Design for Biosecurity

Prof. Mainak Das

Department of Design

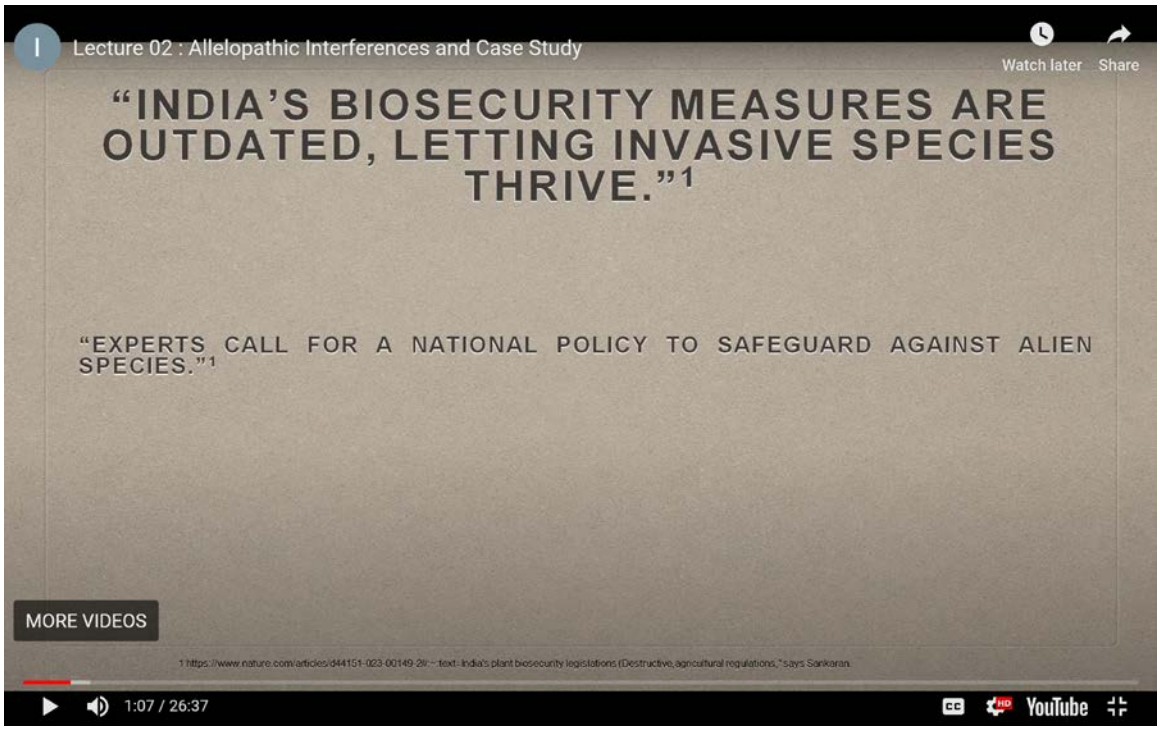
Indian Institute of Technology, Kanpur

Lecture 2

Allelopathic Interferences and Case Study

Welcome back to the second class. In our previous session, I provided a broad overview of the course structure. We explored the diverse biogeographic zones of India, examined the global impact of deforestation, and discussed various human interventions that are negatively affecting water biodiversity, forest diversity, and agricultural land. I also outlined the topics we will cover throughout the course and concluded with a slide emphasizing that India's biosecurity measures are outdated, allowing invasive species to thrive. Today, we will delve deeper into this crucial concept of invasive species, which will be central to our discussion.

(Refer Slide Time: 01:07)



Let’s begin by exploring what we truly mean by "invasive species." To illustrate this, let me show you a slide that might be familiar to some of you, particularly those who consume fish. You may have encountered these fish in the market, these are African catfish. Now, catfish are quite common and can be found across the globe, on every continent. However, it's important to note that each continent or biogeographic zone hosts different species of catfish, which have adapted uniquely to their respective environments. Although they belong to the same family, their characteristics can vary significantly depending on the region.

(Refer Slide Time: 01:34)

