The Concept of Ecosystem Ecology (e.g. forest, deserts, river, ponds...)

It is the study, to a great extent, about mass balances of elements and their interactions. The fluxes of elements are strongly coupled to each other, and often one limiting element regulates the fluxes of the others. This chapter gives an introduction to the most important elements and to some key concepts or cornerstones: mass balance, limiting nutrients, optimality and steady state. At the ecosystem level we are interested in structural and functional attributes of the system as a whole.

The goal of ecosystem science is to integrate information from studies of the interactions between individuals, populations, communities and their abiotic environments, including the changes in these relationships with time. Amid this complexity, several approaches have been used in attempts to synthesize understanding at the ecosystem level.



Figure: Model depicting nutrient relationships in a terrestrial ecosystem. Inputs and outputs to the ecosystem are moved by meteorologic, geologic and biologic vectors (Bormann and Likens 1967, Likens and Bormann 1972). Major sites of accumulation and major exchange pathways within the ecosystem are shown. Nutrients that, because they have no prominent gaseous phase, continually cycle within the boundaries of the ecosystem between the available nutrient, organic matter and primary and secondary mineral components tend to form an intrasystem cycle. Fluxes across the boundaries of an ecosystem link individual ecosystems with the remainder of the biosphere. (From Likens et al. 1977; modified Likens 1992)

Structure and functions of ecosystems

Most ecosystems gain energy from the sun and materials from the air or rocks, transfer these among components within the ecosystem, then release energy and materials to the environment. The essential biological components of ecosystems are plants, animals, and decomposers. Plants capture solar energy in the process of bringing carbon into the ecosystem. A few ecosystems, such as deep-sea hydrothermal vents, have no plants but instead have bacteria that derive energy from the oxidation of hydrogen sulfide (H2S) to produce organic matter. Decomposer microorganisms (microbes) break down dead organic material, releasing CO2 to the atmosphere and nutrients in forms that are available to other microbes and plants. If there were no decomposition, large accumulations of dead organic matter would sequester the nutrients required to support plant growth. Animals are critical components of ecosystems because they transfer energy and materials and strongly influence the quantity and activities of plants and soil microbes. The essential abiotic components of an ecosystem are water; the atmosphere, which supplies carbon and nitrogen; and soil minerals, which supply other nutrients required by organisms.

An ecosystem model describes the major pools and fluxes in an ecosystem and the factors that regulate these fluxes. Nutrients, water, and energy differ from one another in the relative importance of ecosystem inputs and outputs vs. internal recycling. Plants, for example, acquire carbon primarily from the atmosphere, and most carbon released by respiration returns to the atmosphere. Carbon cycling through ecosystems is therefore quite open, with large inputs to, and losses from, the system. There are, however, relatively large pools of carbon stored in ecosystems, so the activities of animals and microbes are somewhat buffered from variations in carbon uptake by plants. The water cycle of ecosystems is also relatively open, with water entering primarily by precipitation and leaving by evaporation, transpiration, and drainage to groundwater and streams. In contrast to carbon, most ecosystems have a limited capacity to store water in plants and soil, so the activity of organisms is closely linked to water inputs. In contrast to carbon and water, mineral elements such as nitrogen and phosphorus are recycled rather tightly within ecosystems, with annual inputs and losses that are small relative to the quantities that annually recycle within the ecosystem. These differences in the "openness" and "buffering" of the cycles fundamentally influence the controls over rates and patterns of the cycling of materials through ecosystems. The pool sizes and rates of cycling differ substantially among ecosystems. Tropical forests have much larger pools of carbon and nutrients in plants than do deserts or tundra. Peat bogs, in contrast, have large pools of soil carbon rather than plant carbon. Ecosystems also differ substantially in annual fluxes of materials among pools.

