Design for Biosecurity

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Lecture 1

Introduction to Biosecurity and Course Overview

Welcome to this course on Design for Biosecurity. I would like to start by expressing my sincere gratitude to all of you who have enrolled in this course. This is the first time I am offering it on the MOOC platform, though I have previously taught it as a regular course in the Department of Design at the Indian Institute of Technology, Kanpur. This time, however, the course will be accessible on a pan-India level and even beyond national borders.

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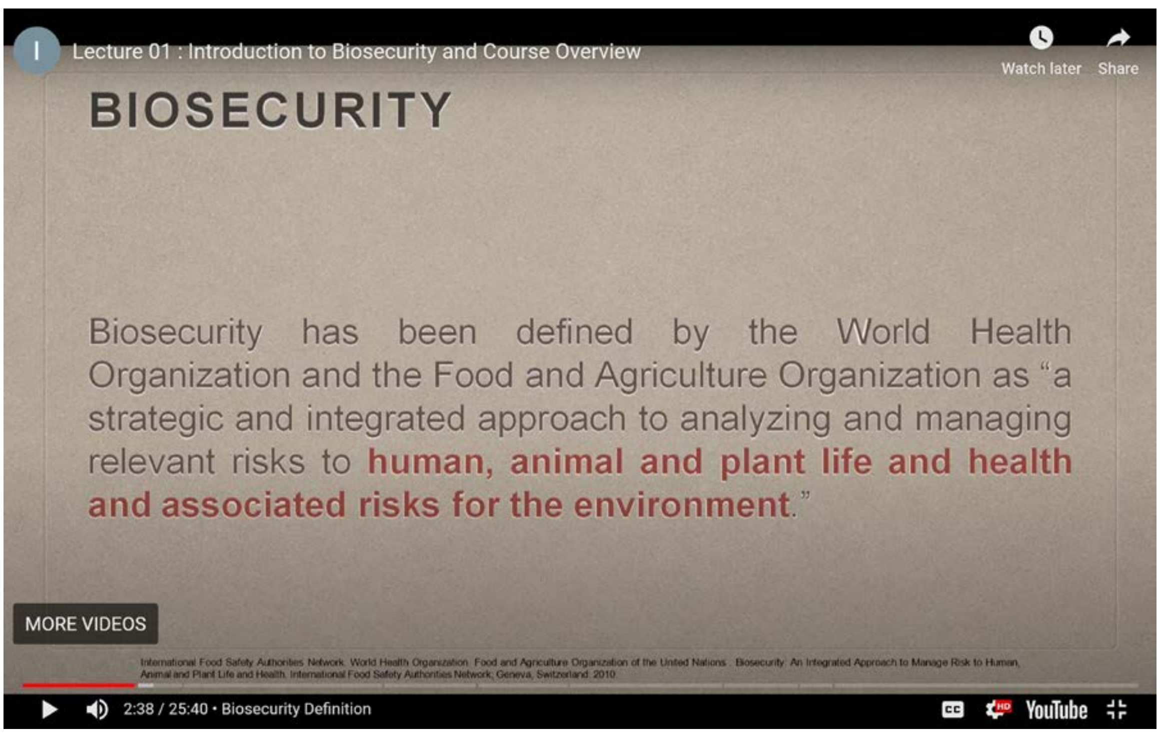

What inspired me to create a course like this? It all began nearly 23 years ago when I started my career in a lab dedicated to the detection of toxins that could pose serious risks to human health. The goal of that early project was to develop a database using a cell-based sensor platform to detect these harmful toxins before they could cause any damage. This project marked the beginning of my journey into the development of cell-based biosensors.

Since then, a tremendous amount of research has been conducted in this field, and today, the global community is striving to develop increasingly sophisticated biosensors. These advancements are crucial for addressing a wide range of concerns, from biosecurity to bioterrorism and even bioweapon development.

In this course, I will be sharing with you the insights and knowledge I have gained over more than two decades. My aim is to help you understand the fundamental concepts and philosophies underpinning the need for biosecurity. This course is essentially a reflection of my journey in understanding why biosecurity is essential and how we can design effective strategies to protect our biological resources.