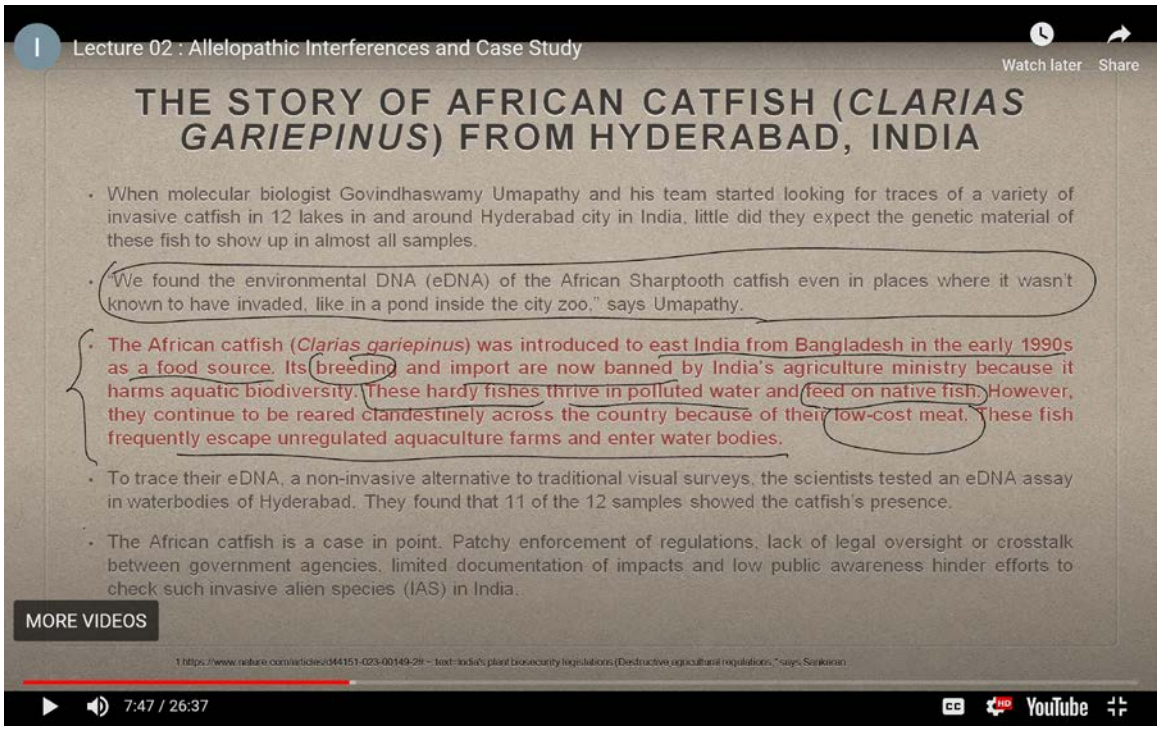
The African catfish, for instance, have adapted to the environments of their native regions. However, when they escape from regulated aquaculture farms, they can enter local water bodies, causing significant disruption. An intriguing study conducted by the Centre for Cellular and Molecular Biology (CCMB) in Hyderabad sheds light on this issue. The story of the African catfish, Clarias gariepinus, in Hyderabad, India, is particularly fascinating. Biologist Govind Swami Mohapatra and his team initiated an investigation into the presence of various invasive catfish species in 12 lakes around Hyderabad. What they

discovered was astonishing: environmental DNA of the African sharp-toothed catfish was found even in places where it was not known to have invaded, such as a pond within a city zoo.

This raises an important question, how did this particular catfish species find its way into the Indian biogeographic zone? Historically, the African catfish was not part of India's aquatic ecosystems. However, as highlighted in the slide, the African catfish was introduced to East India from Bangladesh in the early 1990s as a food source. This ties back to a point I mentioned in our first class, introducing new species into a biogeographic zone without careful consideration can have unforeseen and often detrimental consequences.

As we continue with today's lecture, we will further explore the concept of invasive species, their impact on local ecosystems, and the critical need for updated biosecurity measures to prevent such disruptions.

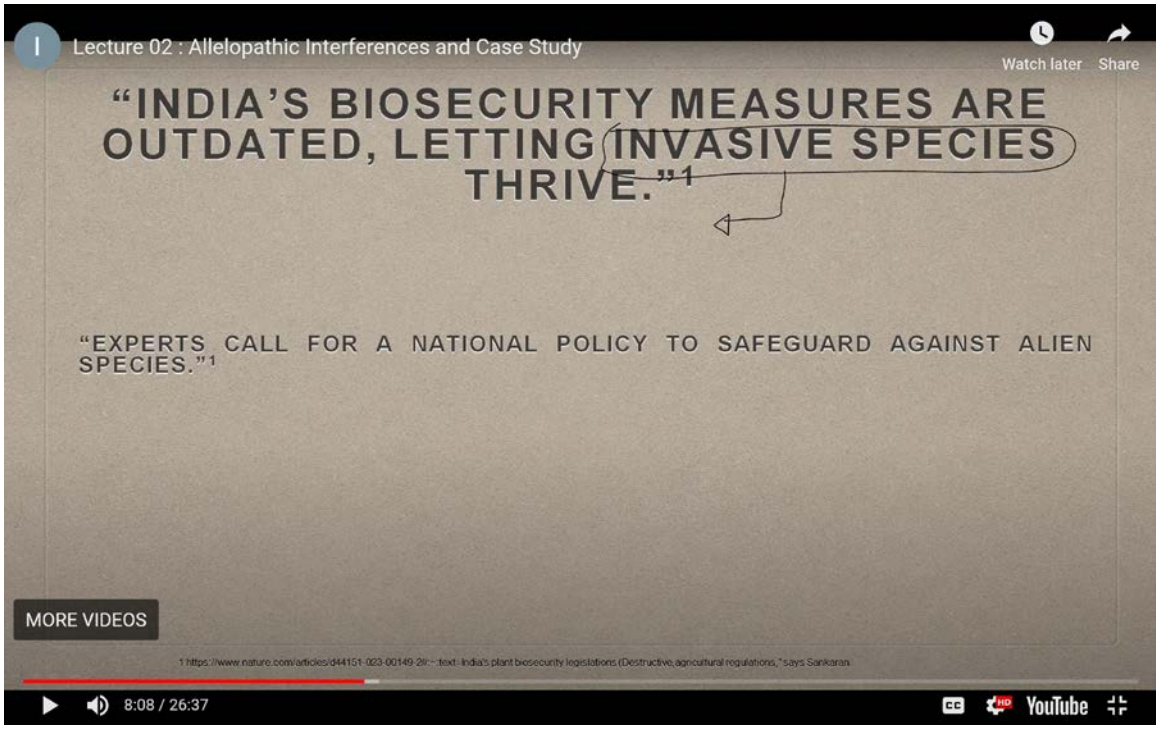
(Refer Slide Time: 07:47)



