COASTAL SYSTEMS AND LANDSCAPES: COASTS AS NATURAL SYSTEMS

KEY TERMS

Landform: Individual physical features, e.g. cliffs, beaches, dunes, etc, formed by processes such as erosion, deposition, and weathering.
Open system: Exchanges both energy and matter with its surroundings. e.g. coastal systems.
Closed system: Exchanges energy but not matter with its surroundings, e.g. the global water cycle.
Many coastal systems can be thought of as a mixture between open and closed systems, as sediment is transferred throughout.

COMPONENTS OF A SYSTEM

Inputs: Elements entering the system, e.g. sediment, energy from waves.
Outputs: Elements leaving the system, e.g. sediment transported away by currents.
Energy: The driving force behind processes, e.g. wave energy, wind energy, solar energy).
Stores: Locations where energy or matter is held, e.g. beaches, sand dunes.
Flows/Transfers: Movements of energy or matter within the system, e.g. longshore drift, wind-blown sand.

FEEDBACK MECHANISMS

Positive feedback: Enhances or amplifies changes; leads to instability, e.g. coastal management leading to increased erosion elsewhere – such as beaches starved of sediment because of groynes.
Negative feedback: Returns the system back towards stability and equilibrium, e.g. erosion of cliffs leads to cliff collapse – the accumulation of material at the cliff base will protect the cliff from further erosion for a period of time.

TIDAL ENERGY

Tides: The periodic rise and fall of sea levels caused by the gravitational pull of the moon and the sun.
Tidal range: The difference in height between high tide and low tide. A larger tidal range results in more significant energy variations.
Spring tides: Occur during the full moon and new moon phases when the sun, moon, and Earth are aligned. The gravitational forces of the moon and the sun combine, resulting in higher high tides and lower low tides. These tides are characterised by their greater tidal range, meaning the difference between high and low tide is more pronounced.
Neap tides: Occur during the first and third quarters of the moon when the sun and moon are at right angles to each other relative to Earth. The gravitational forces of the moon and the sun partially cancel each other out, leading to lower high tides and higher low tides. These tides have a smaller tidal range, meaning the difference between high and low tide is less pronounced.

CURRENTS

Tidal currents: The horizontal flow of water associated with the rise and fall of the tide. These currents can transport sediment and shape coastal features.
Rip currents: Often mistakenly called rip tides, occur due to the interaction between waves and the shoreline. When waves break on the shore, they push water towards the beach, causing a buildup of water that needs to return to the sea. This water typically flows back through narrow, concentrated channels where there is a break in the sandbar or a gap between obstacles like rocks or piers. These channels create powerful, fast-moving currents that pull water, and anything caught in them, away from the shore.

COASTAL SYSTEMS AND LANDSCAPES: COASTAL SYSTEMS AND PROCESSES

WAVE ENERGY:

Waves are generated by wind blowing over the surface of the sea. The energy transferred from the wind to the water creates waves.

Crest: The point at the top of a wave.
Trough: The base of a wave.
Wave height: Distance between the trough and the crest.
Wave length: Distance between two wave crests.
Wave frequency: How often the waves break per minute.
Swash: Waves running up the beach.
Backwash: Waves returning to the sea due to gravity.

TYPES OF WAVES

Constructive waves: Build up beaches by depositing sediment…

- Weak backwash compared to swash
- Long wavelength, but low wave height
- Less frequent gentle waves (6-9 waves per minute)
- Break gently so spread out over a wide area
- Found in sheltered bays - build up sandy beaches
- More common in summer than winter
- Adds material to the beach, hence 'constructive'

Destructive waves: Erode the coastline by removing sediment…

- Strong backwash compared to swash
- Short wavelength, but high wave height
- Frequent waves (10-15 waves per minute)
- Waves break with a lot of energy, concentrated in a small area - can comb the beach of material
- Found in more exposed areas of coastline
- More common in winter than summer
- Removes material from the beach, hence 'destructive'

FACTORS INFLUENCING WAVE ENERGY

Fetch: The distance over which the wind blows – a longer fetch results in more powerful waves.
Wind strength: Stronger winds generate larger, more energetic waves.
Wind duration: The longer the wind blows, the more energy is transferred to the waves.

