# <u>Lecture 4</u>

# Environment and Resources (I): Ecosystem Services



## KEY QUESTION;

## Why is the environment important?

With the completion of this lecture, attached readings and tutorial, you should be able to discuss:

- the importance of ecosystem services provided by the environment
- variations over time and space of what is considered a provisioning service
- human activities which can compromise the ability of the environment to provide ecosystem services
- Lecture Outline
- 4.1 Introduction: What are 'ecosystem services'?
- 4.2 Types of Ecosystem Services
  - (a) Provisioning services
- (b) Regulating services
- (c) Cultural services (d) Support services
- <u>Box 1</u>: What is the Millennium Ecosystem Assessment (MA)?

## 4.3 Variations over Time and Space of What is Considered a Provisioning Service

- 4.3.1 Demand for the provisioning service
  - (a) Economic factors (
    - (b) Social factors(d) Political factors
- 4.3.2 Technology

## 4.4 Human Activities which Can Compromise the Ability of the Environment to Provide Ecosystem Services

4.4.1 Destruction of habitats

(c) Cultural factors

- (a) Deforestation (b) Human-induced climate change
- 4.4.2 Pollution of natural environment
- (a) Agriculture (b) Extractive industries
- 4.4.3 Introduction of invasive species
- 4.5 Concluding Remarks



How have you been justifying that the environment is important to humans? A possible means is to explain how humans rely on the range of 'services' the environment provides.

There are broadly four main types of such 'services', which we shall be learning more about. Just from this diagram alone, can you decide which 'service' is the most important?

#### 4.1 Introduction: What are 'ecosystem services'?

Humans, whether we recognise it or not, are dependent on the environment for multitudes of benefits that sustain us, our societies and our economies. (Landers, Nahlik & Rhodes, 2016)

- As we have learnt in Lect 1-3, the environment is a key dimension of sustainable development, with environmental limits setting the boundaries within which a sustainable society and economy should be sought.
- Everyone in the world depends entirely on the environment to survive and thrive. The concepts of **ecosystems** and **ecosystem services** draw attention to the important and fundamental contribution of the environment to human well-being.
- An ecosystem is a <u>dynamic complex</u> of plant, animal and microorganism communities and the non-living environment interacting as a <u>functional unit</u>. Humans are an integral part of <u>ecosystems</u>. The concept of ecosystem provides a valuable framework for analysing the linkages between people and the environment.
- Ecosystems range from those that are relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use, to ecosystems intensively managed and modified by humans, such as agricultural land and urban areas. Ecosystems also vary greatly in size.
- **Ecosystem services** are the <u>benefits people obtain from ecosystems</u>. (See later, **Section 3.2** on the different types of ecosystem services.)
- Ecosystem services are, by definition, means to the end or goal of sustainable human wellbeing. This does not imply that ecosystems are not also valuable intrinsically (that is, in and of themselves), but that ecosystem services are defined based on their value to the material and non-material well-being of humans.

## 4.2 Types of Ecosystem Services

The Millennium Ecosystem Assessment (MA) (see Box 1) classifies ecosystems services into four types: provisioning, regulating, cultural and supporting services. The MA acknowledges how these services all serve humans by providing for our well-being, which itself is multi-faceted. (See Fig. 1)

#### Box 1: What is the Millennium Ecosystem Assessment (MA)?

- The Millennium Ecosystem Assessment (MA) was called for by the United Nations Secretary-General Kofi Annan in 2000. Initiated in 2001, the objective of the MA was to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being.
- The MA has involved the work of more than 1,360 experts worldwide. Their findings provide a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide (such as clean water, food, forest products, flood control, and natural resources) and the options to restore, conserve or enhance the sustainable use of ecosystems.

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• Fig. 1 depicts the linkages between ecosystem services and the components of human wellbeing that are commonly encountered.