The drive to meet the demand for food, particularly the desire for certain types of fish, often leads to decisions that can have unforeseen consequences. For instance, when there's a shortage of fish, the solution might seem simple, introduce fish from another region, even if that region is as far away as another country. However, this well-intentioned solution can have significant drawbacks. The newly introduced species might be better adapted to survive in the new environment, potentially outcompeting and even displacing the native species. This is precisely what happened in the case we are discussing.

Initially, the introduction of the new fish was celebrated by the business community, especially those involved in the fish trade. Here was a species that grew faster, produced more meat, and was well-liked by consumers. It quickly became a market favorite. However, this apparent success came with a hidden cost.

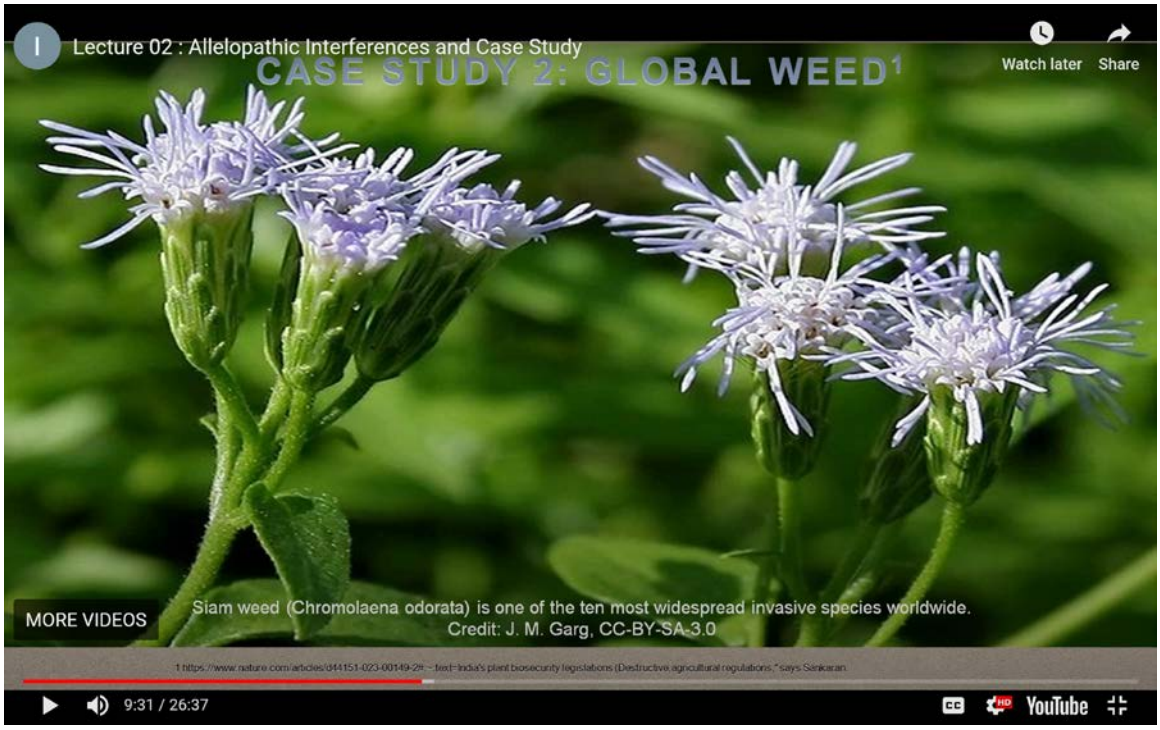
(Refer Slide Time: 08:08)



These new fish, often referred to as "hardy" because of their ability to thrive in polluted waters, began feeding on the native fish populations. This is a critical point to understand, they didn't just coexist; they actively fed on and diminished the native species. Despite the

fact that breeding and importing these fish is now banned, they continue to be reared clandestinely across the country due to the low cost of their meat. Moreover, these fish frequently escape from regulated aquaculture farms and enter natural water bodies.