Ecoregions of the World

Ecoregions are geographical regions that are characterized by specific ecological patterns, including soil health, flora and fauna, climatic conditions, among other factors. Conservation organizations and environmental agencies use the concept of an ecoregion to systematically understand how biodiversity levels and ecosystem dynamics differ across the world. The WWF defines ecoregions as being large units of land or water that share similar biogeographical characteristics, such as endemic species, environmental conditions, and ecological dynamics, and ecoregions are intended to represent the original distribution of distinct natural assemblages. The WWF has identified 867 terrestrial ecoregions, and 450 aquatic ecoregions. It is important to note that ecoregion boundaries are not fixed, and ecotones, or transition areas, occur between distinct ecoregions. Taking into account the inter linkages between different ecosystems; the ecoregion system of classification is intended to allow for an integrated analysis of environmental changes.

Ecological Regions of Pakistan

Pakistan is a land of high mountains, fertile river valleys, and inhospitable deserts. Situated in South Asia, Pakistan's ecoregions are home to a wide range of flora and fauna. The Indus Valley ecoregion is the only one that lies entirely in Pakistan while the rest are shared with its neighbors such as India and Nepal. A brief description of these ecoregions is given as under

A. Himalayan Subtropical Pine Forests:

The Himalayan subtropical pine forests ecoregion in Pakistan is classified under the Tropical and Subtropical Coniferous Forests Biome. This ecoregion stretches for about 3,000 km across the Himalayas through Pakistan, India, Nepal, and Bhutan. The dominant pine species is the chir pine (*Pinux roxburghii*). The trees in this ecoregion are widely spaced, and fire is a common occurrence in the forests. The burnt slopes in the region are home to abundant grass species such as *Imperata cylindrica* and *Arundinella setosa* and shrub species including Rubus and Berberis.

The region is divided into the eastern and the western part of the Kali Gandaki river valley. The eastern part receives more rainfall from monsoon winds from the Bay of Bengal. Fauna in the region do not exhibit a high level of endemism and includes 120 mammal species such as the barking deer, goral, and yellow-throated marten. The ecoregion has been severely degraded through agriculture and deforestation.

B. Indus Valley Desert:

The Indus Valley Desert ecoregion is classified in the Deserts and xeric shrublands Biome. The ecoregion lies in the Indus Valley in Pakistan. The desert is almost inhospitable with annual rainfall ranging a mere 640 to 760 mm. Temperatures recorded in the summer are over 45 degrees Celsius. Shrubs are the most common vegetation, with the most common species being the Prosopis.

32 mammal species have been identified in the region including caracal, Indian leopard, hyena, and Indian wolf. The ecoregion boasts 190 bird species, although none is endemic to the ecoregion. The ecoregion receives less human

influence than other ecoregions due to the extreme conditions. Hunting of the mammal species is, however, a major threat.

C. Indus River-Delta- Arabian Sea Mangroves:

The Indus River-Delta-Arabian Sea mangroves ecoregion is classified in the Mangrove Biome. Mangroves are salt tolerant plants (trees and shrubs) found in tropical area which have adapted to survive in saline and brackish water. They occur naturally in sheltered coastal areas, such as river mouths, creeks, backwaters, lagoons, bays and estuaries where freshwater meets the seawater. Their survival is dependent on tidal inundation. Mangroves make up one of the world's most unique ecosystems because they thrive where no other trees can survive – in the transition zone between the ocean and land. They are also among the world's most productive ecosystems. A total number of 69 species in 27 genera, belonging to 20 families are consideredas true mangrove species. Pakistan's mangrove ecoregion lies on the Arabian Sea coastline of the Sindh Province, which constitutes 97% of the total mangrove cover found in Pakistan; whereas the rest 3% mangroves are found at three locations along the Balochistan coast, at Miani Hor, Kalmat Hor and Jiwani. Rainfall in the region averages between 100 and 500 mm in the months of July to September. Summer temperatures recorded are as high as 50 degrees Celsius.

Mangrove trees are the dominant flora, with the common species being the gray mangroves alongside red, black, and Indian mangroves. The mangroves support a rich undergrowth of saplings. The mangroves are an important breeding ground for fish and crustaceans. The ecoregion is also a significant avifauna migration point, and water birds such as flamingos and pelicans inhabit the region. Extensive irrigation, agriculture, human encroachment and pollution have been identified as major threats to the ecoregion's sustainability.

