abiotic factors can upset the balance and alter the environment to a point where certain species are put at an advantage and have explosive population growth. If the GM plant will be publicly available, the density at which the plant is released into the wild may determine its potential for ecosystem disruption. A few individuals planted sporadically may not cause significant impact, but a more dense or large-scale planting, such as an entire garden or field, can begin to upset the balance because the chance of survival and spread is more likely. The more attractive looking the plant is, the more likely a disruption may occur. Human-influenced changes can have large unintended effects on the environment.

Annual vs. perennial

Annual plants depend solely on seeds for regenerating each year. Perennial plants can be long-lived in a single location, relying on vegetative propagation through rhizomes, corms and tubers to regenerate dying plant material. Perennials

still utilize seeds, which then establish new plants in other areas. Viable seeds from both annuals and perennials can remain in the seed bank for long periods of time. When appropriate conditions are met, the seeds germinate to begin the life cycle anew. If the GM plant is perennial and engineered to be sterile, the plant may persist asexually in the wild for a period of time through vegetative propagation. Staghorn sumac and quaking aspen are examples of invasive plants that reproduce vegetatively, often forming dense monospecific stands.

Competition

Competition is the interaction between two or more individuals whereby the overall fitness of one is affected to due limited resources. For example, if a plant is able to grow faster, bigger, or is more attractive to pollinators than another species, that plant is more competitive, causing the other species to become less abundant over time. Partial or complete species replacement within a community will have ecosystem level effects, altering both species richness and abundance. Invasive species are thought of as strong competitors in many ecosystems, which leads to their persistence and spread.

First, let's look at the aboveground effects of interspecific competition among plants in an area. Many herbivores (animals and insects, mostly) rely on plants as both a food source and, in the case of insects, as an oviposition site. While some species are generalist, others prefer or even require certain plants for their dietary and reproductive needs, termed specialist. Changing the balance of what plants are available could lead to fewer offspring being produced by both types of herbivores causing a change in local abundance. Reduced herbivore abundance will in turn affect the species that rely on them as a food source, like parasitoids, parasites and predators. Similarly, a change in plant species richness means pollinators may not have access to their preferred nectar and pollen sources. This can further weaken the fitness of the remaining plant species due to poor pollination services, if the pollinator has to leave the area to find forage.

Resources in nature are finite. For example, a plant that takes up nitrogen from the soil means less is available for other plants nearby (and for those that emerge later as well). It's important to consider what time of year the GM plant will invest most of its energy into growth. For most plants, this happens in spring and early summer. If the GM plant is one of the first to emerge in an area, it benefits from using available resources, which can lead to strong, vigorous growth. A GM plant with large or broad leaves can prevent light from reaching young saplings of other plants that rely on sunlight for photosynthesis for energy production.

Competition for resources can happen at many different levels. Altered plant richness and abundance within a community will affect belowground processes as well. Microbes, like bacteria and yeast, often form symbiotic relationships with plants, while detritivores rely on decaying plant and animal matter for nutrients. Water and nutrient consumption, as well as what the plant will release after senescence are issues involved in resource competition that should be evaluated on a case by case basis. Resource competition can cause a change in community composition, affecting not only those plants that grow alongside the GM plant, but also those that come after it. Species turnover can have other large ecosystem level

effects. For example, an invasive species of grass that has invaded the Californian grasslands has led to more frequent fire cycles than in the past (Brooks *et al.* 2004).

Invasiveness potential

What is an invasive species?

United States Executive Order 13112 (EO 13112) defines an invasive species as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.'' An invasion is an uncontrolled or unintended spread of an invasive species from its typical range. This is usually initiated by human actions. Within a new environment an invasive species takes a different ecological role. This may include a faster dispersal rate or an ability to overtake neighboring species. There are several reasons for this may occur- an invasive species may not face the same predation pressures or they may be able to exploit more resources in a new environment.

While there is a concrete, legal definition for an invasive species in the United States, the academic community refers to ambiguous and sometimes contrasting definitions of an invasive species. The aforementioned EO 13112 definition altered a definition of invasive species which did not include a clause alluding to harm (Rejmanek *et al*., 2002). Prior to EO 13112 (established in 1999) the definition of invasive species was that of an alien organism in a new environment. This definition acknowledges the fact that many invasive species do not cause harm immediately upon their introduction to a new environment. Therefore scientists cannot immediately determine if an introduced species will cause harm. From a management perspective, this means that actions such as preventing a species from entering the country or aggressively targeting an alien species, cannot be justified until harm has occurred and the species is considered invasive. Scientists remain divided over which is the appropriate definition for an invasive species (Young & Larson, 2011; Humair *et al*., 2014). To further complicate the matter, ecologists commonly define an invasive species as an introduced species that spreads rapidly in a new environment (Ricciardi & Cohen, 2007). The debate is unlikely to be settled anytime soon, invasive species will remain a term with multiple definitions.

What is a noxious weed?

The United States Plant Protection Act (2000) defines a noxious weed as "any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment." The Plant Protection Act enables the United States Department of Agriculture (USDA) to set a list of noxious weeds and regulate the movement and introduction of these species within the country. There is no ambiguity surrounding the term noxious weed, it refers to an unwanted, damaging plant or plant product. Individual states within the United States also establish lists of noxious weeds.

What are the characteristics of an invasive species?

There are many different characteristics which lend themselves to an organism becoming an invasive species. These characteristics vary by taxa (animals, microorganism, etc.), here we will focus on characteristics of invasive plant species.

One of the most important traits for a successful invasive plant is self-fertilization (Radosevich *et al.,* 2007). This association is prevalent enough that it is sometimes called *Baker's rule*: the chance of a population becoming established or spreading are greatly aided when an individual does not need to be fertilized by another individual (Baker, 1974).

Invasive plants have been associated with small seed sizes and short juvenile periods (Kolar & Lodge, 2001). Smaller seed size may help guard against herbivory (Kolar & Lodge, 2001). Lower rates of herbivory improve an individual's chances of reaching reproductive age. Small seed size may also improve seed dispersal range and would thus improve survival rates for the population (Radosevitch *et al*., 2007). A shorter juvenile period allows individuals to reach sexual maturity quicker and increase seed dispersal.

Some invasive plant species have been able to adapt following an introduction to a new environment (Radosevich *et al.*, 2007). This means they are able to adapt to different environmental conditions or alter their reproduction cycles to coincide with a different climate.

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