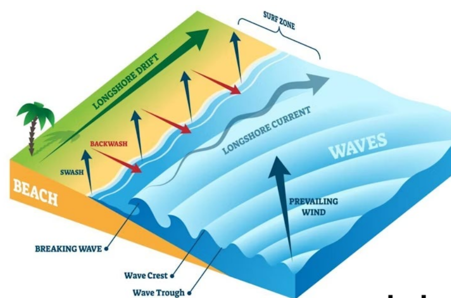
TYPES OF EROSION

Hydraulic action: The force of water hitting the coast, compressing air in cracks and causing rock to break apart.
Abrasion: Waves carrying sediment grind against the coast, wearing it down.
Attrition: Sediment particles collide and break into smaller pieces.
Solution: The chemical action of seawater dissolving rocks.
Wave quarrying: Powerful waves break against the base of cliffs or rocky shorelines, exerting immense pressure on the rock. This pressure forces air and water into cracks and crevices, causing the rock to fracture and break apart. The sheer force of the waves hitting the cliff can directly dislodge pieces of rock, especially if the rock is already weakened by weathering. Additionally, the rapid movement of water can create bubbles that implode with great force, further contributing to the breakdown of rock.

TYPES OF TRANSPORTATION

Longshore drift: The zig-zag movement of sediment along the coast – the swash brings material onto the beach in the direction of the prevailing wind, and the backwash carries it back out to sea at right angles to the coast due to gravity.

Traction: Larger particles rolled along the seabed.
Saltation: The bouncing movement of sand particles
Suspension: Fine particles carried in the water column.
Solution: Dissolved minerals are carried within the seawater.



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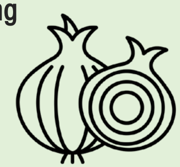
COASTAL SYSTEMS AND LANDSCAPES: WEATHERING AND MASS MOVEMENT

MECHANICAL WEATHERING

The physical breakdown of rocks into smaller fragments.

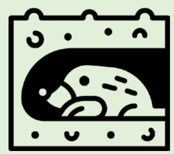
Freeze-thaw: Occurs when water enters cracks in rocks, freezes, and expands then thaws – the repeated freezing and thawing causes the rock to break apart (common in the cliffs of the Holderness Coast).



Exfoliation (onion skin): Happens when heating and cooling causes rock layers to expand and contract, leading to the peeling weathering and outer layers (not that common in the UK).

Salt weathering: Where the growth and expansion of salt crystals within cracks in rocks cause them to fracture and break apart.

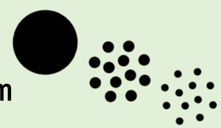
BIOLOGICAL WEATHERING



The breakdown of rocks by plants and animals.

- Plant roots grow into cracks in rocks, expanding them and causing the rock to break apart.
- Animals, e.g. birds, burrow into rocks causing them to break down.

CHEMICAL WEATHERING



The breakdown of rocks through chemical reactions.

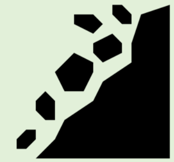
Hydrolysis: Water reacts with minerals, breaking them down and forming new compounds.

Oxidation: Oxygen reacts with minerals, especially those containing iron, forming new compounds like rust.

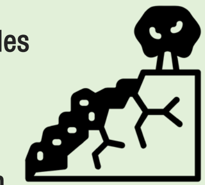
Carbonation: Acidic rainwater (weak carbonic acid) reacts with calcium carbonate in rocks like limestone, dissolving them. This is evident in the chalk cliffs of Flamborough Head.

Dissolution: Some minerals are soluble in water and dissolve, leading to the breakdown of rocks.

MASS MOVEMENT



Rockfall: The rapid free-fall of rock from a steep cliff face. This is common along the chalk cliffs of Flamborough Head, and adds sharp, angular rock to the back of the beach.



Landslide: The movement of rock and soil down a slope, often triggered by heavy rainfall or earthquakes. The Holderness Coast is prone to landslides due to its soft boulder clay cliffs.

Mudflow: The flow of water-saturated earth material down a slope.

Slumping: The downward and outward movement of rock and soil along a curved surface, often occurring on saturated, clay-rich slopes. This is seen along the cliffs of Mappleton.

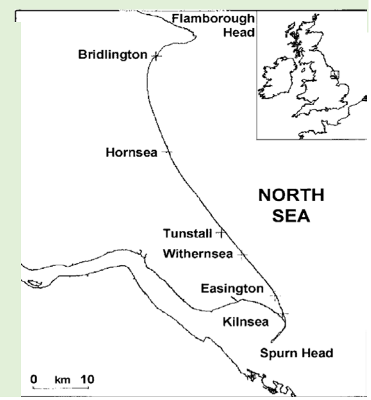
Soil creep: The slow, gradual downhill movement of soil, often imperceptible except over long periods. However, this can also leave a ripple like effect in the landscape, as commonly seen in the Lake District.