(Refer Slide Time: 09:31)



Now, consider the implications if this species is introduced into a new biogeographic zone where it becomes even more successful. It starts to decimate the local fish populations, eating them and surviving in heavily polluted waters. This means that the fish, now laden with pollutants, is being sold in the market, and when consumed by people, these pollutants enter their bodies. Consequently, a health issue arises from a fish that doesn't even belong to the region's natural ecosystem. Not only does this invasive species threaten the local fish population, but it also jeopardizes human health.

This scenario illustrates how a seemingly small decision, made with short-term benefits in mind, can lead to long-term ecological disasters. These are the initial signs of such disasters. Earlier, I mentioned how bringing seeds from another country because you liked

a particular flower can have similar effects, without realizing the potential harm it could cause.

(Refer Slide Time: 10:41)

A comparable situation occurred in India during the 1960s and 70s, when wheat had to be imported from the United States. Along with the wheat, certain seeds like those of the congress grass (Parthenium hysterophorus), also known as Parthenium, were unintentionally introduced. This plant is incredibly aggressive; if you travel across North India today, you'll see Parthenium everywhere. It’s called "congress grass" locally. When such invasive plants enter a new environment, they tend to outcompete other weeds and even beneficial crops. Following this incident, it became clear to the authorities that stricter laws and regulations were needed to prevent such ecological invasions. This incident highlights the critical importance of thoughtful consideration and careful planning in the management of our natural resources.

India's biosecurity measures are currently outdated, allowing invasive species to thrive unchecked. A compelling case study highlights this issue with a particular invasive fish

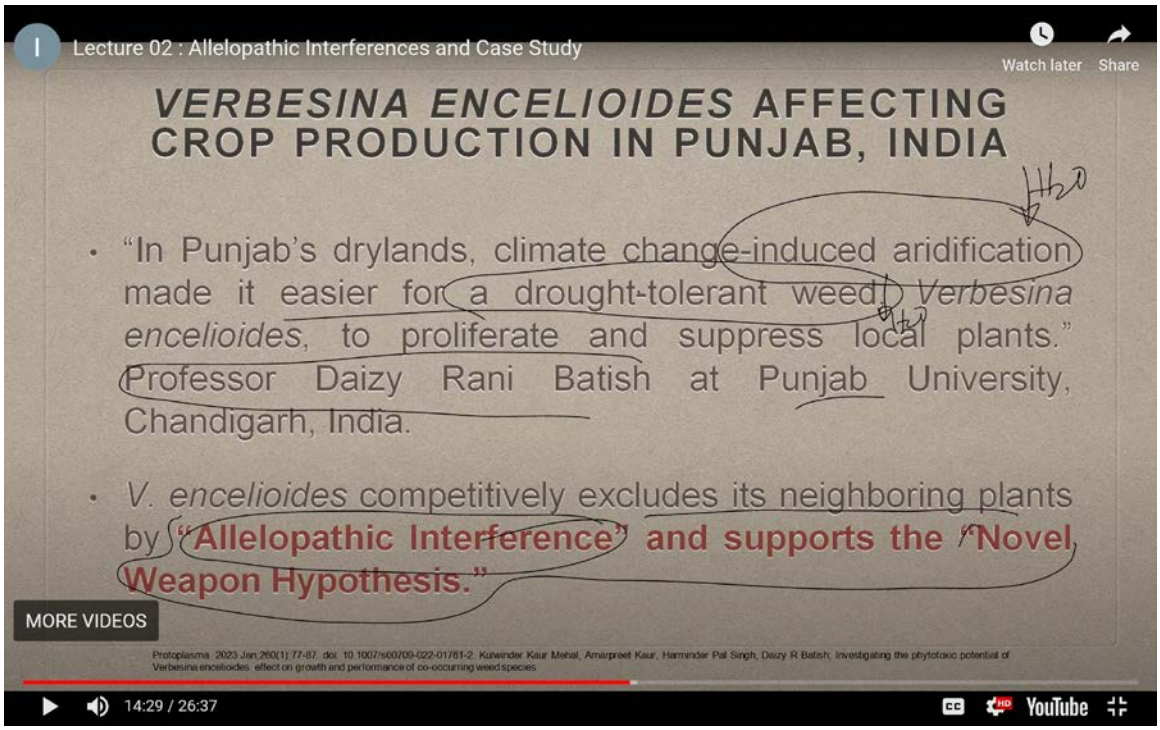
species. But the threat is not limited to aquatic life. You might have noticed certain flowers in various locations, beautiful, vibrant, and seemingly harmless. These flowers are known as Siam weed (Chromolaena odorata), one of the ten most widespread invasive species globally. While they may appear attractive, their impact is far from benign.

(Refer Slide Time: 12:08)

The term "invasion" in this context is apt. These flowers don’t just coexist with local flora; they aggressively outcompete and displace the native herbs and shrubs in the regions they invade. The seeds of such invasive species are often dispersed by birds, other organisms, and even animals, which is a natural process. In a balanced ecosystem, these bio-geographic zones have the resilience to manage occasional introductions of alien species. Nature has its own mechanisms of checks and balances. However, when these invasive species are introduced on a large scale, they disrupt the existing balance. The harmonious relationships among the native species are thrown into disarray because the natural resources they depend on are limited and finite.