Fig. 1 Linkages between ecosystem services and human well-being

- (a) Provisioning services \*\* (This is the most important ecosystem service you have to be familiar with.)
- **Provisioning services** are the <u>tangible products or goods</u> that people obtain from ecosystems for basic human needs such as food, water, minerals, shelter and fuel.
- These ecosystem goods are the **essential inputs to all economic production** and contribute significantly to the global economy.
  - For example, the global wood products market was valued at \$631 billion in 2021 and the world's exports of aquatic products were worth \$151 billion in 2020.
  - Provisioning services, such as inland fisheries and fuelwood production, are particularly important to the economies of and livelihoods of people in **developing countries**. Fisheries provide the primary source of animal protein for more than one billion people, and all but four of the 30 countries most dependent on fish as a protein source are in the developing world. In low-income countries such as Nepal, Uganda, Rwanda and Tanzania, fuelwood meets 80% or more of total energy requirements.
- Throughout the late 20<sup>th</sup> century, provisioning services **grew rapidly** as humans expanded farmlands (160% increase in food production), harvested more water (doubled water use) and cleared more timber (tripling of harvests for pulp and paper, timber by 160%).
- Provisioning services are not necessarily being used in responsible ways, despite being favoured. Nearly half of provisioning services are exploited at unsustainable rates (see Section 4.4).

- (b) Regulating services
- Regulating services are the <u>benefits obtained from the various processes whereby ecosystems</u> regulate the conditions where humans live and make a living. This reduces risks to human health and safety.
- Examples of regulating services include:
  - Climate regulation. Ecosystems regulate the global climate by storing greenhouse gases such as carbon dioxide. For example, plants take in carbon dioxide during photosynthesis. Terrestrial and ocean ecosystems absorb nearly 60% of carbon dioxide emitted to the atmosphere from human activities, significantly slowing the rate of climate change (see Topic 3.2).
  - Moderation of extreme events. Ecosystems, such as mangroves, create buffers against natural disasters such as floods, tropical storms and cyclones. Mangroves, with their dense network of roots (see Photo A), help to break sea waves during storm surges and reduce coastal flooding. Studies show that mangroves can reduce up to 66% of wave energy in the first 100 m of the forest width. Mangroves provide over \$65 billion per year in flood protection benefits.
  - Pollination. Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats. The yields of more than 70% of the leading global crops are dependent on, or enhanced by, pollination. Pollination not only increases crop yields, but also improves crop quality, particularly in fruits such as strawberries and raspberries that produce misshapen fruits if not adequately pollinated.
  - Biological control. This refers to the activities of predators and parasites in ecosystems that act to control populations of potential pest and disease vector. Pest suppression provided by the Brazilian free-tailed bats (see Photo B) to cotton production in the Winter Garden region of Texas, US has been estimated as 2-29% of the value of the cotton crop, depending on the pest pressure in any given year.



<u>Photo A</u>: Mangroves can significantly reduce coastal flooding.

**<u>Photo B</u>**: The Brazilian free-tailed bat consumes a large amount of insects nightly, many of which are agricultural pests and disease vectors.

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#### (c) Cultural services

- **Cultural services** are the <u>contribution of ecosystems to the **nonmaterial benefits** that arise from the interaction between people and ecosystems. They can involve individual species, habitats and whole ecosystems.</u>
- Cultural services are directly experienced in nature and essential to human pursuit of meaning, such as:
  - Recreation and tourism. Ecosystems provide the physical setting for people to interact with the environment and spend their leisure time, through activities such as hiking, mountain biking, snorkelling, scuba diving and whale watching. Many people find beauty or experience a sense of awe in various aspects of ecosystems.
  - **Spiritual and aesthetic experiences**. Many religions attach spiritual and religious values to ecosystems or their components.
  - **Cultural heritage**. Many societies place high value on historically important landscapes and culturally significant species.
  - **Knowledge systems**. Ecosystems and their components and processes provide the basis for scientific exploration and discovery of knowledge.
  - **Inspiration**. Ecosystems provide a rich source of inspiration for art, folklore, architecture, national symbols and advertising.

## (d) Supporting services

- Supporting services are the services that are required for the production of all other ecosystem services.
- They differ from provisioning, regulating and cultural services in that their impacts on people are **indirect**, whereas changes in the other categories have relatively direct impacts on people.
  - For instance, humans do not directly use soil formation services, though changes in this would indirectly affect people through the impact on the provisioning service of food production. Other examples of supporting services include water cycling and photosynthesis.
- These supporting services allow ecosystems themselves to sustain basic life forms. Without these supporting services, ecosystems would not exist, let alone provide provisioning, regulating and cultural services.