ROTATIONAL SLUMPING

This is a key process affecting the soft clay cliffs at Mappleton on the Holderness Coast. When it rains heavily, the water soaks into the soft boulder clay, making it heavy and slippery. This extra weight and slipperiness cause the clay to slide down a curved surface, known as a slip plane.

At the same time, waves at the base of the cliffs erode the material, creating a notch and removing support from below. This combination of added weight and lack of support leads to the clay slumping down and outward in a rotational movement. This creates terraced steps and scars on the cliff face. After the slump, waves often wash away the debris at the bottom, exposing the cliff to more erosion and future slumping.

The time in-between the slump and the creation of a new wave cut notch can be seen as negative feedback.



COASTAL SYSTEMS AND LANDSCAPES: SEDIMENT SOURCES AND BUDGETS

SEDIMENT SOURCES

Rivers: A major source of sediment, especially in high-rainfall environments where significant river erosion occurs. The Holderness Coast receives sediment from rivers such as the River Hull, which contributes to the sediment load in the Humber Estuary.

Coastal cliffs: Contribute significant sediment through erosion (particularly softer rock). This process is evident along the Holderness Coast in East Yorkshire, where rapid erosion of soft boulder clay cliffs provides substantial sediment.

SEDIMENT TRANSPORTATION

Sediment is transported southwards along the Holderness Coast by longshore drift, driven by prevailing north-easterly winds. This process moves material from areas like Flamborough Head down to Spurn Point.

Sediment can be transported from offshore sources to the coast by constructive waves. The beaches along the Holderness Coast, such as those at Hornsea, benefit from this sediment input.

Aeolian processes: Transport fine sand from the beaches and dunes along the Holderness Coast, contributing to the sediment budget.

SEDIMENT BUDGETS

A sediment budget is an analysis of the balance between sediment inputs and outputs within a coastal system.

It helps predict changes in the coastline over time.

Coastal management strategies, such as beach nourishment and the construction of groynes, can influence the sediment budget by altering sediment inputs and outputs. At Mappleton, rock groynes and revetments have been constructed to reduce erosion and maintain the sediment budget.

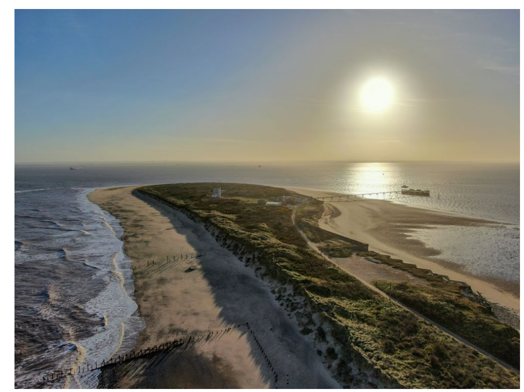
SEDIMENT CELLS

Sediment cells are distinct areas of the coastline where sediment movement is largely self-contained. There are 11 of these in total in the UK, though the main one to focus on is your case study area. For example, the Holderness coastline in this knowledge organiser. These are usually contained between headlands and peninsulas. These can also be referred to as **littoral cells**.

HOLDERNESS SEDIMENT CELL

The Holderness Coast is part of a larger sediment cell that extends from Flamborough Head to the Humber Estuary. Within the Holderness sediment cell, the balance between sediment inputs and outputs maintains a state of dynamic equilibrium. This balance can be disrupted by human activities or natural events. Understanding sediment cells is crucial for effective coastal management, as it helps predict and manage sediment movement and coastal erosion.

The Holderness Coast is a classic example of a sediment cell, with Flamborough Head and soft boulder clay cliffs of Mappleton and beyond acting as a sediment source and Spurn Point as a sediment sink.



COASTAL SYSTEMS AND LANDSCAPES: LANDFORM FORMATION

EROSIONAL LANDFORMS

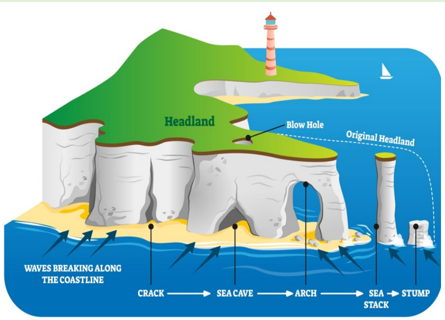
Cliffs: Steep rock faces formed by the erosive action of waves. Wave-cut platforms: Flat areas at the base of cliffs created by wave erosion. Waves erode the base of the cliff through hydraulic action and abrasion, forming a wave-cut notch. As the notch deepens, the cliff becomes unstable and collapses, leaving behind a flat platform, e.g. along the Holderness Coast in the UK and the rugged cliffs of the Algarve in Portugal.

Caves: Form when waves erode weaknesses in headland rock, e.g. joints, faults, or bedding planes. The process begins with hydraulic action, where the force of the waves compresses air in cracks, causing the rock to break apart. Over time, abrasion, where sediment carried by waves grinds against the rock, further enlarges these cracks into caves. Chemical weathering can also contribute to the formation of caves by dissolving soluble minerals in the rock.

Arch: This occurs when waves erode a cave through the headland, creating an opening that extends from one side to the other. The arch is supported by the remaining rock above it.

Stack: The continuous action of waves, combined with weathering processes, weakens the arch until it eventually collapses and leave behind a stack (made of resistant rock) – a tall, isolated column of rock that stands away from the coast. This will eventually be worn down to create a stump.

Famous examples: The Twelve Apostles in Australia, which are limestone stacks formed by the erosion of the cliffs along the Great Ocean Road; The Old Man of Hoy in Scotland, a sandstone stack that stands prominently off the coast of the Orkney Islands.



DEPOSITIONAL LANDFORMS

Beaches: Formed by the deposition of sediment, such as sand and pebbles, by waves. Constructive waves build up beaches by depositing sediment. Examples include the sandy beaches of Bournemouth in the UK and Copacabana Beach in Brazil. Pebbly beaches are normally formed where there are higher energy environments, for example in larger bays. You can see variation in a bay, where a sheltered area away from prevailing wind direction in sandy, but an area that is regularly exposed is pebbly with pebble terraces.

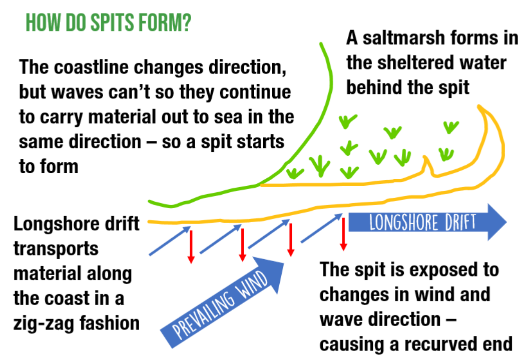
Simple and compound spits: Narrow landforms that extend from the coast into the sea, formed by longshore drift (see diagram below). A simple spit is a single elongated feature, while a compound spit has multiple recurved ends. Examples include Spurn Point on the Holderness Coast and Farewell Spit in New Zealand.

Tombolos: Landform that connect an island to the mainland or another island, formed by the deposition of sediment, e.g. Chesil Beach in the UK.

Offshore bars and barrier beaches: Offshore bars are submerged or partially exposed ridges of sand formed by wave action. Barrier beaches are similar but are above the high tide mark. Examples include the offshore bars along the coast of Norfolk in the UK and the barrier beaches of the Outer Banks in the USA.

Sand dunes: Formed by the wind blowing sand inland from the beach. Vegetation stabilises the dunes, allowing them to grow, e.g. the sand dunes at Studland Bay in the UK.

Estuarine mudflat/saltmarsh environments: Mudflats form in sheltered areas where fine sediments are deposited by tidal action. Saltmarshes develop on mudflats, where salt-tolerant plants colonize the area. These environments are important for wildlife and act as natural flood defences. Examples include the mudflats and saltmarshes of the Thames Estuary in the UK and the Mississippi River Delta in the USA.



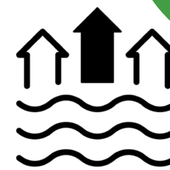
COASTAL SYSTEMS AND LANDSCAPES: ISOSTATIC AND EUSTATIC CHANGE

ISOSTATIC CHANGE

Isostatic sea level change is a local change caused by the rise or fall of land. During the last ice age, the weight of ice sheets caused the land to sink (isostatic depression). When the ice melted, the land began to rise again (isostatic rebound). This process is still occurring in places like Scotland and Scandinavia.

EUSTATIC CHANGE

Eustatic sea level change is a global change caused by the alteration in the volume of water in the oceans, often due to melting ice sheets or thermal expansion. Over the past 10,000 years, eustatic changes have led to significant sea level rise following the last ice age.