Imagine a room designed for four people. If you push in a fifth person, and then keep adding more until there are nine people, the finite amount of oxygen in the room becomes insufficient. This analogy perfectly illustrates what happens when an invasive species with the power to dominate is introduced into a new environment. These species often reproduce rapidly and outcompete the native population for resources, leading to ecological imbalance.

(Refer Slide Time: 14:29)

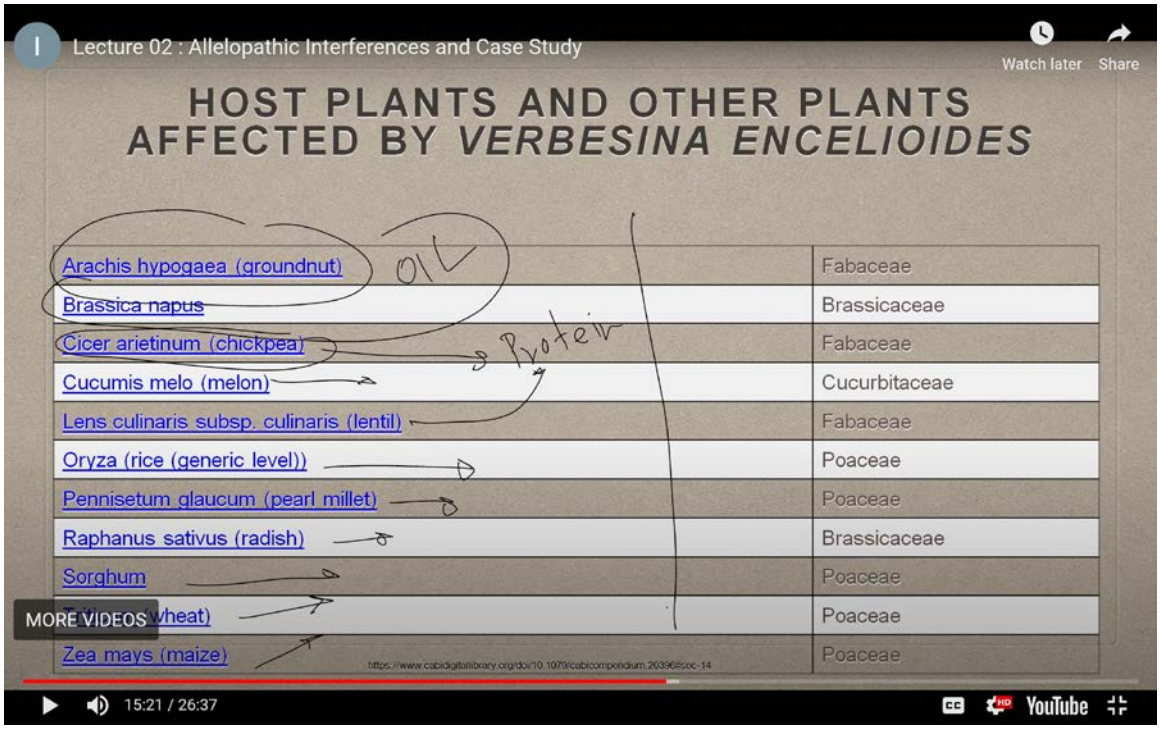


Let's take another example, this time from India. There's a particular flower that many of you have likely seen, a plant that resembles the sunflower and is known as the golden crownbeard (Verbesina encelioides). This flower, belonging to the Asteraceae family, is native to the southwestern United States and the Mexican plateau. However, it has become a troublesome invasive weed in the northwestern states of India, particularly in regions like Punjab and Haryana, where it is now quite common.

If we examine the global spread of this species, we can trace its journey from its origins in North America. It has traveled across the entire United States, reached Alaska, and spread

all the way to the tip of Latin America. It has crossed the Atlantic, reaching as far as Greenland and England. There is a slight discontinuity in its spread, but it has nonetheless established itself in regions like Egypt, Saudi Arabia, South Africa, India, and even Australia.

(Refer Slide Time: 15:21)