D. Thar Desert:

The Thar Desert ecoregion is classified in the Deserts and xeric shrublands Biome. The ecoregion lies in the Thar Desert, found both in Pakistan and India. Little rainfall is recorded from July to September, ranging between 100 to 500 mm. Sand dunes, rock forms, and salt-lake bottoms are some of the landforms found in the region. Scrub species such as Acacia Calligonum polygonoides and Crotalaria and grasses such as Eleusine, Eragrostis, Panicum, and Cyperus are common vegetation in the region.

Several mammal species have adapted to the extreme conditions including the desert fox, the endangered blackbuck, caracal, and the Indian wild ass. 141 bird species have been identified in the region including the great Indian bustard, tawny eagle, and laggar Falcon.

The desert is densely populated and overgrazing and the introduction of alien species have been identified as some of the threats to the ecoregion. The Nara Desert Wildlife Sanctuary and the Rann of Kutch Wildlife Sanctuary are some of the conservation reserves in the region.

E. Coastal region:

Pakistan's coastline is about 990 km long, bifurcated in two parts, Sindh Coast (270 km) and Makran Coast (720 km). The Exclusive Economic Zone (EEZ) of Pakistan covers an area of about 240,000 sq. km. The maritime zone of Pakistan, including the continental shelf, extends up to 350 nautical miles from the coastline. The shelf of the coast is dominated by the Indus (a major river of Pakistan) canyon in the coast. The continental shelf varies in size distinctly along the Sindh and the Balochistan provincial coasts. The seaward coastal zone up to 12 nautical miles (NM) from the coastline is basically within the jurisdiction of the two provinces (Sindh & Balochistan). The coastal zone beyond the 12 NM up to 24 NM is the contiguous zone and beyond the 12 NM up to 200 NM is under the jurisdiction of the federal government. Geographically, the coast of Pakistan can be divided into five parts, starting from the Iran border at Gwatar Bay in the West up to the Indian border at Sir Creek in the East:

- i. Gwadar Coast
- ii. Lasbela Coast
- iii. Karachi Coast
- iv. Thatta Coast from Korangi Creek up to Indian border at Sir Creek
- v. Rann of Kutch from Badin to Tharparkar Districts

Important features of Pakistan's Coasts

1. Indus Delta

The Indus Delta is an important landmark of Pakistan's coastline extending up to 150 km along the Arabian Sea. The delta consists of several major and minor creeks formed by the River Indus before discharging into the Arabian Sea. The delta is a fan-shaped delta consisting of creeks, estuaries, mud flats, sand dunes, mangrove habitat, marshes

and sea bays. The Indus Delta is the sixth largest delta in the world. It is spread over about 600,000 hectares from Korangi Creek bordering the city of Karachi to Sir Creek along the Indian border in the east. The Indus Delta comprises of 17 major creeks and numerous minor creeks and an extensive area of mud flats occupied by mangrove forests. The delta receives freshwater from the Indus River that flows through the delta before reaching the Arabian Sea. In the recent past, a Left Bank Outfall Drain (LBOD) has been constructed on the area located on the left bank of the Indus with the primary aim of reclaiming the agricultural lands by lowering the water table thereby reducing the salinity from the arable lands. The drain was designed to address the problem of waterlogging and salinity by providing a comprehensive system of surface and sub-surface drainage through a network of lateral and spinal drains to transport excess salts and drainage effluents to the coastal zone near the Indian border. This saline effluent, having salinity as high as 30 millisiemens per centimeter, was continuously discharged into the Indus Delta.