ISOSTATIC LANDFORMS – RAISED BEACHES

Raised beaches are former shorelines that have been elevated above the current sea level due to isostatic rebound. During the last ice age, the weight of ice sheets compressed the land. When the ice melted, the land began to rise again, lifting the beaches above their original position. An example of raised beaches can be found in Fife, Scotland, where the land has rebounded significantly since the last ice age.

EUSTATIC LANDFORMS – RIAS

Rias are drowned river valleys formed by rising sea levels (eustatic change). When sea levels rise, they flood river valleys that were previously above sea level, creating long, narrow inlets with a dendritic, tree-like pattern. These valleys typically have a V-shaped cross-section due to river erosion before submergence. Rias are characterized by their irregular and indented coastlines. An example of a ria is the Ria de Arousa in Galicia, Spain, which is a flooded river valley extending inland and creating a complex coastline with numerous branches.

ISOSTATIC LANDFORMS – FOSSIL CLIFFS

Fossil cliffs are old cliff lines that have been uplifted due to isostatic rebound. These can also be called relict cliffs. These cliffs were once at sea level but are now positioned higher due to the rising land. Fossil cliffs often retain features such as wave-cut notches and caves, indicating their previous interaction with the sea. The Isle of Arran in Scotland showcases fossil cliffs that have been elevated due to post-glacial isostatic rebound.

EUSTATIC LANDFORMS – FJORDS

Fjords are deep, narrow inlets formed by the submergence of glacially carved valleys. During the last ice age, glaciers carved out U-shaped valleys through processes of ice segregation and abrasion. When the glaciers melted and sea levels rose, these valleys were flooded, creating fjords. Fjords are typically deeper inland where the glacial force was strongest and often have steep sides or cliffs. An example is the Sognefjord in Norway.

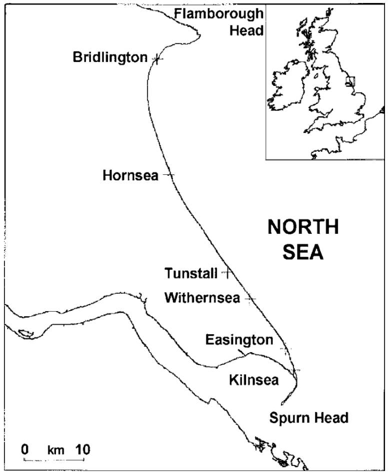
ISOSTATIC LANDFORMS – MARINE PLATFORMS

Marine platforms are flat, elevated areas that were once part of the seabed but have been raised above sea level due to isostatic uplift. These platforms are typically found in regions that experienced significant glacial compression and subsequent rebound. The coast of California features marine platforms that have been uplifted due to tectonic activity and isostatic rebound.

EUSTATIC LANDFORMS – DALMATIAN COASTS

Dalmatian coasts are formed by the flooding of valleys that run parallel to the coastline, creating a series of long, narrow islands separated by narrow sea channels. These valleys are typically formed by tectonic processes that create folds in the rock, which are parallel to the coast. When sea levels rise, the folds are flooded. An example is the Dalmatian Coast in Croatia, where the geological structure has created a series of parallel islands and channels along the Adriatic Sea.

COASTAL SYSTEMS AND LANDSCAPES: CASE STUDY – HOLDERNESS COASTAL MANAGEMENT



KEY TERMS

Shoreline Management Plans: Strategic documents that outline how to manage coastal risks over the long term – considers environmental and socio-economic impacts of different management strategies.

Integrated Coastal Zone Management (ICZM): Holistic approach that coordinates coastal management across different sectors and stakeholders – aims to balance environmental, economic, and social objectives to achieve sustainable development, e.g. Holderness Coast ICZM involves local authorities, environmental groups, and community stakeholders working together to manage coastal erosion and flood risks.

SUSTAINABLE COASTAL MANAGEMENT

1. **Minimise environmental impact:** Using methods that work with natural processes and reduce harm to coastal ecosystems.
2. **Promote long-term sustainability:** Implementing strategies that provide lasting protection and resilience against coastal hazards.
3. **Community involvement:** Engaging local communities in decision-making processes to ensure that management strategies meet their needs and priorities.

HARD ENGINEERING STRATEGIES AT HOLDERNESS

Hard engineering involves the construction of artificial structures to control natural processes. These methods are often expensive but provide immediate and effective protection.

Seawalls: Concrete walls that prevent erosion and flooding by reflecting wave energy back to the sea, protecting the land behind them, e.g. the seawall at Hornsea.