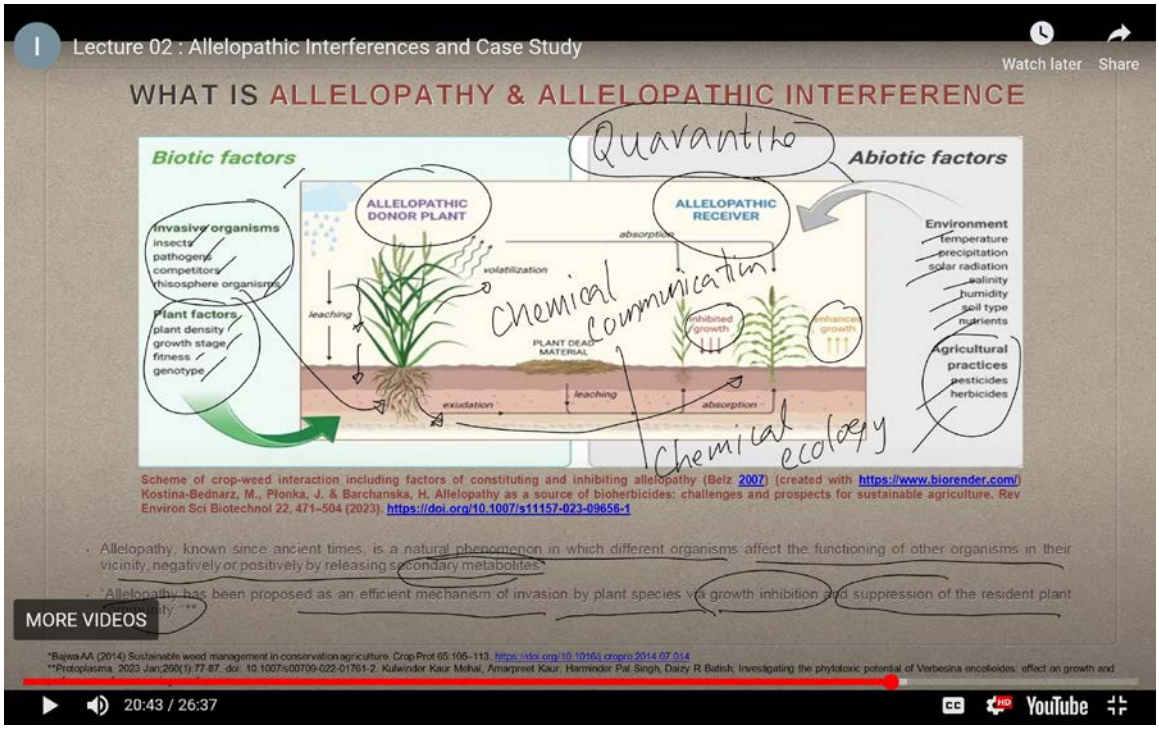
This extensive spread could be attributed to various factors, perhaps birds or animals carried the seeds, or they were inadvertently transported by humans through the global movement of goods such as grains, as countries import and export agricultural products. The reach of these invasive species is vast, and their impact on local ecosystems is profound. This underscores the urgent need for more stringent biosecurity measures to protect the delicate balance of our ecosystems from these formidable invaders.

Consider the extent of spread we are discussing and the invasive power of such species. Currently, there is a fascinating study conducted by Professor Daisy Ranibatish from Punjab University that sheds light on this issue. Her research reveals that in the drylands of Punjab, climate change has significantly exacerbated aridification.

When we talk about aridification, we're referring to regions experiencing very low and irregular rainfall. For example, in dryland agriculture, you might expect 20 millimeters of rainfall, but the distribution is often uneven. Instead of a consistent amount, you might receive 10 millimeters on one day, 1 millimeter the next, 0.5 millimeters another day, or even none at all on some days. This results in highly erratic and unpredictable rainfall patterns.

In the Punjab drylands, climate change has intensified this issue, leading to a severe shortage of water and precipitation. This aridification has created conditions that favor drought-tolerant crops. One such crop is Verbesina encelioides, a type of wheat adapted to thrive in extremely low water conditions. This particular wheat has an impressive ability to outcompete neighboring plants, a concept we will explore in more detail soon.

(Refer Slide Time: 20:43)

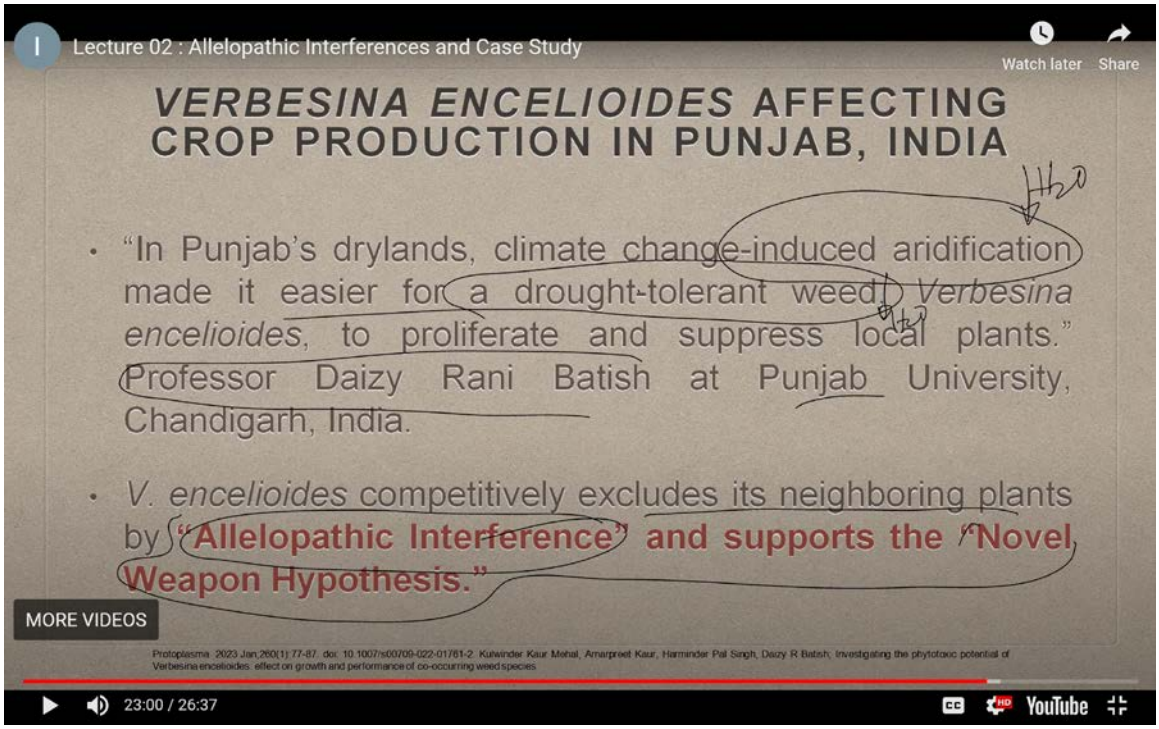


The study highlights how climate change-induced aridification not only challenges traditional agriculture but also facilitates the dominance of certain invasive species, further altering the balance of local ecosystems.

Let's delve into two crucial concepts: allelopathic interference and the novel weapon hypothesis. Both terms are vital for understanding the development of bioherbicides and the mechanisms behind the invasion of species from one region to another. We'll explore these ideas from an evolutionary perspective, examining how such invasions occur and how they continue to unfold almost daily.

Moving on to the next slide, consider the impact of this particular weed on various crops. The presence of this weed has severely affected the production of a wide range of crops: groundnut (for oil), brassica (another oilseed crop), chickpea (for protein), melon, lentil (for protein), rice, pearl millet, radish, sorghum, wheat, and maize. In essence, this weed has drastically reduced the productivity of these crops, which are essential for human food and other uses.

(Refer Slide Time: 23:00)



Now, let's break down the two key terms: allelopathy and allelopathic interference. In simple terms, allelopathy refers to the way one plant affects another through the release of certain substances. For example, imagine a wheat plant and a crop plant growing in

proximity. The wheat plant might secrete chemicals that hinder the growth of the crop plant. These substances could be released from the roots or other parts of the wheat plant, negatively influencing the development of the neighboring crop. This interaction, where one plant's secretions interfere with the growth of another, is what we mean by allelopathy.

Allelopathic interference specifically refers to how these substances disrupt the growth of other plants. Essentially, it's about understanding how one plant's biochemical emissions can impact the development and productivity of another plant in its vicinity.

With this foundational understanding in mind, let’s delve into the specifics of allelopathy. On the slide, you’ll see two key concepts: the allelopathic donor plant and the allelopathic receiver plant. The donor plant is the one that releases allelopathic agents, while the receiver plant is affected by these agents. This interaction can occur in several ways: substances may be secreted through the roots, released as volatiles from the leaves due to solar radiation, or leached into the soil through rainfall, where they are then absorbed by the receiver plant.

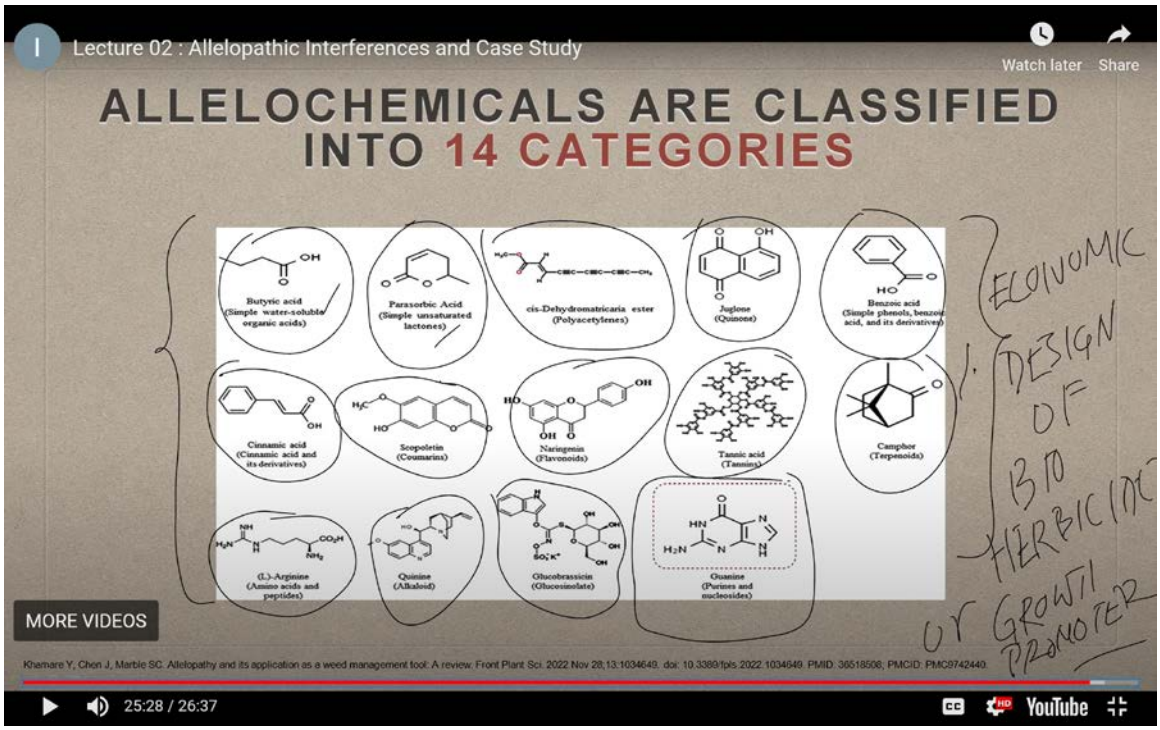
These allelopathic interactions can result in either inhibited or enhanced growth of the receiver plant, depending on various factors. These factors are influenced by both biotic and abiotic conditions. Abiotic factors include temperature, precipitation, solar radiation, soil salinity, humidity, soil type, nutrient availability, and agricultural practices such as the use of pesticides and herbicides. On the other hand, biotic factors encompass invasive organisms like insects and pathogens, competitors, rhizosphere organisms (those in the plant's root zone), and plant-specific factors such as plant density, growth stage, fitness, and genotype.