## 4.3 Variations over Time and Space of What is Considered a Provisioning Service

- Recall from **Section 4.2** that provisioning services are the tangible products or goods that people obtain from ecosystems for basic human needs such as food, water and fuel.
- In the simplest sense, provisioning services are things in ecosystems that have material use to humans. The fruit, tree, insect, fish and water are all natural components of the ecosystems, regardless of whether or not human beings choose to use them. They are the "neutral stuff" that makes up the ecosystem, but they become provisioning services when humans find utility in them.

- What motivates people to select and use some portions of the "neutral stuff" in the ecosystem so that they become provisioning services, while others are neglected? It is here that we focus on the interactions between human beings and the environment (or the "neutral stuff"), with humans as an integral part of the ecosystem.
- When geographers study provisioning services, we ask: What portions of the ecosystem have people found of material value? Why? How do the considerations of what a provisioning service is **vary over time and space**?
- "Neutral stuff" in ecosystems acquire material value or utility as provisioning services only within the context of politics, society, culture and economics, which shapes the demand for the provisioning service and technology available to supply it.

## 4.3.1 Demand for the provisioning service

• A provisioning service only becomes one when there is demand for the material benefits it is perceived to bring to humans. This demand is in turn shaped by an **interplay** of economic, social, cultural and political factors.

## (a) Economic factors

- Economic factors involve the consideration of the value or price of a good. In a capitalist economy a commodity will not be exploited unless it can be done at a profit. Thus, as prices change, demand changes and things become (or cease to be) provisioning services.
  - A deposit of iron ore in a remote location may be too expensive to exploit today, but if prices rise substantially, it may become profitable to exploit and sell that ore; at that time it becomes a provisioning service.
  - Example:
    - In the US, the demand for coal as a fuel is declining because coal is simply not costcompetitive with other fuels in generating electricity. There has been massive displacement of coal-fired generation primarily by cheap and plentiful natural gas as a result of the shale gas revolution with hydraulic fracturing (see Section 3.3.2).
    - From 2000 to 2008, coal supplied about 50% of US power generation, but this has
      declined to about 12% in 2021. Moreover, following the extraction of the wide and easily
      accessible coal seams in central Appalachia, one of the main coal-producing regions in
      the US, the cost of coal production is increasing as firms exploit harder-to-reach reserves.
      Coal production in the central Appalachian Basin in 2015 was 40% below its annual
      average level in 2010-14.

## (b) Social factors

• Social conditions influence the value and use of resources. The composition of societies is constantly changing. People grow older, richer, and poorer, and the cultural makeup of

societies change. All of these factors, particularly ethnicity, gender, education and income, influence how societies appraise and use resources.

- <u>Example</u>: Higher-**income** households would seek out and use resources differently from lower-income households.
  - An extensive survey in 2006 on urban household energy choices in Ouagadougou, the capital of Burkina Faso, found that firewood utilisation rate decreases with increasing household income.
  - Despite public policies adapted to discourage firewood consumption due to the threat it poses to the savannah woodlands, lower-income households still value and use firewood greatly as their low income limits their access to alternative energy sources.
  - Conversely, higher-income households are able to afford and use other sources of energy that are more adapted for urban consumption, such as liquid petroleum gas and its cook stoves.

## (c) Cultural factors

- There are different cultures in the world, and each has a different system of values. What has material value as a provisioning service in one culture may be regarded as a nuisance in another. Hence, different cultures can have varying demand for the same provisioning service.
  - Whaling provides a classic <u>example</u>.
    - Native Americans, especially the Inuit, historically used whales as a source of food and the whale's fat as fuel. Later, the Inuit used whale bones in their arts and crafts, a usage that continues to the present.
    - Today, most of us appreciate the majesty and beauty of these marine mammals and view them not as a provisioning service (food and fuel), but as a cultural service. Whale watching in California and New England draws thousands of people to view these migratory mammals in their natural habitat. Harvesting whales for food has led to protests against commercial whale vessels, actions that garner world headline and public sympathy. (See Photo C)



<u>Photo C</u>: Protests against harvesting of whales, but viewing whales as food is nothing new in some cultures, such as the Inuit's.