Groynes: Wooden, stone, or concrete barriers built at right angles to the coast to trap sediment and prevent longshore drift. This helps maintain beach width and protects the coastline. However, this can increase rates of erosion further down the coast – this is known as Terminal Groyne Syndrome (TGS), e.g. groynes at Mappleton.

Rock armour (rip rap): Large boulders placed at the base of cliffs or along the shoreline to absorb wave energy and reduce erosion, e.g. rock armour at Withernsea.

Gabions: Cages filled with rocks placed along the coast to absorb wave energy and reduce erosion, e.g. gabions at Easington gas terminal.

SOFT ENGINEERING STRATEGIES AT HOLDERNESS

Soft engineering uses natural materials and processes to manage coastal areas. These methods are generally cheaper and have less harmful impacts on the environment.

Beach nourishment: Adding sand or shingle to a beach to increase its width and height, providing better protection against waves. However, this is quickly eroded without the use of groynes or in a high energy environment, e.g. beach nourishment at Hornsea.

Beach reprofiling: Uses existing sediment from the beach to artificially re-shape the beach after destructive waves have removed sand and shingle. In spring, bulldozers are used to move sediment back up the beach following winter storms.

Dune restoration: Stabilising sand dunes by planting vegetation and using fencing to reduce wind erosion. In some examples, Christmas trees have been used to create embryo dunes, e.g. dune restoration at Spurn Point.

Managed retreat (also known as 'coastal realignment'): Allowing certain areas to erode and flood naturally, while relocating infrastructure and human activities further inland. This can lead to the creation of natural wetland areas, such as saltmarshes – which are excellent natural barriers against erosion. e.g. managed retreat at Kilnsea.

COASTAL SYSTEMS AND LANDSCAPES: CASE STUDY – ODISHA MANAGEMENT STRATEGIES

WHERE IS ODISHA?

Located on the eastern coast of India, faces significant challenges related to coastal erosion, flooding, and the impacts of climate change. The state has implemented various coastal management strategies to address these issues, focusing on both traditional and sustainable approaches.

HARD ENGINEERING STRATEGIES IN ODISHA

Seawalls: These have been constructed in areas like Puri to protect the coastline from the strong wave action of the Bay of Bengal. These are mainly in place for high value areas such as ports.

Groynes: Groynes have been used to stabilise beaches and prevent erosion. Though similar to the Holderness coastline, terminal groyne syndrome has occurred in unprotected areas due a negative sediment budget.

Breakwaters: Offshore structures designed to absorb wave energy and create calm waters behind them. They protect harbours and reduce coastal erosion. Breakwaters have been constructed near ports like Paradip.

Geotextile sand tubes: These are used in Pentha village to protect the coastline from erosion. These tubes, filled with sand, act as barriers against wave action, and are flexible, cost-effective, and environmentally friendly, using locally sourced materials. However, they can be damaged by intense storms and require regular maintenance to remain effective. Their long-term durability is also a concern, especially with increasing severe weather events.

SOFT ENGINEERING STRATEGIES IN ODISHA

Beach nourishment: To restore eroded beaches and enhance their resilience to wave action. However, lots of the sediment for these resources has come from offshore sand bars nearby, decreasing the sediment budget for other areas.

Mangrove planting: Mangroves are planted to stabilise the coastline, reduce erosion, and provide habitat for wildlife. Odisha has undertaken extensive mangrove planting projects, particularly in the Bhitarkanika and Chilika regions, to protect against coastal erosion and enhance biodiversity – over 200 hectares of mangroves have been planted as part of the Integrated Coastal Zone Management Project. These mangroves have proven to be long term solutions, able to withstand the effect of increasing storm surges from tropical cyclones in the region.

STRATEGIES TO REDUCE MANGROVE DESTRUCTION IN ODISHA

Mangrove deforestation in Odisha occurs due to several factors, including anthropogenic activities such as land conversion for agriculture and aquaculture, urbanisation, and industrial development. Additionally, natural disasters like cyclones and floods exacerbate the loss of mangrove forests.

Community-based conservation programs: These empower local communities to take an active role in mangrove conservation, significantly reducing deforestation. Initiatives like forming Village Mangrove Councils help in sustainable management and conservation of mangrove resources. Education and awareness campaigns inform communities about the ecological and economic benefits of mangroves, encouraging them to protect these vital ecosystems.

Eco-development programs: These reduce dependency on mangrove forests by promoting alternative livelihoods such as sustainable agriculture, aquaculture, and eco-tourism.