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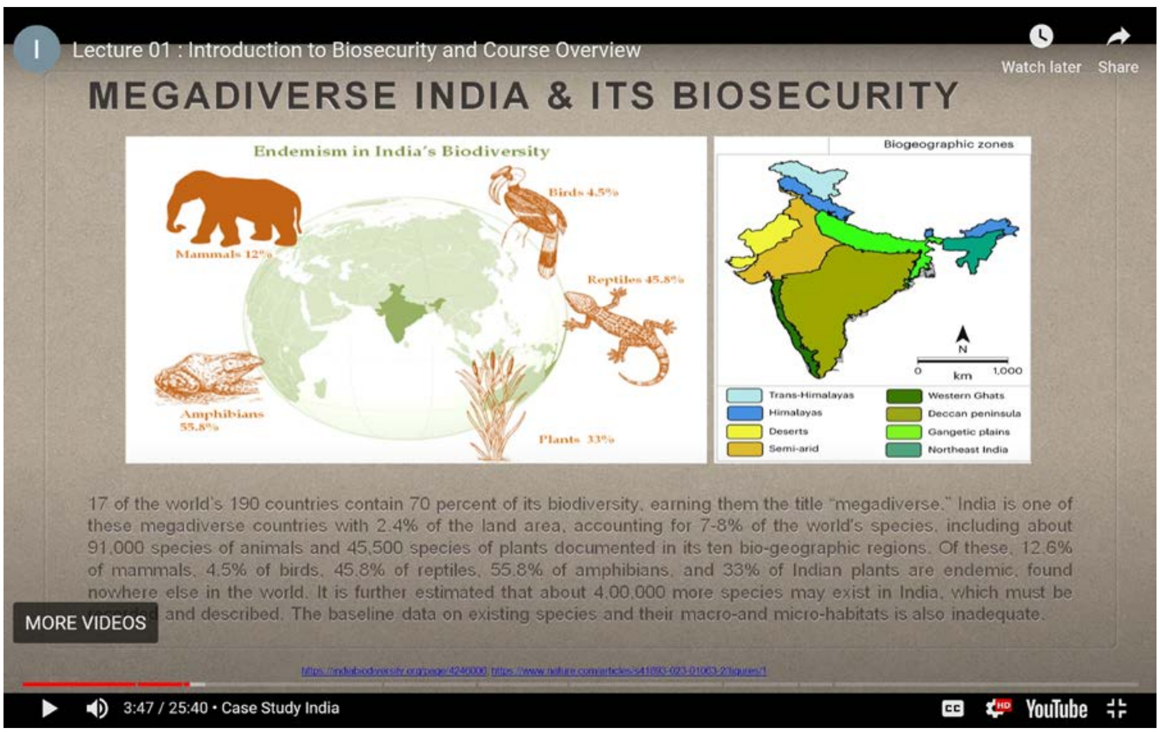

To provide a more formal definition, biosecurity is defined by organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) as a strategic and integrated approach to analyzing and managing risks that are relevant to human, animal, and plant life and health, along with associated risks to the environment. Essentially, what we are discussing encompasses all biological resources on a global scale. However, it's important to note that there is no single, universal law governing biosecurity. The world is divided into different countries, continents, and regions, each with its own set of laws and regulations. Consequently, biosecurity laws and strategies vary from one region or country to another.

To safeguard biological resources effectively, we must delve into various case studies, primarily from the Indian subcontinent, but with some global examples as well. To begin, let me provide an overview of what exactly we are trying to protect.

India presents a fascinating tapestry of diverse regions, each with its own unique biodiversity. The Indian subcontinent is home to eight distinct biogeographic zones, each characterized by its own ecological identity. For instance, we have the Trans-Himalayan zone, as shown on the slide, followed by the Himalayan zone, which extends all the way to the northeastern states. Then, there is the desert zone, predominantly found in the Rajasthan desert, and the semi-arid zone, encompassing parts of Himachal Pradesh, Punjab, Haryana, and the NCR region.

Further south, we encounter the Western Ghats, a biodiversity hotspot that stretches from Maharashtra down to Kerala. The Deccan Peninsula occupies central India, including Madhya Pradesh, Chhattisgarh, and further south into Andhra Pradesh, Tamil Nadu, and Karnataka. The Gangetic Plains span Uttar Pradesh, Bihar, and parts of West Bengal, while Northeast India represents yet another distinct zone.