- As cultures develop and evolve, how a resource is valued within the culture and its demand as a provisioning service can also change.
  - Going back to the example of whaling:
    - In Iceland, whales were once hunted for their meat and blubber as whales were considered a provisioning service. Over time, as basic resource needs are met, Icelanders now value whales as a cultural service instead, with whale watching being an increasingly popular activity among locals as well as tourists. By 2018, a Gallup poll conducted for the International Fund for Animal Welfare found that only 1% of Icelanders ate whale meat regularly, while 84% claimed never to have eaten it at all.

## (d) Political factors

- National resource policies may influence the demand of a country for different provisioning services. The shift in position on sources of energy is a good example. As a country reviews its energy mix, the demand for fossil fuels such as coal and oil may decline, while demand for alternative sources such as wind power, solar power and biomass may increase. Energy mix refers to how final energy consumption in a given geographical region breaks down by primary energy source.
  - Germany is a country that is a leader in this transition. Its ambitious energy transition aims for at least 80% of all power to come from renewables by 2050. This is part of Germany's political aim of mitigating climate change (see **Topic 3.2**) by reducing reliance on fossil fuels and switching to alternative energy.
  - On the other hand, the shifting politics in the U.S. has made the shift towards more use of renewables unstable, raising the demand for oil and gas for fuel in the country.

## 4.3.2 Technology

- A provisioning service becomes one not only when there is demand for the material benefits it brings, but also when there is **technology** available to **supply** it.
- Technological factors relate to our **knowledge** and **technical capability** in exploiting provisioning services.
  - Groundwater is not a provisioning service until it is made available by drilling a well and installing pumps or other means to bring it to the surface. Similarly, desert lands have little agricultural value unless we possess the technical capability to collect and distribute irrigation water, at which time they become very valuable.
  - Deuterium in the oceans is not at present a provisioning service, except for its use in weapons. However, if we learn how to control the fusion reaction for energy production in the future, it may become a provisioning service.
- With advancements in technology, it becomes possible to extract **supplies** of provisioning services that were in the past not possible to be extracted or not economically feasible to do so. Such advancements reduce the cost of extraction and allow profits to be made by firms in

the related extractive industry (see **Lecture 9**). This encourages tapping into these supplies and allows these alternative supplies to be valued and used as provisioning services.

 An example is hydraulic fracturing, or 'fracking', which uses sophisticated technology to extract oil and gas from underground shale rocks (a location with physical conditions that were not helpful to extractive firms) (See Fig. 2). This has now given countries such as USA a renewed confidence in their own energy security as the availability of fossil fuels has gone up.



Fig. 2 'Fracking' has allowed once difficult-to-reach gas to become of service to humans

- Technological advancements could also increase the viability of substitute provisioning services to replace existing provisioning services.
  - An example is solar energy, which has been more extensively tapped on in recent years due to advancements in technology to harness it more efficiently. Solar energy is increasingly valued and used in Singapore to replace fossil fuels due to new technologies such as floating solar panels and installation of special panels on building facades, which help the small city to overcome the land constraint of having large solar farms.

## 4.4 Human Activities which can Compromise the Ability of the Environment to Provide Ecosystem Services

- Over the past century, humans have altered ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet the demands of a **large**, **growing and increasingly affluent world population**.
- The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services. The MA estimates that 60% of ecosystem services were being degraded or used unsustainably, including freshwater and fisheries.
- The degradation of ecosystem services, unless addressed and reversed, will substantially diminish the services that future generations can obtain from ecosystems and pose a significant barrier to achieving the Sustainable Development Goals (see Lect 2 and 3).

 In this section, we examine some human activities which can compromise the ability of the environment to provide ecosystem services for current and future generations. These activities are in turn the result of population growth, economic development and poor management of ecosystems, which are important indirect drivers of changes in ecosystems and ecosystem services.