2. Rann of Kutch

The Rann of Kutch and its adjoining tidal mudflats area is part of the great Thar Desert. The Thar region forms a bigger desert, representing the eastern most link of the great Afro-Asian desert chain stretching eastward from the Sahara. The Rann of Kutch is spread over an area of 566,375 ha and is an ideal habitat for a number of wild animals and birds of global significance. The Rann of Kutch was declared a wildlife sanctuary in 1980, and is located in the central south-east of the Sindh province. This area consists of old stabilized sand dunes that run parallel in southwest to north-east direction with broad inter-dunal valleys between the dune tops. The marshy stretch or tidal mudflat area in its southern end is the most attractive feature of the project area. The Rann was created as a delta of the Hakra River that flows along the eastern boundary of Sindh. The Rann of Kutch comprises fixed sand dunes of which some are more than 170 meters in height with extensive inter dune valleys with alluvial soils. The Pakistan side portion of Rann of Kutch is a desert area with barren land covered with scattered grasses. The area has three distinct habitats, a sand-dune strip, the Karoonnjhar hill range and the coastal saline marshy zone. A large portion of the Rann of Kutch lies in India, which includes permanent saline marshes, coastal brackish lagoons, tidal mudflats and estuarine habitats. It is supplied water from the rain-fed rivulets and streams flowing in from both Pakistan and India. The climatic conditions over the year are semi-arid tropical with very little precipitation measuring less than 300 mm. The summers are usually very warm with temperatures rising to 450 C whereas winters are mild with temperatures dropping to about 50 C. Humidity ranges between 50% and 80% during summers and monsoons, respectively. People are engaged in rain-fed agriculture and livestock rearing, and earn livelihoods from handicrafts, sale of fuel wood and working as skilled and unskilled laborers in coal mining. The common plant species famous in the Rann of Kutch are Salvadora persica (Khabbar), Acacia nilotica (Babul), Acacia senegal (Kumbat), Ziziphus numularia (Ber), Prosopis cineraria (Kandi), Tamarix dioica (Lai), Capparis aphylla (Karir), Azadirachta indica (Neem), Tecommella undulata (Lohiro) and other species. The Rann of Kutch area supports many locally and globally threatened species, including the Great Indian Bustard (Ardeotis nigriceps), Houbara Bustard (Chlamydotis undulata), Sarus Crane (Grus antigone), and more than 1% of the biogeographical population of flamingos. The Rann of Kutch is also home to many large mammals. These include the endangered Asiatic wild ass (Equus hemionus khur), Striped hyena (Hyaena hyaena), Desert cat (Felis lybica), Caracal, a medium-sized wild cat (Felis caracal), Honey badger (Mellivora capensis), Chinkara (Gazella bennettii), Nilgai or Blue bull (Boselaphus tragocamelus), and Gray wolf (Canis lupus) and a variety of reptiles, including the endangered Indian monitor lizard (Varanus bengalensis), Indian sand boa (Eryx johnii) and Saw-scaled viper (Echis carinatus).

3. Sea Turtle Nesting Beaches

The important sea turtle nesting beaches along the Pakistan coast include Sandspit and Hawksbay beaches near Karachi, and Ormara-Taq Beach, Astola Island and Daran beaches along the Makran coast. These beaches are nesting sites of sea turtles which lay their eggs on these beaches during July to December. Sandspit and Hawksbay beaches are two of the eleven globally most important nesting beaches. Thousands of Green Sea Turtles (*Chelonia mydas*) nest on Sandspit and Hawksbay beaches every year.

4. Gwatar Bay

Gwatar Bay is the transboundary coastal/marine wetland area which is shared by both Pakistan and Iran. It is an important area for marine fisheries and other marine animals including whales, dolphins, sea turtles, migratory birds and mangroves.

5. Coastal and Marine Islands

i. Bundal and Buddo Islands

These islands are located in Korangi, Phitti and Jhari creeks. Bundal Island is one of the largest and highest of all the islands along the Sindh Coast, with a length of about 8 km. The width of the island varies - it is about 4 km wide in the north and 1 km in the south. There are shifting sand dunes on the island, some of which gain heights of up to 3 m. A portion of the northern area of the island is covered at high water and has a thick growth of mangroves at the

extreme northern point. Bundal is also used by fishermen as a transit point when they venture out to the high seas for fishing, drying their catch of fish and mending their nets.

ii. Churna and Kaio Island Complex

The Churna–Kaio Islands Complex is located west of Karachi. Churna consists of an island which is medium sized and faces the Hub River Delta, whereas a small islet, Kaio Island, is located near the town of Gaddani. The area is known for high biodiversity because of a variety of habitats, such as, its diversified coral assemblage around Churna and Kaio Islands and the rich mudflats and oyster reefs. Churna–Kaio Islands Complex is known to be an important basking and feeding area for marine mega fauna including baleen whales, whale shark, mobulids and sunfishes. Churna Island is located offshore near Mubarak Village, Keamari Town of Karachi. Churna Island is a small uninhabited island located in the Arabian Sea, about 9 km (5.6 mi) west of the mouth of the Hub River, at the boundary between the provinces of Balochistan and Sindh. Churna is approximately 1.2 km (0.75 mi) long and 0.5 km (0.31 mi) wide. Amateur diving, snorkeling and jet skiing are getting popular in the area. Some of the beaches, including Gaddani and Sonara (at the mouth of the Hub River) are thronged by picnickers, especially on weekends. Due to power plants and a substantially large ship breaking industry present in the area, the ecology is seriously being affected. Considering high biodiversity and the threats it is facing, the area requires immediate steps for its protection to continue to provide livelihood opportunities and tourism facilities for the country. A management option could be to control commercial and recreational activities in the Churna-Kaio Island Complex and designate it as a 'no-take zone or marine protected area'.

iii. Astola Island

This is a small, uninhabited island in the Arabian Sea in Pakistan's territorial waters along the Balochistan Coast. Astola Island is locally known as 'Haft Talar', or the island of seven hills. The island is a part of Pasni sub-district of Gwadar District. Astola Island is 39 km away from Pasni. The island is about 4 km in length, and 1.5 km wide at its maximum width point. The island is located at the latitude and longitude coordinates of 25° 7'20.19"N and 63°50'57.91"E. The Island is an ecologically important site, as it inhabits colonies of corals and its sandy beach provides nesting ground for the endangered green turtle (Chelonia mydas) and hawksbill turtle (Eretmochelys imbracata). The Astola saw-scaled viper (Echis carinatus astolae) is endemic to the island. There is sparse scrub vegetation on the island comprising of halophytic plants indicating the saline nature of the soil. Lithophytes (Lichens), aquatic weeds, sea urchins, sea anemones and corals have also been seen on the coast. Large mammals are not known to have existed on the island, however small terrestrial mammals, like rodents, inhabit the island. Many types of migratory and resident birds can be seen on Astola Island. Waterfowls migrate through the area twice a year and use the island as a staging and wintering ground. The sea off the island's coast is pristine and comprises of pelagic and demersal species. Coral reefs are also found around the Island. The area is also rich in supporting life for cetaceans. 75 finfish species from 36 families have been reported in the waters of Astola Island. Astola Island is an eve-catching site to invite eco-tourists for camping, fishing and scuba diving expeditions and for observing turtle breeding. The wetland is facing threats mainly from anthropogenic activities, pollution resulting from dumping of crude used oil, washing of tankers at sea collection of turtle eggs, use of illegal fishing nets, trawling, dumping of waste materials (ghost nets) and mining of corals.

6. Sites of Ecological Significance/Protected Areas

i. Ramsar Sites

Ramsar sites are wetland areas of international ecological significance. Along the Pakistan coast, there are seven Ramsar sites including Rann of Kutch, Nariri-Jaboh Lagoon, Indus Delta, Miani Hor, Astola Island, Ormara Turtle Beach and Jiwani. They are important sites for roosting and feeding of migratory birds which migrate from Siberia for wintering at various wetlands in Pakistan. These birds migrate along the "Indus Flyway" which is one of the seven bird migration routes in the world. It is also called the "Green Route".

ii. National Parks

Hingol National Park along the Makran coast is the only national park bordering the coast in the Lasbela district of Balochistan. It is the largest national park in Pakistan declared for protection of several endangered species of wildlife.

iii. Wildlife Sanctuaries

There are a few wildlife sanctuaries located along the coast of Pakistan which include the Rann of Kutch, Keti Bundar (North), Keti Bundar (South) and MarhoKotri Wildlife Sanctuaries in Sindh. The Kurkhera Wildlife Sanctuary has an area in Miani Hor and the Buzi Makola Wildlife Sanctuary comprises of the entire Kalmat Hor along the Balochistan coast.

- 7. Sites of Archaeological Significance
- i. Bhambore

Bhambore is an ancient town dating to the 1st century BC located along the Sindh coast. The city ruins lie on the N-5 National Highway, east of Karachi. It dates back to the Scytho-Parthian era and was later controlled by Muslims from the 8th to 13th century after which it was abandoned. Remains of one of the earliest known mosques in the region, dating back to 727 AD, are still preserved on the site. Bhambore was a medieval port city deriving its wealth from imported ceramic and metal goods, an industrial sector, and trade. The city was strategically located at the mouth of the Indus River, linking it with the rest of the Scytho-Parthian empire and international traders in the Indian Ocean.

ii. Rato Kot and Juna Shah Forts

Rato Kot Fort was built as an anchorage and look out post for pirates during the Indo-Arabian sea trade era around 800 AD on the Karachi Coast. Juna Shah Fort is also present, 18 km south of the Port Qasim Complex. These forts were built for defense purposes as well as for monitoring and securing trade routes.

iii. Mud Volcanoes

Among several earth science wonders here, one massive attraction is the presence of eighteen mud volcanoes. The earliest account of the presence of mud volcanoes in Balochistan dates back to 1840. In

fact, the largest and highest known mud volcano in the world is found along the Balochistan coast. These are about a kilometer off the main Coastal Highway leading from Lasbela to Gwadar. One of these termed 'Chandargup' is a sacred Hindu worship place. The Hindus worship these mud volcanoes because they are believed to be the habitat of a god, Babhaknath.

8. Urban and Industrial Developments

With the exception of Karachi metropolitan city along the Sindh coast, and Hub and Gwadar along the Balochistan coast, no other major urban settlements exist along Pakistan's coast. Karachi is a major hub of being the main commercial and industrial center of Pakistan. About 70% of the total industry of Pakistan is located in Karachi city. The major industry comprises of textiles, chemicals, pharmaceuticals, electronic goods, food, oil refineries, tanneries, iron and steel, thermal power generation, etc. The total

number of industrial units in Karachi is estimated to be about 6,000. Most of the industry is located in the Sindh Industrial Trading Estate (S.I.T.E), Landhi Industrial Trading Estate (L.I.T.E), Korangi Industrial Area and West Wharf Industrial Area. Outside Karachi, the main industrial areas include the Hub Industrial Trading Estate (H.I.T.E) including the marble city, and the Gadani shipbreaking yard along the

Balochistan coast. A deep seaport has been constructed in Gwadar and is expected to be an important port for shipping in future.

9. Coastal Agriculture

Traditionally, agriculture, forestry and fishing played almost equal roles in the socioeconomic patterns of the coastal communities. Agricultural activities are still widely practiced in the coastal areas of Thatta and Badin districts in Sindh province and in the Hub, Sonmiani and Phore areas with the major crops being cotton, banana, wheat, rice, pulses, vegetables, fodder and fruits. However, availability of water for agriculture in coastal areas is declining due to upstream diversions and climate induced scarcity.

10. Coastal Tourism and Recreation

Tourism and recreation in the coastal areas of Pakistan is largely limited to beaches along the Karachi coast and a few beaches along the Balochistan coast such as Gaddani and Kund Malir. However, tremendous potential for recreation and nature based tourism exists in the Indus Delta, and along the Balochistan coast at Churna Island and Astola Island, Jiwani and Hingol areas (e.g. Buzy pass, Hindu Temple at Hanglaj and Mud Volcano Chandar Gup.

F. Other Ecoregions in the Country:

Other ecoregions in Pakistan are: Baluchistan xeric woodlands; East Afghan Montane conifer forests; Karakoram-West Tibetan Plateau alpine steppe; Kuhrud-Kohbanan Mountains forest steppe; Northwestern Himalayan alpine shrub and meadows; Rann of Kutch seasonal salt marsh; Registan-North Pakistan sandy desert; Tian Shan montane steppe and meadows; Western Himalayan broadleaf forests and Western Himalayan subalpine conifer forests. Pakistan, being a developing nation, is yet to actually curb environmental threats such as industrial pollution, rapid deforestation and poaching.

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