When you examine these biogeographic zones, it becomes evident that each one harbors a unique array of flora and fauna. The microbial populations in the soil, the diversity of organisms in water bodies, the plant life, and the animal species differ markedly from one zone to another. For example, the biodiversity of the Sundarbans delta along the Bay of Bengal is vastly different from that of Kerala. The diversity of organisms in the mangrove forests contrasts sharply with the ecosystems found in the Kashmir Valley. Similarly, the desert region of Rajasthan hosts organisms uniquely adapted to its arid environment, which are entirely distinct from those thriving on the Deccan Plateau.

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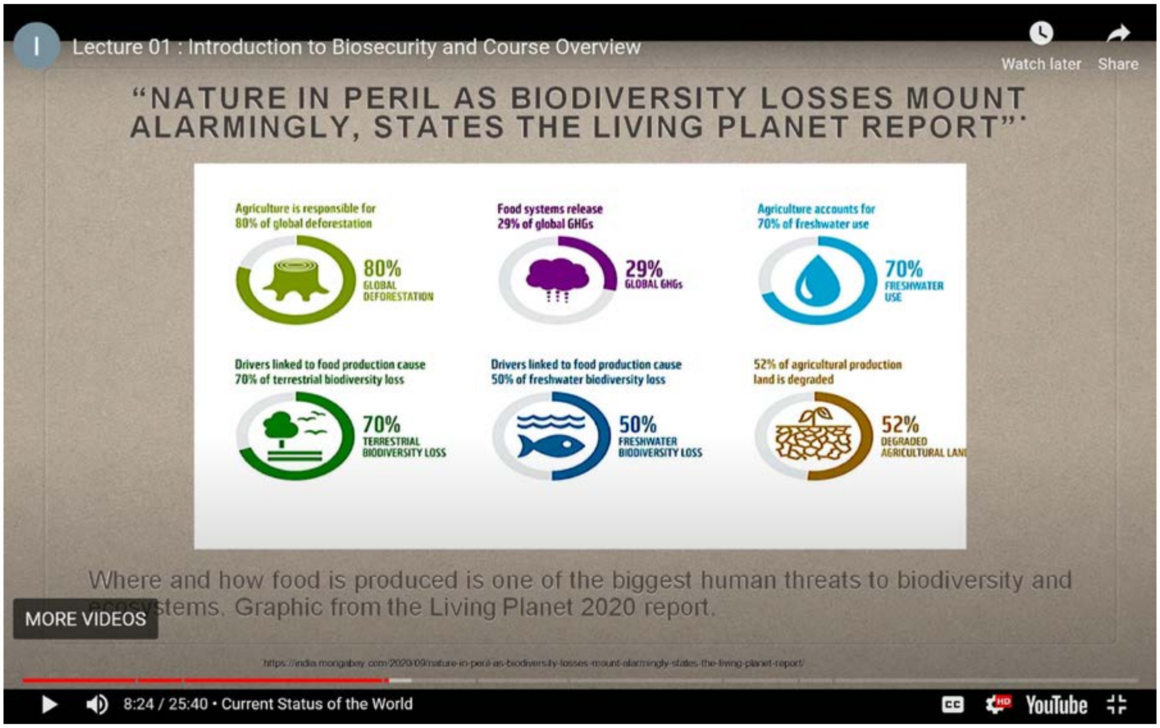

Each of these zones has a distinct habitat that has evolved over centuries, if not millennia, and needs to be preserved. Of course, natural mixing occurs, elephants migrate between states, and birds travel from one region to another with the changing seasons. These natural migrations have been part of the ecological balance for centuries and are not a cause for concern.

However, when we intentionally introduce organisms, plants, microbes, or other biological elements from one biogeographic zone into another without thoroughly assessing the potential impact, we run the risk of disturbing these finely tuned ecosystems. Each zone has established a delicate balance over long periods, and while the system may initially adapt to new entities, eventually, it could be destabilized if the introduced species prove harmful.

This is where the concept of quarantine becomes crucial. Quarantine is the practice of isolating new entities, whether they are organisms, plants, or microbes, before allowing them to integrate into a new environment. This precautionary measure helps prevent unintended consequences and ensures that the intricate balance within each biogeographic zone is maintained.

I will delve deeper into how these factors have impacted India's biodiversity in various ways. When we examine the distribution of biodiversity in the country, we see that reptiles constitute 45.8% of the species, plants 33%, amphibians 55.8%, mammals 12%, and birds 4.5%. This illustrates the incredible diversity of life we have, and it is becoming increasingly evident that we need to do much more than we currently are to protect this extraordinary biodiversity that exists in our nation.