Allelopathy has been recognized since ancient times as a natural phenomenon where organisms affect each other’s functioning through the release of secondary metabolites. It has been proposed as an effective mechanism for plant species invasion, primarily through the inhibition of growth and suppression of resident plant communities. This means that introducing a new species into an environment can have either positive or negative effects on the existing plant community. Understanding these effects requires a thorough grasp of

chemical communication between plants and their surroundings, a field known as chemical ecology.

Without a deep knowledge of chemical ecology and the chemical interactions among plants, insects, microbes, and other plants, predicting the impact of introducing an alien species becomes extremely challenging. So far, many alien species have had adverse effects on the existing populations, highlighting the importance of careful consideration and study before introducing new species into an ecosystem.

(Refer Slide Time: 25:28)



This brings us to the critical concept of quarantine. If you've ever traveled through airports, you've likely encountered questions about whether you're carrying any plant material. If you are, that material might be confiscated or you might be prohibited from bringing it into the country. Similarly, when transporting animals, including pets, across borders, they must go through quarantine procedures. During the COVID-19 pandemic, we saw a similar concept applied to humans: you had to prove vaccination status to be allowed entry.

The official concept of quarantine for biological materials, including seeds, plant material, microbes, organisms, fish, and animals, was established in the last century. This process is crucial for preventing potentially harmful effects when introducing biological materials from one location to another. Without proper cataloging and database management, the introduction of these materials can have devastating consequences, as illustrated by the three case studies we've discussed.

First, we examined the case of the African catfish, which has invaded Indian river systems, impacting human health and continuously destroying native fish populations. Second, we discussed the invasive weed, Vervetania, which has spread throughout northern India and severely affected various crops. There are many such invasive weeds that diminish crop productivity, and we are gradually learning whether these species are native or introduced from outside regions.

These case studies highlight the need for extensive surveillance, understanding, and, most importantly, effective biosensing. This brings us to one of the key terms I mentioned earlier: allelopathic interference. Next, we'll delve into the concept of the novel weapon hypothesis and explore the various types of allelochemicals involved.

Allelochemicals are categorized into fourteen distinct types. These categories include:

1. Butyric Acid: A type of organic acid that is water-soluble.
2. Parasorbic Acid: Another simple water-soluble compound.
3. Simple Unsaturated Lactones: These are also organic acids with various functions.
4. Polyacetylenes: Compounds characterized by their multiple acetylenic bonds.
5. Zeugolones and Quinones: These are specialized chemical structures with distinct biological activities.
6. Benzoic Acids: Aromatic acids known for their various roles in plant defense.
7. Camphor: A volatile compound used in various applications.
8. Tannic Acids: Polyphenolic compounds with astringent properties.
9. Flavonoids: Plant compounds known for their antioxidant properties.
10. Coumarins: Compounds with a wide range of biological activities.
11. Cinnamic Acids: Aromatic acids involved in plant defense.

12. Arginine or Peptides: Amino acids and their derivatives.
13. Alkaloids: Nitrogen-containing compounds with diverse effects.
14. Glucosinolates: Compounds found in cruciferous plants, influencing growth and defense.

This classification is crucial for developing a comprehensive library of allelochemicals. Understanding these chemicals allows for the creation of targeted bioherbicides or growth promoters. By breaking down the problem into chemical components, we can better design biosensors.

As we proceed, we'll explore how these problems can be examined at the molecular level, looking at DNA, RNA, proteins, and chemicals. This approach will help in developing more effective biosensors.

With this overview, I will conclude this second class. In the next class, we will discuss the novel weapon hypothesis and review additional case studies. Thank you.