## 4.4.1 Destruction of habitats

- (a) Deforestation is a major reason for the destruction of terrestrial habitats. (Recall also Lect 2 Section 2.4.1b)
- The rate and extent of deforestation has been alarming. Between 1990 and 2016, the world lost 1.3 million km<sup>2</sup> of forest, according to the World Bank. This is an area larger than South Africa (or, for comparison, Singapore is 720 km<sup>2</sup>). This is equivalent to losing an area of 1,000 football fields in one hour!
- The largest extent of deforestation is seen in the tropical regions (see **Fig. 3**), especially in the Amazon Basin (South America), Congo Basin (Africa) and Southeast Asia, where there has been substantial clearing of tropical forests for farming, ranching, logging, mining and fuelwood collection.



Fig. 3 The extent of change in forest area between 1700 and 2020

- Deforestation destroys forest habitats and leads to significant loss in biodiversity.
  - Tropical forests in particular cover less than 10% of the Earth's land area, but harbour between 50% and 90% of Earth's terrestrial species. 15 of the 25 biodiversity "hotspots" on earth, which are areas with significant biodiversity threatened by high levels of habitat destruction, contain tropical forests.

- These areas once covered nearly 12% of the Earth's land surface, but their remaining natural habitat has been reduced to only 1.4% of that surface that is, 88% of the hotspots' original natural habitat has been destroyed.
- While the destruction of forests is often done to **increase provisioning services** such as food, timber and fuelwood, this is **at the expense of other services**.
- Deforestation and habitat destruction compromise the ability of forests to provide **regulating services** such as climate regulation, flood control and pollination.
  - The destruction of forests leads to **the loss of carbon sinks**, as forests take in more carbon dioxide than they release (see **Topic 3.2**). This contributes to global climate change.
  - At the local scale, the extensive root system in forests binds the soil and prevents erosion. After deforestation, the loose and unconsolidated soil becomes susceptible to erosion and can be washed away into water bodies. The increased deposition of sediments in the river reduces its capacity to hold water, making **floods** more likely (see **Topic 2.1**). The destruction of mangrove forests, which act as buffer against storm surges, increases the risk of coastal flooding.
  - The loss in biodiversity reduces animal pollination. A study showed that during 2000 to 2003, pollination services from two forests with a total area of about 150 hectares translated into \$60,000 a year for a Costa Rican coffee firm due to increased coffee yield (by 20%) and quality. Subsequent deforestation and decline in pollination led to a loss of this service.
- Habitat destruction compromises cultural services provided by forests, such as spiritual and cultural heritage (especially for indigenous communities), recreation and ecotourism. There is also the loss of biodiversity, which is valuable for education and scientific research and can be potentially used for medicine, a provisioning service.
- Lastly, habitat destruction disrupts the various **supporting services** within forest ecosystems, such as photosynthesis and water cycling (see **Topic 2.1**).
- (b) Human-induced climate change is key driver of the destruction of aquatic habitats (see also Topic 3.2).
- **Coral reefs**, one of the most biodiverse and productive ecosystems on the planet, are increasingly destroyed due to higher sea-surface temperatures. Bleaching and the death of corals are possible with only a small rise in water temperature of 1-2°C.
- <u>Example</u>: In the past 30-40 years, Indonesia has lost half of its reefs to bleaching. In the Caribbean, the proportion has reached 80%. Bleached corals are not necessarily dead, but mass bleaching events are occurring so frequently that the corals do not get a chance to recover.
- Coral reefs provide important ecosystem services (see Table 1) which are compromised by habitat destruction.

 Table 1 Ecosystem services provided by coral reefs

Ecosystem Services	Provision by Coral Reefs
Provisioning	Fishery: Coral reefs support more species per unit area than any other
	marine environment, including about 4,000 species of fish. Around half
	of all federally managed fisheries in the US depend on coral reefs and
	related habitats for a portion of their life cycles. The commercial value
	of US fisheries from coral reefs is estimated to be over \$100 million.
	Materials: Sand and coral can be harvested for use in construction and
	land reclamation. Fish and corals are also harvested for use in
	aquariums and curio trade.
Regulating	Coastal protection: Coral reefs dissipate 97% of the energy that would
	otherwise hit shorelines. This protects the coast from storm surge and
	flooding. Across reef coastlines, coral reefs reduce annual expected
	damages from storms by more than \$4 billion.
Cultural	Recreation and tourism: Coral reefs are popular sites for fishing, diving
	and snorkelling.
	Education and research: The rich biodiversity of coral reefs is an
	important source of knowledge and research. Many drugs are now
	being developed from coral reef animals and plants as possible cures
	for cancer and other diseases.
Supporting	This includes services such as photosynthesis and nutrient cycling, which
	supports the rich biodiversity in coral reefs.