Now, let's shift our focus to a broader, global perspective. The current state of the world presents some alarming trends. For instance, agriculture is responsible for 80% of global deforestation. The food system, as a whole, contributes to 29% of global greenhouse gas emissions. Additionally, agriculture consumes 70% of the world's fresh water, leaving only 30% available for other uses. Furthermore, 50% of agricultural production lands are now degraded, largely due to the excessive use of fertilizers, pesticides, and other chemicals. This degradation not only diminishes land productivity but also drives the loss of 50% of freshwater biodiversity. The situation is equally dire on land, where food production accounts for 70% of terrestrial biodiversity loss.

This is the stark reality we face today. According to the Living Planet 2020 report, these trends are where we currently stand. This degradation of biodiversity directly affects biosecurity. When we see a decline in one region, the natural reaction is to introduce species from another region. However, this practice often disrupts the delicate balance of the ecosystem into which these new species are introduced. I will provide examples that highlight the importance of rigorous checks and balances to prevent such ecological disasters.

As we examine biodiversity loss, we can refer to the curve depicted in the Living Planet 2020 report. Historically, as shown on the left side of the graph, there has been a significant decline in populations of animals, plants, and birds, as well as the ecosystems they inhabit. This decline underscores the urgency of addressing the factors that contribute to these losses to protect our global biodiversity and, by extension, our biosecurity.

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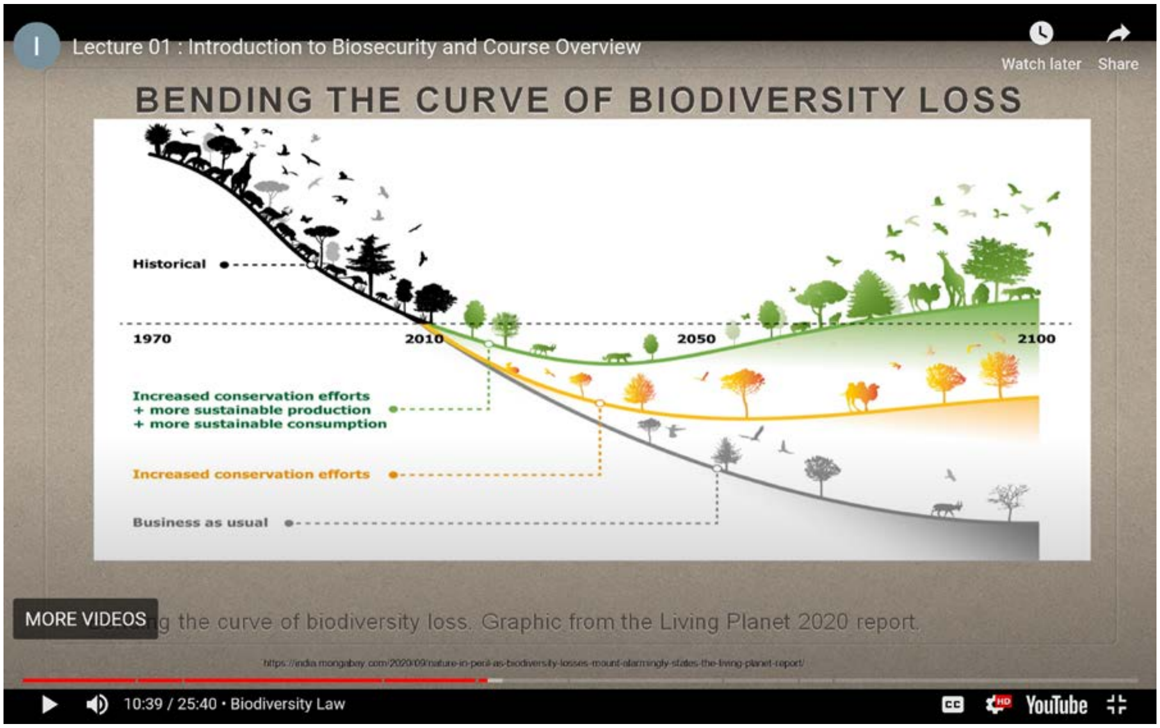

Starting from 2020, we observe a concerning downward trend in biodiversity, the curve is steadily declining. This decline is evident in the decreasing numbers of trees, animals, and birds. If this trend continues unchecked, we face the potential for significant biodiversity loss over the next 25 to 100 years. The goal now is to reverse this trend, an effort commonly referred to as "bending the curve of biodiversity loss."

To achieve this, serious and immediate measures are required on a global scale. Every country, regardless of its status, whether developed, developing, or underdeveloped, must make a united and concerted effort to preserve global biodiversity. Failure to do so will lead to severe consequences, particularly in areas such as food production, public health, and the availability of essential resources derived from forests and other natural ecosystems.

With this foundational understanding, let me guide you through the structure of this course. It is designed to span 12 weeks, each focused on a different aspect of biosecurity.

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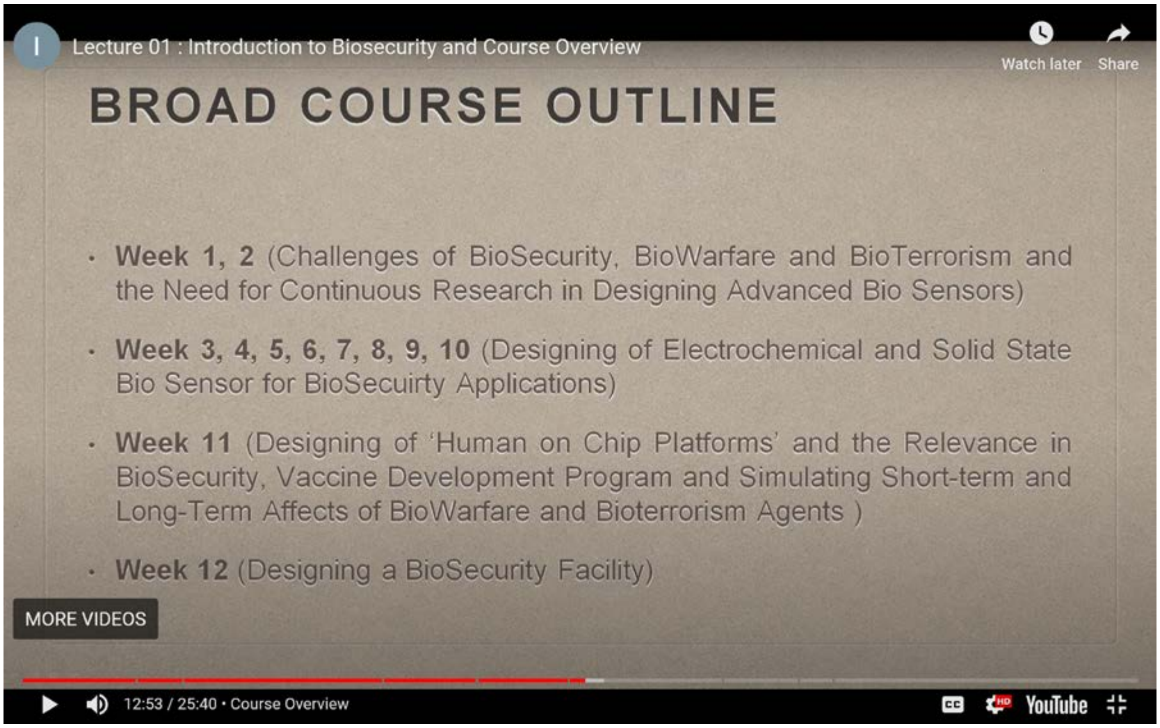

Weeks 1 and 2: We will begin by exploring the challenges of biosecurity, biowarfare, and bioterrorism, emphasizing the critical need for ongoing research in the development of advanced biosensors. In the first week, we will review multiple case studies and their historical contexts. The second week will focus on specific case studies involving sensors that have already been developed.

Weeks 3 to 10: These weeks will be dedicated to the design of electrochemical and solid-state biosensors for biosecurity applications. We will structure these weeks to cover both the theoretical foundations and practical applications. Initially, we will discuss the basic principles of sensor development, particularly the electrochemical processes involved. Following that, we will explore how these principles are applied to create sensors in real-world scenarios. This segment of the course is particularly important for those of you interested in developing sensors, whether for research, industry, or other professional pursuits.

Week 11: We will delve into the cutting-edge technology of "human-on-a-chip" platforms, discussing their relevance in biosecurity, vaccine development, and the simulation of short- and long-term effects of bio-warfare and bioterrorism agents. This emerging field is transforming research that was traditionally conducted on animals. With the reduction in animal testing, human-on-a-chip platforms are becoming increasingly central to studying the effects of various biosecurity threats.