#### 4.4.2 Pollution of natural environment

- Pollution of the natural environment, including water, land and air, disrupts ecosystems and the services they provide.
- The effect of pollution on ecosystem services is well-exemplified in the study of water pollution on aquatic ecosystems.
  - Aquatic ecosystems provide a range of ecosystem services. Provisioning services, notably fish, are particularly important. They also provide regulating services such as climate regulation and cultural services, including those related to fishing. In many of the Native American cultures of the north-western US, for example, salmon fishing is an integral part of identity.
  - Water pollution occurs when harmful substances often chemicals or microorganisms contaminate a stream, river, lake, ocean, aquifer, or other body of water, degrading water quality and rendering it toxic to humans or the environment. According to the United Nations Environment Programme, half of the world's major rivers are assessed to be "seriously polluted".
- (a) Agriculture on industrial scale and its use of chemicals to boost yields since the Green Revolution have increased substantially the provisioning service of food, but led to severe water pollution as fertilisers and pesticides are washed into water bodies. This in turn compromises ecosystem services provided by aquatic ecosystems, including the provisioning services of fish stocks and freshwater.
  - Phosphates and nitrates are nutrients spread on soil to promote growth, but can have a disastrous effect on aquatic ecosystems. High levels of nutrient loading cause significant

**eutrophication**, where there is an abundance of oxygen-hungry algae and weeds, which in turn deprive fish and other aquatic life of the oxygen they need to survive.

- This is seen in the low-oxygen Dead Zone in the Gulf of Mexico (see Fig. 4), which is fed by nutrients carried by croplands in the midwestern US down the Mississippi River. Algae flourish on the added nutrients and deplete oxygen through photosynthesis, causing serious damage to fisheries. It is estimated that the dead zone costs US seafood and tourism industries \$82 million a year.
- (b) Pollution from extractive industries (see Lect 9) through their mineral extraction, transportation and processing can also present serious environmental problems, affecting water quality. Even small flows of polluted water can harm both the flora and fauna of aquatic ecosystems, but damage can be greatly intensified by large accidental discharges.
  - One such incident, the collapse of Fundão dam at an iron-ore mine in Southeastern Brazil in 2015. After the collapse of the dam, 43 million m<sup>3</sup> of iron ore tailings (finely ground residue from ore extraction) were released, polluting 668 km of watercourses from the Doce River to the Atlantic Ocean.
  - This incident was deemed the biggest environmental disaster of global mining industry, in terms of the volume of tailings dumped and the magnitude of the damage. Very fine tailing particles caused severe changes to the physico-chemical characteristics of the river, increasing the turbidity levels up to 6000 times higher than the limit established by law. Forty downstream municipalities were affected and hundreds of thousands of people were left without access to clean water.
  - The disaster occurred in one of the most important regions for biodiversity conservation. Tons of fish from 21 different species died in large numbers, such as the South American Tapir, as well as turtles, birds, amphibians and invertebrates.