Week 12: The final week will focus on the design and management of biosecurity facilities. We will cover the quarantine measures required to contain potential hazards, the layout of these facilities to ensure containment, and the specific equipment and expertise needed to operate them. We will also discuss how to manage such facilities at state, national, and international levels, highlighting the importance of biosecurity labs, such as the renowned CDC facility in the United States.

This course is designed to provide a comprehensive understanding of biosecurity and the tools necessary to protect our biological resources. Through this journey, you will gain the knowledge and skills to contribute meaningfully to this vital field.

Similarly, every country has biosecurity labs that are of immense significance, not just for the present but for the decades and centuries to come. In the first week of this course, we will focus on five key areas: agricultural security, livestock production and its influences, human health, pandemics, and bioterrorism. These are the foundational topics we'll be exploring.

Regarding bioterrorism, it's important to understand that this concept is far from new. Remarkably, historical records suggest that bioterrorism or bioweapons have been used by humans for nearly 800 years, with evidence dating back to the 13th century. During that time, wars were fought using biological agents, albeit unknowingly, since microbiology as a discipline didn’t exist yet. The microscope hadn't been invented, so microbes were not visible to the human eye. Despite this, bio agents were used in conflicts, making bioterrorism and biowarfare ancient practices. However, what sets our era apart is the sophistication with which these threats can now be created and deployed, posing unprecedented risks.

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In the second part of the first week, we'll delve into more specific case studies, focusing on the pressing need for economical sensors to detect emerging biosecurity threats. We will explore viruses such as filoviruses, including Ebola and Marburg, as well as Bacillus anthracis, the bacterium responsible for anthrax, a notorious bioterror agent. Additionally, we will discuss the botulinum toxin and even insulin, a commonly used molecule that can be repurposed for harmful objectives.

Moving on to agricultural security, we will learn from various examples. Agriculture encompasses not just crops but also trees, weeds, and a wide range of plant life. I've highlighted certain terms in red that we'll be discussing in detail. Poultry, including ducks, pigeons, and other birds reared by humans for centuries, will also be covered. We'll discuss the cultivation of aquatic animals such as fish, crabs, and other species used globally for food. Livestock, which includes cows, buffaloes, goats, sheep, pigs, camels, yaks, and many other animals, is another critical area. These animals are essential for producing milk, leather, meat, and a variety of other products.

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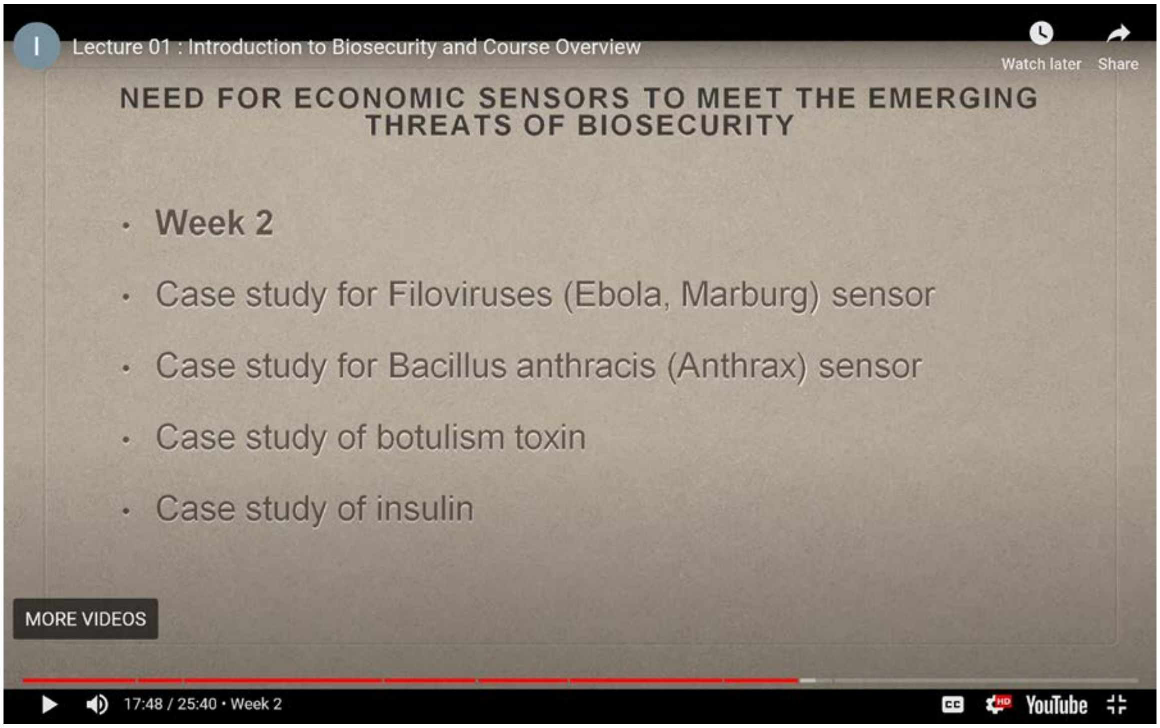

Additionally, we will explore economically important insects like honeybees, silk-producing worms, and lac insects, which are vital for pollination and other ecological functions. This segment will also cover various insects that either harm or help our crops. Forest wealth and biodiversity will be another key focus, as forests are major sources of biodiversity. From them, we derive numerous products, from construction-grade timber to materials used in the paper and pulp industries. Lastly, we will discuss microbial biodiversity, a vast and pervasive field. Microbes are ubiquitous, inhabiting everything from water bodies to plants to the soil, playing critical roles in ecological balance and resource production.

Microbial diversity plays a crucial role in processes like nitrogen fixation and mineralization, and it significantly aids plants in acclimatizing to soil, particularly through root-associated microbes. However, not all microbes are beneficial. Some are harmful to plant and animal health, including vector-borne disease-causing microbes such as those responsible for malaria and Lyme disease. These harmful microbes are often carried by insects that bite humans, transmitting diseases in the process.

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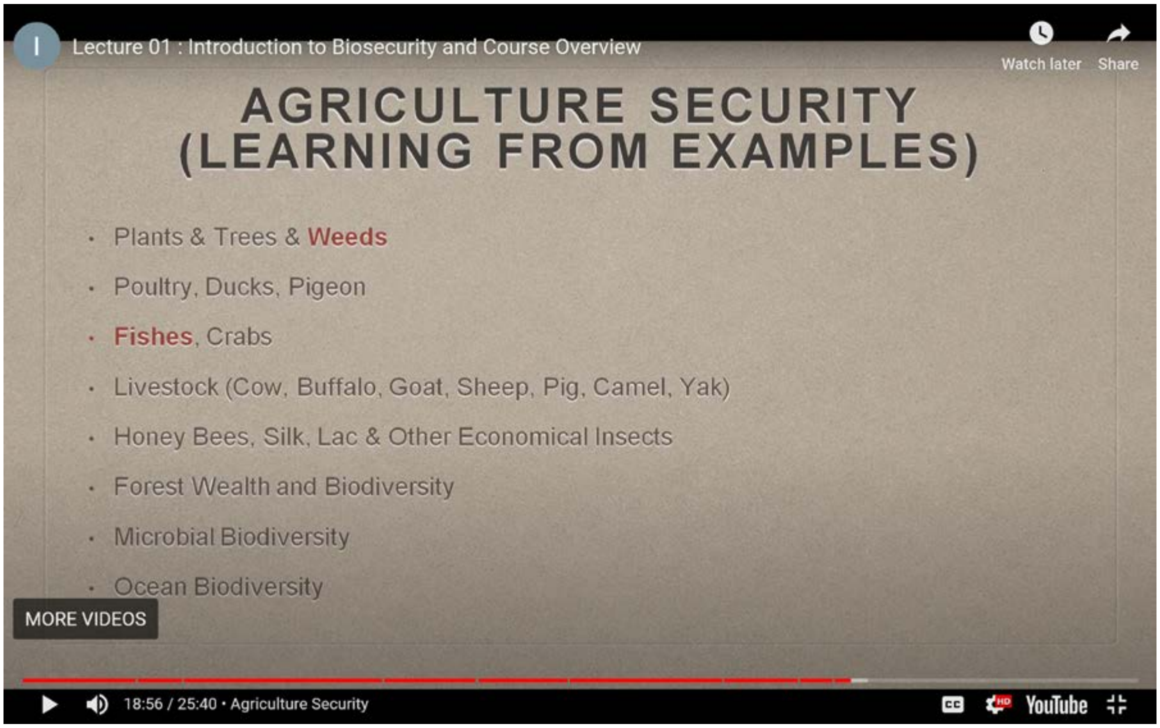

Moving on to ocean biodiversity, this is especially significant for countries surrounded by vast water bodies. For example, India is flanked by the Bay of Bengal, the Indian Ocean, and the Arabian Sea. Similarly, Japan is bordered by two major water bodies. The biodiversity within these aquatic ecosystems is an integral part of agricultural security. To illustrate this, let's consider an interesting report that states, "India's biosecurity measures are outdated, allowing invasive species to thrive." This statement is particularly striking because it highlights the critical issue of invasive species.

As I mentioned earlier in the presentation, India is divided into multiple biogeographic zones, each with its own unique balance of flora and fauna. When a new entity is introduced into such a biodiverse zone, it can disrupt the delicate balance of that ecosystem. Therefore, it is imperative to exercise extreme caution when intentionally introducing new species. Thorough groundwork is essential to assess the potential impacts. Even when species are introduced unintentionally, vigilance and surveillance are necessary to monitor and mitigate any long-term effects.

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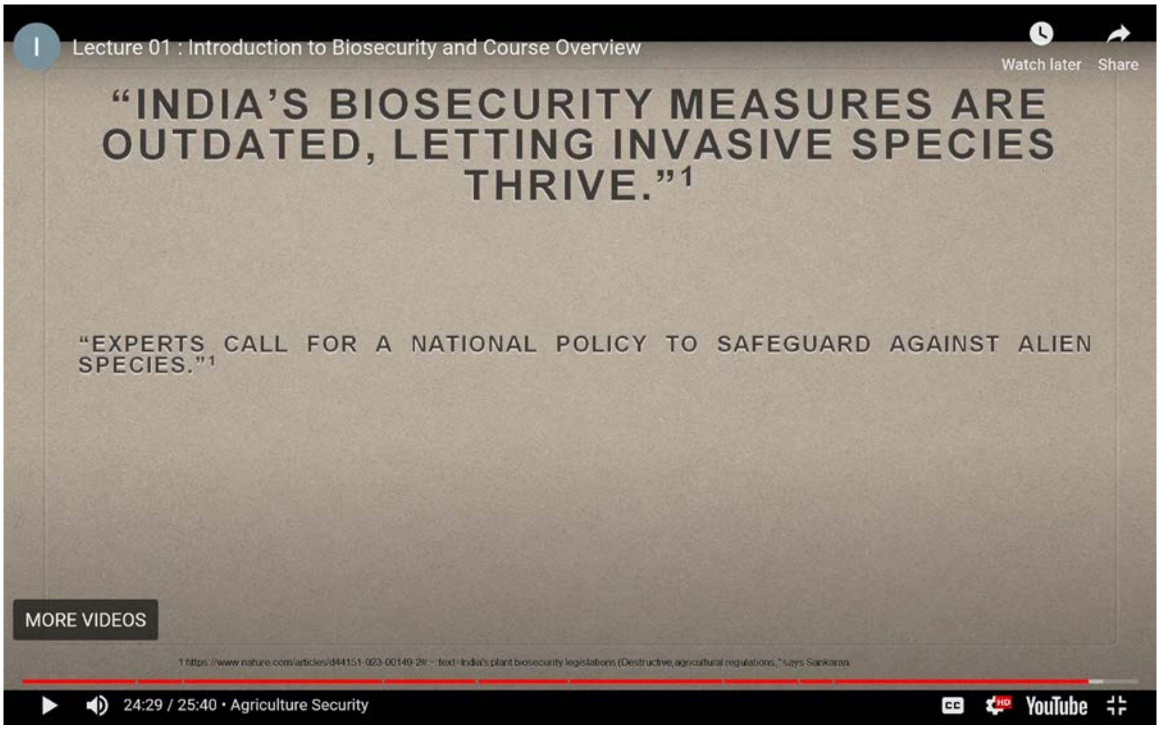

This concern has led experts to call for a national policy to safeguard against alien species, species that do not naturally belong to a particular biodiversity zone. For instance, imagine bringing seeds from a neighboring country and planting them in your own country without considering the consequences. While it may seem harmless, the introduced plant genome could have a detrimental impact on the existing plant community. The new species might be so aggressive that it outcompetes and damages the native flora.

In our next lecture, we will delve into three case studies where the unintentional introduction of alien species into a biogeographic zone has had severe negative impacts on local populations. Legal measures had to be implemented to address these issues. I will conclude today's session here with this introduction. In the next class, we will examine these case studies in detail and discuss the legal measures necessary to manage the proliferation of invasive species. Thank you.