Fig. 4 The dead zone in the Gulf of Mexico in 2021



**Fig. 5** Members of the Krenak tribe looking at the Doce river, one month after the Fundao dam disaster in 2015

## 4.4.3 Introduction of invasive species

- Invasive species are the <u>non-native</u> species that <u>threaten</u> ecosystems, habitats or species. Not all non-native species are invasive. For example, most of the food crops grown in the US, including popular varieties of wheat, tomatoes and rice, are not native to the region. To be invasive, a species must adapt to the new area easily and <u>harm</u> the existing ecosystem.
- Human activities are the biggest cause of the introduction of invasive species. This could be done deliberately, for instance as a form of pest control, to hunt or keep as pets, or accidentally through transport. The globalisation of transport means that increasingly animals and plants have hitched a ride to new ecosystems.
- Invasive species are widely heralded as the second greatest agent of species endangerment and extinction after habitat destruction, inflicting serious impacts on the ecosystem services that are fundamental to human well-being.
- Invasive species can compromise the ecosystem services in both terrestrial and aquatic ecosystems.
  - The **yellow star thistle** (see **Photo D**), native to Eurasia, is an invasive species in California, US which spreads through ranch lands.
    - It is unpalatable to cows and thus negatively affects ranching, an important provisioning service, costing the state \$7.65 million annually in lost livestock forage.
    - The yellow star thistle forms dense infestations and rapidly depletes soil moisture, consuming much more water than native species. This affects the supporting service of water cycling and provisioning service of water, costing between \$16 million to \$75 million a year in lost water to the Sacramento watershed.
    - By lacerating (i.e. cutting the skin) hikers, the yellow star thistle has decreased the cultural service of recreation in large areas in California.
  - Native to the tropics of South America, the **water hyacinth** now thrives in Lake Victoria, the largest lake in Africa (see **Photo E**).
    - The fast-growing water hyacinth forms a thick mat of vegetation at the surface, obstructing waterways and the access of fishing boats to the lake. The water hyacinth also blocks sunlight, hindering photosynthesis by native plants. The die-off and decomposition of native plants further deplete oxygen levels, which can reach dangerously low concentrations for fish and reduce the production and quality of fish.
    - Water hyacinth clogs irrigation canals and pipes used to draw water from the lake for cities and villages on its shore, disrupting the key provisioning service of freshwater.
    - Water hyacinth has negative effects on the regulating service of biological control. By impeding the usual water flow in the lake, the plant creates stagnant conditions that are ideal for disease-carrying insects like mosquitoes.

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#### H2 Cluster 1: Development, Economy and Environment (Topic 1.1)



**Photo D**: The yellow star thistle infests between 10 and 15 million acres of land in California.



**Photo E:** The water hyacinth is one the world's most prevalent invasive aquatic plants and commonly forms dense mats, as seen here in Lake Victoria, Kisumu, Kenya.

- However, the impact of invasive species on ecosystem services is not always negative and can be difficult to assess, because it is based on personal and local value systems and invasive species are often incorporated into local livelihoods and cultures. The feral pig in Hawaii (see Photo F) epitomises the conflicting effects of invasive species on ecosystem services, reminding us that not all ecosystem services are valued equally by everyone.
  - During the past 200 years, the Polynesian race of the feral pig has hybridised with the European boar introduced to Hawaii and moved into the rainforests.
  - Feral pigs consume a massive amount of native understory plants, leading to native plant extinction and reducing biodiversity. By aggressively uprooting tree and underground plant masses with their trunks, feral pigs damage tree composition and root systems and create massive erosion of soil and organic matter. This disrupts supporting services such as soil formation and nutrient cycling. Over the past 30 years from the 1970s to 2000s, about 50% or more of rainforests in Hawaii, along with the ecosystem services they provide, were being degraded by feral infestations, mostly pigs.
  - By knocking down and carving out tree ferns for their fleshy interior, feral pigs create breeding habitat for mosquitoes, which host infectious diseases such as avian malaria and dengue fever that impact wildlife and human communities. This negatively affects the regulating service of biological control.
  - The damage caused to trails in rainforests also compromises the cultural service of recreation and tourism, with \$450,000 per year in damage caused to national parks.
  - On the other hand, the feral pig has become an integral part of Hawaiian hunting culture. Hunted for subsistence, ceremony and recreation, feral pigs provide meat and cultural and religious value to local communities.



Photo F: The feral pig in Hawaii

#### 4.5 Concluding Remarks

- Human well-being and progress towards sustainable development are vitally dependent upon improving the management of the Earth's ecosystems and ecosystem services to ensure their **conservation** and **sustainable use**.
- With the rise in population size and affluence globally, there is ever-growing demand for ecosystem services. At the same time, ecosystems around the world have been increasingly degraded by human activities, compromising the ability of the environment to provide ecosystem services. This seriously diminishes the prospects for sustainable development, unless urgent action is taken to protect ecosystems and the services they provide.
- In the subsequent lectures, we will discuss whether our supply of provisioning services would ever be depleted to support population growth.

#### Summary of this lecture:

